THE HEADS AND TAILS OF GANGA

VIJAY PARANJPYE

RADHIKA MULAY & CHAITRALI KULKARNI

INTACH

Ganga Emerges From Its Glacial Source Situated Amidst The High Sentinels We Know As Himalayas

THE HEADS AND TAILS OF GANGA

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MESSAGE FROM THE CHAIRMAN, INTACH

Time is playing a requiem for our rivers.

While efforts to conserve Ganga River have been gathering pace for quite some time, it has been considered by INTACH that the critical role of the cryosphere and delta and the transboundary nature of the river have received inadequate attention resulting in conservation approaches which may yield sub-optimal results.

'Heads and Tails of Ganga', sponsored by INTACH, weaves together an extraordinarily broad range of aspects of the Ganga River. It covers a large part of the Ganga River System (approximately 10,87,852 sq.km.), from its uppermost reaches in the snow and ice-covered regions of India and Nepal, through its vast river basin spread across eleven states within India, passing through the political boundaries of neighboring countries of Nepal, Bhutan, Tibet (China), right down to the delta of Ganga Brahmaputra-Meghana (Tails) in Bangladesh, a total length of 2616 kms.

It is my earnest hope that this rare scholarly work, authored by Vijay Paranjpye, Environmental Economist and a mountaineer and his research team, Radhika Mulay and Chaitrali Kulkarni, will draw attention of the powers that be, of the need to widen the sphere and scope of action needed to holistically conserve Ganga.

Maj. General [Retd] Lalit Kumar Gupta
Chairman, INTACH

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I begin by expressing my deep gratitude towards the Five Great Natural Elements *(Panchamahaboot)*, Land, Water, Fire, Air and Ether, which have together formed not only the great Indian landmass, but also the mighty Himalaya, from whose folds have emanated the great rivers of South Asia. They have over-awed me with their beauty, and sometimes exposed me to their wrath as well. Together, they have been my Supreme Guru. I offer them my humble respects.

For the Report at hand – 'Heads and Tails of Ganga', I am thankful to INTACH for sponsoring this project. I am also particularly appreciative of Mr. Manu Bhatnagar's, Principal Director, Natural Heritage Division, INTACH, New Delhi and young Dhruv Sah's painstaking efforts in editing and designing this volume, in addition to being supportive and patiently bearing with the repeated delays in the submission of the Final Report. My thanks to Dr Sharvey Dhongde, Convenor of the Pune Chapter, INTACH for providing the administrative support for the Ganga Project. I am also thankful to Ms. Supriya Goturkar-Mahabaleshwarkar (Co-convenor and Co-ordinator, INTACH Pune Chapter) and Mr. Mukul Mahabaleshwarkar (Executive Committee member, INTACH Pune chapter) for reviewing the report drafts and for overall coordination support for the Heads of Ganga Project.

I would like to express my appreciation and gratitude to our key Research Team members, Chaitrali Kulkarni and Radhika Mulay who spared no efforts in gathering the voluminous data, and helping to draft the lengthy chapters. My sincere thanks to Omkar Kulkarni for drawing new maps as required by the specific context of this study, based on Toposheets of the Survey of India, the US Bureau of Engineers and NASA images and other sources. I am grateful to Swanand Kulkarni, my son Ashwin, and Anagha Athavle, for individually conducting Field trips or accompanying me on Field Trips to Uttarakhand and Nepal and helping with the surveys and documentation.

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On a more personal note, I thank my parents, late Major P.H.Paranjpye and Vimla Paranjpye,

whom I accompanied as a child in the mountains of Kashmir, and as a teenager, on horseback, through the length and breadth of Himalaya in Eastern Nepal, where I unknowingly crossed some of the deepest gorges of rivers Tamur and Arun, and trekked up to Namche Bazaar near the Khumbu Glacier. I was unaware of the significance of these Experiences at that time. It was as if I had imbibed the 'pahadi' culture as a matter of day to day living.

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And finally, my thanks are due to my wife, Anjali, for her unstinting support, and for the endless hours she spent in editing the chapters and tying up the loose ends. Without the contribution of these, and many others, this Report would not have seen the light of day.

FOREWORD

'Heads and Tails of Ganga' paints an extraordinarily broad canvas of the Ganga River. It covers most of the Ganga River System (approximately a million sq.km.), from the cryosphere regions [Heads] of India and Nepal, through its vast basin spread across 11 states in India, passing through the political boundaries of neighboring countries of Nepal, Bhutan, Tibet (China), down to the Ganga Brahmaputra-Meghana delta (Tails) in Bangladesh, a length of 2616 kms.

This study provides insights into the complex and little-known aspects of the Ganga River System, such as the cryosphere (uppermost frozen regime), the permafrost, glaciers, snowfields, the largest and tallest freshwater towers in the world and the critical role they all play in maintaining water flows in the river and sustaining eco-systems and human populations in the upper, middle, and lower regimes of the river basin.

The study also describes the diversity of the flora and fauna and the role of bacteriophages which may hold a long-term and sustainable solution to the dreadful problem of pathogenic river pollution.

This study stands apart from most studies on the Ganga which are either technical papers about a specific feature, or focus on the problems due to pollution in its middle regime. It gives the reader a comprehensive and holistic understanding of the Ganga River system, highlighting the inter-dependencies and linkages between its unique geographical and geological features, hydrological cycles, eco-systems, human settlements and the historical and socio-cultural canvas.

Besides providing scientific information, the study rings a warning bell about the adverse impacts of climate change on this region. For instance, it points out that the alarming rate of recession of glaciers in the cryosphere will adversely affect biological diversity and human habitations not only in the Himalayan region, but also in the Ganga-Brahmaputra and Sindhu River Basins, and in fact, the whole of northern India as well. Similarly, the study cautions about the frantic pace of development and infrastructure, unbridled promotion of mass tourism and pilgrimage without factoring in the unique and fragile nature of the Himalayan mountains, which have already resulted in disastrous landslides at Rishi Ganga, Uttarkashi and Joshimath during recent years.

The study, therefore, advocates the need for an Integrated River Basin Management approach, which would require continuous co-ordination and co-operation between the scientific community, all development agencies - inter-state and international riparian, and stakeholders living up-stream, mid-stream, as well as downstream, in order to mitigate the adverse impact of climate change and human interventions in this fragile river system.

The study also emphasizes the need to appreciate the fact that the Ganga River is truly an entity 'beyond borders'. The physical origin of its northern-most tributary, the Jad-Ganga, lies in Tibet (China). Other large tributaries like Karnali, Gandak and Sapta Kosi, which lie in Nepal and China, contribute over 40% of the total annual yield of the Ganga River. Similarly, the river figures in the cultural history and mythology of all the different riparian countries in the Ganga River System. It is equally important to consider the Ganga-Brahmaputra-Meghana Delta (commonly called 'Bengal Delta'), as an integral part of Ganga River Basin planning and management, for ensuring the sustainable use of Ganga's resources. During the post-independence period, the administrative and political establishment in India has largely neglected the Ganga Delta since it lies beyond India's borders, even though almost 80 to 90 % of the Ganga River (called the 'Padma' in Bangladesh), joins the Brahmaputra and Meghna and travels for 482 kms in Bangladesh before discharging into the Bay of Bengal . The Bengal Delta, too, is greatly vulnerable to climate change impacts of enormous proportions.

The study refers to recent research by the British-Antarctic Survey that has recorded significant meteorological changes in the Bay of Bengal. These are already causing severe storms and typhoons. Sea-level rise is expected to reach up to 1.5 m. during the next few decades, leading to social disruption and northward human migration of a magnitude never experienced before.

The study points out that blocking of natural flows of the river and its tributaries, piece-meal resource development projects which do not take into consideration the fragile geographical eco-systems and downstream impacts, are all grave problems associated with the Ganga River needing urgent address. By 2022, the main stem of Ganga and its tributaries have been either intercepted or blocked by about 1500 dams, hydel power stations, barrages, diversion channels and lift irrigation schemes which have drastically reduced the flows by more than 50% during the last five decades. Currently, the existing projects are working at less than 30% efficiency. Their efficiency, could be increased to augment environmental flows for ecological needs and simultaneously provide water security for humans and animals.

The study, therefore, recommends a paradigm shift in the entire management and governance system for the Ganga River in order to avoid the current fragmented and haphazard development. This would be possible by adopting an Integrated River Basin Approach. Further, it emphasizes the need for strict enforcement of existing laws.

This study is relevant not only for India, but also for its riparian States and multilateral, national and international agencies for achieving sustainable development of the Ganga River Basin and attaining resilience to climate change disasters. It puts forth actionable recommendations, based on scientific evidence, which could be applied or adapted not just to the Ganga River system.

Time is not on the side of the holy river. Thus, we need to adopt the 'Integrated Basin Management Approach' as of yesterday.

Last, but not the least, the study offers the lay reader interesting scientific information about complex elements of the Ganga River, normally not easily available in a single study.

Manu Bhatnagar
Prinicpal Director
Natural Heritage Division
INTACH

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Maps at the Rear :

PROLOGUE

The idea of working on a research study titled 'The Heads and Tails of Ganga' had been in my mind for some time, but finally germinated in November 2018, during our deliberations, at the time of the 3rd India Rivers Week held in Delhi. The panel discussions about the Ganga River mainly concentrated on the impact of human interventions on the mainstream section of the river, from Gangotri to the Farakka Barrage. Since the Ganga River Basin covers an enormous land area, from its origins to the delta, measuring approximately 1543 km in length and 1024 km in width, and contains a wide range of physical features, eco-systems and human settlements, I realized that there was a need to develop a perspective which includes the upper, middle as well as the tail regions of the river and understand their inter-relationships and inter-dependencies, since the impact of any human interventions, climate change or natural disasters is inevitably linked to all the three segments.

I was convinced that only a radical change in our perspective of the Ganga River would enable us to understand the nature and magnitude of the problems which plague the river and to meet the current challenges in an effective manner. The rapidly increasing and alarming effects of human interventions and climate change on the glaciers in the cryosphere, on river flows, on habitat and bio-diversity needed to be viewed in a holistic and integrated manner.

I strongly felt that it was important that the discourse on the Ganga River includes the uppermost segment of the Ganga, which lies in the cryosphere region in the Himalayan Mountain ranges, stretching from Banderpoonch, (i.e., origins of Yamuna River), up to the Kangchendzonga ridge-line on the border of Nepal and Sikkim. It is also important to study the role of rivers originating in these regions and flowing through Nepal and Tibet Autonomous Region, China, which together contribute about 42% of the average annual yield of water and impact the water quality and flow in the mainstream Ganga. Similarly, the last stretch of about 300 km of the mainstream Ganga which forms the delta region in Bangladesh, and which is currently not taken into consideration while planning Ganga's resources, also needs to be included in the study in order to make it holistic.

Deeply concerned and frustrated with the efforts made by the governance structure over the last four decades, I felt that there was an urgent need to bridge these gaps in the understanding of the entire Ganga River basin, and to bring about changes in approach to planning and development of natural resources in the river basin so as to orient future policies in a new direction. I therefore approached Mr. Manu Bhatnagar, Principal Director of the Natural Heritage Division, INTACH, with a proposal to study the 'Heads and Tails of Ganga', which was readily supported by him.

The objective of this study was to include two important segments of the Ganga River, namely, the 'cryosphere' (figuratively referred to as 'Heads' of the Ganga in our Study), or the frozen areas lying in the uppermost segment, above the origins of River Ganga and its major tributaries; and the delta region (figuratively referred to as the 'Tails' of Ganga in our Study), which partly lies in West Bengal, south-east and south of the Farakka Barrage, India, and the rest in neighboring Bangladesh. The cryosphere is rarely, if ever, visited or studied because of its inaccessibility and extremely harsh physical and environmental conditions. Similarly, since a substantive portion of the delta lies outside the political and administrative boundaries of India, this region too is not taken into account while planning for impact-mitigation due to climate change, disaster management, pollution control, flood control and sustainable development of the Ganga basin. Further, this approach would enable the assessment of the cumulative impact of human interventions in the cryosphere and the delta, which have a bearing on the problems on the mainstream Ganga.

The significance of these two regions (Heads and Tails) lies in the fact that they greatly influence, and are, in turn, affected by the serious and still unresolved problems experienced in the central/middle regimes (from Dev Prayag to Farakka) of the Ganga River, such as dangerous levels of water pollution, rapidly dwindling mainstream flows, non-integrated and fragmented approach to planning, development, and management of water resources and neglect of the hydrological and ecological balance.

At the same time, other vexatious issues related to governance, such as inadequate and outdated formal bilateral agreements, lack of co-operation/co-ordination between the eleven Riparian states within India and between India-Nepal, India-Bangladesh etc., have led to an inordinate delay in the completion of projects. Therefore, another important objective of this study would be to advocate for mutually acceptable and beneficial solutions for the timely completion of projects , (e.g. hydro-power/irrigation projects on the Mahakali, Karnali and Kosi Rivers on the Indo-Nepal border; flood control and disaster management programs which affect both India and Bangladesh, co-ordinated efforts for conservation of biodiversity in the Sunderbans.

Our study commenced in May 2019, when we undertook a field-trip to Gangotri, Gomukh, and areas beyond Gomukh. While collating and integrating the information thus collected, and dovetailing it into the understanding gleaned from the reviewed literature, it was realized that, the cryosphere of Ganga and Yamuna river basins were critical for determining the extent and severity of impacts on midstream segment. Similarly, the inclusion and understanding of the cryosphere in Nepal is equally important for the understanding problems and finding possible solutions beyond the confluence of Rivers Ghagra and Ganga, especially, with regard to floods in Bihar and West Bengal and Bangladesh, and disasters associated with climate change. Therefore, in November 2019, we undertook another field-trip to Upper Bhote-Kosi River Basin in Nepal in order to get a better understanding of the cryosphere which lies in Nepal. During this trip, the interconnection between the physical environment and its impact on socio-economic dynamics in both these regions situated in the upper regime of Ganga's left bank tributaries, became abundantly clear to us.

In 2020, the Covid-19 pandemic completely disrupted our work schedule and caused our research team to disperse. In spite of this long hiatus of over two years, when further field trips or even research visits were not possible, we continued our study for another two and a half years, primarily relying on a vast amount of data available from secondary sources such as private research papers, historical records, reports from institutions like the Geological Survey of India (GSI), Zoological Survey of India (ZSI), India Water Resources Information System (WRIS), Wadia Institute of Himalayan Geology (WIHG), Indian Meteorological Department (IMD), etc. In addition we gathered data from several international institutions like World Glacier Monitoring Services (WGMS), Bangladesh Climate Change Strategic Action Plan (BCCSAP), Department of Electricity Development, Nepal (DEOD), International Water Management Institute (IWMI), International Center for Integrated Mountain Development (ICIMOD), and many others.

The data from these national and international institutions provided valuable information about the respective government policies and legal frameworks and the official position taken by them with regard to the larger Ganga River Basin. A rather disturbing revelation was that the data sets and the derived quantitative values varied significantly from institution to institution and country to country, thus highlighting the need for an integrated and holistic perspective involving inter-state, regional and transboundary international collaboration for conducting scientific studies of the Ganga River Basin, and promoting multilateral co-operation and co-ordination while developing its resources and dealing with the impact of climate change on its eco-systems and human population.

Our Report, as it stands, contributes to a broader understanding of the Ganga River Basin, and attempts to fill the knowledge gap with regard to the upper, middle and lower regimes of the Ganga. It also describes in detail how each of the three segments is inter-related and inter dependent. In addition, the second half of the Report describes how the socio-economic changes/developments have in turn impacted the cryosphere, and led to an aggravation of glacier recession and disintegration of the cryosphere, thus compromising its ability to provide eco-system services so essential for maintaining the qualitative and quantitative health of the middle segment. This reciprocal relationship has been highlighted.

Even though the Report does not claim to be exhaustive, it deals with practically all the important and critical aspects of the Ganga River Basin. It offers a broad and deep perspective of the river basin for both the lay reader and subject experts, avoiding technical jargon and clarifying concepts through foot notes. It has been our aim to focus on scientific and verifiable facts. The cultural context and mythological beliefs have been described and woven into the narration wherever appropriate.

Conclusions and recommendations for govt. depts/institutions and policy makers, public and private enterprises have been given at the end of each chapter, with the objective of plugging knowledge gaps, rectifying past or present errors, modifying and contemporizing the policies and legal framework. In the case of climate change impact, our approach has been to describe the primary impact on the cryosphere, and then analyze the sequence of impacts downstream, up to the mouth of the river, with recommendations for solutions and actions, not only for the current problems, but also for problems which may emerge in the foreseeable future.

The first 6 chapters give a detailed description of the hydrosphere, cryosphere, and biosphere in the Upper Ganga Basin and their impact on the downstream river regime. The remaining 7 chapters describe the changes taking place in the mainstream regimes due to human interventions. Chapters 7 to 12 analyse current governance and management systems in the river basin, showing how distorted priorities have jeopardized the state of the river regime, thus leading to major disasters. The last chapter has been devoted entirely to the Bengal Delta (Tails) where the Ganga exits into the Bay of Bengal.

This Report also highlights the significance of the transboundary nature of the Ganga River Basin. Even though 80% of it lies within India, and provides us with 60% of its water, need to recognise that any interventions and actions in segments of the river within India, will affect the river regimes lying within other countries and vice versa. Therefore, chapters one, two and three describe the inter-related hydrological links with Nepal and Bangladesh and the need to keep in mind international conventions, transboundary river basin policies, and the rights of other countries while planning the development of Ganga's water.

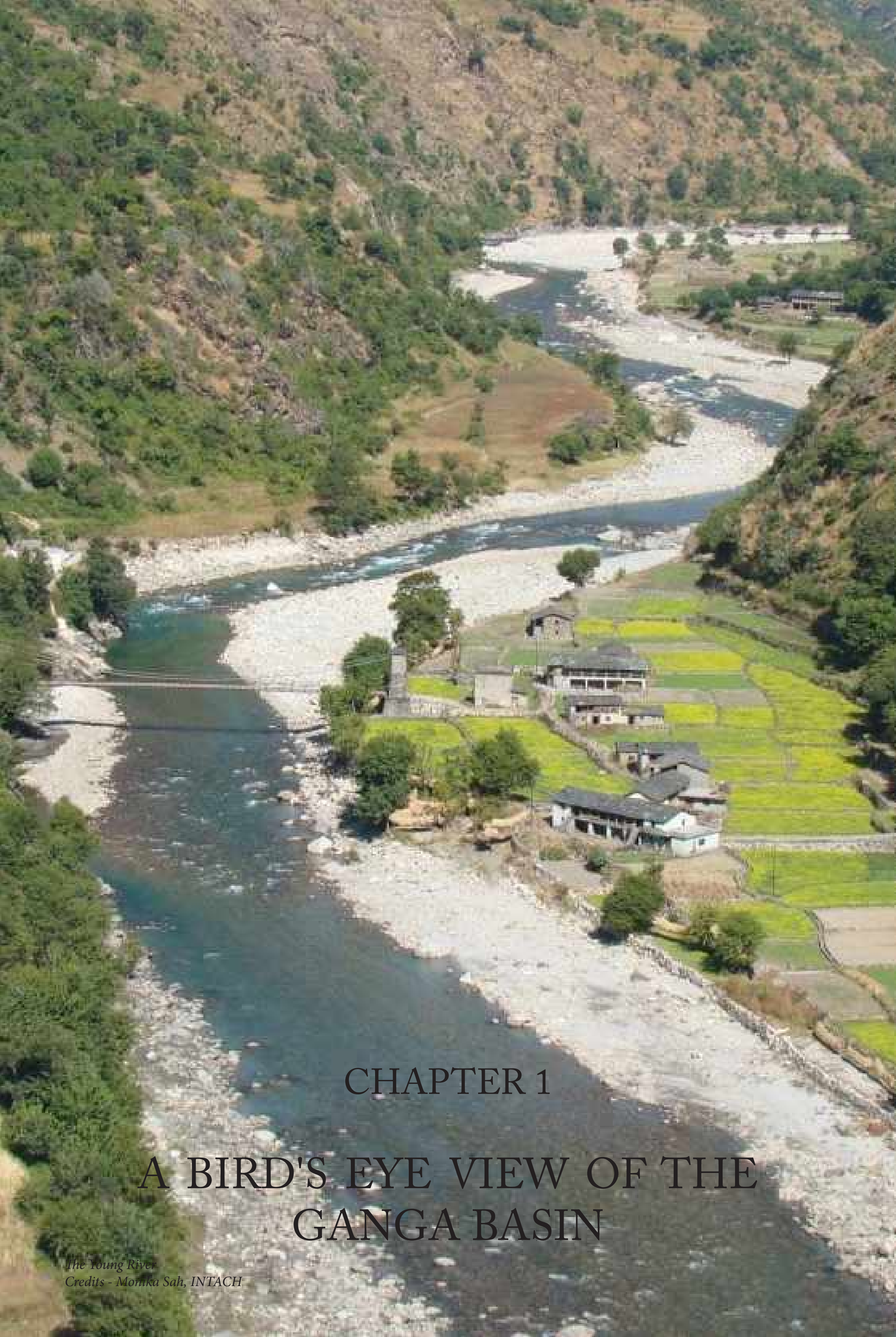
In view of the vastness and trans-national nature of the Ganga River Basin is spread over a vast area, 7 geo-referenced maps have been prepared for the segments in India, Nepal, Bhutan and Bangladesh.

It is hoped that this study will lead to a more inclusive, integrated and holistic approach to River Basin Management and show the path for changing the orientation of our management policies, organizational structure, governance, inter-state agreements and those with other riparian countries.

Further, it is hoped that it will correctly and effectively address the two major pressing problems that India is currently facing in relation to the Ganga River, and for which very large financial allocations have been made over the last four decades: namely, heavy pollution in the middle regime, seriously compromising the purity of the Ganga River (*nirmalta*), and an alarming decrease in water flows leading to a decrease in perennial flows of the river (*aviralta*). These are the two problems which need to be solved immediately, for which we feel our holistic approach would be valuable in removing roadblocks like the lack of sufficient data about natural and social factors affecting the quality and flow of the Ganga River, lack of multi-agency and multi-state co-ordination and community involvement.

So far, the fragmented and often parochial and top-down approach has proved to be ineffective in combating the adverse effects of Climate Change. This study offers more effective coping mechanisms and more benign, eco-centric and people-centric solutions for managing water resources and handling natural catastrophes in the Ganga River Basin.

And finally, it is hoped that the larger objective of formulating an 'inclusive, integrated and sustainable trans-boundary Master Plan' for all riparian countries and communities within the Ganga River Basin can be achieved, and possibly serve as a model for other river basins in India and Asia as well.



CHAPTER 1

A BIRD'S EYE VIEW OF THE GANGA BASIN

The Young River
Credits - Monika Sah, INTACH

1.1 INTRODUCTION

Ganga is undoubtedly the most enigmatic and revered river in India. For centuries, it has been the life-line of millions of people living along its banks. In addition to pollution, several issues have emerged in recent times, such as, water availability, management of flood waters, conservation of ecological flows and eco-systems, identification and protection of origins, the interdependence with riparian communities, its transboundary linkages with other rivers and various political entities, and myriad other issues. This study focuses these inter- dependencies and analyses them in the context of the current discourse on hydrological, ecological, cultural, and geo-political aspects of exploitation of water resources.

This Report attempts to elaborate primarily on what the author feels are the least understood aspects of the Ganga River Basin, namely the Cryosphere (the 'Heads') in the Central Himalaya and the Delta (the 'Tails') located in the erstwhile Bengal Delta. In addition, the report deals with the socio-environmental impacts of climate change on the river system, and especially on the communities living all along its banks. Further, the report looks at the short and medium - term impacts on the seasonality and variability of the riverine hydrology. In this opening chapter, therefore, we have taken a bird's eye view of the unique physical and morphological characteristics, the socio-economic interrelationships, the ecological diversity, and the interdependence and linkages between these important aspects of the Ganga River and its basin.

1.2. IMPORTANT FEATURES OF THE GANGA

1.2.1 Area and Water Yield

The Ganga River System forms one of the major river basins in the world, covering an area of 10,87,852 sq.km. Being a transboundary river basin, the Ganga Basin jointly belongs to four different riparian countries, which represent a great diversity in their political, economic, social, and ecological circumstances. Even though a major part of the basin lies in India, this transboundary nature of the Ganga River cannot be ignored. Although the Ganga was declared the National River of India on the 4th of November, 2008, the geopolitical reality, and the laws on transboundary rivers must be kept in mind while formulating policies and negotiating international treaties. Since she symbolizes the vastness and diversity of the nation in both physiographical and metaphorical terms, this Report represents the Ganga as a "river-beyond-borders".

Table 1.1 Country-wise Area and Water Share Contribution in Ganga River Basin

Country	Area (Sq. km)	Area (%)	Water-Share contribution (%)
India	8,61,452	80	54
Nepal	1,47,100	13	40
Bangladesh	46,300	4	5
Tibet	33,000	3	1
Total	**10,87,852**	**100**	**100**

Source: Based on CWC 2014, FAO Water Report No. 37 and Water Resources of Nepal in the Context of Climate Change, Water and Energy Secretariat, 2011 (Aryal & Rajkarnikar)

The water yield of Ganga is 525 Billion Cubic Meters (BCM) per year. However, it needs to be appreciated that about 40% (i.e., 226 BCM) of Ganga's water comes from Nepal through Ghaghara, Kali-Gandaki and Sapta Kosi rivers. In fact, out of this 40%, a considerable flow originates in Tibet, in the uppermost catchments of Sapta Kosi as per FAO Water Report No. 37 and Water Resources of Nepal in the Context of Climate Change, Water and Energy Secretariat, 2011*(Aryal & Rajkarnikar, 2011)*. Similarly, what is not widely known, is that the northernmost catchment of Kali-Karnali in Nepal lies in Tibet, and further, that a small portion of the upper Ganga (Gangotri Region), in the form of Jadhaganga and her tributaries, namely, Rongmach, Mana, Ghora, and Nilapani, have their origin in Tibet!

1.2.2 Ganga: A Young and Dynamic River

Another unique and unknown characteristic of the Ganga is that the river is in its geological youth and is still evolving and changing due to a series of river-migrations, technically known as avulsions. Due to this dynamic character, and the fact that the Ganga is among the last few rivers to be created on the Indian sub-continent, geologists consider her to be a very young, evolving river, unlike all other peninsular rivers, which are millions of years older than Ganga. For example, a significant avulsion is believed to have taken place about 5000 to 6000 years ago, due to a major earthquake, described by geologists as a major tectonic event which substantially changed the morphology of the western Ganga Basin. This was mainly because the Yamuna River, which at that time travelled towards the west to join the river Sindhu, gradually migrated towards the east to meet Ganga on her right bank. The confluence of Ganga and Yamuna was considered as a divine event in ancient times, and thereafter a large town called 'Prayag' came into existence.[1]

1.2.3 Length of Ganga River

When the mouth of the river is considered to be at the Gangasagar Island, located south of Kolkata in West Bengal, the total length of the river is estimated to be about 2,525 km (India- WRIS, 2021). However, as discussed above, the main flow of the Ganga currently does not discharge into the Hooghly, but flows directly into the Brahmaputra mainstream as Padma River and then continues till the Bhola Island where it finally discharges into the Bay of Bengal. Thus , if we consider the length of the Ganga from Gomukh to her confluence with Brahmaputra in Bangladesh, it is estimated to be 2,388 km *(Verma et al., 2014)*. Further, from the confluence of Ganga and Brahmaputra to the Bay of Bengal at Bhola Island, the distance is approximately 228 km;[2] and therefore, the total length of Ganga adds up to 2,616 km (elaborated in Chapter 2).

1.2.4 World's Loftiest Mountains And Deepest Gorges

The world's deepest gorges, the Kali Gandaki Gorge, also known as the Andha Galchi or Thak Khola Gorge also lie in the Ganga Basin. Near the northern border of Nepal and south of Tibet stand the great sentinels of Himalaya. The tallest of them all was known as Chomolungma (meaning mother Goddess of the world in Tibetan language), and Sagarmatha (the forehead of king Sagar) or Mt. Everest as we know it. The Sherpas, who reside in its vicinity, perceive it as the protector of all Sherpa people. In 1856, when the British surveyor Andrew Waugh topographically mapped the Central Himalaya, he declared Chomolungma to be the highest peak in the world standing at an elevation of 8840 meters. Later, the Survey of India recalculated its height as 8848 meters amsl (29,029 ft. amsl). Interestingly, of the twenty highest peaks in the world, thirteen are located on the northern Himalayan ridge of the Ganga River Basin, while the remaining seven are in the Karakoram ranges of the Himalaya within the (Indus) Sindhu Basin. Besides Mt. Everest, there are twelve other peaks which are all higher than 7500 m amsl (or higher than 25000 ft. amsl): Mt. Kangchendzonga, Mt. Lhotse, Mt. Makalu, Mt. Cho Oyu, Mt. Dhaulagiri I, Mt. Manasalu, Mt. Annapurna I, Mt. Shishapangma, Mt. Gyanchung Kang, Mt. Annapurna II, Mt. Himalchuli.

Mt. Nuptse, named after the Thakali community, has a height of 5571 meters from the deepest river-bed level. The Tsangpo Gorge, also known as the Yarlung Tsangpo Grand Canyon, lies in the Tibet Autonomous Region of China and is the deepest gorge on the Brahmaputra, lying within the Ganga-Brahmaputra-Meghna (GBM) Basin. It may be emphasized that in comparison to these gorges, the immensely popular Colorado Grand Canyon in USA is only 1800 meters deep. Kali Gandaki Gorge and the Brahmaputra Gorge are gaining popularity as tourist destinations.

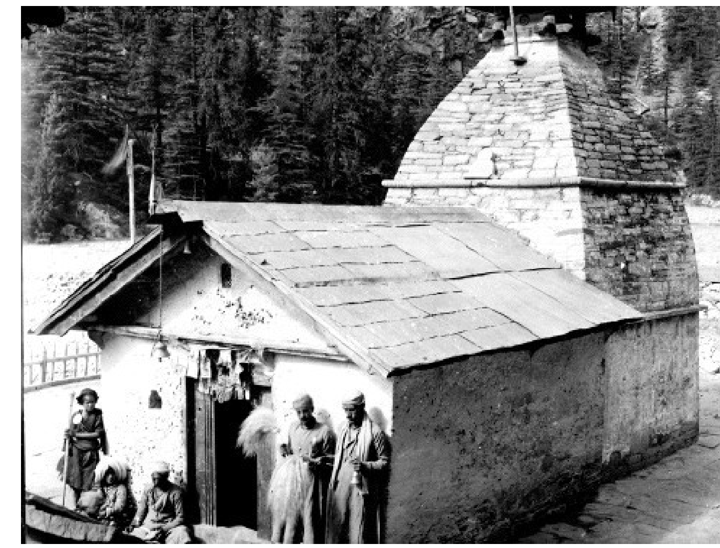
1.2.5 Hydrological Origin of Ganga River and Cultural Beliefs

While it is generally accepted that the Ganga originates at Gomukh (16 km. upstream of Gangotri), there is an equally strong belief that Ganga actually emanates from Mt. Kailash, the abode of Shiva and Kali. Rivers emanating from Manasarovar Lake, like the Indus, Brahmaputra, Kali Karnali, Kali Gandki, Irrawadi (which flows into Myanmar) and others all represent splinters of the Ganga, known in Hindu mythology as the fragments of the river Ganga after she leapt to the earth from Shiva's hair-locks, forming 10 major rivers and a multitude of smaller ones.

1.2.6 Gomukh or Gangotri: Which is the true origin of the Ganga?

Historically, Gomukh, the origin of the Bhagirathi River and the snout of the Gangotri Glacier must have been at the same place, that is, at the current location of the Gangotri temple, a place identified as a sacred site in the Chardham yatra designed by Adi Shankaracharya around 8th century CE. However, due to glacial recession over the last 1200 years, the origin of the river has shifted about 16 km. upstream. Today, only few a travellers go up to Gomukh, the actual place of origin, while others visit the temple at Gangotri, thus demonstrating that the cultural belief has remain unchanged, despite the changing morphology of Ganga's origin. Similarly, Hindus also consider Mt. Kailash to be the cultural origin of Ganga, since it is considered to be the abode of Lord Shiva and the central axis of the world - *Merudanda*.

Although most *yatras* still end at Gangotri, this did not become a major site for pilgrimages until the latter part of the 20th century. Swami Sundaranand, a yogi and author of 'Himalaya: Through the Lens of a Sadhu' states that: "About seventy years ago, only around five to six thousand pilgrims visited Gangotri each year and that only four or five sadhus remained there in winter. They lived alone in their caves and occasionally went to meet one another." The Gangotri temple was built around the beginning of 18th century by the Nepalese General, Amar Singh Thapa, and rebuilt in the 20th century by the Maharaja of Jaipur.

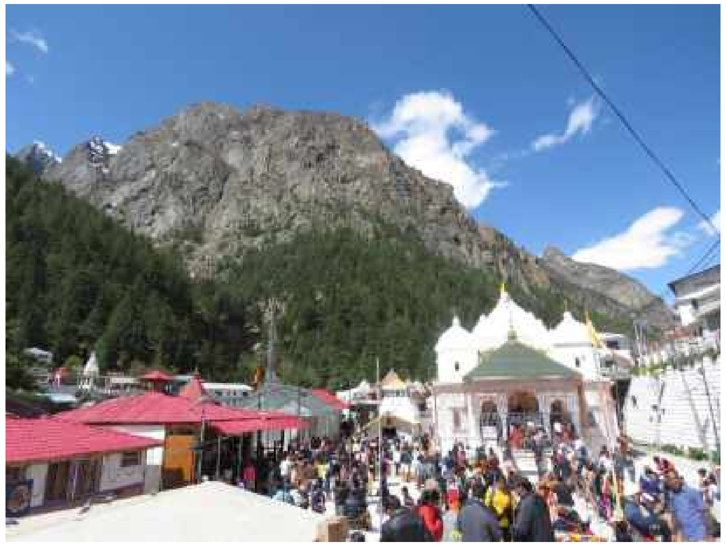


Photograph of the (old) Gangotri Temple in 1883
(Source: Geological Survey of India, 2013)

Thus, the beliefs about the origin of the Ganga change in different contexts (geo-morphological, mythological, philosophical, geo-political etc.) and over different periods of time. All these systems are interlinked through surface and sub-surface flows, while the political borders are recent.

"It matters little, O Mother Ganga, whether you originate at Vishnu's big toe or at Sri Gomukha… the fact remains that Ganga is Ganga. O Mother, thou art the Supreme Mistress of all the world" (Sundaranand, 2001).

Similarly, the names of rivers and mountains also reflect the changing natural landscape and the perceptions of communities over several thousand years. The ancient and traditional perceptions of the Ganga River System, anecdotal history of peaks, glaciers, springs, lakes, places of eminence having bio-physical and cultural value all stem in the vernacular and local histories about these physical entities. The original intention behind elaborate stories in epics like Ramayana, Mahabharat and the Puranas must have been to explain the physical or geographical form of the locations and events which they described. This was meant to simplify the complexities of the geo-physical forms of the Himalaya and rivers emanating from it, especially since the origins and environmental conditions were too remote and harsh for people other than ascetics and sages to physically visit.



New Gangotri Temple rebuilt by the Maharaja of Jaipur in the 20th century
(Photo:Vijay Paranjpye, 2019)

In order to get a holistic and integrated understanding of the Ganga River Basin, one must weave together the cultural strands and the physical aspects of the Ganga River System and look at them in the contemporary socio-economic scenario. The association of these physical or geographical formations with abstract entities helps us in appreciating the perception of rivers during ancient times.

Considering the mountain-top to be Shiva's abode, the names of all the geographical features at the origin of the Ganga River are associated with Lord Shiva. The location from which water emerges from the Gangotri glacier is called 'Gomukh' (cow's mouth[3]), the peak that is due east of Gomukh was named Shivling. Though the Shivling is not the highest peak in the region, it is considered important because of the striking features of the mountain which are very similar to the shape of a *linga*.[4]

Further, it is believed that the hydraulic power and energy of the Ganga would have been too much for the Earth to bear, and therefore, it was held back in Shiva's locks and dispersed through a large number of tributaries in order to transform Ganga's fury into several benevolent streams. The mythological story speaks about how King Bhagirath guided Ganga across the Indian subcontinent, thus providing relief to humans and other life forms on earth.

As a symbolic representation of this myth, most of the mountain tops and forests which are the sources of origin of rivers are considered to be the '*Shankar-jata*' (matted locks of Lord Shiva's hair), and are therefore considered to be sacred groves (devban, devrai, oran, etc). Besides reducing the hydrologic energy of the flowing water, these forests also induce higher rates of water infiltration and reduction in rate of water runoff.

Similarly, almost all rivers in India have a Shiva temple followed by a cascade of water tanks. Water from the spring comes in a small trickle which falls on the *linga* representing Lord Shiva, and then it flows through a series of tanks meant for drinking water, other human uses, drinking water for animals, and then finally released into the forests, representing the rights of all life forms over water.[5]

The different glaciers and peaks surrounding Gangotri glacier are also associated with mythological characters in different epics, such as Bhrighupanth bamak[6], Kalindi bamak (Kalindi is the daughter of Sun God and also the Sanskrit name of Yamuna River), Vasuki peak (Vasuki was the second king of the serpents in Hindu religion), Chaukhamba peak which refers to four peaks which represent the four cardinal directions in Hindu mythology. Further, Dronagiri (refers to Dronacharya, the royal preceptor of the Kauravas and the Pandavas in the epic, Mahabharat) in Nanda Devi National Park. References to the epic Ramayana are found in the name of mountain range, the Banderpoonch mountains which refers to Lord Hanuman, the monkey god. There is also a mountain range known as Mahalangur in Nepal, literally meaning the great monkey.[7]

Different tributaries of the river flowing through Himachal Pradesh and Uttarakhand also have their own regional myths and anecdotes. The Himalaya (*Nagadhiraja*), represents the King and father of Goddess Parvati, the consort of Shiva, who is also known as Kali, the ferocious one. Hence, the name Mahakali was associated with the untameable, wild flowing river on the Indo - Nepal border. When the Mahakali River flows through the plains and becomes a gentle flowing river, she is known as Sharada, representing the gentle, benevolent goddess in the Hindu pantheon. Sharada is another name for Goddess Saraswati. While most of the rivers are named after feminine characters, Brahmaputra is the exception which represents the son (*putra*) of Lord Brahma and therefore defines the masculine character of the larger sub-stream in the GBM basin.

These mythological stories and epics were probably a way of demystifying and explaining the complex geological and hydrological features of the region and a symbolic representation of the actual physical geography. This may provide an insight into why India became part of the multilateral and multi- institutional initiative for demarcation and governance of the Kailash Sacred Landscape (KSL) Conservation and Development Initiative.

1.2.7 Importance of Pilgrimages and Yatras

While mythological stories and epics help to understand the origin of the river, and the landscape around them, the pilgrim routes, Chardham Yatras[8] were designed for people to walk along the river upstream, enabling them to reinterpret and rediscover the significance of the different river basins woven into the folklore and epics. The Chhoti Chardham Yatra begins from different cities and towns located in the middle regime or lower regime of Ganga. Pilgrims originally walked the entire distance right up to the four final destinations, namely Yamnotri, Gangotri, Kedarnath and Badrinath. Besides yatras like Kanwar Yatra, and the Kumbh Melas, etc. there is the well-established yatra to the Gangasagar Island in West Bengal, near the mouth of the river, which is believed to have commenced when the original temple of Kapil Muni was built in 437 AD.

These Yatras were designed to develop a holistic understanding of the river basin in all its forms - from extreme fury, to life-sustaining benevolence (*Jeevan Dayeeni*). Those who completed the Yatras were considered to be wise, learned and knowledgeable because they had experienced and learnt the languages, cultures, crops, dialects, social values and belief- systems of different communities, developed broader perceptions about the variety of natural landscapes, forests, water bodies and their relationship with flora, fauna and human communities along the route of pilgrimage. Thus, the yatras, if performed as they were originally conceived, would be in fact beneficial in gaining a broad spectrum understanding of the Ganga River Basin.

1.2.8 Prayag as a Generic Concept

The Ganga River is considered to be magnificent and great, not only because she carries a massive volume of 525 BCM of water to feed a human population of 650 million people in India, Nepal and Bangladesh, but because hundreds of rivers which flow into her have their confluence (*Prayag*) along her course, bringing together waters which have flown through diverse valleys containing a huge consortium of elemental metals, and organic compounds secreted by the flora and fauna residing in these catchments. Both figuratively and literally, the rivers offer each other different elements and substances, thereby increasing and elevating the synergy at Prayag. In addition, the confluence creates a grid-network which enables the smooth flow and intermingling of cultural heritage, linguistic diversity, and historical experiences, culminating into a vibrant and organic lifestyle, which is still the reality of modern India.

In geographic terms, 'Devprayag' is considered to be the most important confluence between two major head-streams, the Bhagirathi and Alaknanda rivers, which formally creates the mainstream known as Ganga. Upstream of Devprayag there are four other lesser-known confluences, namely, Nandaprayag, Karnaprayag, Rudraprayag, Vishnuprayag, where the rivers Nandakini, Mandakini, Dhauliganga and Pindar have their independent confluences with Alaknanda River. Each of these five are treated as a *Tirthakshetra* or divine locations of pilgrimage in Hindu mythology.

Similarly, the city of Allahabad at the confluence of Ganga and Yamuna was known as Prayag prior to the Mughal period (today renamed as Prayagraj). It was commonly accepted that various sub-cultures co-existed in harmony for several centuries, creating a synthesis (Prayag) of religious thought, music, cuisines, and literary traditions.

1.2.9 All Rivers are 'Ganga'!

Besides being the name of the longest and largest river in India, Ganga is figuratively a profound concept. Conceptually, Ganga is a generic term, - in Sanskrit meaning 'to flow' and in Boro language meaning 'to quench thirst.' It represents the flow of all rivers and is often used for describing any pure and inspired flow of music, thought, and scriptures of Saints in vernacular literature.

As is well known, there are several rivers in India (even within Ganga River Basin) which have the suffix or prefix 'Ganga' in their names, e.g., Gangabari, Luptaganga, Dudhganga, Kishenganga in Kashmir; Gangavali in Karnataka; Damanganga in Gujarat; Painganga, Baanganga and Pataalgangain Maharashtra. Similarly, Wainganga which emanates from Madhya Pradesh, is the largest contributory of Godavari also called the 'Vriddha Ganga' or 'Dakshinganga' when she flows through Andhra and Telangana. This tradition is practiced right down to Sri Lanka, where the principal river is Mahaveliganga.

Additionally, it is well-known that the ancient name for the Bay of Bengal was Gangasagar, i.e., the ocean fed and created by the waters of the Ganga.

Ganga -A Generic Name
(Courtesy : Vijay Paranjpye, 2017)

The ancient mainstream of the tail reaches of the Ganga, the Bhagirathi-Hooghly is about 260 km. in length, originating in the district of Murshidabad in West Bengal, India. Since this was the flow of the stream for the entire prehistoric and historical period of several thousand years, the Bhagirathi-Hooghly, known as Adi Ganga was engraved in socio-cultural and historical perceptions as the end point of the Ganga River.

Therefore, when we take on the task of creating an *aviral* and *nirmal* Ganga, the lesson to be learnt from this expanded perception of Ganga is that we must bear in mind the full implication of the venture, that is, accept the responsibility of keeping Ganga *aviral* (flowing incessantly) and *nirmal* (pure). This implies that we have accepted the responsibility of keeping all rivers in India and its neighbouring countries clean and flowing! All these instances illustrate the fact that the concept of river basin goes beyond existing political boundaries and anthropocentric understanding.

1.3 SOURCES OF GANGA WATERS: CRYOSPHERE WATER TOWERS, GROUNDWATER (DEEP AQUIFERS) AND SURFACE FLOWS

Ganga is the only river system in India, which has three sources of water, namely, (a) the huge stock of water stored in the glaciers (ice), snow-capped mountains (water towers) and permafrost, accumulated over millennia, (b) the enormous groundwater aquifers which are spread under the sub-soil layers as mega-groundwater-aquifers (*Jala-Bhandaars*) within the vast Indo-Gangetic plains, and (c) the summer and winter monsoon clouds, which annually precipitate and flow through an enormous network of streams, rivulets, and rivers carrying surface water through thousands of small and large perennial streams (*Aviral dhara*).

These three hydrological sources are described in Indian philosophy through the concept of '*Tripathaga*' - literally meaning '*tripatha*' - three roads, and '*gā*' - who goes, in this case 'flows'. Near the source of origin of Ganga i.e., at Gomukh, the first relatively minor river which comes down from Mt. Shivlinga is called Akashganga. The terrestrial river which flows on the surface is called Ganga and the third river called Patalganga represents the sub-surface flow (currently a tributary of the Alaknanda River), thus completing the entire hydrological cycle (Trinity).

This makes the conjunctive use of the 'stocks' and 'flows' of Ganga amenable to optimal management for simultaneously satisfying the needs of nature and those of almost 650 million people residing in the river basin.

1.4 RIGGING UP 'THE GANGA WATER MACHINE'

The concept of conjunctive water use is not new. In the United States, the idea has been in practice over a hundred years in the arid states of Ohio, California, Colorado, and other water-scarce areas. In India, the idea was brought into focus through a seminal paper entitled, "The Ganges Water Machine" which was published in the prestigious American journal, 'Science,' on 9th of May 1975, vol. 188, pg. 611 to 616; and authored by Roger Revelle and V. Laxminarayana. The authors demonstrated that a carefully designed but simple method of augmenting underground storages of water along the Ganga and its major tributaries could lead to a dramatically better use of the region's groundwater resources, substantially increase food output, and considerably reduce the severity of droughts and floods. The measures suggested for groundwater recharge were:

a. spreading flood waters in the Terai region,

b. constructing bunds at right angles to the flow-lines of smaller rivers and rivulets, especially close to uncultivated fields for increasing infiltration

c. pumping out the groundwater from aquifers during the dry season for summer crops, thus creating space for groundwater recharge during monsoons,

d. utilizing the groundwater along canals which experience huge seepages and leakages.

Unfortunately, this simple but effective idea has not found much support among irrigation engineers or legislators of concerned states (mainly Madhya Pradesh and Uttar Pradesh), perhaps because it does not involve expensive and grandiose infrastructure projects like dams and barrages *(Acciavatti, 2015)*.

The special character of the triple water sources of the Ganga and the great size of its river basin area of 10,86,000 sq.km. makes it one of the largest single fresh water bodies in the world, where the sedimentary layers below the erstwhile Sea of Tethys have created an impervious layer. The annual sustainable recharge and discharge volume is estimated to vary between 59 BCM per year to a maximum of about 124 BCM, which could, in principle, satisfy the unmet demand of water that exists today. However, the caveat for achieving this goal is the existence of an Indo-Bangladeshi agreement on the cooperative and integrated use of water for satisfying the unmet demands. Reaching such an agreement will require negotiations between the two countries for investing in a well- planned infrastructure for establishing a system of groundwater recharge during the floods (June to October), and a well-planned implementation of pre-determined cropping pattern, suitable for utilizing the stored water during the winter and summer months.

The Bangladeshi riparian region downstream of the Ganga has a large net cropped area, which is irrigated by groundwater. And contrary to general perception, these areas which face severe droughts and scarcity in summer months (Aman-season: July to November and Boro-season: December to May) in Bangladesh, do have the potential to increase its water use by up to 4.8 BMC per year.

A similar exercise could be carried out for Indian basins like Middle Yamuna, Banas, and Lower Chambal, which have little or no water resources to realize the estimated irrigation potential in future. Similarly, Ramganga, Upper Chambal, Kali Sindh, and the up-stream areas of Gomti also have the opportunity of using additional groundwater, albeit to a moderate extent. In addition, some areas in lower Ghaghra, Son, the doabs between Ghaghra, Gomti and Tons also have a moderate potential for increasing groundwater use. In total, the overall potential for increasing the groundwater use within the Indian segment of Ganga Basin is estimated to be 45 BMC to 84 BMC per year.

To sum-up, if we could rig-up the Ganga Water Machine, it would be possible to make

Fig. (a): Ganga rock figurine at Ellora Cave No. 21
Fig. (b) Ganga at the National Museum (Ahicchhatra) (Deglurkar, 2017)
Note the vessel of water held aloft by Ganga

the greater Ganga River Basin resilient to the impact of Climate Change and also sustain food-security during the next few decades.

In recent years, the idea of reviving the potential of the Ganga Water Machine was substantially expanded by Upali Ananda Amarsinghe, Lal Muthuwatta, Lagudu Suri Naidu, Sumit Anand and Sharad Kumar Jain from the International Water Management Institute (IWMI), Sri Lanka; National Geo-Physical Research Institute (NGRI), Hyderabad, and National Institute of Hydrology (NIH), Roorkee. In their paper entitled 'Reviving the Ganges Water Machine', published by Hydrology and Earth System Sciences, in 2016, the focus was on the use of Sub-Surface Storages (SSS) and the acceleration of surface, sub-surface water exchange. (Amarasinghe et al., 2016).

Bas-relief of Ganga Avataran at Mahabalipuram, Tamil Nadu *(Deglurkar, 2017)*

1.5 SIGNIFICANCE OF THE TITLE: 'HEADS' AND 'TAILS' OF GANGA

The headwater streams and major tributaries of the Ganga are not located merely around its origin in Uttarakhand, but are actually spread across the broad band of Central Himalaya, consisting of the upper regimes of Yamuna, Ganga (India), Mahakali (India and Nepal), Karnali, Gandaki, and Sapta Kosi (Nepal). These mountain ranges, lying within the Central Himalaya take the metaphorical shape of the hood of the mythological serpent, Shesha Naag[9] which blocks the south-westerly clouds during the monsoons, resulting in copious flowing pulse in the major tributaries of the mainstream Ganga on her right bank, an area stretching from Banderpoonch range, (i.e., origins of Yamuna River), up to the Kangchendzonga ridgeline on the border of Nepal and Sikkim[10], lying in the Cryosphere region. These major tributaries and scores of other minor tributaries form the ''water towers or the 'Heads' of the Ganga.

Like the 'heads', the 'tail-end' reaches of the Ganga River, unlike many other rivers, are not just located at a specific location but have been shifting over a considerable period of time. There have been a series of changes in the tail reaches of this river system as the delta is still evolving, leading to one of the most dynamic configurations of deltas in the world. What is not commonly known is the fact that till about 250 years ago, Ganga and Brahmaputra were independent and discrete river basins, with two well separated exit points, which discharged their water into the Bay of Bengal. However, between 1776 and 1787, the mainstream Ganga migrated to the east, while the Brahmaputra migrated towards the west, consequently creating a confluence of the two rivers in Rajbari district in Bangladesh, and then travelling together southwards for about 250 kms, taking along the waters of the Meghna River. The three rivers eventually travel together as a single mammoth stream to exit into the Bay of Bengal.

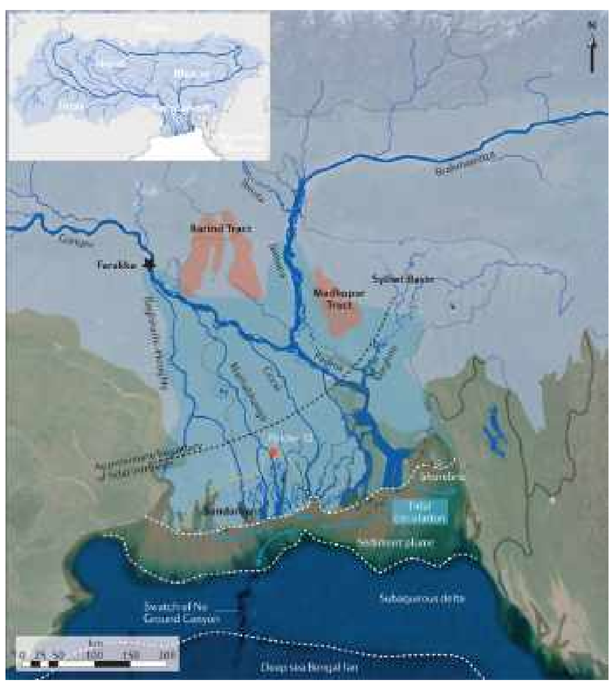
Around the same time, the Teesta River, emerging from Kangchendzonga (Sikkim), migrated from Ganga to Brahmaputra. Teesta originally flowed south from Sikkim and joined Ganga, but due to a tectonic event combined with a mega-flood, the river suddenly shifted her course eastwards, where she created a new confluence with the Brahmaputra at Phulchhari Upazila in Bangladesh (these avulsions are elaborated in Chapter 2). Incidentally, the traditional name of the Bay of Bengal was Gangasagar, i.e., the sea which receives the waters of Ganga.[11] These rivers form multiple minor distributaries and keep merging and braiding periodically, hence, the allegory of the 'tail' which swings and swishes from east to west and west to east. Therefore, the 'tails' of the Ganga consist of the entire deltaic region spread over parts of West Bengal in India and the entire region of Bangladesh from the Gangasagar Island to the west and the Bhola Island to the east.

This Deltaic region, also known as the 'Bengal Delta' or GBM Delta has the distinction of being the largest Delta created by any river system in the world. It spreads across an area of 1,05,641 sq.km., of which two-thirds is in Bangladesh and one-third is in India. The Bengal Delta is in fact, the combined area of the Ganga, Brahmaputra and Meghna deltas put together. In the case of the Ganga River, a large number of tributaries contribute to the main stem till the river reaches the northern limits of the Murshidabad district in West Bengal, India, where the main stem starts its dispersion or attrition from the Farakka barrage. Therefore, according to our study, the tails of Ganga River begin from this first attrition point where a tiny flow is diverted to the south in the form of Bhagirathi-Hooghly through the artificial feeder canal; while the predominant flow of the Ganga (well over 90%) proceeds east as the Padma River into Bangladesh where it meets the Brahmaputra (known as Jamuna in Bangladesh) and later Meghna, and forms the Great GBM Mega-Delta (elaborated in Chapter 13). The question therefore arises, that when planning for the Ganga, should India not take the riparian nations on board?

The reason for making this bold statement is, that in practically all literature and maps about the Ganga, produced in India, the main stem of the river is shown to be cut off at the Bangladesh border and only the relatively tiny Bhagirathi-Hoogly is shown as the lowest regime of the Ganga flowing up to the Sagar Island where it exits into Gangasagar (Bay of Bengal). Such depictions create a morphologically false impression that the Ganga finally exits at Sagar Island in West Bengal and not in Bangladesh where the enormous main stem of the Ganga continues to flow for another 300 km at least.

1.6 GANGA-BRAHMAPUTRA-MEGHNA (GBM) BASIN: TRANSBOUNDARY AND GEO- POLITICAL SIGNIFICANCE

From the Heads to the Tails i.e., from the Cryosphere to the Delta, this entire river system forms the larger Ganga-Brahmaputra-Meghna (GBM) River Basin. The GBM River Basin covers a geographical area of about 1.745 million sq. km in India, Nepal, Bangladesh, Tibet and Bhutan (as Drangme Chhu or Manas River, Wang Chhu, Torsa Chhu and other rivers join Brahmaputra). The combined discharge of GBM has been estimated to be 1,38,700 cumecs, which makes it the third largest sweet water outlet in the world, after the Amazon and Congo in South America and Africa respectively *(Chowdhury & Ward, 2004)*. Of the total volume, the independent annual average yield of Brahmaputra is 537.24 km³ (making it the largest of the three), that of Ganga is 525.20 km³ and that of Meghna is 48.36 km³. Thus, the total yield of GBM is 1110.80 km³ (India-WRIS, 2012). To put it in context, the entire utilizable water of all the rivers including Ganga within Indian borders is 1123 km³ *(River Basin Atlas of India, CWC 2012)*. The map below provides the current geographical status of the three rivers.



Map 1.1 Geo-morphology of the GBM Delta *(Source: Paszkowski et al., 2021)*

Even though the Ganga, Brahmaputra and Meghna River Basins have very special characteristics of their own, the three together form one single transboundary river basin, since geo-hydrologically they converge into one large stream in the final stages. Further, even though the focus of this study is on the Cryosphere (Heads) and the Delta (Tails), the larger context of GBM cannot be lost sight of, because the climate change consequences emerge from, and are determined by, the Cryosphere of the GBM as a whole, and ultimately impact the tail-end reaches of the river system. In addition, an Integrated River Basin Management Approach for achieving sustainable development also requires an inclusive and holistic understanding of the Ganga, Brahmaputra and Meghna River Basins as a single entity.

Therefore, in order to understand the Heads and the Tails of the river it is important to develop a complete understanding of the larger river basin. As stated above, almost all the surface water from Nepal, amounting to about 225 billion cubic meters, flows into the Ganga mainly through four major rivers, and constitutes about 40% of the annual average flows. The contribution from Nepal can go up to 70% or more during the dry season, when the contribution from rainfall is relatively insignificant. It is important to highlight the fact that all this water which comes from Nepal is rich with nutrients and is practically unpolluted.

Table 1.2 Position of Ganga-Brahmaputra-Meghna Basin in the Global Context, taking 'Average-Water-Discharge' as the Criterion; Presented in a Descending Order

Sr. No	Continent	River	Length (km)	Drainage area (km²)	Average Water Discharge (m³/s)	Final Outflow
1	South America	Amazon	6,400	61,12,000	2,09,000	Atlantic Ocean
2	Africa	Congo (Zaire)	4,370	40,14,500	41,200	Atlantic Ocean
3	Asia	Ganga-Brahmaputra-Meghna	2,704	17,31,334	38,129	Bay of Bengal (Gangasagar)
4	South America	Orinoco	2,250	9,89,000	37,740	Atlantic Ocean
5	South America	Guainia / Negro	2,230	6,91,000	35,943	Amazon River

(Source: Lina, 2011; Lodrick & Nafis, 2021)

The moot point is, that unlike the origin and end of peninsular rivers, where our understanding of water dynamics is relatively better, we need to carry out serious and detailed studies of the Cryosphere, a unique natural heritage of enormous proportions. We (government agencies and civil society) appear to be unaware of the importance of this unique store of freshwater which gradually releases water in adequate quantities, which could satisfy not only our present needs, but also those of future generations. One must realise that such studies will essentially need to be collaborative projects between India, Tibet, Nepal, Bangladesh and Bhutan, and they will require a more honest and long-term cooperative approach rather than a short-term pecuniary rent-seeking one. It is thus clear that we cannot understand the Cryosphere by having research stations located only in the Indian part of the river basin.

In the tail-end reaches, a substantial portion of the flood waters and 40% of lean period flows from India enter Bangladesh. It must be noted that these discharges beyond the Farakka Barrage are loaded with sewage and toxic liquid effluents. It is in these floodplains beyond Farakka, that the flow of Ganga, known as Padma in Bangladesh, becomes sluggish. Therefore, besides the waters from Nepal, it is the rivers Brahmaputra and Meghna which maintain the unhindered continuity of the Ganga River System. Therefore, in the case of Bangladesh, the Ganga-Brahmaputra-Meghana (GBM) together form a single river basin. This is a rare scenario where three rivers meet; their waters intermingle and again spread out into numerous distributaries to form the GBM Delta. The river water, sea water and groundwater are all mixed together in the end-line region of this Delta, forming a unique ecosystem with an interface between the river and the sea waters. A large number of floodplain ecosystems and breeding grounds of birds and fishes are supported by this Delta (elaborated in Chapter 13). While it is obvious that cleaning up of the horrible mess we have created along the mainstream needs to be given top priority, we cannot afford to ignore the less publicised issues related to the rapid recession of the Cryosphere and the disastrous effects of pollution on the Delta. When the phenomenon of sea level rise is added to this scenario, the overall impact could be catastrophic.

1.6.1 Transboundary Nature of the River Reflected in Cultural Traditions

A holistic perspective of a river basin starts with broadening our understanding of its hydro-geological, political, economic as well as socio-cultural aspects. Every river follows a hydrological as well as an ecological succession. The physical characteristics of the river influence the ecological regime from the origin to the confluence with the sea. Both function in tandem, forming a vertical as well as horizontal integration throughout the flow of the river. Therefore, the idea of watershed development or river basin planning follows the logic of the stream flow, which needs to begin at the origin of the river and end towards the meeting point at the sea/ocean, in this case the Cryosphere and the Delta of the Ganga River.

The cultural or mythological beliefs and traditions do not necessarily match the hydrological principles, but they do shed a light upon the holistic nature of the basin, the interconnectedness and integrity of the basin as a whole, and the linkages between upstream and downstream regimes. Ancient epics, anecdotes, pilgrimages and *yatras* were one way of emphasizing this holistic path for understanding the entire river basin, as will be elaborated in the next few sections.

1.6.2 Kailash-Manasarovar: Cultural Beliefs and Modern Initiatives

Indian, Buddhist and Jain scriptures mention the Kailash-Manasarovar region as the origin of the Ganga. Spread over an area of 31,000 sq.km, this area represents the most sacred locations in Hindu, Buddhist and Jain mythology. It could not have been a simple coincidence that this place had become a congregation of five different religions – Jainism (1st Jain Tirthankar Rishabhnatha), Buddhism (Vajrayana Buddhists believe that Mount Kailash is the home of the Buddha Cakrasamvara - also known as Demchok in Tibet), Sikhism (Hemkund Lokpal Sahib), Hindu (practically entire Hindu pantheon) and the pre-Buddhist Bon (Shenrab Miwo), synergizing the centrality and divinity of Mt. Kailash as well as Manasarovar. It must be mentioned here that the Bon religion to which the Tibetans belonged, pre-dates the Buddhist period and includes several ethnic communities, which reside right up to distant Mongolia. This region includes the origin of several other south-Asian rivers, such as Sutlej, which drains into Sindhu; and Brahmaputra and Karnali, which eventually drain into the Ganga.

Map 1.2 Kailash Sacred Landscape
(Source: The Himalayan Climate and Water Atlas - Pravettoni, 2015)

Interestingly, the Kailash Sacred Landscape (KSL) was declared as a Cultural Heritage Zone by the UNESCO in the year 2012. At the behest of the Indian Government, the origin of Ganga (Gangotri and Gomukh) and some of the surrounding areas were also included in KSL. The cultural heritage landscape includes not only temples and monasteries but also lakes and mountain peaks, the pilgrimage path where the pilgrims circumambulate, and the *dharamshalas* where they reside during their pilgrimage. Initiated by ICIMOD and funded by BMZ (German Federal Ministry of Economic Cooperation and Development) from 2012 to 2017, this collaborative program, supported by UNEP and Global Resource Information Database (GRID), was implemented by a multi-institutional body which included representatives from China, India, and Nepal (See Chapter 12).

1.7 THE GANGA FROM 1770 ONWARDS

Today, many of these cultural symbols and perceptions have become irrelevant as the physical characteristics of the river have undergone changes due to rampant human interventions, pollution, and recent climate change impacts. For example, after the 1770s, the Bhagirathi-Hooghly River in the tail-end reaches started shrinking and the socio-cultural perception of Adi-Ganga and the geo-physical reality of the river became asynchronous. The virtual drying up of the river is often connected to her being artificially linked to the lower channel of the Saraswati (a distributary of Ganga River in the Delta)[12], whereby that became the main channel for ocean-going ships, as the original Adi-Ganga almost stopped flowing.

1.7.1 From Pristine Purity to Present Day Pollution

We see today that the original purpose of cultural anecdotes, symbolism, and sanctity of such pilgrimages and *yatras* is getting replaced by blind rituals, which are often misrepresented and converted into opportunities for commercial gain. One example of misconstrued socio-cultural perception is the belief that *'Ganga toh maili ho hi nahi sakti'*- Ganga can never be polluted because of her divine self-purifying character and one dip in the river or sight of river will take away all the sins. For example, the original purpose of Kumbh Mela was to enlighten the pilgrims on the need to never sin again, purify their minds and thought processes and remind them of their true path. Instead, it has become a license to keep adding sewage, chemicals, and plastic waste in the river system, all of which is overlooked due to the misconception that the Ganga's ability to purify sins (and toxins) is infinite. The reality however, is that humans have well surpassed the ecological limits of Ganga to internalize pollution.

1.7.2 From Reverence to Arrogance

The story of King Bhagirath who changed the course of the Ganga River and requested Ganga to turn south in order to be beneficent to all life forms. However, this story has today been misconstrued to justify acts like completely blocking/damming or diverting the

river through barrages. We forget that King Bhagirath's story is not about winning against the natural flow but about gently diverting it for the greater common good.

The ancient structures such as ghats along Ganga indicate that the river flowed freely and the ghats were a means to reach the river and not to block it. However, the post-renaissance period was guided by western thinking or the Age of Enlightenment, where 'conquest of nature' became the objective of science and technology rather than 'living with nature'. So, instead of understanding and living with nature, the age of enlightenment started transforming itself into a 'conquest syndrome'. Around 1500 existing and newly sanctioned River Valley Projects on the mainstem and innumerable others on the tributaries are testimony to this 'taming of nature' syndrome (for details see Chapter 8). Along with rapid proliferation of River Valley Projects such as dams, hydropower projects, etc., the growing infrastructure for tourism, unplanned urban expansion, roads, and bridges for defence purposes have further altered the river basin.

The government has enacted a major amendment to the Forest (Conservation) Act, 1980, known as Forest (Conservation) Amendment Bill, 2023. According to the amendment, the land acquired for railways and roads prior to 1980 will not attract this Act anymore. It has allowed construction for so-called 'bonafide' purposes, oil and gas extraction in forests, strip plantations along roadside and exempt forests on private lands. The amendment allows construction of defence projects especially near international borders which will have a major impact on the Cryosphere region. Forest officials have admitted that many forest patches in the Uttarakhand state are likely to disappear in future, since about 4% of forest land in Uttarakhand falls under private ownership. These are unpublicised silent disasters and do not figure in the Ganga discourse. Such amendments will give rise to indiscriminate hill cutting, deforestation and increasing pollution levels in the upper, middle as well as lower regimes in the Ganga River Basin.

1.7.3 The Unique Self-Purifying Qualities of Ganga

The unique characteristic of the river, which kept the waters clean in the upper reaches till the 18th century, could be identified as (a) extremely high Dissolved Oxygen (DO) content in Ganga's water, ranging between 7 to 13 mg/lit; (b) very sparse human population and settlements and practically no industries in the upper regime; (c) the natural existence of Bacteriophages literally meaning 'bacteria-eaters' because they destroy their host cells, harmful bacteria, and other pathogens such as E-coli, etc. Bacteriophages, which give unique characteristics to Ganga waters, are released in the Cryosphere region when the permafrost melts and they come alive from hibernation. Although they flow all along the river, they become much less effective in highly polluted areas (for details see Chapter 10).

The phenomenon of melting-permafrost and glaciers continuously provides the 'source-bacteriophages' to Ganga and all her Himalayan (glacial) tributaries. However, complete loss of glaciers and Cryosphere due to rising temperatures may dry out the seed source of these bacteriophages in the Ganga headwaters. As about 40% of Ganga water is contributed by Nepali rivers such as Maha Kali, Kali Karnali, Kali Gandaki, and Sapta Kosi. Therefore, further research on bacteriophages also needs to be conducted in the glacial region in India,Nepal, and Tibet, instead of focusing only on the Gangotri glacier.

However, present pollution levels have demonstrated that the self-purification character has its limits, and has now been crossed by human callousness and irreverence. Contrary to common perception and religious belief, 'fecal-coliform-count' was found to be unexpectedly high in the samples taken from the farthest exit point of the Gangotri glacier, where it was calculated to be equal to or greater than 500 MPN/100 ml of water during summer and 300 MPN/100 ml during winter *(Baghel et al., 2005; Chandra, 2017; DNA Correspondent, 2018)*.[13] This was a cultural shock and a revelation to the scientific community.

Another unexpected and worrisome finding was that most varieties of bacteria in the upper reaches of Ganga had developed a resistance to 11 different antibiotics generally being used in the area between Haridwar and Gomukh. It is a well-known fact that at Gangotri and during the 16 km journey to Gomukh, a large number of unequipped pilgrims and amateur trekkers suffer from various ailments to which they are predisposed, (pains, colds, bronchial diseases), for which they randomly collect medicine at Gangotri, often without any prescriptions. In addition, they suffer from sudden high altitude ailments such as headache, nausea, loss of appetite, severe fatigue and oedema. A combination of self-medication and random antibiotics often leads to severe upset of the stomach and diarrhea. Needless to say, all these infected human excreta and the excess drugs and antibiotics flow directly into the sacred mainstream (*pavitra-dhaara*) of Ganga. There is a complete and near criminal absence of any kind of facility for sanitizing or treating such wastes. Another worrisome finding is that the waters of Ganga are highly vulnerable to human and animal fecal-matter and bacterial contamination even in the highest reaches of the Cryosphere, where indiscriminate use of antibiotics has made these bacteria immune to modern medicines.

1.7.4 Ganga River Pollution: Past and Present

During the 20th century it was the Ist and IInd World War, which gave an impetus to industrialization, which in turn triggered-off a huge increase in population after 1930. During the British Raj, the textile industry prospered at Kanpur, Delhi, and Calcutta (located along the rivers Ganga and Yamuna) on the lines set by the Bombay textile mills. While, in the case of Bombay and Calcutta, all pollutants were unabashedly washed away into the sea, in the case of Delhi and Kanpur the entire wastewater was poured into the streams of Yamuna and Ganga. Post- independence (around the 70s), the industry saw a boost. The toxins released from these industries not only contaminated the river but also percolated into the groundwater aquifers. Effectively, about 90% of the toxic discharge passed directly into the river.

Since the leather industry accounts for an annual turnover of about Rs. 478,000 crore and creates employment not only for local residents, but also for over a hundred thousand migrants from Bihar, banning or shutting down the industries has not been successful, despite orders from the Central Pollution Control Board (CPCB) and strict and punitive orders by the Supreme Court (and the National Green Tribunal).

By 2021, about 56 stretches purely on Ganga mainstream have been categorised as ecologically dead zones (2019 CPCB). Therefore, about 23% of the Ganga River within India is severely polluted (does not include polluted stretches in Bangladesh and Nepal). As of October 2019, 318 pesticides were registered for use in India, of which 18 were extremely hazardous (Class Ia) or highly hazardous (Class Ib) according to World Health Organization toxicity criteria. Despite several official bans, many highly hazardous pesticides are still available and in use.

The Pesticides Management Act, 1968 notwithstanding, the ground realities have not changed. Recently, Shri Narendra Tomar, Minister for Agriculture placed a Pesticides Management Bill, 2020 in the Parliament, which has not yet been passed. And therefore, the problem of pesticide pollution continues to be a blind spot in India's environmental policy and debate. The concerned department and ministries appear to be implicitly encouraging the indiscriminate use of pesticides. It is thus no surprise that India is the fourth largest producer and the user of pesticides in the world. We produce about 6000 tons of DDT annually, primarily for mosquito eradication. In addition, we also produce at least 100 other pesticides that are banned in most of the industrialized countries.

1.7.5 Efforts to Clean Ganga River

In 2011, National Mission for Clean Ganga (NMCG) was created as the implementing agency for the overarching program – NGRBA, which received a World Bank loan of 1.556 billion USD for achieving its targets. The government's flagship National Mission for Clean Ganga (NMCG) has created sewage treatment capacity of just over 259 million litres per day (MLD), which is about 11% of the 2,311 MLD the Programme seeks to create. With sewage treatment capacity being a fraction of what is required, over 1,300 MLD of untreated sewage continues to flow into the main stem of the Ganga.

Overall, the Mission planned for 193 projects, including 100 sewage treatment projects on its agenda. So far, only 49 projects, utilizing only 21% of the funds sanctioned, have been completed. Till March 2018, it had completed only 20 of the 100 sewage treatment projects, even though the Namami Gange Program initiated on May 13, 2015 with a total cost outlay of Rs. 20,000 crore for five years. Data available from the CPCB till 2018, shows that the total sewage generated from major towns/cities in the catchment of the Yamuna is 5,236 MLD, whereas the treatment capacity developed is 3,805 MLD. *(Source: TOI, April 2018)*

Although, senior bureaucrats in charge of the Namami Gange Program claim that Ganga's water quality has significantly improved, there are studies which indicate that the pollution levels and content of microplastics are very high and show a dramatic increase at populated cities such as Rishikesh, Haridwar, Kanpur, Varanasi and other river stretches creating 'ecologically dead zones' along the river stream (Saha et al., 2020). Water quality in the lower stretches of the Ganga river is also found to be in an alarming situation by a team of scientists who developed baseline of Water Quality Index (WQI) for the region (Kumar et al., 2021).

To summarize, it is evident that we have enough laws, policies, by-laws, GR's, Action Plans, Missions, and most importantly, we have sufficient funds for cleaning the Ganga River. What is missing is the strict enforcement and implementation of these provisions, and appropriate utilization of funds. Unless and until these measures are followed, the Ganga is not likely to be nirmal and aviral in the foreseeable future (for details see Chapter 10).

1.7.6 Reduction in River Flows

Due to large scale impoundment and major diversion of river water at dams and barrages, a dramatic reduction in the flows of many rivers in the basin has taken place. For example, the Farakka Barrage has led to increase in pondage and siltation causing a backflow effect in the river leading to increase in flooding events in Bihar. After the barrage, the velocity of water reduces, which leads to the river becoming sluggish with periodic episodes of heavy flooding in the lower regime in Bangladesh.

The National Wetland Atlas of India, 2011 has stated that about 36% of wetlands / water bodies have disappeared in the states of Madhya Pradesh and Uttar Pradesh *(Panigrahy et al., 2011)*. Reduction in wetlands leads to lowering in water infiltration, thereby decreasing return flows from the groundwater aquifers, thus reducing the river flows. The 2019 Ganga Citizen Report states that Ganga River has seen a 45% reduction at the Farakka Barrage and 57% reduction at Ganga Sagar in its flow in just over 30 years *(WWF & SANDRP, 2019)*.

In retrospect, it appears that the efforts since the establishment of interstate water tribunals for Godavari, Krishna, and Cauvery rivers under the provisions of Interstate River Water Disputes Act – 1956, to statutorily impose and implement regulations regarding E-Flows, have generally failed to achieve the desired result. Rivers in the Upper Ganga Basin stand completely fragmented due to the series of hydropower tunnels, converting large stretches of the Bhagirathi River into nearly dry stretches of river-bed during summer. And in the middle reaches, barrages and projects have failed to release requisite discharges to maintain the prescribed E-Flows. The current minimum E-flow standards are so low, that every project would inevitably achieve compliance *(Pardikar, 2020)*. Providing the E-flow standards would have been meaningful if the bar was set higher than the flows being currently released, since that would have been truly beneficial to the river system as a whole. The situation is similar in Nepal which mandates that 10% of water should be left to flow below the dam to maintain the ecosystem, without issuing any bye laws and guidelines regarding how this is to be achieved.

Further, it is erroneously assumed, without any scientific basis, that mini and micro projects do not significantly alter the flow of the river and have thus been exempted from E-flow norms. However, each of these mini or micro projects break the longitudinal connectivity in the upstream and downstream regimes due to divergence through tunnels creating dry patches in the natural river bed, thus fragmenting the river. All such interventions have a cumulative impact on the tail-end reaches of the river basin (See Chapter 9).

1.7.7 Biodiversity in the GBM Basin

Due to a great variety of physiographic conditions, the Himalayas supports a very large variety of vegetation with close to 8000 angiosperms, 44 gymnosperms (about 40% of them being endemic to the Himalaya), about 2900 bryophytes (lichens, mosses and liverworts) and 6900 species of fungi *(Singh & Hajra, 1996)*.

In Uttarakhand and Nepal, there are well over 5,400 species of plants of which 750 are specially known for their medicinal value. Nepal also has a rich faunal diversity with 175 species of mammals, 850 species of birds, 650 species of butterflies and 170 species of freshwater fish. The Department of Forest of the Government of Nepal acknowledges that with just 0.15% of forest-land in the entire world, Nepal harbors 9.4% of all bird-species and 2.2% of all known plants, and a considerable number of these species are in Protected Areas (PAs), which form about 16% of the geographic area of Nepal.

The Delta region is home to about 138 mammal species, more than 566 species of birds, 167 species of reptiles, 49 species of amphibians *(IUCN, 2015)*. Some of the major threats to the mangrove ecosystem are destruction of forests, reduction in nutrient levels, and al-

Brahmakamal, State Flower of Uttarakhand *(Courtesy: Ushaprabha Page)* kalinity consequent to rapid urbanization over the last three decades. As per IUCN, among the forest animals, the swamp deer, barking deer, hog deer, the Javan-Rhino, Asian small clawed otter, estuarine crocodile, Asiatic wild water-buffalo have been known to exist for a long time but have not been recorded during the last few decades. The IUCN has declared the Indian segment of Sundarbans as endangered under their Red Data List Framework which covers an area of about 4,260 sq.km in India out of the total area of about 10000 sq. km. Currently IUCN has listed 40% of the species as endangered. (See Chapters 5 and 13)

The Brahmakamal (*Saussurea obvallata*) is one of the rare flowers that bloom only after sunset in these mountain ranges at altitudes of around 3000- 4500 m from August to mid-September. Due to its beauty, it has been declared the State Flower of Uttarakhand.

1.7.8 Natural Catastrophes or Manmade Disasters?

Earthquakes, floods, cyclones, tidal surges, and natural catastrophes have always been difficult to anticipate or control. The GBM River Basin is considered to be the world's most disaster-prone basin, especially in its uppermost and tail-end reaches. This is clearly not just the result of technological incompetence, but because we do not realise that river basins are complex and intricate and there are many factors which are beyond human control. A false sense of security has been created by advocating that science and technology can help to predict and prevent the risks of natural phenomena. Two major disasters in 2020 and 2021 have further strengthened our premise that any major intervention on large rivers or large tributaries will lead to destructive environmental consequences. The collapse of the hanging glacier and the resulting avalanche in the Rishiganga valley in February, 2021 was a reminder that we are nowhere close to being able to predict or control natural catastrophes. Instead, these events exacerbate into manmade disasters due to unplanned and environmentally hazardous human interventions. (See Chapter11).

1.7.9 Lack of Integrated Planning & Multilateral Co-operation

The Ganga-Brahmaputra and Meghna River Systems inalienably bind together the socio-economic, environmental and commercial interests of all the riparian countries namely, India, Bangladesh, Nepal, Tibet, and Bhutan. However, despite this, India and China have both failed to take the lead in formulating a regional perspective while planning, or engaging in multilateral co-operation to arrive at regional water-sharing agreements and conventions which could optimize the overall economic and social development of all the riparian countries. Nepal and Bangladesh see themselves at the wrong end of the stick and feel helpless while dealing with their giant neighbours. India has always avoided the question of equitable water sharing, and has been unenthusiastic towards transboundary approaches regarding water resources of the Ganga.

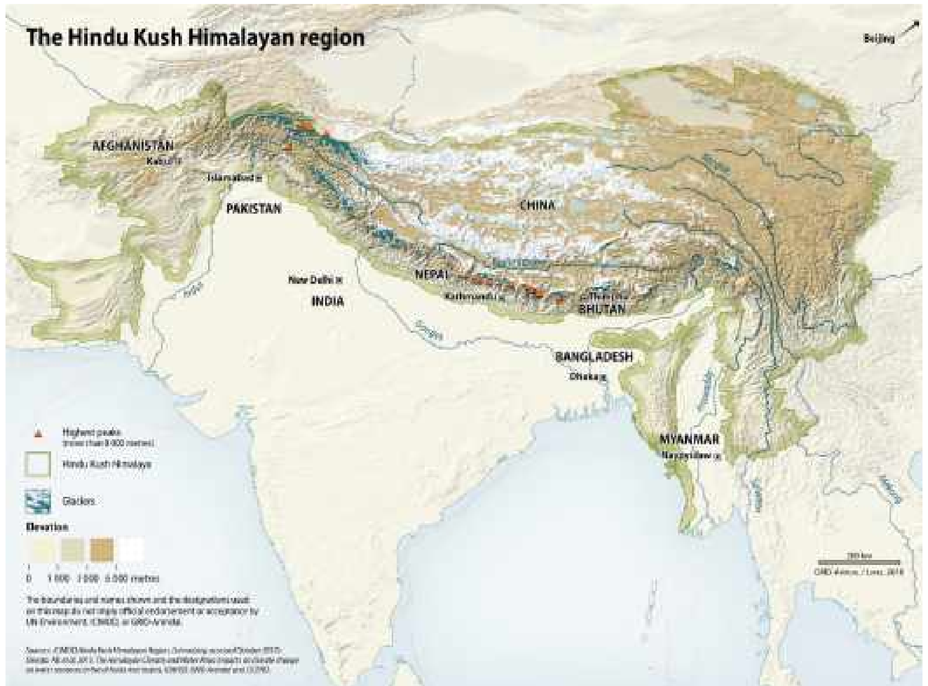
For example, in order to improve the benefits of data sharing, the existing MOU between India and China over data exchange on Brahmaputra River needs to be re-negotiated and immediately amended. There is a need to establish gauging stations at Gompo Ne and Mêdog, in the southern part of the Yarlung Tsangpo (Brahmaputra) River in Tibet near the Indian border, since they fall in the high rainfall zone. This would enable India to acquire accurate and timely data on high season flows for establishing a meaningful early warning system and avoiding huge damages and losses, especially during the flash-floods.

In the spirit of 'realpolitik', the Nepalese claim that Indians have appropriated the river. The perception of Ganga in Nepal and in India is quite different. Throughout the pre-colonial period, Nepal and India were not considered as distinct sovereign nations, and thus, the need for allocating water shares did not arise. However, in the post-colonial period, the Indo-Nepal border became a reality which has led to an artificial division in the perception of upper Ganga. Similarly, the scale and magnitude of the Delta of GBM needs special attention. In the case of the Delta region, India and Bangladesh share 54 transboundary rivers which eventually intertwine and spread into the Delta and discharge into the Bay of Bengal. The Indus Water Treaty between India and Pakistan was signed as early as in 1960, despite the hostilities between the two countries. Since then, India has only signed one treaty on the Ganga River, namely the Farakka Treaty. This treaty, signed with Bangladesh as recently as 1996, i.e., almost 49 years after the borders were demarcated, demonstrates the low priority given to the transboundary aspects of rivers and the indifference to the interests of downstream riparian nations in the process of River Basin Management (for details see Chapters 12 and 13).

1.7.10 High Level of Uncertainty in the Cryosphere and the Delta

In the introductory paragraphs, we have raised several concerns related to the Ganga River Basin. As stated earlier, in this study, we will primarily focus on the headwaters and Deltaic tails of the Ganga. **The premise of this study is that in our anxiety to overcome the immediate crisis of river pollution and dry stretches which threaten the perennial flows in the river, we have ignored the impact of changes taking place in the water towers of the basin, i.e., the Cryosphere of Ganga and the tail reaches beyond Farakka, in West Bengal and Bangladesh**. This reflects an 'ostrich-syndrome' where we presume that by erecting Sewage Treatment Plants (STPs) and Effluent Treatment Plants (ETPs) we can clean up the Ganga; and that by promulgating a notification asking for minimum water flows, we will in fact ensure pure and wholesome water and an ecologically integrated river system. This syndrome smacks of myopia, because we have neglected the enormity of the changes taking place in the Cryosphere and the possible domino effect in the Deltaic region, both of which are already facing high levels of uncertainty in terms of water availability and water quality.

1.7.11 The Cryosphere of the Ganga



Map 1.3 Relief Map showing the Cryosphere of the Hindu Kush Himalaya, including Indus, Ganga, Brahmaputra and other river basins.
(Source: Isquierdo, 2018 based on ICIMOD, 2017)

The total area of the Cryosphere, in the Upper Ganga and Upper Brahmaputra basins is about 38,935 km² which waxes and wanes from season to season *(ISRO report, 2010)*. The total contribution of snow and ice melt is about 9-10% (52 BCM) in the case of Ganga; 19-21% (about 106 BCM) in the case of Brahmaputra; and none in the case of Meghna *(Miller et al., 2012)*. But regardless of the absolute annual share/volume, the importance of the snow and ice melt should not be underestimated since its contribution forms a crucial and reliable share of base-river-flows during the three summer months.

During the next three decades, the contribution of water from the cryosphere is likely to increase considerably. Unfortunately, after the 2050s and 2060s, there will be a dramatic fall in the percentage of water contributed by ice and snow melt.

The Hindu Kush Himalaya as a whole, holds a total of about 54,000 glaciers, and covers an area of about 60,000 sq. km. ISRO has mapped 6,237 glaciers in Ganga River Basin having a glaciated area of 18,393 sq. km. The Gangotri Glacier, which is the largest glacier in the Ganga basin, has a length of 30.2 km.

1.7.12 Climate Change Impact on the Cryosphere

The critical impact of climate change on the Cryosphere of Ganga will be a differential rise in temperature. Contrary to general belief, whenever there is a rise in temperature at lower

altitudes, there is a disproportionately higher rise in the average temperatures at higher altitudes as in the case of Ganga's Cryosphere. The glaciers will recede faster than the current rates of recession. Glacial melting and recession due to atmospheric warming in the cryosphere region will lead to increase in snow and glacial melt during the next three decades. The direct effect of global warming will be that 50% of all glaciers in the Ganga Basin are likely to disappear by 2050, especially those located at lower altitudes, and those which are relatively shorter and narrower in width. This in turn will lead to a substantial increase in the Ganga's flows, thereby further aggravating floods and inundation along the initial 120 km of the Upper Ganga Basin. These floods will have a domino effect, amplifying floods in the middle regime. This aggravation of floods will take place on all the glacial rivers, namely Yamuna, Ganga, Mahakali, Karnali, Gandaki and SaptaKoshi; and subsequently, it will aggravate the floods in Bihar, West Bengal and Bangladesh as well.

Besides atmospheric warming, climate change is also expected to reduce the number of rainy days, while increasing the intensity of rainfall. Consequently, summers in the Ganga basin are likely to be more extreme, while reducing the humidity in the atmosphere and moisture in the soil.

Another important climate change impact predicted by the IPCC is the increase in the number of Extreme Point Rainfall Events (EPREs), i.e. precipitation exceeding 204.4 mm in 24 hours. India recorded 125 extremely heavy rainfall events during September and October in 2021, the highest in five years, owing to the late withdrawal of the southwest monsoon and higher-than- normal low-pressure systems *(PTI, 2021)* Needless to say, the ultimate impact will be the aggravation in the variability of rainfall, increase in the intensity and frequency of floods, and increase in the intensity and length of the drought periods. The resulting impact on output of food crops and the loss of property and life during the floods will also be serious.

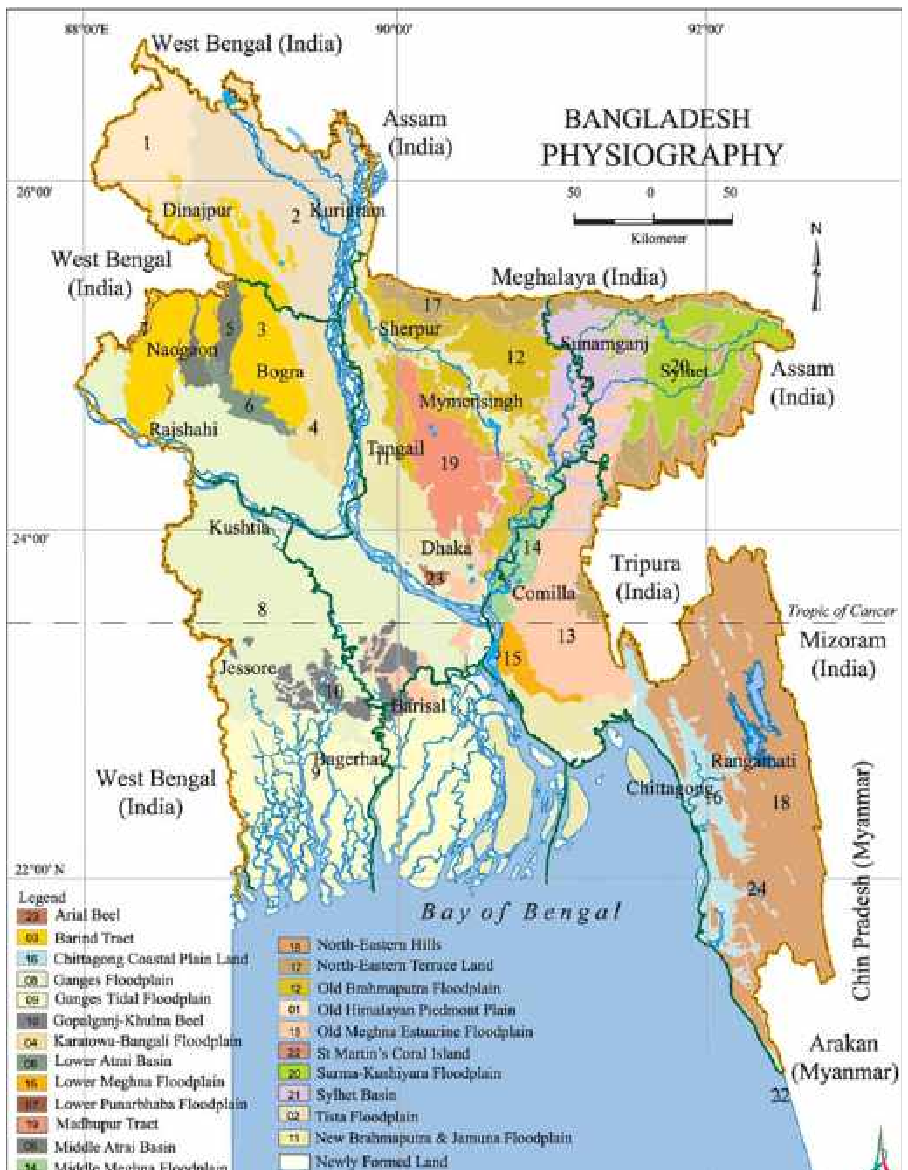
1.7.13 Shifting Sands in the Deltaic region

In the tail-end region of the enormous GBM basin, there are almost 700 rivers within the Delta with a combined length of around 24,000 km. However, the Delta is the largest, not because it drains water from two of the largest Asian river sub-basins, but because these rivers transport the largest number of suspended sediments and bed load from the youngest and tallest mountain ranges, which are unstable, fragile, and brecciated. About 75% - 80% of this Delta has been created by sediment deposition over a period of 100,000 years consisting of the (a) Upper-Fan Delta, (b) Fluvio-tidal Delta and (c) Tidal Delta. It is estimated that about 2.4 billion tons of sediments are carried every year and deposited partly in the Delta and substantially in the Bay of Bengal *(Banglapedia, 2021)*. It spreads about a billion tons of sediment per year across the southern Delta front, which is 380 km in width. This makes it the largest sediment dispersal system in the world *(Allison, 1998)*.

Such deposition has created a shallow submarine shelf which extends several kilometers into the Bay of Bengal. However, with changes in the upstream regimes, i.e., glacial recession and intense precipitation due to climate change leading to periodic floods and droughts, the rate of sedimentation is also likely to change, altering the Delta region significantly. The Delta region is influenced by four major geological phenomena :

1. Gravitational force
2. Tidal back-lift from the sea which leads to ingression of sea water
3. Bed load or silt load
4. Geologically long-term plate tectonic shift (which is still active in this region).

In addition, the last couple of hundred kilometers of the lowest regimes are subjected to severe climate change-induced catastrophic floods and occasional droughts, migrations/avulsions, storms, cyclones and typhoons, land subsidence and tidal wave surges which makes the region highly disaster prone (See Chapter 13).



Map 1.4 Physiography of the GBM Delta within Bangladesh Territory

(Source: Banglapedia, 2021)

Climate change impact on the Bengal Delta is expected to displace well over 3-4 million people who will inevitably migrate to the northern parts of Bangladesh, creating a domino effect which will cause major migrations into the middle regimes of Ganga and Brahmaputra. In addition, the sea-level rise will create a back-lift effect which could submerge not only several islands, but also parts of lowlands (up to 5 meters amsl) in West Bengal and Bangladesh. These changes are expected to occur during the next three decades and the current Indian policies and plans for Ganga River Basin appear to be indifferent to these challenges.

So far, we have briefly demonstrated how the high levels of uncertainty in the Cryosphere as well as in the Delta continuously impact the mainstream river. The effect of both these aspects will have huge impacts on human population causing migration or exodus due to reduction in land availability and lack of water security. In both these cases, none of these dynamics are controlled by the national and state boundaries, nor are they affected by boundaries set in historical time. The Deltaic region has not been much studied or understood in India, as most part of it lies in Bangladesh. Only when we understand these factors will it be possible to design a truly integrated management plan for the river.

1.7.14 Glaring Absence of an Integrated Ganga River Basin Management Plan

Having an integrated perspective does not necessarily translate into an Integrated Action and Management Plan. And thus, it has been stated time and again that there is an urgent need to arrive at a multilateral regional agreement between China, Nepal, India, Bhutan, and Bangladesh, which recognizes the legitimate interests of these nations as regards sharing of waters, sharing data on river flows and floods, irrigation, hydropower and creating common protocols and strategies for managing flood disasters and climate change impacts. Despite this awareness, there exists no Master Plan for responding to such issues. Note that the GAP-1 and 2, the Yamuna Action Plan, and the Namami Gange Program have not addressed these issues, either in concept or in practice.

Unlike peninsular rivers where we have considerable knowledge and data, there is a major gap in understanding the 'stock' and 'flows' of the Ganga River System from water stored in the Cryosphere and from groundwater aquifers. The current annual water availability of water in the Ganga River Basin is considered to be about 525 BMC, but this does not take into account the water stored in the Cryosphere and groundwater accumulated over millennia, which is not a part of the annual water cycle, but eventually becomes a part of the river flow over a historical period of time. Due to global warming, we have been goaded into using technology for dipping into the millennial water reserves for satisfying our annual water requirement. However, currently, the discipline of hydrology is only capable of annual hydrological assessment, and therefore, has skewed our assessment about availability of water in future. The hydrological implication is that we are looking at all these sources in a fragmented manner. Therefore, conjunctive use of water really includes conjunctive use of all the three sources and resources of water, which requires foresight and long-term planning.

Unless the five riparian countries proactively agree to prepare such a Master Plan on shared waters, the optimisation of Ganga's waters cannot be achieved. Not only have the four countries failed to cooperate on trans-river basin planning, but have failed to clinch bilateral treaties or plans. This is not just necessary because of the riparian laws and international requirements, but is essential in India's own interest. Currently, we have an agreement with Bangladesh on Ganga (1996), which needs to be immediately re-negotiated, since it has lapsed in 2016. The situation on Indo-Nepal water treaties is even more confused and convoluted (See chapters 12 and 13).

1.7.15 Fragmented Data and Absence of Foresight

As stated above, the formulation of an integrated plan, multilateral agreements and regional perspective demands integration of data management and foresight. However, in reality, there is an absence of real-time flow data, and lack of centralized and integrated data management system for the river basin. The existing data is fragmented amongst different government agencies and research organisations not only within India but also between the riparian countries, due to conflicting interests and lack of clear mandates.

The latest available report titled 'Ganga Basin' published by the Ministry of Water Resources, GoI, in the year 2014, provides detailed information about the topography, geology, land-use, hydrological units, water resource projects, groundwater observation wells, tourism sites, inland navigation waterways, inter basin transfer links, etc., but fails to provide real-time flow data about the Ganga River System. Further, the report is limited only to the River System which lies within the Indian borders, without meaningfully acknowledging the river's existence in other riparian countries. There are numerous other reports and studies such as: (1) The Inventory of Himalayan Glaciers published by the Geological Survey of India in 1999 and updated in 2009, (2) Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region - Nepal, 2001 published by ICIMOD, (3) Climate Hazards and Vulnerability Atlas of India, 2022 published by India Meteorological Department (IMD), (4) River Basin Atlas of India, 2012 published by Central Water Commission and Indian Space Research Organisation, (5) Glacial Lake Atlas of Ganga River Basin, 2021, published by Bhuvan, Indian geo-platform for ISRO (National Remote Sensing Centre) under the National Hydrology Project. These reports provide valuable data but which remains fragmented, with multiple blind spots and differences over measurement parameters, methodologies, and time- scales employed by different agencies (elaborated in Chapter 4). This is a typical example of fragmentation of data leading to a lack of understanding of the entire Ganga River Basin.

Although there is no dearth of agencies and trained researchers for creating a centralized data resource system, lack of centralized funding is a major hindrance. The funds allocated for Namami Gange are reserved for identifying and mapping issues related chiefly to pollution. This in itself is a fragmented approach. In addition, there is no repository of retrospective data or ex-post-facto evaluation which includes lessons and errors from previous initiatives. Nor is there a repository of centralized projected data related to water use, changing flow regimes, population, livelihood, disasters, etc. which are needed for better management and evaluation for the future. Therefore, one of the main reasons for the absence of an Integrated River Basin Management Plan lies in the inadequacy of integrated data systems, both within the country and between the Riparian countries.

1.7.16 Creating an Enabling Legal Framework and Institutional Disposition for IGRBMP[14]

The Indian Constitution has elucidated on the topic of water, its management, and related issues at different junctures within its structure. In the Constitution, 'water' is a matter included in State List as devolution of Subjects and Powers under Entry 17 under List II of Seventh Schedule. Entry 17 largely grants the rights and responsibility of managing, utilizing, developing, planning water sources and resources to the State; and further, in its elaboration, talks about water supplies, irrigation and canals, drainage and embankments, water storage and water power subject to the provisions of Entry 56.

Entry 56 of List I of the Seventh Schedule states that the Union is made responsible for water management of inter-state transboundary river systems between two or more states. As such, the Central Government is conferred with powers to regulate and develop Inter-State rivers under Entry 56. However, as per this entry, the Union is not responsible for planning, allocation, development but only has the power to make laws for the adjudication of any dispute relating to waters of Inter-State River or River Valley under Article 262 of the Constitution. Thus, Entry 56 gets reiterated in Article 262 of the Constitution with the Interstates Water Dispute Act 1956 where the procedures for setting up dispute resolution mechanism have been implied. In brief, the State is responsible for management, planning, allocation and regulation of water and the Union is responsible for dispute resolution related to inter-state rivers and river valleys. It becomes clear that the Constitution had not anticipated the need for including a mechanism that addresses issues related to trans-boundary rivers.

1.7.17 Rights of Rivers: From Anthropocentric to Eco-centric Jurisprudence

The existing status of rivers and the failure of legal systems to protect them has propelled the law makers in moving towards an eco-centric jurisprudence which emphasizes on the 'Rights of River' approach, wherein rivers are not treated as inanimate property, but rather as individual entities, with an agency and rights to protect themselves. Stemming from the Rights of Nature movement, the River Rights perspective was developed in liberal democracies with large aboriginal populations, such as Australia and New Zealand and has spread across the globe[15].

In 2017, the Uttarakhand High Court ruled (in two separate orders on March 22nd and

30th) that the Ganga, the Yamuna, their tributaries, and the glaciers and catchments feeding these rivers in Uttarakhand had rights as a "juristic/legal person/living entity". However, this was overruled in the Supreme Court due to practical difficulties in implementation. Simultaneously, in the tail-end reaches, the Appellate Division of the Supreme Court of Bangladesh upheld the 2019 decision of the High Court (in Writ Petition No. 13989) which declared that the Turag River and all other rivers in the country as "living entities" with rights as "legal persons." In this landmark decision, the National River Conservation Commission of Bangladesh is declared "*in loco parentis*" for the rivers of Bangladesh, to protect and conserve them, and prevent pollution and encroachment (Margil, 2019).

In the case of the Ganga, the existing E-flows Notification of 2016 and other legal provisions state the technical necessity of obstruction and abstraction of river flows for human consumption, but they do not state that E-flows are a part of the natural functions of the rivers in order to maintain their ecological functions such as carrying and transporting water, silt, and other material from the basin to the sea i.e., from higher to lower elevation. Maintaining these functions is intrinsically related to the sustainability and viability of the river system.

1.8 NEED FOR INTEGRATED RIVER BASIN MANAGEMENT PLAN

Although the concept of Integrated Water Resource Management has been widely promoted since 1987[16] and further reiterated in the National Water Policy in India (2012), it has still not been operationalised. Today there is no Integrated Ganga River Basin Management Plan and we feel that one of reasons for this could be embedded in our existing constitutional and legal framework.

1.8.1 Brief History of Integrated River Basin Management (IRBM)

As stated above, Integrated River Basin Management is not a new concept in India. It existed in the pre-Constitution period before 'water' was included as a state subject. The creation of the Damodar Valley Corporation (DVC) in 1948, similar to the formation of the Tennessee Valley Authority of the United States, based on the recommendation of the high-powered "Damodar Flood Enquiry Committee" is a case in point. DVC was formed with the Central Government and the governments of Bihar (later Jharkhand) and West Bengal participating as equal riparian partners. Although today the Committee's operations are limited to the management of thermal power stations and hydel power stations in the Damodar River Valley, the Corporation was initially formed to manage flood control, irrigation, generation and transmission of electricity, year-round navigation, etc. Post DVC, the Planning Commission and Central Water Commission have made several recommendations for implementing IRBM principles, however, there is no law to back such a recommendation. The only state which made such a law was Maharashtra (Maharashtra Water Regulation Act 2005), but unfortunately it has no relevance for the Ganga River Basin.

There are a few legal and parliamentary provisions available for creating IRBM Plans. For instance, the River Boards Act of 1956, and further, the National Water Resources Council (NWRC) established in 1983 had the mandate to address the issue of federal inconsistencies over the subject of water. The River Boards Act had briefly addressed the issue of regulation and development of interstate waters, similar to the NWRC. However, it was unable to take action in this regard since such attempts for integrated conservation and protection of water resources were nullified due to non-existence of any River Basin Plans in India. Although water is treated as a national asset, flowing water and its management and planning is accorded to the States. Groundwater, on the other hand, is treated as a private asset.

Such a fragmented and disintegrated perception of the water system has created obstacles in the implementation of IRBM. The 2012 National Water Policy states that all water and rivers in India are to held under the principle of 'public-trust-doctrine' where all water is to be treated as commons and confers the responsibility on the State as a trustee and not as the owner.

However, this is not actionable as policies cannot be enforced through courts. Further, even though the principles of equitable distribution of water are mentioned in policies and are generally accepted, there are no legal provisions for implementing these principles and enforcing them in the court of law.

These constitutional provisions have resulted in the promulgation of Acts such as the Water (Prevention and Control of Pollution) Act 1974, legal debates and verdicts such as the 1985 MC Mehta case on pollution in the Ganga River, which resulted in the creation of Ganga Action Plan in 1986 with the objective of pollution abatement in Ganga River.[17] Further, the 2016 E-flow Notification was an outcome of the protest led by Prof. G.D Agarwal. The government and departments were instrumental in creation of these plans and notifications; however, these are actually the result of Supreme Court strictures and civil society movement.

In the case of Ganga, 11 different states from Uttarakhand to West Bengal need to align their interests and cooperate for preparing an Integrated River Basin Management Plan. Even though solutions are available, achieving a consensus appears a remote possibility given the current political scenario.

1.8.2 Major Recommendations for Effective IGRBMP

1. The old River Boards Act of 1956 should be brought on the table in Parliament once again in order to enable the preparation of integrated river basin management plans

2. The defunct National Water Rivers Council needs to be re-activated in order to align the interests of all the 11 states in the Ganga basin

3. The focus of the National Ganga River Basin Authority (NGRBA) which has been

re-christened as Namami Gange is currently narrowed to pollution abatement. This needs to be expanded to include all issues including the trans-basin problems for preparing an Integrated River Basin Management Plan

4. Revisiting the existing legal provisions to include the 'Rights of Rivers' approach which alone can grant legal rights to rivers.

1.9 OBJECTIVES OF THIS STUDY

1. To focus and elaborate on the importance of the uppermost river regime (Cryosphere) and the Delta for a holistic understanding of the entire Ganga River Basin.

2. To understand and describe the characteristics of Ganga's Water Towers and their role in maintaining the Environmental Flows and Ecological Integrity of the River System.

3. To identify and describe the impact of anthropogenic interventions on water quality and integrity of the ecosystem.

4. To identify information (data) gaps, strengths/weaknesses of the existing Ganga Water Management Plans, governance, and research mechanisms.

5. To identify strengths/weaknesses in laws, policies and practices in the Riparian countries and their impact on socio-economic and cultural development.

6. To analyse existing Bilateral Treaties between India and the Riparian countries of Nepal, China, Bangladesh and recommend approaches for reviewing, modifying existing agreements in order to hasten and achieve the process of meaningful regional co- operation.

7. To provide an inter-disciplinary understanding which enables policy makers and civil society to appreciate the need for formulating and implementing an Integrated Ganga River Basin Development and Management Plan.

1.9.1 Assumptions and Approach

a) All sources are priceless and all resources are priced

There is a conceptual distinction between the terms 'source' and 'resource,' even though these terms are used synonymously across the available literature and discourse related to water. Naturally available water such as natural springs, river flows, precipitation, saline water in sea and oceans, water stored in the cryosphere and aquifer over millennia is a 'source.'

On the other hand, a 'resource' is created by converting the intrinsic value of water into use value through investment of labour, technology, and capital. For example, till the 17th century, the waters of Ganga were a source, since they contained only intrinsic value and were therefore not priced. However, after the construction of barrages such as Hathni Kund (erstwhile Tajewala barrage) constructed in 1873 and Bhimgoda in 1854 which supplied water for irrigation through enormous canal systems, the water of Ganga was 'priced' and sold to farmers as a resource.

Thus, the concept of resources is essentially an economic construct and therefore, it involves a 'revenue model' as investments are expected to generate returns without which the system would be economically non-sustainable. The confusion between source and resource has resulted in the unfortunate consequence that when people pay a water charge, they presumably acquire the right to use more than their share by virtue of being able to pay more. In addition, where the use of water becomes a contractual relationship, the responsibility of treating the polluted water is shrugged off and/or externalized by both parties. This is the fundamental reason behind the failure of water governance, translating into unacceptable and dangerous levels of pollution in Ganga.

b) An Ecosystem Approach

These natural sources mentioned above are part of ecosystems which provide services both physical i.e., services which arise purely because of the geohydrological layout of the river system, and those which are biological i.e., which arise as a consequence of there being a biodiverse ecosystem in different regimes. For example, storage of millennial water in the Cryosphere and groundwater, and its gradual release is a physical service, while the release of bacteriophages is a combination of physical as well as biological ecosystem services.

Although we have not listed an exhaustive inventory of ecosystem services in this report, a significant range of ecosystem services has been included in relevant chapters.

c) A Bird's-Eye View

Since the geographical area to be covered is very large, the approach has been to look at the broad canvas and a get a bird's-eye view of the entire river basin. Similarly, literature to be reviewed is also vast, and only a selected and prioritized number of books, documents, reports, research papers, and media items published have been covered. The assessment of Ganga in this Report is based on focused field trips and interviews and on secondary data. No primary studies were conducted.

Most studies on the impacts of climate change and glacial recession reviewed in this study are still in a nascent stage. Hence, precise assessment, quantifying, and predicting the magnitude of such impacts (negative or otherwise) has not been an objective of this Report.

Our approach has therefore been restricted to data available with international and national institutions like International Water Management Institute (IWMI), Colombo, National Aeronautical Space Research Administration (NASA), USA, Indian Space Research Organization (ISRO), Water Resources Information System of India (WRIS), Central Water Commission (CWC), Ministry of Water Resources (MoWR), India Water Portal, etc. The assessment has therefore analysed and interpreted what may be called 'received-wisdom' from several disciplines. However, the Report also offers our considered interpretation and recommendations. These have been made keeping in mind the practical limitations of the legislative and administrative structures in the five countries within the Ganga River Basin. However, the approach has been to recommend synergistic actions and programs beneficial to all stakeholders and countries concerned.

1.10 OBSERVATIONS

In conclusion, we would like to reiterate that even a broad-spectrum perspective of the Ganga River Basin reveals that there exists a vast array of features and subjects which need to be understood before one can come to even a minimalist understanding of the geo-physical, ecological, socio-political complexities of the Ganga River Basin. The sequence of chapters start with the uppermost regime of the Ganga River Basin and continues to the lowest regime since these are all inter-connected and any natural event or man-made intervention will have a dominos effect on downstream Riparian regimes. Thus, each chapter constitutes an independent component of the Ganga River Basin. The Conclusions and Recommendations for each chapter are stated at the end of that chapter.

As mentioned earlier, this Bird's Eye view of the Ganga River Basin highlights the need to look upon the Ganga River from a holistic Integrated River Basin Perspective. Even though the focus is on two of the least understood or appreciated aspects of the Ganga, namely, a)The Cryosphere of the Ganga, which lies largely above 4000m amsl, the enormous threats that it faces due to climate change and global warming, and the likelihood of it melting and completely disappearing from the Himalaya Mountains; and b) the Tail end or Delta of the Ganga River System, which is today a huge blind spot in our understanding and policy framework. It is likely to create an enormous negative impact due to flooding, aggradation of the delta, and sea level rise, accompanied by an acute rise in the incidence of deadly cyclones and storms. It could significantly dislocate and devastate the lives of millions of people.

Needless to say, only relying on techno-centric solutions and commercial gain, without this holistic perspective which involves good governance, multilateral co-operation, focussed research studies and effective legislation, would be suicidal. Understanding the heads and tails of Ganga is crucial for understanding the Ganga River System and taking timely and effective steps for sustainable and effective development of its water sources.

ENDNOTES :-

1. With the advent of the Mughal period, it was renamed 'Allahabad' by Emperor Akbar in the 1575 AD. Recently, on 16th October 2018, the Government of UP, headed by Chief Minister Yogi Adityanath, renamed the city as 'Prayagraj'.

2. Based on the calculations made on Google Earth Pro, provided by Dr. Khalequzzaman, Professor at the Department of Geology and Physics, Lock Haven University, USA.

3. In Hindu religion, the belief is that the cow is representative of divine and natural beneficence and should therefore be protected and venerated. The origin of the veneration of the cow can be traced to around 3000 BCE in the Indus valley and later in the Vedic period (2nd millennium–7th century BCE) back to the pastoral communities, who considered cattle to be their measure of wealth and therefore worshipped them.

4. A lingam, sometimes referred to as linga, is an abstract representation of Shiva's phallus.

5. The Indian legal system (starting with the Constitution and the subsequent legal framework) has still not recognized the rights to water of other beings.

6. Bamak means glacier in Garhwali language.

7. Some of highest peaks such as Mt. Everest (Chomolungma), Lhotse, Nuptse, Makalu, etc. in the world are located in the Mahalangur mountain range.

8. The larger original Chardham Yatra included Badrinath in the north, Rameshwaram in south, Dwarka in the west and Puri in the east of India. The Chhoti Chardham Yatra was initiated by Adi Shankaracharya in the 8th century.

9. Shesha Naag : In the Hindu tradition, the great cobra Shesha Naag is said to hold all the planets of the universe in his hoods and to constantly sing the glories of Vishnu from his multiple mouths, and is also depicted in the form of a coiled bed for Lord Vishnu.

10. From the western slopes of Kangchendzonga perched on the borders of India, Nepal, and China, emanate three rivers (Yangma, Ghunsa, and Simbua) which join the Tamor river in Nepal, a tributary of the Sapta Kosi River, which eventually merges with Ganga at Kursela in Katihar district of Bihar.

11. As a corollary, in the case of the Sindhu, the Arabian Sea was traditionally known as Sindhusagar in ancient times, i.e., the sea created by waters of the Sindhu.

12. Not to be confused with the Saraswati River which Indologists and historians claim was part of the Ghaggar-Hakra river system that flows between Yamuna and Sutlej through north-western India and Pakistan before ending in the Thar. Also, not to be confused with a small tributary which joins Alaknanda River in the upstream basin.

13. Most Probable Number (MPN) is used to estimate the concentration of viable microorganisms

in a sample by means of replicating liquid broth growth in ten-fold dilutions.

14. IGRBMP : Integrated Ganga River Basin Management Plan

15. For details see Rights of River Global Map published by International Rivers.

16. National Water Policy, 1987 stipulates that 'resource planning in the case of water has to be done for ahydrological unit such as basin or sub-basin as a whole'.

17. In 1985, M.C. Mehta filed a writ petition in mandamus to prevent these leather tanneries from disposing off domestic and industrial waste and effluents in the Ganga River.

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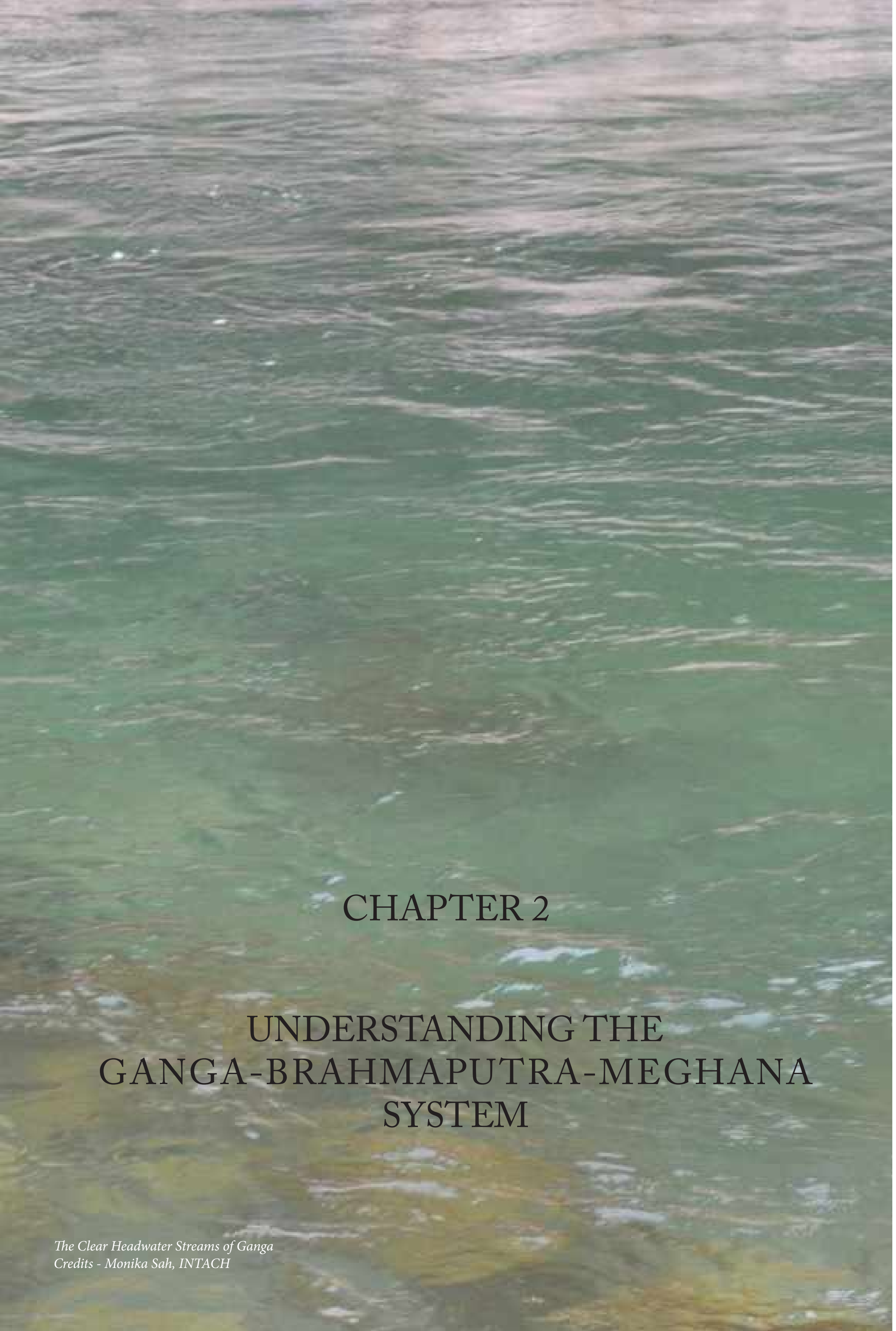


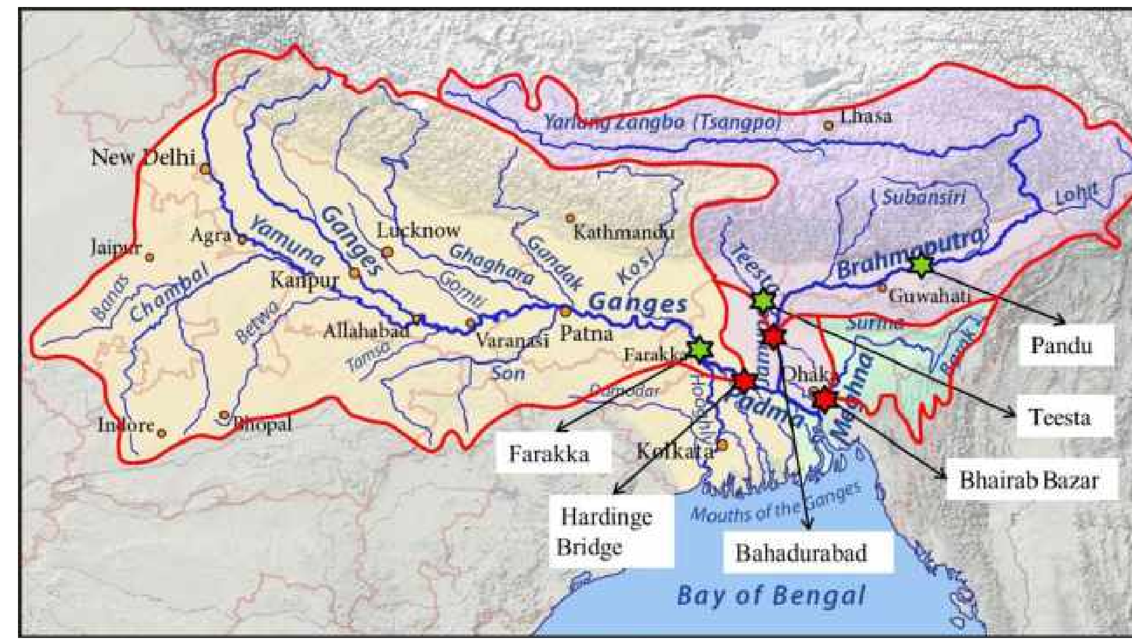
CHAPTER 2

UNDERSTANDING THE GANGA-BRAHMAPUTRA-MEGHANA SYSTEM

The Clear Headwater Streams of Ganga
Credits - Monika Sah, INTACH

2.1 AN INTEGRATED RIVER BASIN PERSPECTIVE

A holistic understanding of the Ganga starts with a broadening of our understanding of the river basin as a whole, in terms of its hydro-geological and cultural aspects. Further, an Integrated River Basin Management (IRBM) approach for achieving sustainable development requires an inclusive understanding of the Ganga, Brahmaputra, and Meghna (GBM) as a single and discrete basin. Even though the focus of this study is on the Cryosphere (Heads) and the Delta (Tails) of the Ganga River, the larger context of GBM cannot be ignored, since climate change consequences are determined by the Cryosphere of the GBM basin as a whole and its impacts are most severe in the Delta.



Map 2.1: The Boundary Of The Ganges–Brahmaputra–Meghna (Gbm) Basin (Thick Red Line), With The Three Outlets (Red Star): Hardinge Bridge, Bahadurabad And Bhairab Bazar For The Ganges, Brahmaputra And Meghna River Basins, Respectively. Green Stars Indicate The Location Of Three Additional Upstream River Gauging Stations (Rgs) Namely, Farakka, Pandu And Teesta

(Source: Masood et al., 2015)

The GBM is the world's third largest freshwater system in terms of annual average discharge of water to the ocean through a common point, namely the Bengal Delta which, incidentally, is the largest delta in the world (FAO, 2011). The multiple mouths of the delta are spread over a coastal distance of about 300 km., from the Gangasagar Island in West Bengal, India, to the Bhola Island in Bangladesh. Two of the three rivers (Ganga and Brahmaputra) flow together for well over 200 km. from the point of their confluence. Since the Meghna converges with the combined flow of the Ganga and the Brahmaputra just about 50 km. downstream of the Ganga- Brahmaputra confluence near the Chittagong Division[18], technically, the three sub-basins together form a complete geo-hydrological entity.

This merging of the two rivers (Ganga and Brahmaputra) took place sometime around 1787, that is, just 235 years ago!

Map 2.2 Cartographer James Rennell's Original Map Based On His Survey In 1786. Note That Ganga And Brahmaputra Flow Separately Into The Bay Of Bengal
(Source: Rennell, 1786)

Map 2.1 shows Ganga and Brahmaputra meeting near the Rajbari district in the Sundarban. However, Map 2.2 shows these two rivers flowing separately till they reach the Bay of Bengal. This raises questions such as: When did the Ganga and the Brahmaputra meet? What caused their confluence? The answer to these questions lies in the geological history and evolution of rivers in the region and consequently of the entire GBM basin, which has been briefly discussed below.

2.2 EVOLUTION OF THE GBM BASIN

2.2.1 Geological Origins

Physicists, geologists, and scientists of several disciplines have studied the evolution of planet earth and it is now generally accepted that the earth came into existence approximately 4.54 billion years ago. It is also believed that water in some form - gaseous or liquid has also existed since then. When molten lava emerged from the core of the earth to the surface, it formed a crust which broke and drifted, and when most of the gaseous water precipitated on these pieces of land masses, they created huge oceans and covered an area of about 71% of the global surface. The plates of the hardened crust moved and floated before they finally settled into their current continental configurations. The terrestrial areas were higher than the oceanic elevation and so a part of the precipitation or condensation

of gases/clouds fell on land and started flowing by gravity towards the oceans, thus creating rivers. The 'Encyclopedia of Life Support Systems' (UNESCO- EOLSS), states that rivers came into existence about 1 to 2 billion years ago.

Subsequently, about 75 to 80 million years ago, a piece of the Australian plate broke off and started drifting northwards towards the Eurasian plate at a speed of about 15 cm. per year. Eventually, this piece (the Indian plate) collided into the Eurasian plate. Prof. Dietmar Müller and Kara Mathews, the lead authors of the study, discovered a micro-plate from the time of the collision, which places the event 47 million years ago. The Indian plate being smaller, got subducted under the Eurasian plate and has continued to lift the southern portion of the Eurasian plate upwards. In simple terms, this was the period when the former 'Sea of Tethys' began its subduction (that is, going under the Eurasian Plate), and the great Himalayan uplift began.

The south-westerly air currents were blocked by the rising Himalaya and taken up to great heights. Most of the moisture in the higher elevation precipitated as snow for millions of years and created the Great Himalayan and Tibetan Water Towers. The condensation which came down or melted in the form of water or rains from all sides of the Himalaya and the Tibetan plateau started flowing in the north-eastern, eastern, southern and western directions, forming 10 major river basins, namely - Indus, Ganga, Yangtze, Brahmaputra, Salween, Mekong, Irrawaddy, Amu Darya, Tarim and Yellow River. Therefore, when the last Ice Age or the Pleistocene Epoch began about 2.6 million years ago and ended about 11,700 years before present, these three river systems - Ganga, Brahmaputra, Indus and others came into existence.

2.2.2 The Third Pole

These rivers (Ganga, Brahmaputra, and Indus) are now denoted by geologists as Circum-Himalayan rivers; and the Himalaya, including Tibet which holds the largest stock of freshwater outside the North and South poles, has been named the "Third Pole", which currently supplies water to 18 countries in Asia. Interestingly, Vedic literature also mentions Mount Kailash as the Sumeru or the sacred five-peaked mountain and is mentioned as such in Hindu, Buddhist and Jain cosmology. It is considered to be the *Merudanda* (axis or center) of the physical, metaphysical and spiritual universe *(Tilak B.G. 1903, 1955).*

2.3 MAJOR RIVER AVULSIONS

Based on this geological evidence, morphologically, the configuration of the present river system as a whole has evolved just over 12,000 years ago, after the end of the last Ice Age. These rivers and their channels were further altered due to tectonic events, gradient, aggradation[19] and sediment deposition. Of all the river systems in the world, the unique characteristic of this basin is the number of river avulsions which have been witnessed in this basin, and which have led to its present-day geomorphology and hydrology.

2.3.1 Yamuna Avulsion (Proto-historic period)

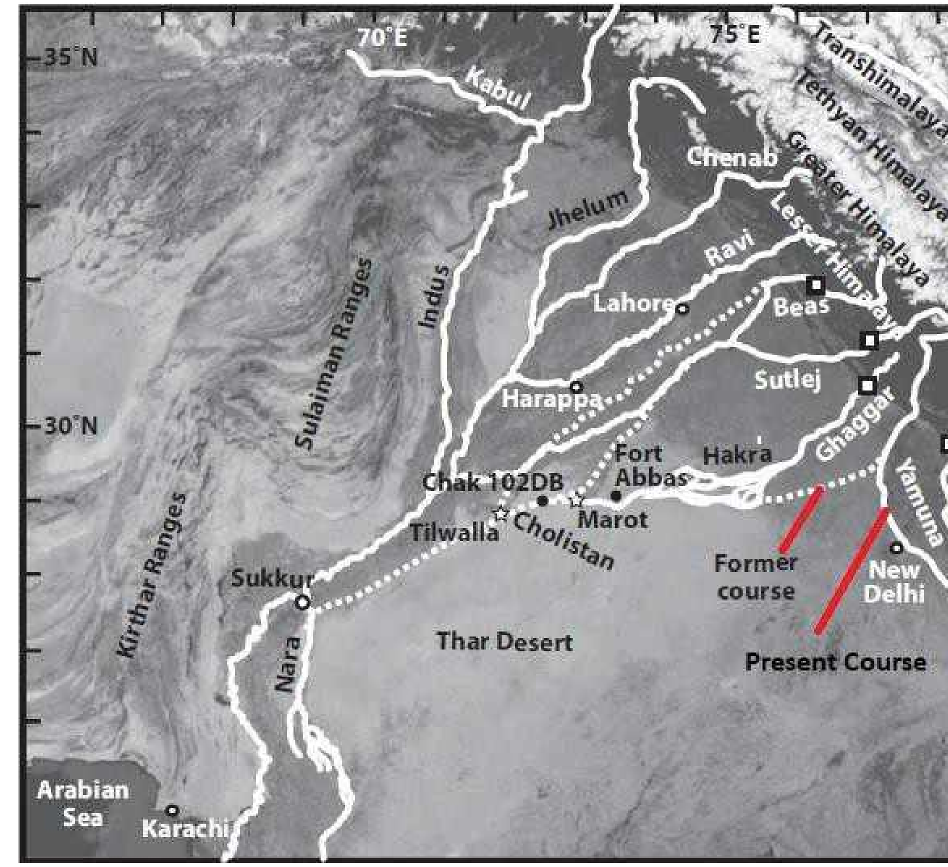
The first major avulsion took place about 5000 to 6000 years ago due to a cataclysmic tectonic event, when the River Yamuna changed its course and joined the Ganga River at present-day Prayagraj (Allahabad). Until then, the Yamuna was part of the Ghaggar-Hakra Paleo-channels (Saraswati) which disappeared in the late Holocene period *(Valdiya et al., 2016)*. Geologists believe that the Yamuna may have stopped flowing into the Ghaggar and Saraswati around 50,000 years ago, and started shifting its course eastwards till it eventually joined Ganga. The Beas and the Sutlej stopped flowing into the Ghaggar/Saraswati and joined the Indus about 10,000 years ago, that is, several thousand years prior to the establishment of the Harappan civilization. It is believed that the Harappan (or Indus Valley civilization) fully declined between 2000-1750 BCE, and that one of the many reasons that contributed to this was the drying up of the Saraswati River.

However, if the Saraswati did dry-up about 10,000 years ago (8000 BCE) due to a tectonic event, then this huge time gap of 6,000 years between the drying up of Saraswati and the decline of the Harappan civilization suggests that the decline was very gradual or was not connected to the drying up of the Saraswati at all! Although there is no general agreement on the reasons why the Harappan civilization declined, the three most commonly accepted factors are (i) a gradual environmental change, shifting in climate patterns and consequent agricultural decline, (ii) a tectonic event leading to the flooding of Mohenjo Daro and drying up of the Saraswati River (iii) an epidemic/ pandemic. It's important to note that discussions about the existence of the ancient Saraswati River often involve a mix of scientific, historical, and cultural perspectives. The concept of Saraswati continues to be a subject of fascination, and different people may interpret it in various ways, whether as a once-existing physical river or as a symbol of cultural and spiritual significance.

Over the years, scientific research and advancements have shed light on the potential existence of the Saraswati River and its subsequent drying up. It is believed that the river Saraswati originated from the river Har-ki-dun glacier in Gadwal, Uttarakhand, well before historical times. It actually flowed sometime between 6000 BCE and 4000 BCE, and then gradually dried up, due to tectonic events and other morphological changes. During recent decades the Geological Survey of India and ISRO have located underground paleo channels (dried-up channels lying one on top of the other) – at about eight locations. This series of palaeo channels currently lie to the west of the Aravali Ranges, which are considered to be amongst the oldest mountain range in the subcontinent. Geographers believe that the drying up of Saraswati, may have also been due to the eastward migration of Sutlej to the Indus, and westward migration of Yamuna towards Ganga.

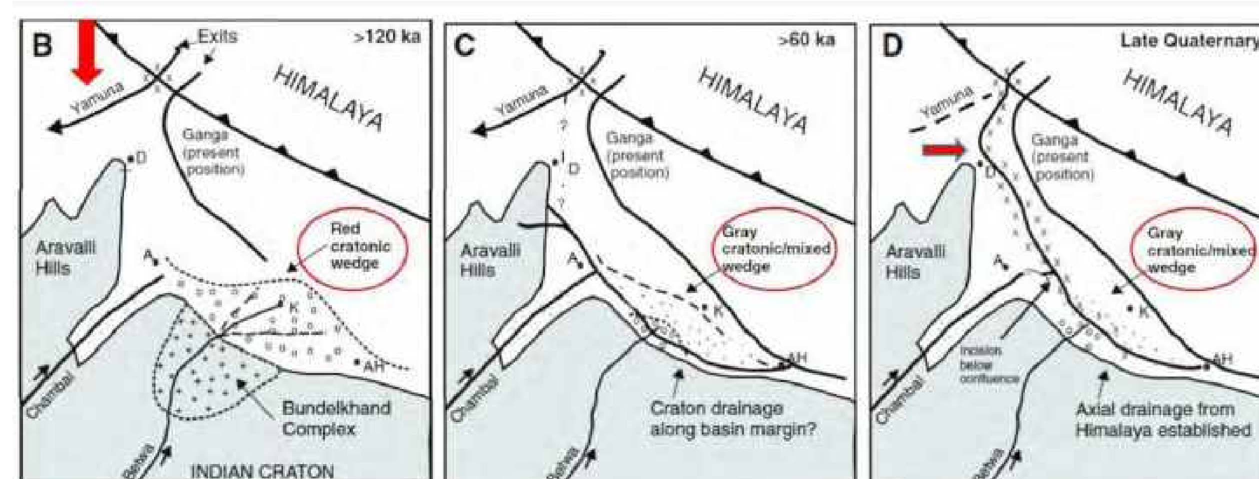
2.3.2 Ganga Avulsion (Historic period)

Compared to the Yamuna avulsion that took place almost 50,000 years ago, the Ganga avulsion was a relatively recent phenomenon which took place during the last 300-250 years, and it has determined its present morphology in the delta (Tails) when the Ganga



Map 2.3 Direction Of Avulsion Of River Yamuna From West To East Shown By The Dotted Lines Based On North Western Paleolithic Channels Studied By GSI

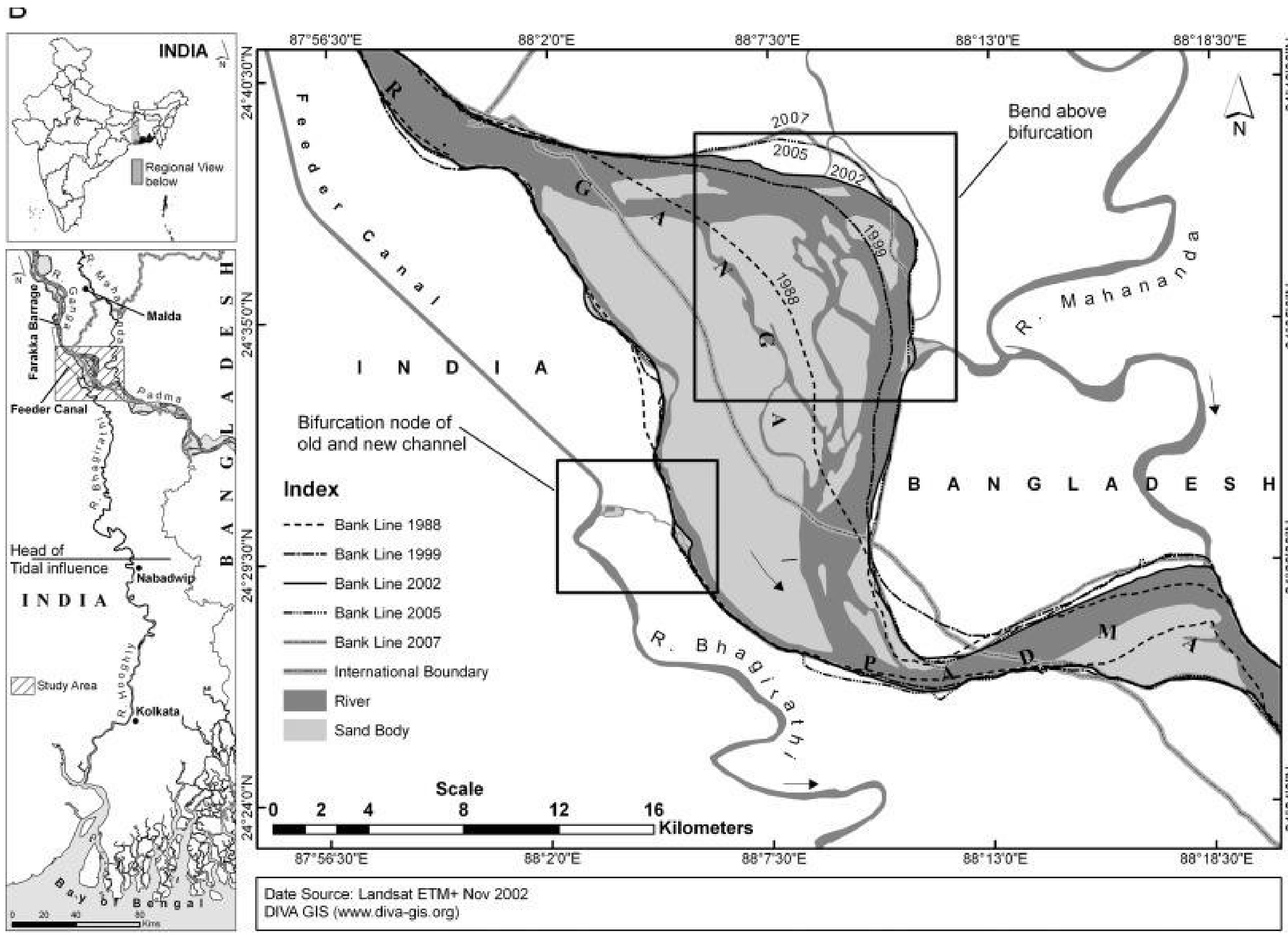
(Source: Clift et al., 2012)



the eastward shift of Ganga's channels.

Map 2.4 Schematic Map Showing Migration Of River Yamuna, Showing Avulsion Over 120,000 Years Ago To The Late Quaternary Period, Say About 12000 Years Ago

(Source: Valdiya et al., 2016)



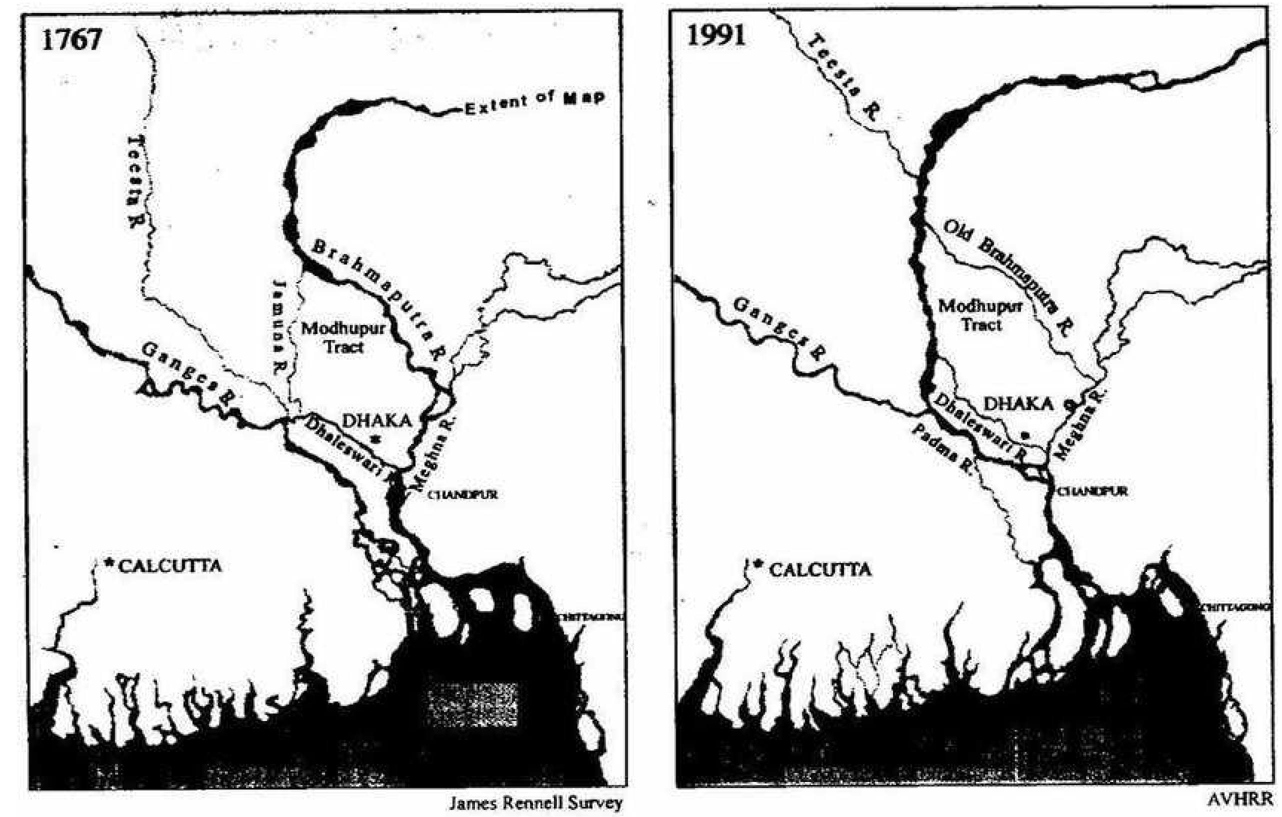
Map 2.5 The Farakka Feeder Canal And The Bhagirathi-Hooghly River As It Flows Today. The Recent Meander Migration History And The Bank-Line Location As Extracted From A Landsat Time-Series Are Demarcated. The Bifurcation Node Of The Old Channel As Well As The Bend Above Bifurcation Node Of The Old Channel Are Also Marked

(Source: Gupta et al., 2014)

2.3.3 Teesta and Brahmaputra Avulsion

Around the same period, after the destructive floods of 1787, the Teesta River which originates in the Pahunri Glacier (or Teesta Kangse) in Sikkim and joined the Mahananda River, changed its course towards the southeast, ultimately joining Jamuna (Brahmaputra) in Bangladesh. Consequently, this also led to a major westward shift in the Brahmaputra where it met with the eastward-shifting Ganga. This new channel is called Jamuna in Bangladesh while the old channel which still flows sluggishly is known as the old Brahmaputra. It is after this confluence that Ganga and Brahmaputra together flow and merge with the Meghna, ultimately joining the Bay of Bengal past the Bhola Island.

Together with the 1787 mega floods, geologists claim that the 1762 earthquake with a magnitude of 8.8 on the Richter scale which caused a tectonic uplift of the Modhupur tract just 25 years before the floods, would together have led to these series of avulsions determining



Map 2.6 The River Courses Of Ganga, Brahmaputra And Teesta Before And After The 1762 Earthquake And 1787 Mega Floods When The Major Avulsion Took Place

(Source: Gupta, 2012)

the present-day morphology of the GBM basin. Both these events substantially increased the flow of the Ganga River.

In the case of the Brahmaputra avulsion and confluence of Ganga and Brahmaputra, this hydro-morphological phenomenon is also called 'river capture'. The question arises - Did Brahmaputra capture Ganga or did Ganga capture Brahmaputra? Of the two rivers which come together, the river which has a larger annual average discharge, a higher elevation and gradient and therefore, a higher velocity, is said to have captured another river which has a lower flow, discharge and velocity. In other words, the river which is more sluggish and smaller is said to be captured. So, in this case, Brahmaputra is hydrologically the larger river with a higher average discharge, gradient and velocity as compared to Ganga; and therefore, Brahmaputra is said to have captured Ganga (total yield of Brahmaputra is around 537 BCM and Ganga is around 525 BCM).

Table 2.3 Discharges of Ganga and Brahmaputra River

(Source: Jain et al., 2007; National Institute of Hydrology, 2022)

Discharge Rates	Ganga At Farakka Barrage	Brahmaputra Before The Confluence
Maximum Discharge	65,072 cumecs	80,984 cumecs
Annual Average Discharge	16,650 cumecs	19,820 cumecs

However, if one compares Brahmaputra and Ganga, it is the Ganga which hosts a majority of the population of the larger basin and is culturally and historically better known as the primary river. It may be culturally rather difficult to digest the idea that Ganga was captured by Brahmaputra, since the number of people living in the Brahmaputra basin is just around 83 million, whereas the population of Ganga basin is much greater, estimated to be 448.3 million as per the 2001 census *(Mahanta et al., 2014; National Mission for Clean Ganga, 2021)*. Therefore, here again, the geo-hydrological conclusion is that Brahmaputra has captured Ganga, even though the societal perception will continue to be that of Ganga capturing Brahmaputra, because of its cultural and historical significance.

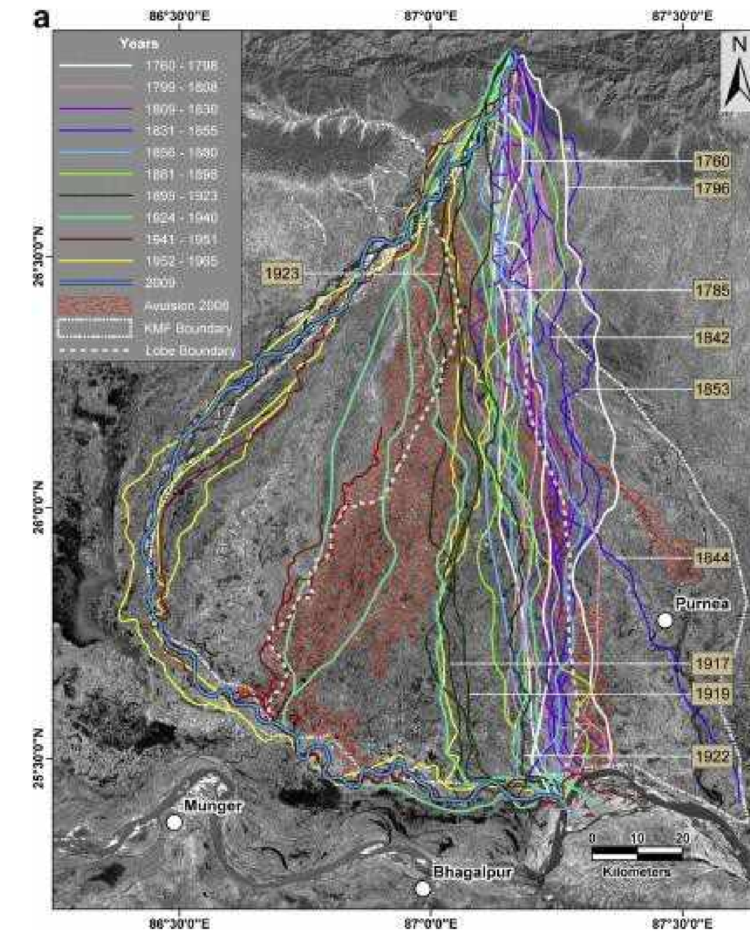
2.3.4 Kosi Avulsions

It is important to understand that these changes in river courses and channels are not episodic, but are still ongoing and continuously altering the drainage patterns and flows in the river system. One such example is the Kosi River avulsion which shows that the Sapta Kosi River has been shifting its channel westward, as seen in Map 2.6 given above. Although this avulsion must have taken place over several millennia the evidence based on palaeo-channels is available from the 1730s onwards.

After flowing in higher gradients and cutting through the Himalaya, the Kosi River has a funneling effect as it exits and meets the plains which have a very low gradient. The reduction in the velocity of river water leads to millions of tons of silt being deposited in this section every year. When the river deposits silt in its course, it increases the height of the river bed compared to the neighboring land, causing the river to change its course and find a new path. This has led to the formation of an alluvial 'mega-fan', which is the largest of its kind in the world (See Map. 2.6).

This phenomenon, along with increasing precipitation levels, destruction of natural drainage channels, wetlands and lakes have been the main causes of the annual flooding events in the states of Bihar and Uttar Pradesh. Since 1963, the Kosi River has breached its natural and artificial embankments seven times leading to major flooding events. Studies suggest that the relocation of the Kosi River in the past was through an oscillating avulsion rather than a systematic unidirectional shift *(Chakraborty et al., 2010)*.This was witnessed during the breach at Kusaha (Nepal) which led to a 120 km. eastward migration of the river resulting in the disastrous 2008 Kosi floods which will be discussed in detail in Chapter 11.

Therefore, although this timescale is relatively insignificant in the geological time frame, the present configuration of the river system is based on a very recent historical time span. The anabranching[20], braiding, twisting and migration of the river channels is continuously altering the river system. A recent example of such anabranching took place in October 2021, when four major rivers of Uttarakhand - Kosi, Gaula, Nandhaur and Dabka changed their course due to heavy rainfall *(Azad, 2021)*.Therefore, on the geological timescale, the recent history of the GBM basin is only about 250 years old and is still evolving.



Map 2.7 Kosi Mega-Fan: Historical Records, Geomorphology And The Recent Avulsion Of The Kosi River
(Source: Chakraborty et al., 2010)

2.4 THE NEW GBM RIVER BASIN PERSPECTIVE

In 1947, undivided India was partitioned into India and Pakistan, inclusive of East Pakistan. Later in 1971, after the Independence of Bangladesh, water experts started focusing on the emerging riverine issues on Ganga, (known as Padma in Bangladesh) since it had become a trans- boundary river. Therefore, it was not till the end of the colonial period i.e., after the partition of India and Pakistan/East Pakistan that the Ganga, Brahmaputra and Meghna started being discussed as one single river basin.
Subsequently, the Joint River Commission was established. It was a bilateral Working Group established by India and Bangladesh as part of the 'Indo-Bangla Treaty of Friendship, Cooperation and Peace' that came into being in November, 1972. As per the treaty, the two nations established the commission to work for the common interests and sharing of water resources, irrigation, floods, and cyclone control. The studies and reports of the Commission contributed directly to the efforts of both nations to resolve the dispute over the sharing of Ganga water, facilitating bilateral agreements in 1975, 1978 and finally in 1996. It took 25 years before an agreement could be reached between India and Ban-

gladesh, known as the 'Ganga Water Sharing Treaty of 1996' (also known as the Farakka Treaty).

However, most of these agreements and discussions focused only on the Ganga, while Brahmaputra and Meghna were still not part of the negociations, although both were important trans-boundary rivers. In 2001, the well-known water expert and advocate of river basin planning, Prof. Asit K. Biswas published his landmark paper entitled 'Sustainable Development of the Ganga, Brahmaputra, and Meghna Basins'.[21] Later on, the role of the Joint Commission was expanded to include Brahmaputra, Meghna and 51 other trans-boundary rivers between India and Bangladesh. Thus, considering the GBM as a holistic entity for sustainable development and co- operation was brought on to the agenda.

The GBM basin covers a total catchment area of 172,700 sq.km, is spread over five countries and divided between India (64%), China (18%), Nepal (9%), Bangladesh (7%) and Bhutan (3%) *(FAO, 2011)*. The combined discharge of GBM has been estimated to be 1,38,700 cumecs, which is the third largest in the world, after the Amazon and Congo in South America and Africa respectively. Of the total volume, the independent yield of Brahmaputra is 537.24 km^3, that of Ganga is 525.20 km^3 and that of Meghna is 48.36 km^3. Therefore the total yield of GBM works out to be 1,110.80 km^3 *(India-WRIS, 2012)*.

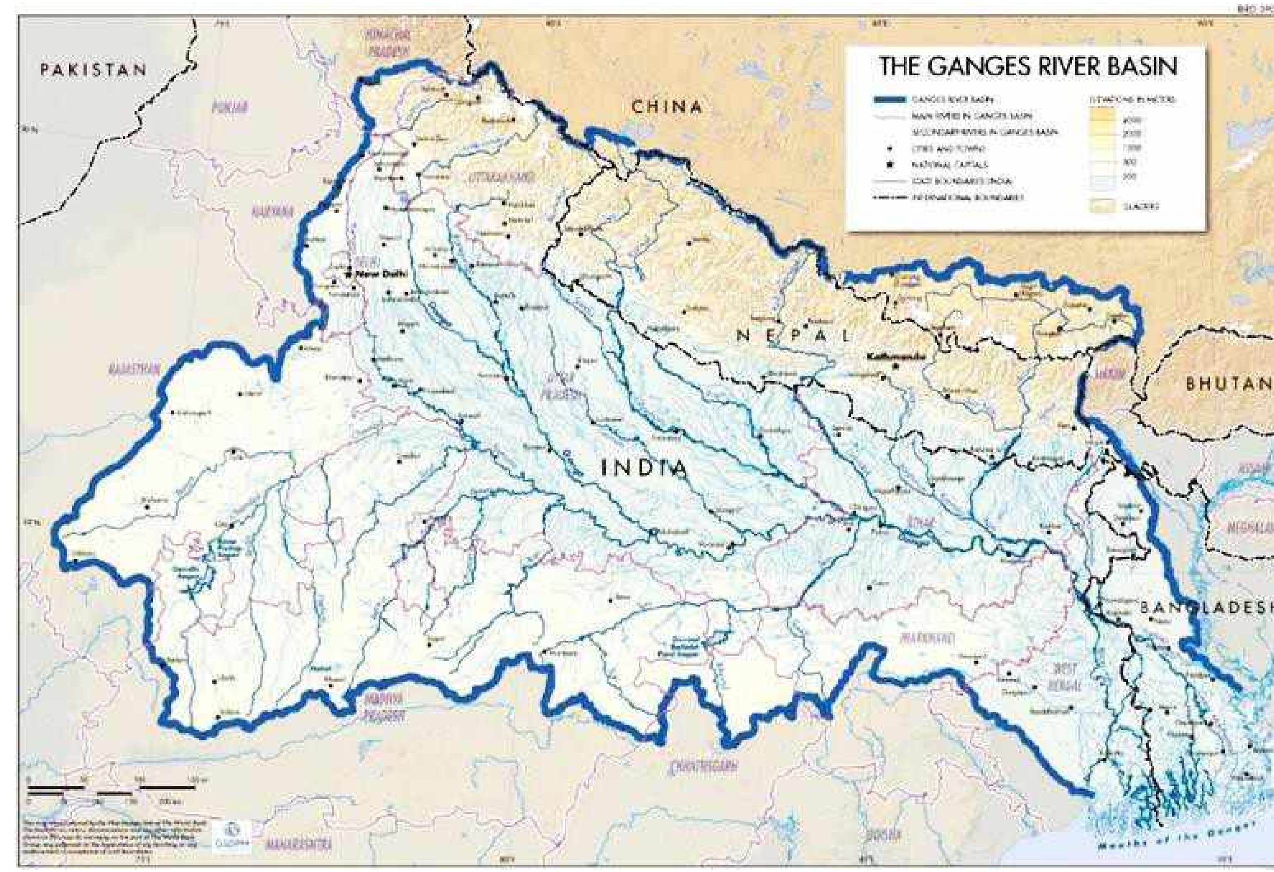
The annual groundwater potential of the basin is estimated to be 140 km^3 of which 108.5 km^3 is in Nepal and India (Ganga), 10.7 km^3 is in North-Eastern India and 21 km^3 is in Bangladesh (Ganga-Brahmaputra combined). Thus, there is obviously no shortage of water per se, but there is a serious issue of too much water (floods) during the monsoon months and a drought like situation during the three summer months i.e., 15th March to 15th June. The total water availability of GBM is 1110.80 km^3 + 140 km^3 = 1250.80 km^3.

2.5 THE CRYOSPHERE OF GBM

The total area of GBM covered by snow, ice and permafrost, i.e., the cryosphere, is about 38,935 km^2 which waxes and wanes from season to season. The total contribution of snow and ice melt is about 9-10% in the case of Ganga, 19-21% in the case of Brahmaputra and none in the case of Meghna *(Miller et al., 2012)*. But regardless of the absolute annual share, the importance of the snow and ice melt should not be underestimated, since its contribution forms a crucial and reliable share of river flows during the three summer months. Unfortunately, due to climate change, the contribution of water from the cryosphere is a gradually but inevitably vanishing entity (See Chapters 3 and 4).

2.6 TRANSBOUNDARY NATURE OF GANGA RIVER SYSTEM

Within the GBM basin, the Ganga River Basin (GRB) forms the larger component with an area of of about 10,00,000 sq. kms between longitude 73.37º E and 89.31º E and latitude 22.45º N and 31.47º N *(Central Water Commission, 2020(b)*.[22] The entire drainage basin/catchment area[23] begins high in the Himalaya Mountains from Tibet, Nepal and India and empties out through Bangladesh into the Bay of Bengal forming a delta of the Ganges- Brahmaputra-Meghna (GBM) River Basin.[24]

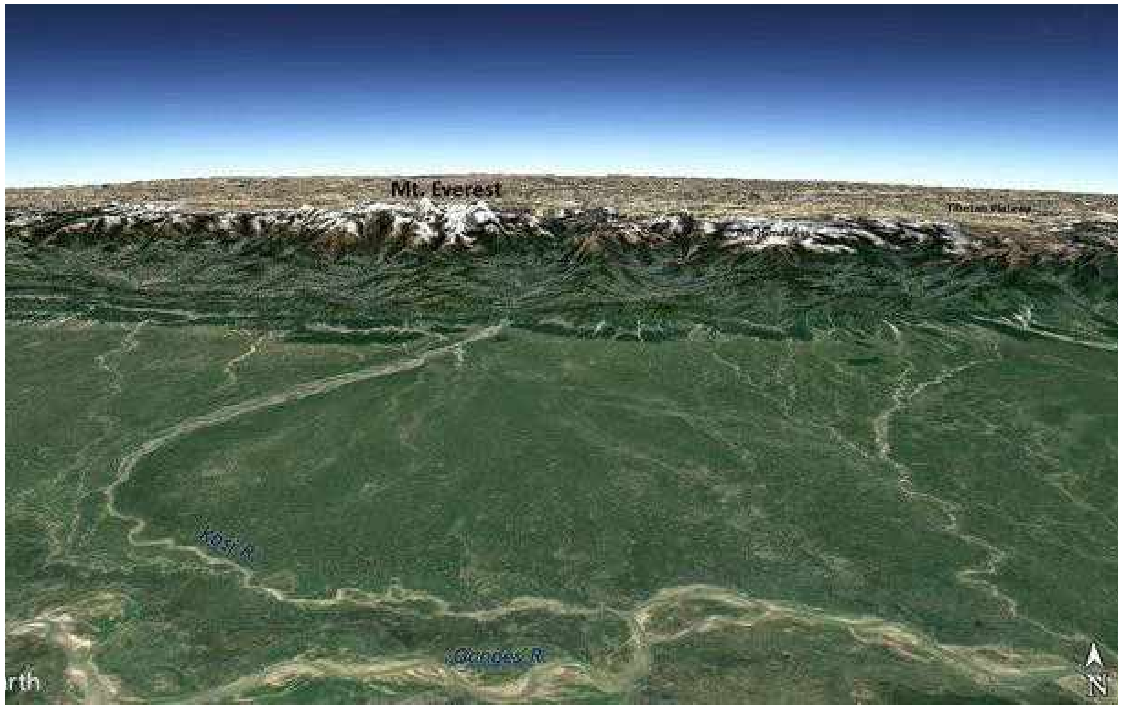


Map 2.8 Map of the Entire Ganga Basin spread across Tibet, Nepal, India and Bangladesh
(Source: Sadoff et al., 2013)

2.7 HEADWATERS OF GANGA RIVER BASIN

The headwater streams and major tributaries of Ganga, instead of being located only in and around its origin at Gangotri in Uttarakhand, are actually spread across the broad-band of Central Himalaya, consisting of Yamuna, Ganga (India), Mahakali (India and Nepal), and Karnali, Gandaki, and Sapta Koshi (Nepal). Thus, the Greater Himalayan Range forms a water divide between Brahmaputra to the North and Ganga to the South. The Himalaya takes the shape of Shesha Naag's hood.[25] This hood (Himalayan ranges) consists of an area stretching from Banderpoonch mountains, (i.e., origins of Yamuna River), up to the Kangchendzonga ridgeline on the border of Nepal and Sikkim. From the western slopes of Kangchendzonga three rivers emanate (Yangma, Ghunsa, and Simbua) and join the Tamor River in Nepal, which is one of the tributaries of Sapta Kosi River, which merges with Ganga at Kursela in Katihar district of Bihar. However, if we accept the GBM perspective then the heads of Gangawould extent from Banderpoonch to eastern corner of Arunachal Pradesh, i.e., the eastern border of Brahmaputra River as well.

2.8 GANGA RIVER SYSTEM IN NEPAL

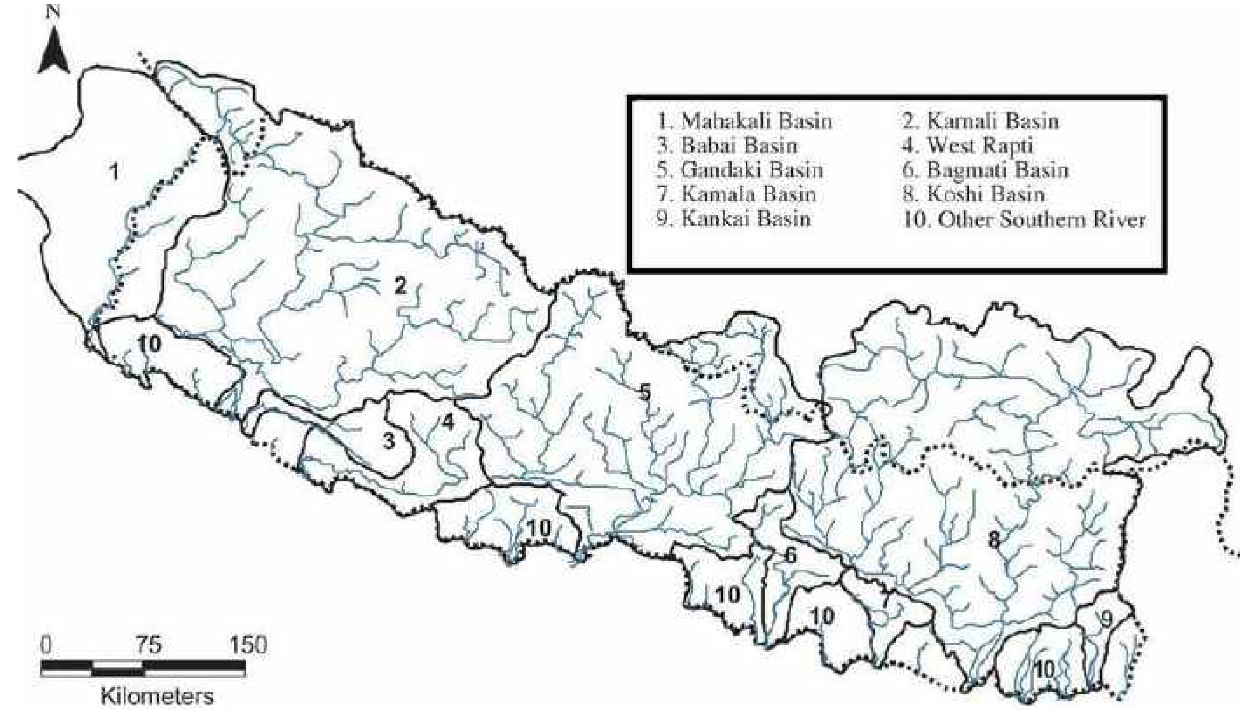


Map 2.9 : Kosi River Basin With Proverbial Hood Of Shesha Naag (Serpent), With Laxmi-Narayan In Reclining Position

(Source: Google Earth, Palanichamy, 2020)

The entire area of Nepal is constituted by ten sub-basins, and all of them eventually enter India and join mainstream Ganga as Ghaghara (inclusive of waters from Sarda, Mahakali and Karnali), Gandaki, Sapta Kosi(inclusive of Kankai) and the four southern river basins, as shown in the following map.

The Karnali (later known as Ghaghara), Gandaki and Sapta Kosi rivers form the major river basins and account for 80% of Nepal's water resources. Out of these three major left bank tributaries of the Ganga, the Gandaki and Sapta Kosi have their origins in Tibet. Within Nepal there are several medium-sized rivers which originate within Nepal borders, namely, the Babai, West Rapti, Bagmati, Kamla and Kankai, which together contribute about 7% of the total run-off. In addition, there are several smaller rivers which originate in the Shivalik hills, like Bering, Balan, Khutia, Pathraiya, Lal Bakaiya, Ratu, Sirsia, Manusmara and Banganga. Three large tributaries (Ghaghara, Gandaki and Sapta Kosi) and five medium rivers (Babai, West Rapti, Bagmati, Kamala, and Kankai) form the river system. Notably, the cryosphere of the Ganga river basin, part of which lies in Tibet contributes about 5% of water resources which enter Nepal. The FAO Water Report No. 37, states that almost 225 BCM of surface water from Nepal flows into the Ganga, constituting about 40% of the annual average flow, and about 60-70% of the dry season flow of the Ganga, when flows from southern tributaries such as Chambal, Betwa, Rind, Son and others are negligible *(Frenken, 2012)*. The total yield of Ganga amounts to about 525 BCM, as per Central Water Commission, GoI.



Map 2.10 Major Tributaries Of The Ganga River Entering From Nepal. The Map Indicates That The Entire Geographical Area Of Nepal Actually Lies In The Greater Ganga River Basin

(Source: Gautam & Acharya, 2012),
Adapted from (Water and Energy Commission Secratariat Nepal, 2002)

It is largely because of these left bank tributaries coming from Nepal, that the quantity and quality of Ganga water is maintained up to the Farakka barrage, and thereafter. The Bhagirathi Hooghly River is kept alive partly because of the discharge from Nepali rivers. Further this flow helps India to comply with the 30-year Ganga Water Sharing Treaty of 1996 with Bangladesh *(Dyurgerov & Meier, 1997)*. Without the significant contribution of these rivers, the stem of Ganga within India would have a substantially lower quantity of water, and suffer from serious pollution and contamination.

2.9 TAIL-END OF GANGA RIVER BASIN

The Indian perception of the Ganga still refers to the ancient geology of the river when Ganga used to flow through the Bhagirathi-Hooghly channel and enter the Bay of Bengal at Gangasagar in West Bengal within the current Indian borders. Unfortunately, this understanding of Ganga does not acknowledge the eastward migration of the river into Bangladesh where Ganga is known as Padma (discussed in sections above related to river avulsions).

The mean annual discharge of Ganga at the Farakka barrage is around 62,600 cumecs near the Baruria transit point before its confluence with Jamuna. Similarly, the mean annual discharge of Brahmaputra before its confluence with Ganga is 79,340 cumecs. Thereafter, at the Ganga- Brahmaputra (Jamuna) confluence at Aricha in Bangladesh, the total discharge of the two rivers combined is 141,940 cumecs. It may be noted that the present discharge of Bhagirathi-Hooghly, when it splits away from mainstream Ganga is between a minimum of 1315 cumecs to a maximum of 1669 cumecs.*(Gupta et al., 2010; Rahman et al., 2017)*

Had it not been for the artificial Farakka Feeder Canal (42 km long) built in 1972 which adds about 1812.28 cum/s of water, the discharge in Bhagirathi-Hooghly would have been even smaller than it is today. The main stem obviously moves in the eastward direction into Bangladesh where it merges with the Brahmaputra (Jamuna).

We can now describe the entire Ganga River System by including left bank contributaries which start from the higher Tibetan Himalaya near Mansarovar Lake and right bank tributaries of Yamuna, rising from the Himalayan ranges in the North and Vindhya Ranges in the South and continue up to the confluence with Brahmaputra (Jamuna) in Bangladesh.

2.10 SPLITTING OF DISTRIBUTARIES AND THEIR DISCHARGE INTO BAY OF BENGAL

Near the Farakka Barrage the gradient of the river bed is very gentle, the flow becomes sluggish, and the first distributary to split off is the Bhagirathi Hooghly, which is the first attrition point. After entering Bangladesh, the Ganga splits further into several distributaries which meander and braid towards the Bay of Bengal. The final discharge point of GBM extends from Gangasagar Island in India (West Bengal), to the Bhola Island in Bangladesh towards the eastern-most point of the Bangladesh delta. There is a complex series of eight major mouths from east to west within a distance of around 350 km of the coast line of the Bengal Delta.

2.10.1 Different Perceptions of the Length of Ganga

The length of a river depends on the point of origin and point of discharge into the ocean. However, the Ganga has two major tributaries, namely Brahmaputra and Meghna. Interestingly, the Brahmaputra happens to be much longer than Ganga and its origin can be taken as the origin of the greater GBM River System.

a)When the mouth of the river is considered to be at the Gangasagar Island, located south of Kolkata in West Bengal, the total length of the river is estimated to be 2,525 km *(India-WRIS, 2021)*. However, as discussed above the main flow of Ganga currently does not discharge into Hooghly, but flows directly into the Brahmaputra mainstream and then continues till the Bhola Island where it finally discharges into the Bay of Bengal.

b)Therefore, if we consider the length of Ganga from Gomukh to its confluence with Brahmaputra in Bangladesh, it is estimated to be 2,388 km *(Verma et al., 2014)*. Further, from the confluence of Ganga and Brahmaputra to the Bay of Bengal at Bhola Island the distance is approximately 228 kilometers[26]; and therefore, the length of Ganga adds up to 2,616 km.

2.11 MAJOR TRIBUTARIES OF GANGA AND THEIR ORIGINS

There are about 30 major sub-basins/tributaries with sub-catchments greater than 3000 sq.km, which form the Ganga River Basin. In addition, there are several tidal rivers which cover about 15,500 sq.km. in the delta regions, including the tidal zone of West Bengal and Bangladesh. The principal contributaries of the Ganga River are Bhagirathi, Alaknanda, Ramganga, Yamuna, Gomati, Ghagara (Sharada/Karnali), Gandaki/Kali Gandaki, Sapta-Kosi, Mahananda, Son, Mayurakshi and Damodar.

Bhagirathi River starts its journey at Gomukh (the traditional and cultural origin) and is joined by seven major contributaries: Kedar Ganga at Gangotri, Jadh Ganga at Bhaironghati, Kakora Gad and Jalandari Gad at Harsil, Siyan Gad at Jhala, Asi Ganga at Uttarkashi and Bhilangana at Old Tehri. Further, Bhagirathi joins Alaknanda River at Devprayag, after which the river is called Ganga.

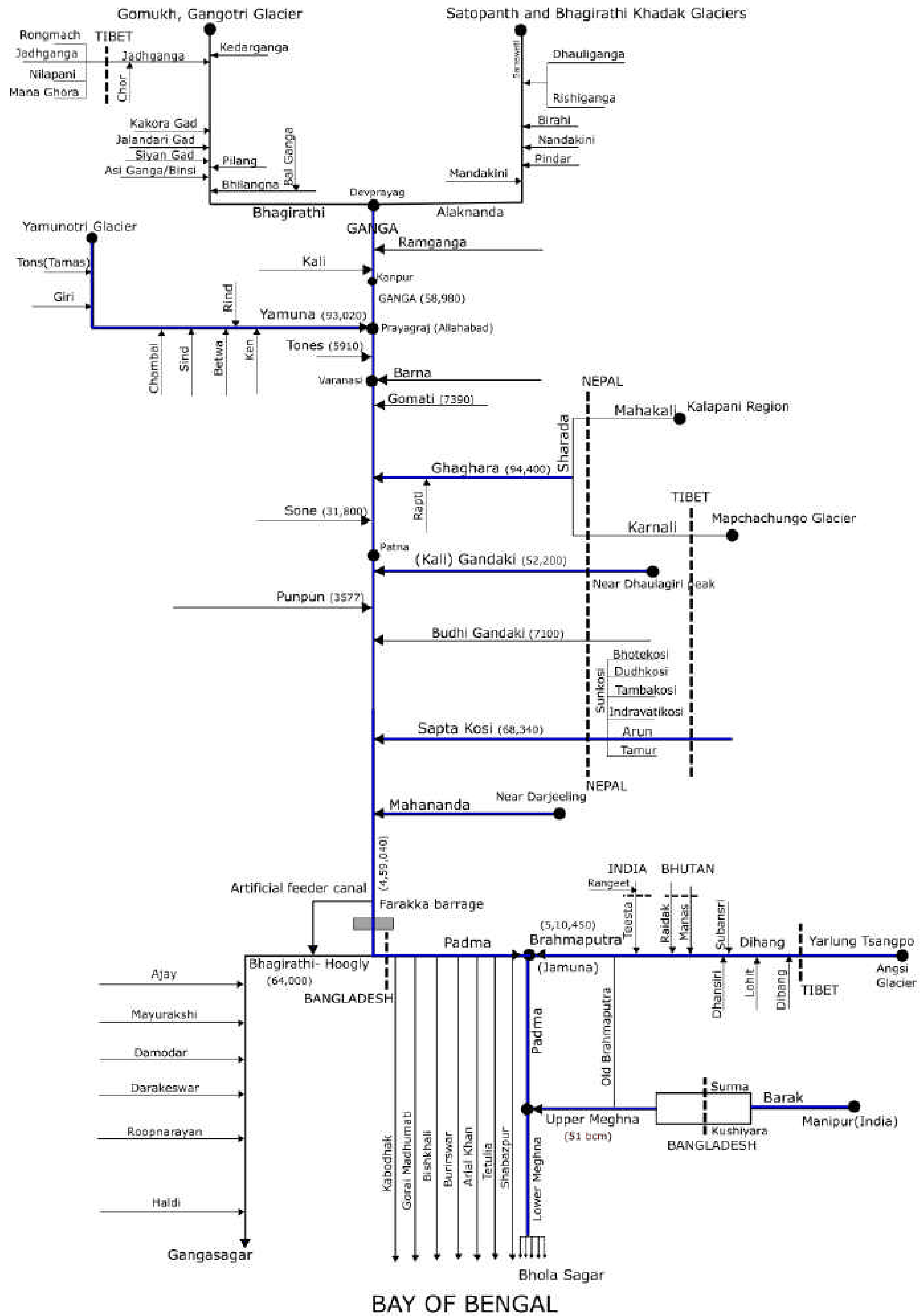
Jadhganga River originates beyond the Indian border from the Tibetan region and it has three tributaries - Rongmach, Nilapani, Mana Ghora, which lie just below the Sutlej river basin in Tibet. These three have a confluence with each other and then finally form the Jadhganga River also known as Janhavi River. After entering India, it is joined by the Chor tributary which lies entirely in India and then joins the Bhagirathi River at Bhaironghati. The map given by the Government of Uttarakhand titled 'Major and Minor Rivers of Uttarakhand' shows all these tributaries within Indian territory *(Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, 2005)*. However, the Survey of India map shows it outside India. As per the standard practice, the position given in the map of Survey of India, is considered as authoritative since it coincides with the ground reality.

Alaknanda River has its origin at the terminus of two major glaciers namely: Satopanth Glacier and Bhagirathi-Khadak Glacier near the Nanda Devi massif/glacier. The seven major contributaries of Alaknanda are Mandakini, Nandakini, Pindar, Dhauliganga, Vishnuganga, Rishiganga and Birahi. The confluence of these rivers with each other, are known as the Pancha Prayag, 'five sacred confluences':

(1) Dhauliganga River at Vishnuprayag,
(2) Nandakini River at Nandaprayag,
(3) Pindar River at Karnaprayag,
(4) Mandakini River at Rudraprayag,
(5) Bhagirathi River meets Alaknanda at Devprayag.

2.11.1 Right Bank Tributaries Beyond Devprayag

The major right bank tributaries of Ganga are Yamuna and Son apart from several minor



Ganga River Line Diagram, Showing All Tributaries Entering From India, Nepal, Tibet And Bangladesh

(Adapted from 'Ganga Basin', CWC, 2014)

ones such as Punpun and Damodar. The Yamuna River originates from the Yamunotri glacier near Banderpoonch peaks in the lower Himalaya in Uttarakhand at an elevation of about 6,387 meters amsl. Tons, Chambal, Sind, Betwa and Ken River are its main right-bank tributaries. Hindon, Sharada, Varuna and Giri River are its major left-bank tributaries. Yamuna further merges with the Ganga River at Triveni Sangam at Allahabad city, now known as Prayagraj, where the Kumbh Mela is held.

2.11.2 Left Bank Tributaries Beyond Devprayag

The major left bank tributaries include Ramganga, Ghaghara (Karnali), Gandaki (Narayani), Sapta Kosi and Mahananda. The Ramganga River is the first major tributary to join Ganga on its left bank. It rises in the lower Himalayas at an altitude of about 3110m above mean sea level (mamsl) from the Dudhatoli range in Chamoli district of Uttarakhand. The Gomati River is the left-bank tributary of the Ganga which rises from Gomat Taal in the Pilibhit district of Uttar Pradesh. It joins Ganga at Ghazipur in Uttar Pradesh after flowing through the cities of Lucknow and Jaunpur.

Ghaghara River is also known as Gogra, Nepali Kauriala, Manchu or the Karnali, literally meaning 'holy water from the sacred mountain' (the term Karnali also means "Turquoise River"). It is the second largest tributary of Ganga River with a length of approximately 1080 km. It rises from Mapchachungo Glacier in the high Himalayas of southern Tibet, and flows southeast through Nepal. The Karnali River Basin has 1,361 glaciers and 907 glacial lakes, with glaciers covering an area of 1,740.22 km² and an estimated ice reserve of 127.72 km³ *(Rai & Gurung, 2005)*. Cutting southward across the Siwalik Range, it splits into two branches that rejoin south of the Indian border and converges with the Mahakali or Sarada (Sharada) river[27] at Brahmaghat in India and forms the Ghaghara. It flows southeast through Uttar Pradesh and Bihar states to enter the Ganga below Chapra after a 970 km. long course.

The Sarada River (Mahakali in Nepal) originates from Kalapani in the Himalayas at an elevation of 3,600 mamsl in the Pithoragarh district in Uttarakhand. It flows along the Indo- Nepal border before leaving the Himalayas at Baramdeo. The river is known by different names: Mahakali, Sarda, Sharada, Kheri, and Chauka. In addition, Gori Ganga, an important tributary, which originates in the Milam glacier near Nanda Devi merges with Mahakali River at Jauljibi.

Gandaki River is also known as Kali Gandaki/Kalyani in Nepal. The river rises at 7620 mamsl in Tibet near the Nepal border and is overlooked by the Dhaulagiri peak. It is known as Narayani after the confluence with Trisuli in Nepal. The Gandaki River Basin is known to contain 1025 glaciers and 338 glacial lakes *(Bajracharya et al., 2002)*. It is formed by the union of the Kali and Trisuli rivers, which rise in the Great Himalayan Range in Nepal, and from this junction to the Indian border the river is called Narayani. It flows southwest into India and then turns southeast along the Uttar Pradesh–Bihar state border and across the Indo-Gangetic Plain. It enters the Ganga River opposite Patna after a winding course of 765 km. The Burhi/Budhi (old) Gandaki flows parallel to and east of the Gandaki River and joins the Ganga northeast of Munger.

The Sapta Kosi River or Kosi River drains the northern slopes of the Himalayas in the Tibet and the southern slopes in Nepal. From a major confluence of tributaries north of the Chatra Gorge onwards, the Kosi River is also known as Sapta Kosi for its seven upper tributaries. These include the Tamur Kosi, originating from the Kangchendzonga area in the east, Arun River from Tibet; and Sun Kosi from the Gosainthan area. All glaciers and rivers south of Mt. Everest drain into Sapta Kosi River. The Sun Kosi's tributaries from east to west are Dudh Kosi, Bhote Kosi, Tamba Kosi and Indravati Kosi.

The Sapta Kosi crosses into northern Bihar where it branches into distributaries before joining the Ganga near Kursela in Katihar district. The Kosi is 720 km. long and drains an area of about 74,500 km² (28,800 sq m.) in Tibet, Nepal, and Bihar. The Dudh-Kosi sub-basin alone consists of 36 glaciers and 296 glacial lakes. The Sapta Kosi River catchment covers six geological and climatic belts varying in altitude from above 8,000 mamsl to 95 mamsl comprising the Tibetan plateau, the Himalayas, the Himalayan mid-hill belt, the Mahabharat Range, the Siwalik Hills and the Terai *(National Institute of Hydrology, 2018)*. The catchment area of the river receives very heavy rainfall leading to floods. The Kosi is euphemistically called Bihar's 'River of Sorrow.'

The Mahananda River originates in the extreme north of West Bengal, from the northern hills of Darjeeling, at an elevation of 2100 mamsl and merges into Ganga at Godagari Ghat after flowing for 360 km. It is the last left-bank tributary of Ganga.

The Damodar River rises in the Chota Nagpur Plateau and flows in the eastern direction in Jharkhand while passing through a rift valley. It joins the right-bank of Hooghly River near Fulta. The Barakar River is an important tributary of the Damodar (See Line Diagram above of Ganga River System).

2.12 DISTRIBUTARIES OF GANGA RIVER SYSTEM (BENGAL DELTA)

At the Farakka barrage the gradient of the river bed becomes so gentle that distributaries start splitting off from the main stem. The Hooghly (also called Bhagirathi-Hooghly) is the first distributary, which splits off to the south at Murshidabad near Farakka Barrage, West Bengal which can be considered as the first attrition point *(Kawser & Abdus, 2016)*. A little distance after the barrage the river splits into the Bhagirathi-Hooghly River which flows through West Bengal, and then splits into Padma River which enters Bangladesh and further joins Brahmaputra and Meghna. The construction of the barrage began in 1962 and was completed in 1972, mainly for the purpose of diverting about 1150 cum/s of water from the main Ganga stem into Bhagirathi-Hooghly River for flushing out the sediment deposition from the Kolkata Harbour. Thus, the Farakka Feeder Canal (42 km. long) carries water from above the barrage right up to Bangabari, West Bengal where it joins the Bhagirathi-Hooghly River. Therefore, the Bhagirathi-Hooghly River forms the first distributary which is augmented by the artificial feeder canal and tributaries such as Mayurakshi, Jalangi, Ajay, Damodar, Rupnarayan and Haldi.

After the split of the main Ganga stem into Bhagirathi-Hooghly and Padma, the river flows through Bangladesh and further spreads through various distributaries like Jalangi, Mathabhanga, Icchamati, Bhairab, Bhadra, Kobadak, Nabaganga, Gorai-Madhumati, Arial Khan and many others. Further, the river is captured by Brahmaputra (known as Jamuna in Bangladesh) and the Barak River (known as Meghna in Bangladesh). The Ganga-Brahmaputra-Meghna River systems then diverge into multiple distributaries forming an intricate web of waterways which is constantly changing in the delta composed of thick alluvial deposits, ultimately joining the Bay of Bengal forming a complex series of mouths from east to west at several locations spread right across the coastline spanning a distance of about 350 km, the important ones being Bhola, Tetulia, Shahbazpur, Hatia, Bamni, Gangasagar Island and many small ones.

2.12.1 Ganga Beyond the Farakka Barrage

Map 2.11 Eight Major Discharge Locations Along With Their Complex Networks Of Randomly Branching And Migrating Rivers Along The 350 Km Coastline
(Source: Perkins, 2020)

Contrary to general belief, the mainstream Ganga does not exit at Sagar Island, near Kolkata, West Bengal. Only a miniscule volume of about 1150 cumecs (1.5%) of the mainstream discharge actually flows down through the Bhagirathi-Hooghly, whereas the mainstream Ganga flows beyond the Farakka barrage into Bangladesh (76,500 cumecs). What flows out at the Sagar Island from the mighty Ganga River at Farakka in Murshidabad is only through an artificial canal from the Farakka reservoir, and that too for a period of three to four months only. The Bhagirathi-Hoogly River remains delinked from the Ganga for about nine months of the year and receives water from a 38 km. long feeder canal originating from the Farakka barrage *(Rudra, 2018)*. Note that the Bhagirathi-Hooghly is later joined by several rivers such as Ajay, Mayurakshi, Damodar, Darakeshwar, Roopnarayan, and Haldi which considerably augment its flows, thereby giving a false impression that the Bhagirathi-Hooghly itself is the main stem of Ganga.

2.13 CONTRIBUTION OF GROUNDWATER IN GANGA RIVER SYSTEM

Groundwater releases through springs contribute substantially to the total flow of the Ganga, that is, about 35% during the pre-monsoon period and about 11% during monsoon period. Recent analysis suggests that groundwater contribution directly depends on the altitude as well as the season. Since more than three fourths of Nepal is highly mountainous and undulating, the groundwater recharge forms a very small fraction of the annual precipitation, and is mainly available for abstraction in the Terai belt which forms the edge of Indo-Gangetic plains. It is estimated that about 8.8 billion cubic meters is available as ground water in Nepal *(Poudel, 2019)*.

At Gangotri, groundwater releases are almost negligible during the post-monsoon season and are at its maximum at Devprayag during the pre-monsoon period. Towards the south of the Siwalik zone, the alluvial plains are underlain by loose unconsolidated river borne sediments and form a very good repository of groundwater. Just below the land surface, the alluvium is saturated with groundwater. Water table occurs between 10m to 60m Below Ground Level (BGL) in the sub-mountainous tract but generally lies between 3m to 10m BGL in the alluvial plains. The aquifer nearer to the land surface area is of unconfined nature, but with increasing depth in regional or sub-regional areas it extends through layers of low permeability. Here the groundwater occurs in semi-confined to confined conditions. Thus, lower the altitude, greater the groundwater yield and vice versa, thus showing an inverse relationship between altitude and groundwater contribution.

2.13.1 Brahmaputra River System

Until very recently, it was not known that Brahmaputra, Siang, Yarlung Tsangpo, Dihang, Sema, Luit, Tilao and others were actually the same river.[28] It was probably only after the 10th century CE that the Bengali and Assamese sages, including the Buddhists, Jains and Hindus had intuitively perceived that the river in India must be the same as the one in Tibet , since a flow as large as that of Yarlung Tsangpo could not have simply disappeared. Thus, Yarlung Tsangpo was in fact the Brahmaputra River. The earliest available reference is that of the Lauhitya which finds mention in canto 58 of the Markandeya Purana, whereas the name Brahmaputra was first mentioned in a much later work, the Kalika Purana which scholars believe was written by an anonymous poet of Assam around the 10th century CE *(Dutta, 2012)*.[29]

2.13.2 Why This Hiatus About Understanding Brahmaputra?

The lack of knowledge about the Brahmaputra is not surprising, because till then the entire river had still not been properly surveyed, mapped, or physically traversed. Contrary to general knowledge, it had never been followed from the origin to the end by anybody simply because it was physically impenetrable from Mt. Gyala Peri (Tibet) to its entry into Arunachal Pradesh, which is a distance of more than 500 km. Traditionally, there were five or six pilgrimage routes or *yatras* to Kailash-Mansarovar, the region from where Brahmaputra originates. But there were no *yatras* which went along the river from the origin of the Brahmaputra to its mouth. The ancient Buddhist monks were probably the only people who knew about it but had not ventured to physically travel through a series of gorges which, in several segments, had rocks which rose almost vertically for several thousand meters. In Buddhist philosophy, the river and the mountains were to be revered and understood only as much as they would reveal themselves. Physically travelling through or along the river, from one end to the other, was never an objective to be achieved.

Consequently, after the point where the Brahmaputra turns to the north and takes a Great Bend southward, the area was considered to be sacred and known as 'Pemaco' or the area of revered waterfalls. The Great Bend contains the deepest canyon in the world which measures 6,009 m. from the river bed level of about 1,773 m amsl to the summit of Mt. Namche Barwa (7,782 m amsl). The two important waterfalls were known as the Rainbow falls (about 21 m in height) and the Hidden falls (about 33 m in height). The Buddhist monks preferred to treat 'Pemaco' as an entity of ethereal beauty and not as a physical challenge to be overcome or 'conquered'.

It was in the 1860s that the Geological Survey of India, (established in 1851), started surveying the river up to Mt. Namche Barwa. Indian explorers of the 19th century (in the period 1865-85) such as Pundit Nain Singh, Mani Singh, Pundit Kishen Singh, Hari Ram, Kalian Singh, Kinthup, Nem Singh, Rinzin Namgyal, Lama Ugyen Gyatso, Lala, Atta Muhammad and others were the pioneers of mapping and surveying of the Brahmaputra in particular and Tibetan region in general *(Rawat, 2002; Survey of India, 1990)*. In 1911–12 as part of the Abor Expedition, the Geological Survey of India conducted widespread surveys of the tributaries of the Brahmaputra *(Bentinck, 1913)*. Many other expeditions were later undertaken, one of them being the Bailey-Morshead exploration of the Tsangpo Gorge in 1913 which, for the first time, established the definite route by which the Tsangpo river reaches the sea from north of Himalaya, through the Tsangpo Gorge.

When the Communist government came to power in China, they dismissed this remote area as economically useless and gave the Buddhist monks to believe that the communists actually respected the beliefs of the Tibetan community. However, towards the end of the 20th century, when they realized the enormous hydropower potential of the river, and when the population of southeastern China had grown so much that south and south east China could face water shortages, that they started thinking about the river seriously. By then, they had developed the technology and economic strength to envisage mega water transfers from the south to the north. Thus, it was towards the end of the 20th century, that they also started surveying and mapping the river due to its hydropower potential of about 60,000 MW. The first dam commissioned on Brahmaputra River was Xangmu, with an installed capacity of 640 MW, and which became operational very recently in 2015. The Chinese have, in the last 30 years, conceived six other mega dams namely Gyatso, Zhonda, Giexu, Langzen, Dagu and the Bayu, all located in the Upper Brahmaputra regime in the Tibetan region. One should therefore not be surprised if all these dams are built for producing hydropower; especially since India and China have no agreement on water-sharing or development of hydro power plants.

Based on remote-sensing and satellite imagery studies, the Chinese Academy of Sciences announced to the Chinese news agencies that they had fully surveyed not just the Brahmaputra but the four major rivers emanating from Tibet, and calculated the length of Brahmaputra to be 3,900 km., which was at great variance from estimates made by the Brahmaputra and Barak Basin Organization, Shillong Division (established in 1980) of Central Water Commission in India which has calculated the distance to be around 2,900 km *(Central Water Commission, 2020a; Krishnan, 2016)*. The Brahmaputra basin extends over an area of 5,80,000 sq.km spread across Tibet, Bhutan, India and Bangladesh. Out of which 194413 sq.km (about 34%) lies in India between the Himalayan ranges in the north and the Patkai range running along the Assam-Myanmar border. The basin covers six states in India, namely Arunachal Pradesh, Assam, Meghalaya, Nagaland, West Bengal and Sikkim.

The origin of the Brahmaputra lies about 100 km southeast of lake Mapan in south-western Tibet at an elevation of about 5150 mamsl. It has three head streams emanating from glaciers - Kubi, Angsi and Chemayungdung. In Tibetan it is also called Tsangpo (meaning purifier) and Yarlung Zangbo in Chinese. On the left bank the Raka and Lhasa Kyi rivers meet Brahmaputra, while the Nyang Qu joins the mainstream on the right bank. The river flows almost entirely from west to east for about 1,130 km, at an average elevation greater than 4,500m amsl, till it reaches the Yarlung-Tsangpo-Grand-Canyon where the river passes between Mt. Gyala Peri and Mt. Namche Barwa. Unlike other canyons of the world, it had not acquired any fame because it was simply unknown till the end of the 20th century.[30]

In Assam, after meeting the two rivers Dibang and the Lohit, it meanders through the narrow valley as 'Brahmaputra' and the locals also know it as the Lohit, Luit, Borluitor or Siriluit. In India the main tributaries are Dibang, Lohit, Subansiri, Dhansiri, Manas, and the Teesta. One of its channels in Bangladesh retains the old name of Brahmaputra while the main channel is called the Jamuna, which meets the Ganga near Rajbari district and the combined flow is called the Padma, which merges with the Meghna before merging into the Bay of Bengal.

2.14 MEGHNA RIVER SYSTEM

The Meghna rises in the hills of Manipur in India where it is known as Barak while the midstream and downstream lie in Myanmar and Bangladesh. The total catchment of Barak-Meghna is 4724 sq km., with the Barail mountain range separating it from the Brahmaputra sub-basin. The Na Lushai hills lie to the east while the lower regime lies in Bangladesh. As the river flows down from the hilly areas of Manipur into the plains, it splits into two rivers, namely Surma and Kushiyara, which is an interesting feature known as ana-branching in morphology where both branches continue to carve out their own course as they enter Bangladesh. In these alluvial plains they meet once again after which, together, they are called Meghna. In the Chittagong Division the river meets Padma-Jamuna (Ganga-Brahmaputra) in the Lower Meghna Basin, ultimately flowing into the Bay of Bengal, past the Bhola Island.

The principal tributaries of Meghna are Jiri, Dhaleshwari, Singla, Longai, Sonai, and Kathekhal. The Karnaphuli River flows in from the eastern hills of Bangladesh, on which a dam has been constructed, creating the largest man-made lake in Bangladesh known as Kaptai Lake, created in 1956. While the Manipur hills are sparsely populated, the alluvial areas in Assam and Bangladesh are very densely populated.

The population of the seven districts together known as *haor* in the Upper Meghna Basin in Bangladesh, is around 19.37 million (2010 census) with an average household size of 5.3 people. A *haor* is a wetland ecosystem in north east of Bangladesh, also known as a back-swamp. During monsoon, the *haors* get submerged as they receive surface run-off water from rivers and canals, to become vast stretches of turbulent water. This is also the region where the contentious Tipaimukh dam is proposed to be constructed (See Chapter 12 for details). There are three barrages - Gumti barrage, Chakmaghat barrage and Manu barrage on the river in the plains of Tripura. The construction of Aizawl dam (Mizoram) and Khoupum dam (Manipur) has been completed.

2.15 CONCLUSIONS AND RECOMMENDATIONS

1. This chapter demonstrates that we have a hugely inadequate understanding, if not a total misunderstanding of the Ganga River System. More importantly, the scientific fact is that the Ganga, Brahmaputra, and Meghna are a part of a singularly defined and discrete river basin.

It is therefore recommended the GBM be considered as an integrated river system, especially for purposes of planning and management.

2. The combined discharge of GBM has been estimated to be 1,38,700 cumecs, the third largest in the world. Of the total volume, the independent yield of Brahmaputra is 537.240 km^3, that of Ganga is 525.20 km^3 and that of Meghna is 48.360 km^3. Therefore, the total yield of Ganga, Brahmaputra and Meghna Basin is 1110.80 km^3. These three rivers are trans-boundary in nature.

It is therefore recommended that all planning and development be consultative and inclusive of all the Riparian countries in the GBM.

3. The confluence of Ganga, Brahmaputra and Meghna took place just about 250 years ago, and contrary to common perception, the Ganga today exits into the sea at the eastern extremity of Bangladesh and not at Sagar Island in West Bengal.

It is recommended that all official documents recognize that Ganga is as much a part of other riparian countries and does not exclusively belong to us.

4. A fragmented understanding of the greater Ganga basin due lack of adequate, accurate and updated data has led to flawed policies regarding the basis on which water sharing and disaster management policies have been framed.

It is therefore recommended that a mechanism for data sharing between all the Riparian countries and Indian states be put in place.

5. As mentioned in the previous chapter, *there is an immediate need to extend and enlarge the scope of the National Mission for Clean Ganga (NMCG), to include and take cognizance of the reality on ground in deciding the strategy for ensuring aviral (unhindered and perennial) and nirmal Ganga (clean and pure).*

6. The migration and avulsion of several Himalayan rivers is the most distinguishing feature of the GBM basin, as it is different from all other river basins in South Asia.

7. The GBM is water-abundant but has an accompanying problem of massive floods during monsoons and near arid conditions during summer months (15th March to 15th June).

It is recommended that a Flood Management Plan be prepared for the entire basin.

8. Catastrophic events due to climate change impact, can be best understood if we look at GBM as a whole; since it is the entire cryosphere of Brahmaputra and the cryosphere of Ganga that will together determine the acceleration and aggravation of the impending environmental crisis in future.

Therefore, it is recommended that any River Basin Plan prepared for the Ganga should fully take into consideration the inferences and conclusions derived from this study and those from different disciplines, taking a holistic and integrated perspective of the GBM basin.

9. The Yamuna is the largest tributary of Ganga, and Ghaghara (Kali Karnali) is the second largest tributary. In recent years, the abstraction and use of water in the Yamuna basin has been so exploitative that its contribution to the main flow has reduced enormously and the major rivers almost completely dry up during certain months, discharging little water into the Ganga. It is therefore recommended that policy makers should address the need to convert the closing Yamuna basin into an open basin where it will perennially feed Ganga. In order to achieve this, there should be a moratorium on all large reservoirs, dams, barrages, and canals on Yamuna, since Yamuna basin is about to become a 'closed basin' (i.e., a basin which ceases to reach the recipient river, lake or ocean). Further, there should be no further inter and intra basin transfers in the Yamuna River basin. Restoration work should begin in the Yamuna River Basin with immediate effect, in order to replenish it, maintain the E-flows, increase water use efficiency in the basin, and aid in controlling the severe pollution plaguing the Yamuna.

10. If we consider the current population growth and increase in consumption patterns, the demand for water in the GBM basin will rise continuously in the next few decades. Therefore, it is important to implement practices that enhance water-use efficiency in agriculture, and demand management in domestic consumption and industrial use in the entire river basin. Investment in water-use efficiency will significantly improve water-use optimization.

It is therefore recommended that an embargo on all further abstraction of water, and construction of large and medium dams / barrages in the main stream and tributaries of Ganga. This will be an essential condition for maintaining environmental flows at least at the current level.

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ENDNOTES :-

18. Chittagong Division, officially known as Chattogram Division, is geographically the largest of the eight administrative divisions of Bangladesh.

19. Aggradation: The deposition of material by a river, or stream usually over a geological time span.

20. An anabranch is a section of a river or stream that diverts from the main channel or stem of the watercourse and rejoins the main stem downstream*(North et al., 2007).*

21. For details see 'Sustainable Development of the Ganges-Brahmaputra-Meghna Basins, 2001' edited by Asit K. Biswas and Juha I. Uitto; 'Management of Ganga, Brahmaputra, Meghna: way forward, 2006' by A.K. Biswas and 'Integrated Water Resources Management, Workshop on IWRM, Dhaka, 2007' by Ahmed M.F.

22. The India-WRIS states that the basin covers an area of about 10,86,000 sq.km. and lies between East longitudes 73°02' and 89°05' and North latitudes of 21°06' and 31°21'.

23. Drainage Basin/Catchment Area: Drainage basin, also called catchment area, or (in North America) watershed, is the area from which all precipitation flows to a single stream or set of streams.

24. The main physical subdivisions of the GRB are 1) The Northern Mountains, which comprise the Himalayan ranges including their foothills, b) The Gangetic Plains between the Himalayas and the Deccan plateau and c) The Central Highlands, lying to the south of the Great Plains which consist of mountains.

25. Shesha Naag: in the Hindu tradition, Shesha Naag is said to hold all the planets of the universe in his hoods and to constantly sing the glories of Vishnu from all his mouths, and is depicted in the form of a coiled bed for Laxmi-Narayan.

26. Based on the calculations made on Google Earth Pro, provided by Dr. M. Khalequzzaman, Professor at the Department of Geology and Physics, Lock Haven University, USA.

27. When the characteristics of the flow change, the name of the river changes as well. In its initial stages when the river is flowing through the mountains and has a lot of force it is called Mahakali, as soon as it reaches the plains, the flow becomes placid and gentle, and is called Sharada. Thus, names of rivers often reflect the natural character of the river.

28. Closer to its source, the Brahmaputra River is known as the MutsungTsangpo, then the Moghung Tsangpo and finally the Tsangpo, while Chinese maps have it as the YarluTsangpo. On entering India, the Tsangpo takes on the name of Siang and further down, Dihang as it rushes down the hilly terrain of Arunachal Pradesh. In the past, the river in Assam was known as Tilao in Tai and Bodo and Taluk in the Singpho-Mishimi languages, whereas the ancient scriptures point to a host of other names such as Lauhitya, Hiranyo, Mandakini, Hridini, Khatai, Brahmi, Karkaya and Digama.

29. The first story about the origin of the river is found in the Srusti-khanda of the fifth book of the Padma Purana, while the Kalika Purana devotes an entire section to its birth. According to one myth, the river's gestation was in the womb of Amogha, the beautiful wife of sage Santanu, after she had imbibed the semen of Brahma, Hindu god of creation. Amogha delivered an aqueous form at a place called Yugandhara, and Santanu placed this form called Brahmakund in the middle of four mountains - Kailash, Gandhamadana, Jarudhi and Samvartaka. With the passage of time, it grew into a lake, swelling up to 40 miles and much later it was sage Parshuram, who cleaved the bank of Brahmakund to make the Brahmaputra flow as a river. The myths contain "some rudiments of geological truth, even though it was primarily a figment of imagination and poetic expression of the origin and course of Brahmaputra". The blows of the axe of Parshuram could well have been a metaphor for some ancient geological upheaval which caused the river to flow *(Dutta, 2012)*.

30. In Anglo-Saxon literature (English), the Colorado Canyon with a depth of 2,074 m., becomes the Grand Canyon However, the Yarlung Tsangpo Gorge with a depth of 6,009 m. from the river bed level and the Kali Gandaki .orge also known as the Andha Galchi or ThakKhola Gorge (named after Thakali community) with a depth of 5571 m. from the river bed are not considered great and grand simply because they were unknown to the west. The Kali Gandaki Gorge was well-known to Hindus and Buddhists because it formed the trade route between India, Nepal and Tibet and passed through the ancient kingdom of Mustang in Nepal. It was on the pilgrimage route between Pokhra and Muktinath, through the Kore La pass, and was well known since ancient times for the Shaligram stones. Shaligram are fossils of marine fauna from the geological times when the Great Himalaya was actually a part of the Sea of Tethys.

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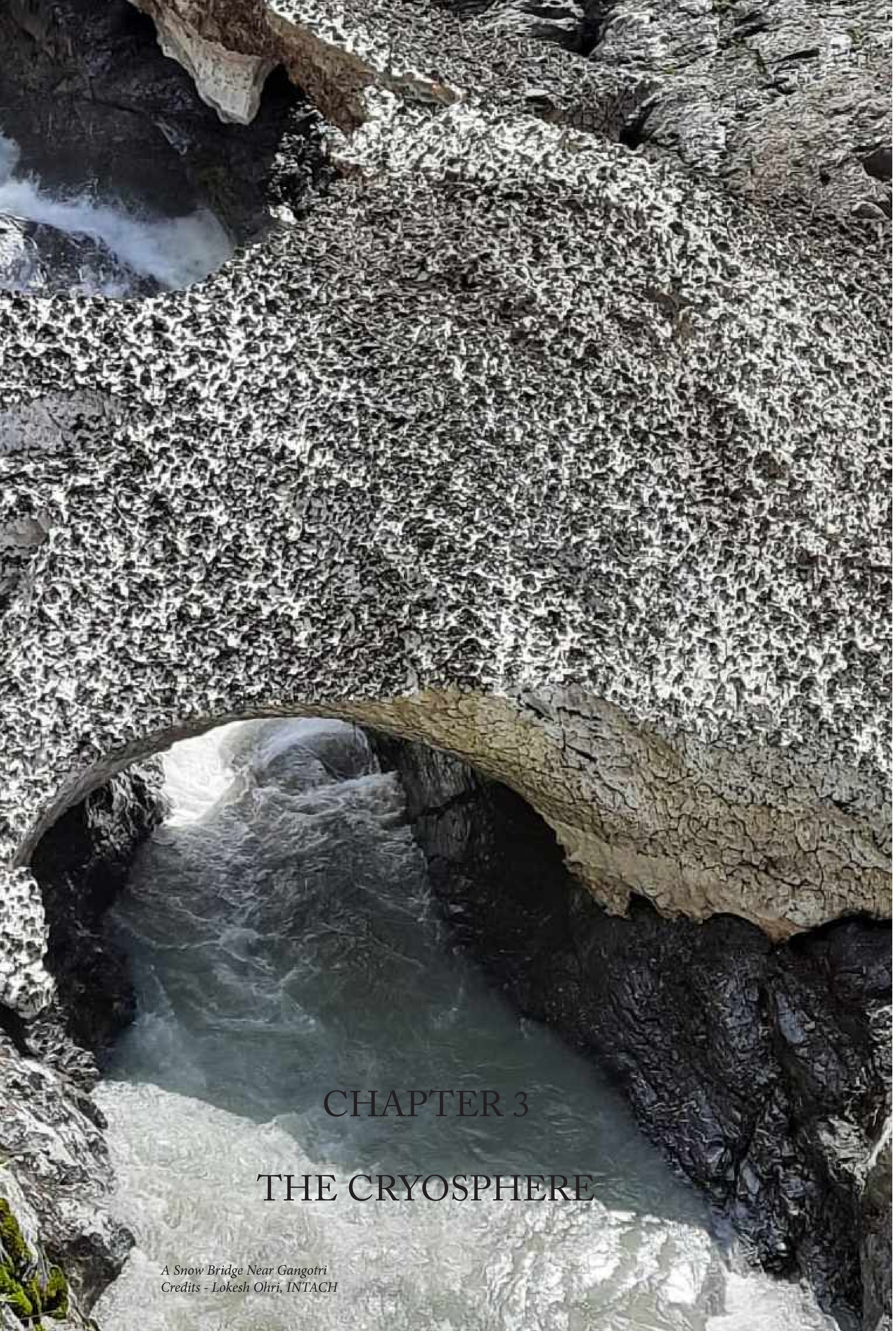
The Shivling Peak



CHAPTER 3

THE CRYOSPHERE

A Snow Bridge Near Gangotri
Credits - Lokesh Ohri, INTACH

3.1 WHAT IS THE GANGA'S CRYOSPHERE ALL ABOUT?

Cryosphere[31] of the Ganga consists of the entire area of the Central Himalayan Mountain ranges, which includes snow covered mountain peaks, permafrost (permanently frozen ground) thermokarst lakes, glaciers, glacial lakes, and other minor components like snow dust, verglas, snow-plumes, etc. The residence time of water in each of these sub-parts varies widely, because they wax and wane seasonally, annually as well as in longer geological cycles. This character of the Cryosphere makes it a very complex system. Further, due to its extreme heights, temperatures, and remoteness, it is the least understood or appreciated part of the hydrological cycle. In the following discussion we will specifically consider the Cryosphere of the Ganga River Basin. The Cryosphere of the GRB lies in the Central Zone of the Hindu Kush Himalaya.

3.2 WHY IS THE HINDU KUSH HIMALAYA CALLED 'THE THIRD POLE'?

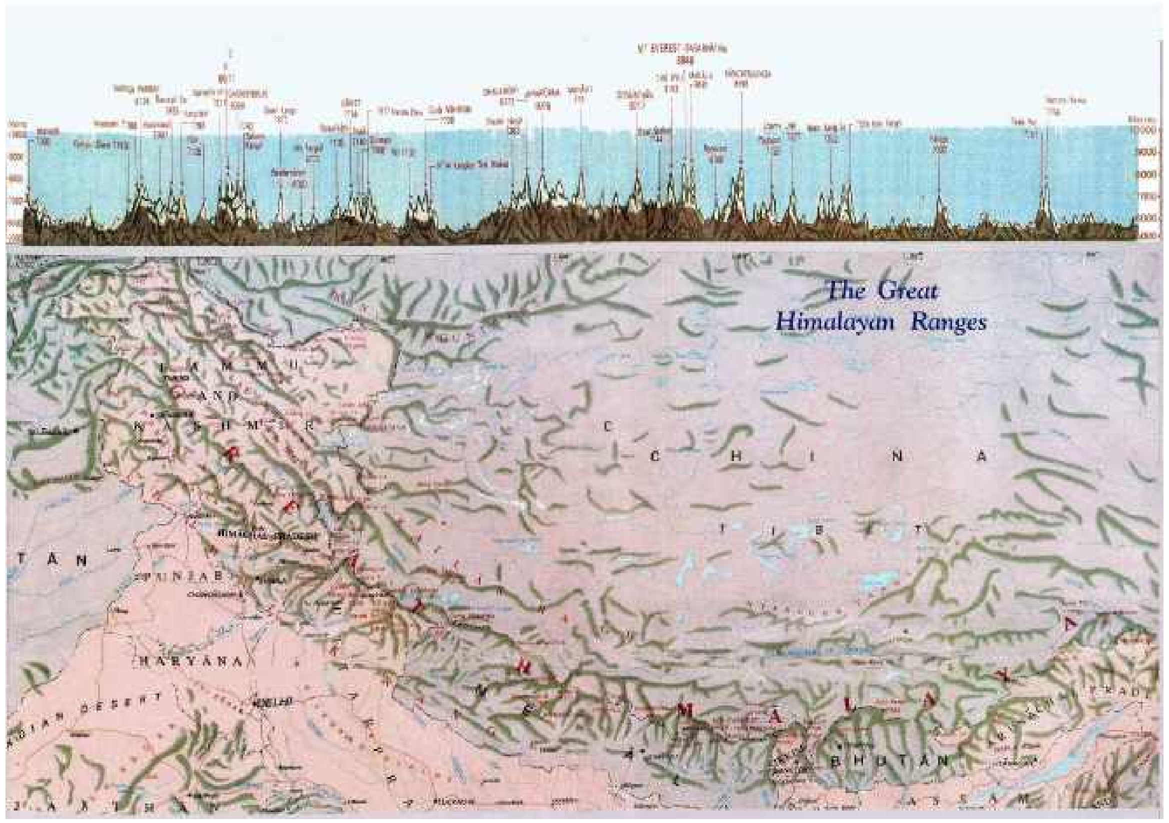
Besides the North Pole (Arctic) and the South Pole (Antarctica), the Hindu Kush Himalaya[32] is the only large area in the world which is perpetually covered with snow and ice. It contains the largest reserve of freshwater in the world outside the polar region, within a geographical area of around 4.2 million sq. km *(Bajracharya SR, 2011)*. The Hindu Kush Himalaya is therefore called 'The Third Pole.' The Himalayan ranges act as a climatic water-divide or a barrier, which hugely influences the air, and water circulation systems that predominantly determine the average annual precipitation and its spatial and temporal variability in the Indian subcontinent (India, Tibet, Nepal, and Bhutan).

In ancient Indian literature like the Vedas, Puranas, Mahabaharata, Ramayana and Kumarsambhava, the vastness, immensity, height and imminence of Himalaya and the rivers emanating from it, were described either metaphorically or romantically. In his epic poem Kumarsambhava, the poet Kalidas (mid-5th century CE) describes the mighty Himalaya:

अस्त्युत्तरस्तययां दशिर्वितय्मय दमियलयो नयम नगयधरियजः । पुवयापरौ तोयननीिं वगयह्य स्स्ततिः पधृ वि्यय इव मयनणि्डः ॥

The verse translates as follows: To the northern most side lies the King of Mountains – the Divine Soul, whose arms are spread to the east and to the west right up to the seas; who stands as the measuring rod for the earth.

Figuratively, it may be said that the mighty Himalaya doesn't just measure the physical height or immensity but it is also the yardstick for gauging progress (intellectual height) of human civilization. It provides a scale for understanding where humans stand in the larger scheme of things. The Great Himalaya is therefore a reminder of our existence which is insignificant compared to nature's power. Literally, the term Himalaya means the abode of snow, spiritually the abode of Shiva, and physically the origin of River Ganga. It is important to note that Kumarsambhava was written when country borders did not exist and the entire Hindu Kush Himalaya was considered as one continuum.

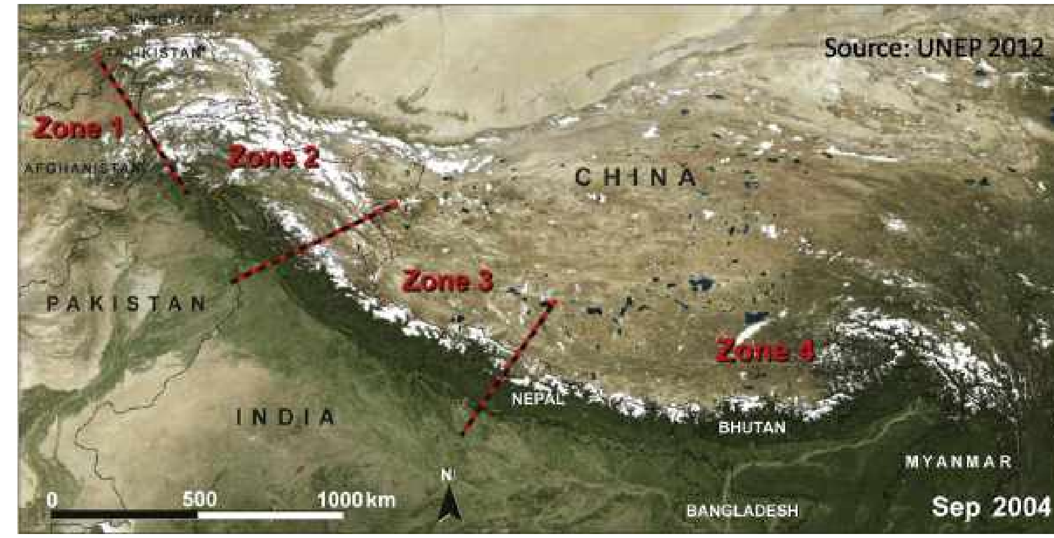


Map 3.1: The Great Himalayan Range (year not known) by Survey of India
(Sundaranand, 2001)

3.3 CRYOSPHERE OF THE GANGA RIVER

The Cryosphere of the Ganga basin includes primarily the areas above the snowline i.e., above a height of 4000-5000 m approximately[33], which includes states of Uttarakhand and very small parts of Himachal Pradesh and Sikkim[34] in India, parts of Nepal, and a significant part of Tibet. However, depending on the local climatic conditions the snowline differs from region to region. For example, in the case of Gangotri Glacier in the Bhagirathi sub-basin and Nanda Devi Biosphere Reserve in the Alaknanda sub-basin, the snowline can be observed between 4500-5000 m. The location and altitude of the snowline depend on various factors:

a. **Latitudinal differences**: as we move away from the equator either to the north or south, the snowline shifts to a lower altitude. Therefore, at Greenland, the snowline appears to be as low as 100 m.



Map 3.2 The Cryosphere and Four Major Climate Zones in the Hindu Kush Himalaya and Adjacent Regions. Background image from NASA Blue Marble MODIS data, Image based on UNEP 2012 *(Pathak, 2012)*

Zone 1: Includes the Afghanistan region which is dominated by the westerlies. Within this zone glaciers grow mainly by winter snow accumulation.
Zone 2: Includes Karakoram and Western Himalaya dominated by the westerlies and the summer monsoon.
Zone 3: Includes the Central Himalaya Zone which includes parts of India, SW Tibet and western Nepal. Within this zone, glaciers are covered with debris and the retreat rate is high.
Zone 4: It is the eastern-most zone, summer monsoon dominates this zone and glaciers grow due to summer snow accumulation and are most unstable.

Note: The cryosphere area which has been explained in this report falls in Zone 3 and 4.

b. **Geological features and regional differences**: If there is only one peak in a region, e.g. Mt. Kilimanjaro (Tanzania), the snowline will be at a much higher altitude. The snowline in the Western Himalaya is at a lower altitude than in the Eastern Himalaya. While the glaciers of the Kangchendzonga in the Sikkim portion are mostly at a height above 4000 m, those of Kumaon and Lahaul can descend to 3600 m, the glaciers in the Kashmir Himalayas may descend up to 2500 m above the sea level. In the Great Himalayan ranges, the snowline is at a lower elevation on the northern slopes as these regions receive less sunlight as compared to the south-facing slopes in the Northern Hemisphere.

From now to the end of the 21st century, the existing differentiation notwithstanding, the snowline will continue to rise up across the Himalaya. As the snowline is dynamic, the climate change impact will alter it significantly. This region feeds different tributaries of the Ganga river basin thus forming an important part of the hydrological budget of the Ganga basin. Therefore, changing snowlines will dramatically alter river flows in all these rivers.

3.4 SIGNIFICANT CONTRIBUTOR TO THE HYDROLOGICAL BUDGET OF GANGA RIVER

As discussed above, the uppermost watersheds of the Ganga River Basin, namely those of

Yamuna, Upper Ganga - Bhagirathi and Alaknanda, Mahakali/Sharada, Karnali, Gandaki and Sapta Koshi rivers both in India and Nepal, which hold water predominantly in the form of snow, ice, and permafrost, land slopes, peaks, rocky outcrops, valleys and gorges, form the Cryosphere of Ganga River. In the case of Ganga's cryosphere, at the bottom of most of the large glaciers there is a continuous flow of snow and ice melt which emerges as a stream. As seen in the Gangotri glacier, the snout is called the origin of the river because until Gomukh, the stream is not visible since it is flowing below the glacier. This stream is formed by a combination of snow and ice melt. Snow is frozen atmospheric vapour which falls in winter as snowflakes whereas ice is simply frozen water either formed due to natural compaction or artificial compaction. Snow melt is water which forms a part of the annual hydrological cycle whereas the ice melt forms that share of the stream which is a part of water which has accumulated over millennia. In practical terms, the snow and ice melt contribute to almost 9-10% of the Central Ganga Basin, 19%-21% of the Brahmaputra Basin and 50% of the annual flows of the Indus *(Miller et al., 2012).*

In case of the Ganga River as a whole, the contribution of snow and ice melt from this cryosphere region has been estimated to be in the range of 9% to 10% of the entire flow and the remaining 90% to 91% comes in the form of rainfall. The fraction (percentage) contributed by the Cryosphere to the river flow is the highest at Gomukh and Gangotri and keeps reducing as the river moves downstream towards its confluence with the Bay of Bengal. This is due to the fact that the contribution of rainfall to the Mean Annual Flow (MAF) is much greater and keeps rising as we move downstream, because of the monsoon bearing clouds which are blocked by the Central Himalayan Range leading to heavy precipitation on the southern slopes. The Ganga River Basin (GRB), understandably, does not receive uniform rainfall throughout its region. The average annual rainfall in the GRB varies from 350 mm at the western end to 2000 mm near the delta at the eastern part. The amount of rainfall received by the basin not only changes throughout the region, but it is also limited to only a few months of the year mainly during monsoon months of June through October, thus causing low flow conditions in the Ganga river and its tributaries during the dry period (November to May).

It is based on this meteorological understanding that many researchers reject the possibility of the Ganga River becoming seasonal or ephemeral in the near future, and claim that receding glaciers will not have a major impact on the flow of the Ganga. However, it is important to note that although the major contributor to the water flow in these rivers is rainfall, in the summer, when the rainfall contribution is almost negligible, the contribution of snow and ice melt is significant. Further, it has been generally accepted that while the annual precipitation may increase in the future, the Extreme Point Rainfall Events (EPREs) will also rise. Consequently, even if the total annual precipitation increases, the number of rainy days will fall, possibly resulting in longer drought periods.

Consequently, its contribution is crucial for maintaining the minimum Environmental Flows (E-Flows) during the lean period. As explained in Chapter 1, nearly 40% of the water in the Ganga River comes from rivers in Nepal, which are fed by glaciers. The Cryosphere thus regulates the annual flows, especially during the eight months from October to May. This is possible because the Cryosphere (i.e., area above 4000 m) holds back all precipitation during summer which falls in the form of snow, and similarly during winter the area receives only snowfall which is also held back. This release of water stored as glacial ice is particularly significant in years of low precipitation and during the late summer period, when seasonal snow packs have largely melted. Thus, glaciers provide a buffering effect on stream flow, acting as regulators and providing insurance against times of low flow *(B. Sharma & Condappa, 2013; P. Singh et al., 2011).*

Therefore, the cryosphere constitutes a significant contributor to the hydrological budget and regime of the Ganga basin. To put it in perspective, if all this frozen water that melts annually from the hood of the Ganga River basin i.e. from Banderpoonch mountains to the west to Sikkim in the east was to be regulated through dams and reservoirs as in the case of peninsular rivers, we would require at least thirty reservoirs of the size of Tehri dam on Ganga upstream of the Indo- Gangetic plains.

3.5 SIGNIFICANCE OF SNOW AND ICE MELT TO RIVER FLOWS

- Considering an area of 40,800 km^2 (i.e., 22,800 km^2 for the Himalaya and 18,000 km^2 for Karakoram), and an average thickness of about 125 m, the approximate estimated ice volume can be calculated to be around 5100 km^3 (or 4590 km^3 of water equivalent). This is four times the total annual availability of water in India (Khan et al., 2017).

- Therefore, the Cryosphere holds an enormous stock of frozen water collected over millennia i.e., the largest storehouse of fresh water in Asia which regulates the annual flows by holding all the snowfall and glacial melt during the winter and releasing it in summer, when human communities face severe scarcity of water.

- Ice melt or glacial flow does not fluctuate greatly from year to year or season to season. In some cases, it might actually increase during the summer season due to higher temperatures but does not reduce very much during winter. Therefore, it may also be perceived as a base-flow which remains relatively constant right through the year, and is therefore of great importance to the lower reaches of the river basin. Thus, its contribution is crucial for maintaining the minimum Environmental Flows (E-Flows) during the lean period.

- The fresh water stored in glaciers and released in the form of ice-melt is not a part of the annual water cycle of the river, but a part of the stock of water gathered over several millennia. It has a direct bearing on the fluctuations of the local climate as well as 'climate- change' in general through its moderating influence on surface energy and moisture fluxes, clouds and precipitation, ocean and atmospheric circulations, and short, medium and long-term hydrology of the river basin.

- Thus, even though snowfall might continue every year, the loss of enormous water stock in the form of ice currently stored in glaciers will be irreplaceable at least in the context of human historical timescale.

3.6 THE IMPACT OF GEOLOGICAL CHANGES ON THE CRYOSPHERE

From south to north, the subdivisions and major bounding faults are, the Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), and Main Central Thrust (MCT). All three happen to lie under the cryosphere. All major tectonic movements in this region begin at the MBT and the other thrust lines. The physical impacts of these movements are felt the most at the highest elevations from the focal point of the tremor which in the case of Himalaya happens to be the cryosphere. In case of glaciers, existing crevasses and fault lines may close and new ones may emerge and accumulated ice or snow would collapse into the valley, wherever the mass has reached the tipping point.

All this has a cumulative impact on the velocity of glacier movement, incidence/periodicity of landslides, avalanches and changes or avulsions in the course of rivers and their tributaries downstream. Of all these the least understood and known are the impacts on the cryosphere mainly because there are very few climate stations which measure seismic activity, blizzards, wind velocity, etc., and the sheer remoteness and near impossibility of reaching certain locations. Therefore, the existing geological configuration has to be understood in order to appreciate the eventual impact of the cryosphere on the course of rivers and their tributaries in the Ganga basin. The moot point is that reliable data, especially about the variability of ice-melt and snow-melt in the cryosphere, will be available only when snow and ice gauging stations are established in a much larger number than those existing today.

3.6.1 Contribution of Snow and Ice Melt to Agriculture and Livelihoods

When water is needed for irrigation and other uses during winter and summer, the contribution from snow and ice melt acquires a special significance. In the Ganga basin, sugar cane, grown predominantly in the north-western areas of the basin, relies substantially on melt- water. Although small in size, this region is a very important food-producing region with the highest yields in India. In the Ganga basin, 3% of cotton production and 7% of sugarcane production can be attributed to melt-water. Therefore, the whole of the Rabi[35] crop, summer crop and small part of the Kharif[36] crop depends on the snow and ice melt. The total rural population that is substantially dependent on upstream melt-water for their irrigation-based livelihood (about 80% of population in Nepal and Uttarakhand and about 9% in the Indo-Gangetic plains) is estimated at around 55 million, with about 24 million in Nepal, 1.2 million in Uttarakhand, 0.4 million in Himachal Pradesh, 24 million in Uttar Pradesh and 8 million in Bihar. Note that the figures mentioned above refer to communities which do not have easy access to groundwater for various reasons. These are the approximate shares of the state populations dependent on snow and ice melt worked out from the degree of dependence of farming communities on irrigation-based livelihoods. Therefore, the stabilizing role played by the cryosphere in general, and glaciers in particular, in regulating the climate and the hydrological cycle are extremely crucial for the resilience of our agricultural sector and for livelihoods of millions of others who are dependent on rivers. Ice and snow-melt therefore determines the water availability for the communities and villages living around the entire periphery of the Cryosphere and in the river basins.

3.6.2 Trans-boundary Nature of Cryosphere

One of the key characteristics of the cryosphere in the Ganga basin is the fact that it forms a continuous geo-morphological zone going beyond political borders and covering the southern part of Tibet Autonomous Region of China, entire Nepal and the Indian states of Uttarakhand and Himachal Pradesh and parts of Sikkim. With global warming, increasing glacial melt will lead to excessive flooding. These floods are different from the floods caused due to excessive rainfall as the disappearance of glaciers will be a long-term phenomenon which will have a serious impact on the annual flow regulation. Lean period flows will change considerably, changing the water security of downstream areas. Temperature changes in the region will also have a significant impact on the lower Brahmaputra regime which forms a part of the Ganga river basin in the last 200-250 km of the river system in the delta region in Bangladesh.

In spite of these physical realities, the cryosphere is not taken into account by any of the countries while conducting any water budget or water balance studies due to its trans-boundary nature, extraordinary altitude, and its remote and hazardous terrain. Although the cryosphere forms a small part of the Ganga river basin, the critical changes which take place at the margin have a negative 'last-mile' impact in terms of the standing crops, environmental flows and water availability for the downstream region of the river. Similarly, the impact of changes in the cryosphere is not treated as a major variable for planning, formulating, development plans, and infrastructure projects. In fact, no attempts have been made so far to prepare an Integrated River Basin Development and Management Plan, (IRBM Plan) for the Ganga Basin. Therefore, in order to examine, understand and formulate an IRBM Plan for the Ganga River, it is necessary to consider this area as an important management area, which recognizes the administrative boundaries of the five countries, but accounts for and includes the hydro-geological data on from the cryosphere for policy decisions, planning and management. In view of these implications, it is important to understand various components of the cryosphere and their interrelations.

3.7 COMPONENTS OF THE CRYOSPHERE

The major components of the cryosphere are glaciers, glacial lakes, snowbound areas, permafrost, thermokarst lakes, rocky outcrops, meadows, snow dust and others. These different components melt at different times of the day or night or during different seasons, and may change their form due to lower or higher surface or ambient temperatures, resulting in a dynamic relationship between each other and with the ecosystem.

3.7.1 Glaciers

Glaciers are the uppermost sections of Himalayan Rivers which appear in the form of a body of dense ice which is constantly moving. They can also be perceived as frozen rivers at the bottom of which flows a stream of water which emerges at the snout of the glacier. They form the oldest stock or reservoir of water as they have accumulated over millennia and are not a part of the annual hydrological cycle (or water-budget). Glaciers also flow but at a very slow rate, i.e. a few meters per year (ranging between 10 m to 40 m per year, depending on altitude and gradient) *(Jain, 2008)*.

Each glacier has a unique form and a rate of accumulation/ablation which depends on the altitude at the origin, the rate of descent of the valley below, the thickness of the glacier and the presence/absence of rock and debris within or on top of the glacier. When a major glacier system reduces in thickness and retreats, sometimes the tributary glaciers are left in smaller valleys, high above the shrunken central glacier surface *(National Snow and Ice Data Center, 2020)*. Hanging glaciers formed on mountain cliffs are often the reason for numerous icefalls and avalanches. One recent example was the collapse of the hanging glacier in the Nanda Devi massif in February 2021, which was a result of the crash of the entire rock face along with its ice wall, and led to floods in the Rishiganga River (For details see Chapter 11).

There are an estimated 54,000 glaciers in the Hindu Kush Himalayas. These glaciers cover an area of about 60,000 sq. km and have estimated ice reserves of 6,127 km^3. This reveals that only 1.4% of the HKH region is glaciated; the total ice reserves are roughly equal to three times the annual precipitation *(Scott et al., 2019)*. This area serves as a major source of water in the region's ten major rivers, including as much as 40 percent in the Indus River system. The Himalaya in India alone contains more than 9,500 glaciers spread over 33,050 sq.km and releases about 8.6x106 m^3 of water every year *(Dyurgerov & Meier, 1997; Khan et al., 2017)*.

3.7.2 Reasons for Variations in Estimates of Number of Glaciers

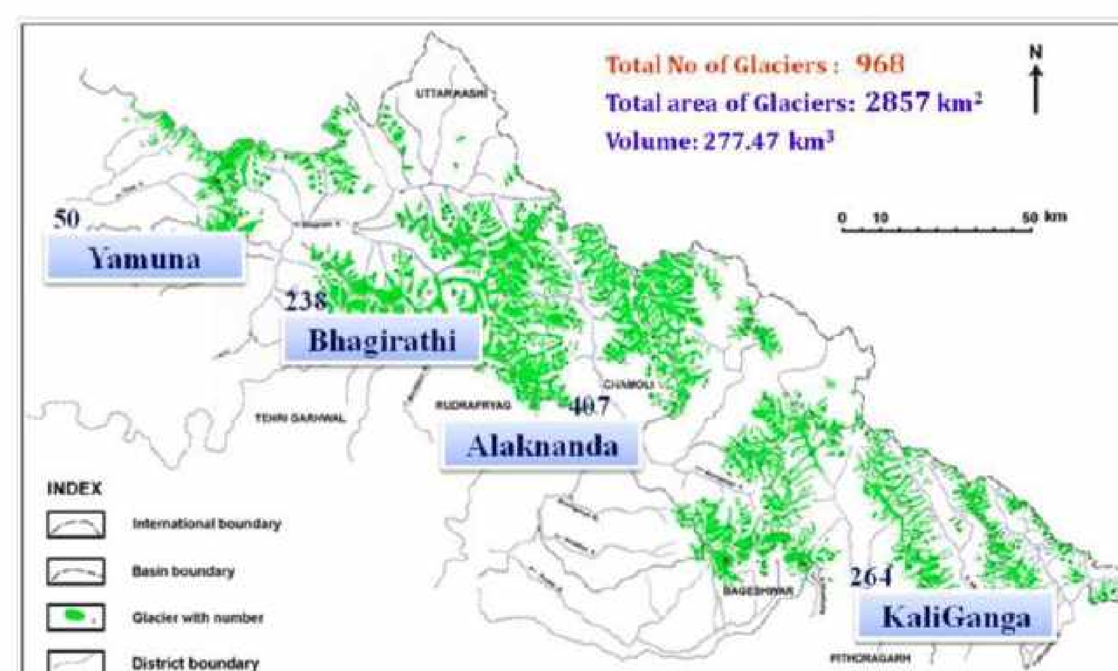
Variations in estimates in the number of glaciers, areas covered by snow and glaciers, total ice reserves, annual release of water from cryosphere, etc. are due to different criteria of size, length, seasons, area covered, etc., applied by different agencies. There are different values of the number of glaciers found in the region. In a temporal study as part of Monitoring Snow and Glaciers of Himalayan Region, the Indian Space Research Organization (ISRO) mapped a total of 6,237 glaciers in the Ganga basin with the glaciated areas in this basin estimated at 18,393 sq.km[37] *(Ajai et al., 2010)*. The International Centre for Integrated Mountain Development (ICIMOD) estimated a total of 7,963 glaciers covering an area of about 9,012 sq.km and with a total ice reserve of 793.53 km^3 for the Ganga river system

(Bajracharya SR, 2011). Based on the values provided by Gangakosh (NIH, Roorkee), the Nepal Himalaya has 3,252 glaciers at and above 3,500 m above mean sea level. These glaciers cover an area of around 5,323 sq.km with a probable ice reserve of 481 BMC *(National Institute of Hydrology, 2018)*. According to another estimate by ICIMOD, the cryosphere of all the rivers in Nepal contain a total of 3,808 glaciers and covers an area of 30,902 sq.km *(Bajracharya et al., 2014)*.

In the case of Uttarakhand region, there are about 968 glaciers in the Ganga basin which cover an area of about 4050 sq.km in total *(National Institute of Hydrology, 2018)*. The well-known glaciers of Kumaon and Garhwal region in Uttarakhand are Kaphini, Maiktoli, Milam, Namik, Pindari, Ralam, Sunderdhunga, Chorbari Bamak, Dokriani, Doonagiri, Gangotri, Khatling, Satopanth, Bhagirathi-Khark, Tipra Bamak and Nanda Devi group of glaciers. The glaciers in the Banderpoonch[38] , the mountain range in Himachal Pradesh forms the component of the cryosphere of the Yamuna basin which joins Ganga River at Prayagraj. Locally, these glaciers are known as *Bamak* or *Shigri.*[39]

3.7.3 The Gangotri Glacier (Bhagirathi sub-basin)

As the Gangotri Glacier in Uttarakhand is treated as the cultural origin of Ganga, it is one of the few glaciers which have been studied in great detail. Gomukh is at an altitude of 3920 mamsl which forms the terminus of Gangotri Glacier. It is 30.2 km in length and covers a geographical area of 143.60 sq. km. The average thickness of the glacier is 200 meters. While the Ganga River is popularly considered to originate at Gomukh, the actual flows emanate about 30 km upstream i.e. at the foot of the Chaukhamba Peak. As the name denotes there is a group of four major peaks (6736 m, 6974 m, 7068 m, and 7138 m amsl



Map 3.3 Distribution of Glaciers in different river basins of Uttarakhand, India

(Raina & Srivastava, 2008)

respectively), which form the Chaukhamba, or four pillars or water towers and constitute the hydrological origin of Bhagirathi Glacier, since there are no significant streams upstream of this massif.

3.7.4 Geomorphology of the Gangotri Glacier

The Gangotri Glacier Basin consists of six different basins, with the Bhagirathi-Ganga Basin lying more or less at the centre. The Bhagirathi basin has 75 sub-watersheds as indicated in the Survey of India topographic sheets on a scale of 1:250000 and 1:50000 . The river basin tends to flow from southeast to northwest, the origin being at the south-eastern end.[40] The Bhagirathi- Ganga basin is surrounded by the Vishnuganga Basin on the east, Mandakini on the south, Bhilangna Ganga on the West, and Janhavi Ganga to its north.

Chaukhamba Peaks, Uttarakhand *(Source: Giripremi, Pune)*

As shown in the Map 3.4, the Gangotri Basin is demarcated by a line with dashes as shown here in the bracket, thus [- - - -], which joins a locus of points (peaks and troughs), which form the 'ridge-line', or the 'water-divide' of the basin. In simple terms, all rain or snow, which falls within the dot-dash line (-.-.-.-.-), has to flow eventually down to the Gangotri Glacier and finally emerge at Gomukh as the Bhagirathi River. The demarcation starts from the right bank of the glacial snout (Gomukh) and rises to the top of Sudarshan Parbat in the North East direction up to a height of 6507 meters. Two glaciers namely Shwetvarna and Thelu originate at the bottom of Sudarshan Peak and flow into Gangotri glacier.

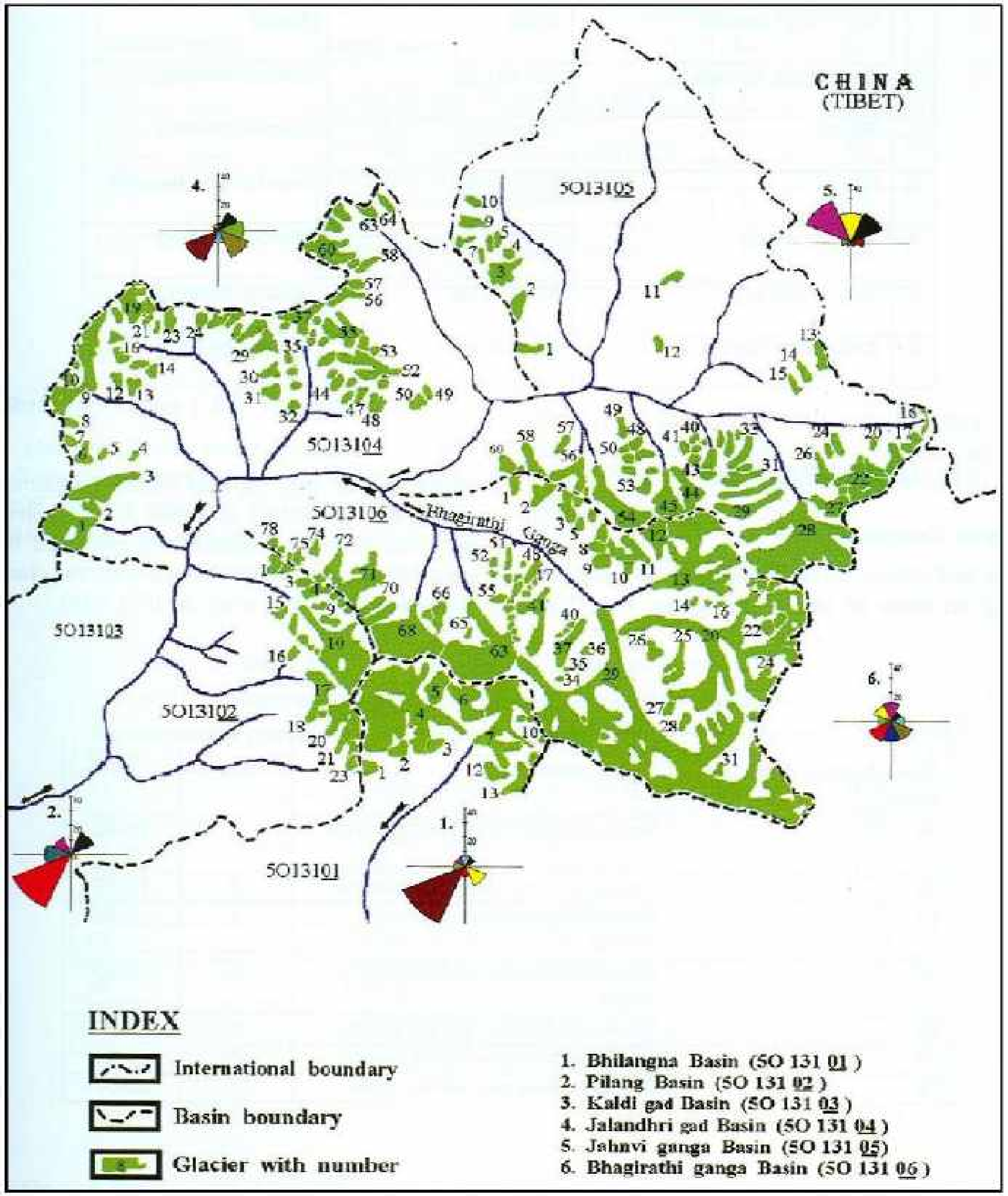
Gangotri Glacier with Bhagirathi Massif (background)
(Photo: Vijay Paranjpye, May, 2019)

The Bhagirathi-Ganga Basin covers an area of 6183.32 sq. km and contains a network of 238 small and large glaciers. The area of this network is 755.47 sq.km, i.e., 12.2% of the Bhagirathi – Ganga Basin. The central trunk of the glacier is 30.20 km long. Contrary to the general belief that all Himalayan rivers flow from North to South the Gangotri glacier actually flows from southeast to northwest, and then curves down to the south. In fact, the entire length of the glacier flows from southeast to northwest. The portion of the glacier just below Chaukhamba is called 'accumulation zone' which spans 4.2 km, that is, the uppermost segment where the volume of snow / ice melt is less than the average annual snowfall. At lower altitudes the snow and ice melt is greater than the average annual snowfall, and this section is therefore known as the 'ablation zone' (26 km).

3.7.5 The Equilibrium Line Altitude (ELA):

The Equilibrium Line Altitude is an elevation where mass-balance equals to zero. The portion of the glacier upstream of the ELA is the accumulation zone, and the segment downstream of the ELA is the ablation zone. The altitude where the mass-balance curve crosses Y-axis, i.e., accumulation equals ablation, is ELA.

In the case of Gangotri Glacier, the 'accumulation zone' is above an altitude of 6000 m, and the 'ablation zone' is below 6000 m, reaching down to approximately 4255 m. The average



Map 3.4 Glacier Map of Bhagirathi Basin

width of the glacier in the accumulation zone is 2.15 km, while the average width in the ablation zone is 1.35 km. At Gomukh, that is, at the snout of the glacier, the width is just about 1 km. The gradient of the glacier is very gentle near the snout (5^0) and it increases sharply as it reaches Chaukhamba (25^0).

Generally, one visualizes a glacier as a smooth white surface, or a river which is suddenly frozen in its tracks. However, in reality, this mental picture is true only in the uppermost

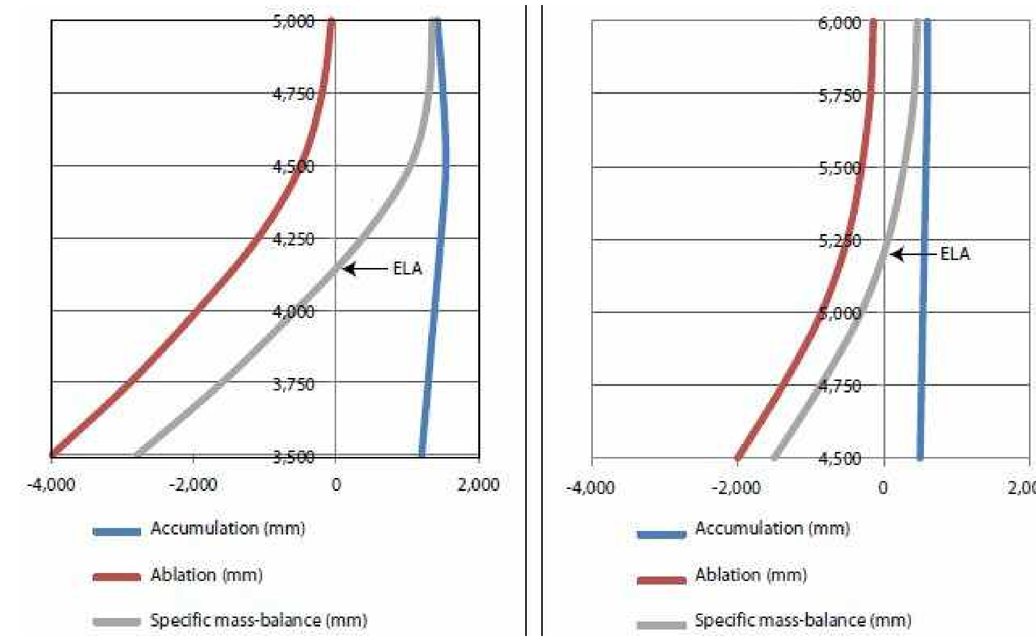


Figure 3. : Schematic diagram of Equilibrium Line Altitude (ELA)

segment of about 5 km or the accumulation zone of the Gangotri glacier. In the middle and lower sections, the glacier is covered with a thin layer of grey and blackish loose sand, rocks and boulders spread almost over the entire glacier except for the wide crevasses and cracks that show a bluish white colour. In addition, the glacier is covered with several small and medium lakes that change their colour from blue to white when they freeze. Usually such lakes are in the form of depressions surrounded by moraine and rock.

In reality, the main Gangotri glacier flows from south to north i.e. from an altitude of 7138 m to about 4000 m. The glacier experiences a fall of a little over 3000 m within a distance of 30 km (i.e. a fall of 100 meters per km). Downstream of Chaukhamba, at a distance of 4.5 and 7.5 km, the Maindi and Swachhanda glaciers have a confluence with the main trunk of Gangotri Glacier, and thereafter, at intervals of every three or four kilometers, other tributaries like Kirti Bamak and Ghanohim glacier also come and meet the main glacier. Several other contributing branches (glaciers), e.g. Raktavarna, (which contains ferrous material and imparts a red hue to the glacier), and others like Shwetavarna (white colour), Chaturangi (four colours), Pilapaani (yellow colour), Neelambari (blue colour), each reflecting characteristic colours, join the Gangotri glacier. Downstream of the main glacial configuration, they are joined by the Surlayaa (which flows rhythmically) and the Swachchanda (which has a random flow), were probably named after their unpredictable and erratic behaviour. There are 968 glaciers, big and small, spread across the uppermost areas of the Ganga basin in Uttarakhand alone, covering an area of 2850 sq .km. Of these, 407 glaciers are found in the Alaknanda sub- basin. Alaknanda and Bhagirathi together have 645 identified glaciers.

There are some tributary glaciers on the right bank that used to meet Gangotri glacier but have now shrunk considerably. The Chaturangi glacier for example which used to directly

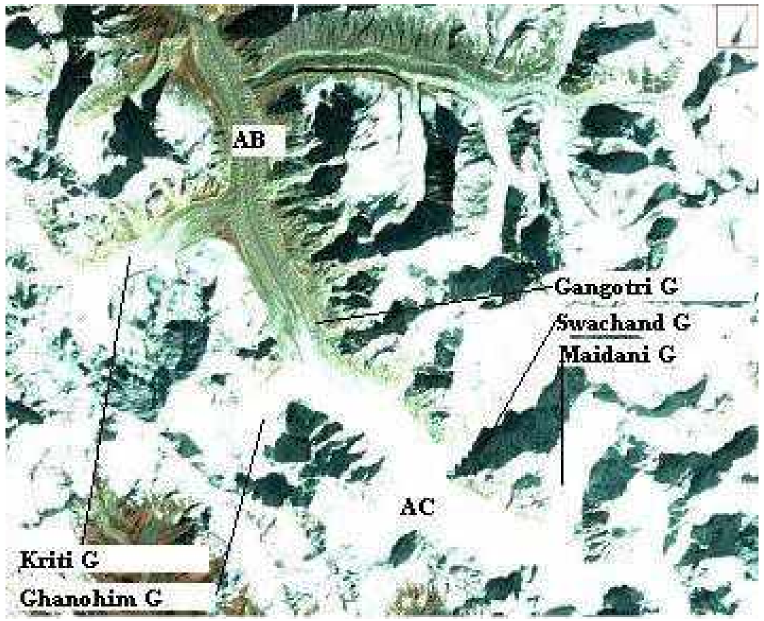


Figure 3.1 False Colour Composite (FCC) of RED (4) Green (3) Blue (2) in the Gangotri Glacier, Subset of Landsat-7 ETM+ Image (G=Glacier, AB= Ablation zone and AC= Accumulation Zone
(Haq et al., 2011)

have its confluence with Gangotri till about 1975 (personal observation by the author), now occupies only half the width of its glacial-bed and the rest flows in the form of a stream of water into the main trunk of the Gangotri glacier. The portion vacated by Chaturangi several decades ago, has now silted-up completely and is currently designated as 'Nandanban', where most mountaineering expeditions set-up a base camp.[41] During summer, i.e. early June to September, the Nandanban area blooms with herbs and flowering plants, which thrive in the rarefied atmosphere, and the rich silt coming down from the mountains. Over the last few centuries, several such areas vacated by receding (tributary) glaciers have been used as high altitude grazing grounds or meadows (called *Bugyals* in Garhwali language) by shepherds. Other fauna such as wild mountain goats / blue sheep and other alpine fauna also feed on such *Bugyals*. Although this phenomenon may be beneficial to the local community in the short run, once the glacial mass reduces even more, there will not be enough melt-water to sustain the *Bugyals* in the medium to long term (20-50 years).

3.7.6 Tributary Glaciers of Main Trunk Gangotri Glacier:

1. Bhrigupanth Bamak (Glacier):

Bhrigupanth Glacier is located on the left bank of the Bhagirathi River about 4 km of downstream of Gomukh. This glacier also flows in a northerly direction and is heavily covered with surface moraine. Its snout is perched at a considerable height above the Gangotri valley. Like Gomukh, there is a small cave from which the Bhagirathi River (Not to be confused with Bhagirathi emerging from Gangotri Glacier) emerges and trickles down to the Gangotri Glacier.

The Snout of Gangotri Glacier, Gomukh *(Basak, 2015)*

2. The Meru Bamak (Glacier):

The Meru Glacier is also located on the left bank but it lies upstream of the present Gangotri snout. Its valley is 300 m higher than the Gangotri glacier and there is no confluence between the Meru and Gangotri glaciers. The Meru glacier forms a ridge surrounded by low level fields on all sides. During summer, this area is devoid of snow cover and transforms itself into a *bugyal*. Currently, this triangular area is known as Nandanban.[41] These meadows are held up by lateral moraines on two sides, and on the third side the lateral moraine of the main trunk Gangotri holds up the Tapovan area. The Meru glacier is probably one of its kind where the high point of the snout rises higher than the lateral moraines.

The author successfully led an expedition to Kalindi peak in 1976, and also participated in an expedition to the Shivling peak (1975) which unfortunately could not be summited due to inclement weather. Since then, the author had made four more visits to the Gangotri glacier upto Thalay Sagar and Nandanban .

3. Raktvarna Bamak (Glacier):

This glacier is located on the right bank and the snout has receded 3 kms from its erstwhile confluence with Gangotri glacier. Its lateral moraine reaches down to the confluence next to the stream of water and then turns along with the lateral moraine of the main Gangotri glacier. Interestingly, this moraine can be seen today right up to the Gangotri town. The shape and direction of the moraine suggests that Raktvarna extended right up to the Gangotri temple. However, currently there is no ice or snow in this last segment of the Raktvarna glacier. Today, a small stream of water flows from its snout into the main trunk of Gangotri glacier.

4. Chaturangi Bamak (Glacier):

Chaturangi is the longest tributary of the Gangotri Glacier and joins the main Gangotri glacier 3 km upstream of Gomukh. Its surface is almost completely covered with brownish- black moraine. The Chaturangi Bamak (glacier) is about 21.1 km long and occupies an area of about 43.83 sq. km. It meets three major glaciers (Shweta, Suralaya, and Vasuki) on its left flank and one on the right flank. There are two smaller glaciers on the right flank which have receded at least a kilometre away from Chaturangi main trunk and have a length of about 3 km each. Right at the end of Chaturangi glacier lies the Kalindi Khaal or Pass (19520 ft) and to its north lies the Kalindi peak (about 20,020 ft). Currently, the snout of the glacier is situated at 4380 m and appears to have receded from the main trunk of the Gangotri glacier. However, in the early 1970's one could see the curvature of the confluence between Chaturangi and Gangotri quite clearly. Kalindi Khaal is on the ridge line, and after crossing the pass the valley slopes down to the town of Ghastoli situated on the Alaknanda River.

5. Kirti Bamak (Glacier):

Kirti Glacier is located on the left bank of the Gangotri Main Trunk Glacier and lies 5 km upstream of Tapovan. This glacier has its origin at the bottom of Mt. Kedarnath, and when it is measured from the Kirti Sthamb peak, the Kirti glacier is about 11 km long. This glacier is also covered with moraines and a series of crevasses. The moraine consists of rocks having reddish bands of gneiss and schist. The main trunk and Kirti glacier can be clearly distinguished since Kirti is brown in colour while Gangotri is dark grey in colour.

Near the confluence one can see a few small confined lakes near the right bank of the Kirti glacier.

6. Ghanohim Bamak, Maindi Bamak, Swachhand Bamak:

Almost near the top (origin) of the Gangotri glacier there are three relatively small glaciers, at an interval of about four km each. The topmost being Ghanohim Bamak (glacier), followed by the Maindi Bamak (glacier), which again is followed by Swachhand Bamak (glacier). These glaciers are in the range of five to six km long, and have their origin in the close vicinity of Mahalaya peak.

3.7.7 Morphological profile of the Gangotri Glacier

Since the period when human settlement first took place at Gangotri, the valley downstream of it had already been inhabited by ancient communities, and the glacier actually had its snout at the current location of Gangotri temple-township. There was probably only a footpath and a mule-track created by pilgrims who thought of Gangotri as the origin of Ganga. There were small villages and all weather settlements up to Harsil where people had started creating terraces and paddy fields mainly for their own sustenance. Gangotri, being too inhospitable and cold in winter, was probably abandoned for several

Twin Sources Of Bhagirathi River At Gomukh Formed Due To Glacial Melt
Image taken by the author during field trip May, 2019

centuries. For all practical reasons the history of the Gangotri glacier can be traced back only till the period when the snout of the glacier or Gomukh was located at the same place where one sees the Gangotri temple today. From the current Gangotri town up to Harsil, which is about 25 km by road; there is a sudden fall in altitude and the area is covered by ancient coniferous forests mainly dominated by Deodar trees[42] and other pines which are found well below the snowline.

The Gangotri Glacier is not only the biggest glacier in Uttarakhand Himalaya, but it is also the largest producer of glaciogenic sediments (moraines) *(D. Sen Singh et al., 2016)*. Presently, the relics of moraines, representing the past glacial expansion or recession are observed only around the village Jhala, which is located at a distance of about 40 km downstream of Gomukh, i.e. the snout of the Gangotri Glacier *(M. C. Sharma & Owen, 1996)*.
Since the early 18th century, the Gangotri Glacier has been visited and studied extensively. As one starts walking upstream of Gangotri at least three major and two minor moraines can be identified mainly on the right bank and one on the left bank as one proceeds towards Gomukh. The first stage of the moraine is on the left bank of the steep wall of the Gangotri valley and can be distinctly seen running parallel to the river for about 4 km. The second and third stages of the moraine can be seen just below the first stage at a slightly lower altitude. The fourth and fifth stages can be seen on the opposite bank and have a gentle slope. Besides the moraines one can also see small conical debris at certain intervals. These have been formed by landslides and scree deposits. There are a few larger ones as well which have been formed by incessant rock- fall and debris activated by small tributaries of erstwhile glaciers (or what can currently be seen as streams). The most prominent of these moraines peters off and ends near Bhojbasa. This moraine represents sudden but

minor episodes of glacier advances and recessions, and they probably represent the extent of the 'Little Ice Age'.

3.7.8 The Little Ice Age

The Little Ice Age (LIA) is a phenomenon which occurred from the 16th to the 19th century, when the earth cooled down. This anomalous situation was called LIA because the earth is known to be continuously warming since the last Ice Age, which ended about 12,000 years ago. From the 16th to 18th century there was a short period of colder climate during which glaciers in the Himalaya expanded for a short duration. This was a brief cold period between two warm periods. It is this period which has left its traces near Bhojbasa. A similar phenomenon can be seen on the lateral moraine of Raktavarna Glacier upstream of Gomukh.

The lateral moraines described above can be seen only if one has an eye for them, and only if one is willing to spend extra time at Chirbasa. They are not easily visible at some places because they are covered with pines and other vegetation. The situation changes as one approaches Bhojbasa, because during the last fifty years or so human intervention has almost completely decimated the Bhoj forest (birch). The Bhojpatra (Himalayan birch) is also called *Bhurjapatra*. It has a white bark which contains several thin layers, each of which can be peeled off. In ancient times it was used for writing scriptures and it is still used in many of the religious ceremonies. Unfortunately, these trees have become greatly endangered because of the enormous increase in demand by pilgrims travelling to the well-known Char Dham locations. Currently, the Forest Department of Uttarakhand has banned the cutting, lopping, or stripping of the bark of these trees, because even if a strip of a few centimetres in width is cut right round the trunk, it can completely kill the tree.

The main trunk of the glacier and most other tributaries indicate a U-shaped valley, the notable exceptions being the Chaturangi and the Meru glaciers, which are V-shaped valleys. This means that the main Gangotri Glacier and most others are almost flat bottomed with near perpendicular sides while Meru and Chaturangi have steep sides and a very narrow bottom. Another unusual glacier is the Sukhi Glacier, especially the vacated part which is present with a large number of erratically strewn boulders with striations, which are both indicative of severe glaciations. The shape of the valley in general, especially between Gangotri and Gomukh, is asymmetrical, i.e., the distance from the current stream, the steepness of the slope on both sides, the location and nature of scree-fans, are quite dissimilar.

In practically the entire valley, one can see exposed portions of Badrinath granite. This type of rock extends well beyond the Ganga basin and can be seen right up to the Kinnaur district of Himachal Pradesh and also in the Chandra glacier. These have been geologically dated to about 495 million years ago. This granite is exposed all along the upper reaches of the Bhagirathi River and forms the largest body of the High Himalayan Leucogranite (HHL). If one were to estimate the age of the river basin it would be about 21 million years.

3.8 GLACIAL RECESSION

The Gangotri glacier is perhaps the only glacier in India which has been fairly well documented as regards the phenomenon of glacier recession. Practically all the studies have concentrated their attention on the snout or lip of the Gangotri glacier (Gomukh). As mentioned earlier, the last cyclical period of the last ice age is estimated to have started sometime around 10,000 to 12,000 years ago. Consequently, the recession of the Gangotri glacier may also have started around the same time. However, the scientific documentation of the physical changes and the recession of the snout commenced from 1935. The Geological Survey of India (GSI) has regularly monitored the snout from 1935 to 1996 and then from time to time during that last two decades. These studies reveal that during these 60 years alone, the glacier has retreated by 1147 meters, i.e. an average rate of 19 meters per year. It is also estimated that the total area vacated by the glacier during these 60 years is about 0.58 sq. km.

Scientists and glaciologists have now accepted that the most authentic record of recession, which can be relied upon, is from direct field measurements, from which the following inferences can be derived.

1. The first such record of recession was made in 1935 by Auden. After that it was measured by Jangpangi 1956, Vora 1971 and then several times by Puri from about 1974 to 1991. In 1997 it was recorded by Sangewar. These records and elevation drawings based on physical measurement clearly suggest that glacial recession is not a recent phenomenon, and that it has gone on not just for hundreds but thousands of years.

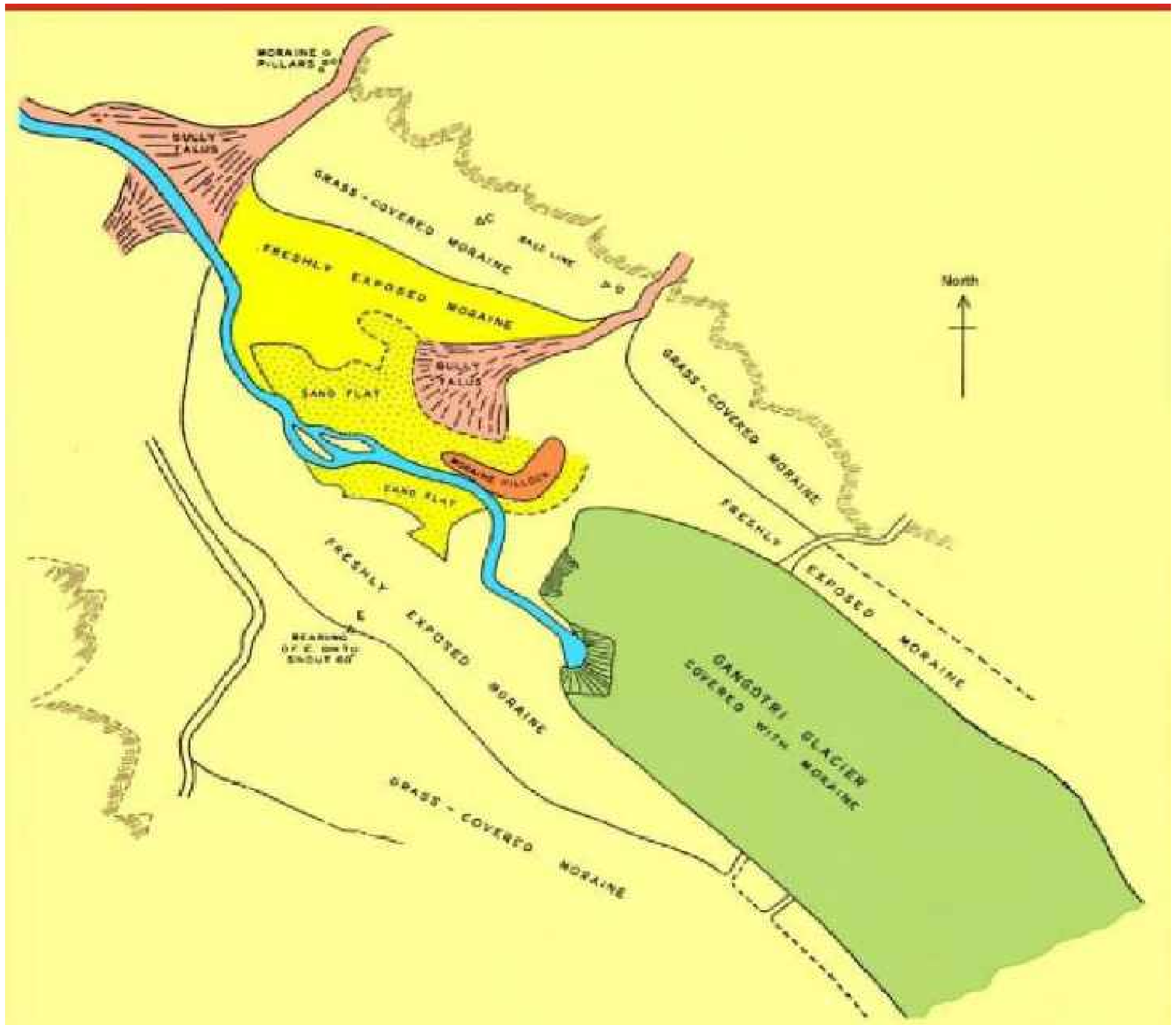
2. Secondly, the data also reveals that the recession depends upon freak events like the 'Little Ice Age', when the glacier not only stopped receding but actually expanded slightly, around the 16th to the 18th century CE.

3. Thirdly, recent studies have indicated that recession also depends upon the altitude, and that the smaller glaciers at lower altitudes recede faster than the larger glaciers located at higher altitudes. This happens not only because the temperatures are higher at lower altitudes, but also because the glacier is much thicker as we proceed towards the origin.

4. Fourthly, the glaciers located at altitudes greater than 5000 meters are almost completely virgin and expose a bright white surface which reflects far more light and heat than the glacial area near the snouts which are covered with scree, moraine and boulders, and which absorb much larger quantities of heat during the day causing snow and ice melt faster.

5. And lastly, at higher altitudes the mountains are steeper and lead to frequent and more intense snowfalls which in turn cause greater piling-up and accumulation.

Therefore, contrary to the common perception, the larger glaciers are not likely to disappear for a long time to come. Another important conclusion one can derive is that there are too many variables and uncertainties, and thus, making predictions about the future rates of recession cannot be reliable.



Map 3.5 Snout map of Gangotri Glacier. (Auden, 1935)

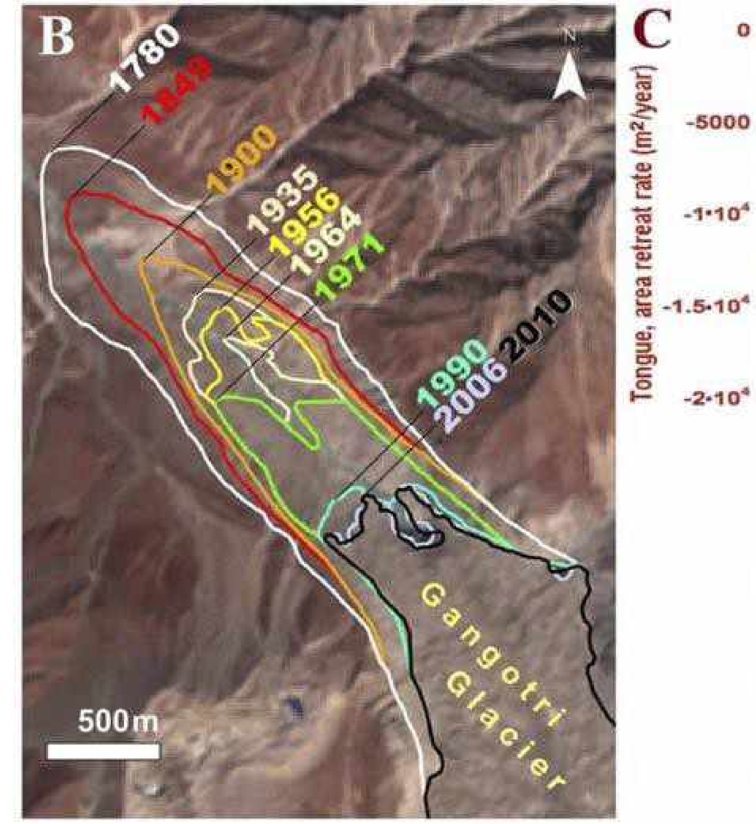


Figure 3.3 Receding Trend Line Of The Gangotri Glacier Snout Since 1780 To 2010. Currently, 30.2 Km Long And Between 0.5 And 2.5 Km Wide. Receding Since 1780, Its Retreat Quickened After 1971 *(Kargel et al., 2011)*

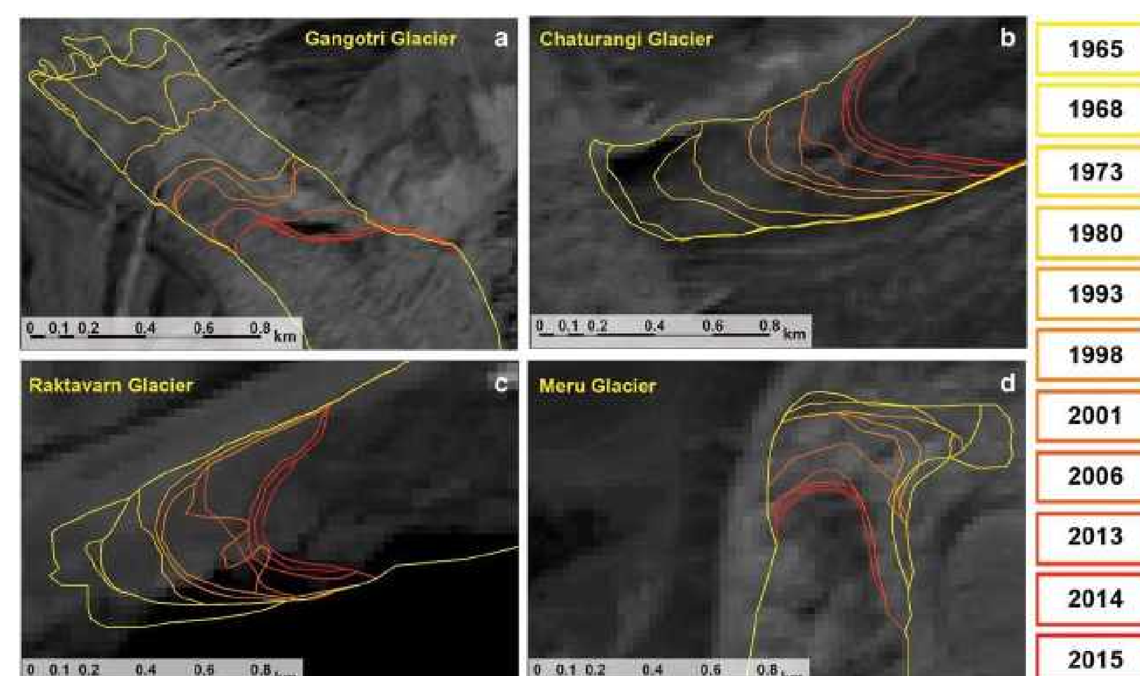


Figure 3.4: Receding trend lines of Gangotri, Chaturangi, Raktavarna and Meru glaciers from 1965 until 2015 *(Bhattacharya et al., 2016)*

3.8.1 Glacial lakes and GLOFs

Whenever and wherever glacial melt formed due to glacial recession was blocked it created small and large lakes which accumulated behind natural frontal walls of moraine. The Hindu Kush Himalaya is home to around 25,614 Glacial Lakes in and around an area of 60,054 sq. km of snow and glacier covered mountains. The phenomenon of global warming which is believed to have begun during the period 1850 to 1905, i.e. after the end of the 'Little Ice Age', was one of the primary causes for the creation of these glacial lakes. Most of the glacial lakes are fed by snow-melt water which comes down from very high peaks, eight of which are greater than 8000 m in height. Most of these regions are in low rainfall areas having an annual precipitation ranging from 300-600 mm, and an exposure to higher ultraviolet radiation. Some lakes in Himachal, Kumaon and Jammu & Kashmir have underground springs. In such cases, one often does not see the inlet of water on the surface. Similarly, such lakes do not have any outlet of water. Depending on the rocks through which the springs emanate, some of them are saline lakes, while all others are sweet-water lakes.

3.8.2 Glacial Lakes in the Ganga River Basin

Saptarishi Kund, Yamuna sub basin
(Bharat, 2020)

Recently on 29th June 2021, Bhuvan, Indian geo-platform for ISRO published The Glacial Lake Atlas of Ganga River Basin (National Remote Sensing Centre) under the National Hydrology Project. Glacial lakes of size greater than 0.25 ha were identified and mapped using high resolution satellite data (Resourcesat-2 Linear Imaging Self Scanning Sensor-IV MX) in all the three river systems (Indus, Ganga and Brahmaputra) covering Himalayan region in this project. The atlas reveals that there are around 4707 glacial lakes in the Ganga basin with a catchment area of 247,109 sq. km.

Table 3.1 Glacial Lakes Located In Different River Sub-Basins Of Ganga River Along With The Percentage Distribution In Different Countries. Based On The Glacial Lake Atlas Of Ganga River Basin Published By National Remote Sensing Centre, India *(Rao Et Al., 2021)*

River Sub-basins	Number Of Glacial Lakes	Percentage	Country
Gandaki	624	13.26	Nepal
Karnali (Ghaghara)	1260	26.77	Tibet and Nepal
Sapta Kosi	2437	51.77	Tibet and Nepal
Mahakali	55	1.17	Nepal and India
Upper Ganga	295	6.27	India
Yamuna	36	0.76	India
Total	**4707**	**100.00**	

The maximum number of glacial lakes are in the Kosi sub-basin (51.77%), followed by Karnali (Ghaghara) sub-basin (26.77%), Gandaki sub-basin (13.26%) all located in Nepal and some parts of Tibet and parts of Mahakali sub-basin (1.17%) lie within Nepal and Indian borders. Upper Ganga sub-basin (6.27%) and Yamuna sub-basin (0.76%) lie in India. The important point is that most of the glacial lakes in the Ganga Basin are located either in Nepal or Tibet, while there are only a few glacial lakes in India!

The glacial lake having the lowest elevation is located in the Gandaki basin at an altitude of 2462 m, and the lake at the highest elevation is in Sapta Kosi sub-basin (6190 m). Further, it is observed that the largest number and percentage of lakes i.e. 57% is found at an elevation zone of 5000 - 6000 m and all these are characteristically dammed by moraines.

3.8.3 Classification of Glacial Lakes

All the glacial lakes in the cryosphere are also classified as High Altitude Wetlands (HAWs) and are defined by the Ramsar Convention on Wetlands (Article 2.1) as,

"Areas of swamps, marshes, meadows, fens, peat-lands or water bodies located at an altitude higher than 3000 m, whether natural or artificial, permanent or temporary, with water that is static, flowing, fresh, brackish or saline, including areas of marine water the depth of which at low tide does not exceed six meters. They are characterized by a seasonal or diurnal layer of permafrost, and are fed by snowmelt, precipitation or springs. The Hindu Kush Himalaya harbours the largest number of glacial lakes in the world."

Glacial Lakes are further classified in four categories, namely

1. End-Moraine Dammed Lakes,
2. Ice-Dammed Lakes (supra-glacial lakes),
3. Bed-rock-Dammed Lakes, and
4. Other Glacial lakes formed by material not directly a part of glacial process (e.g. debris flow or landslide blocked lakes).

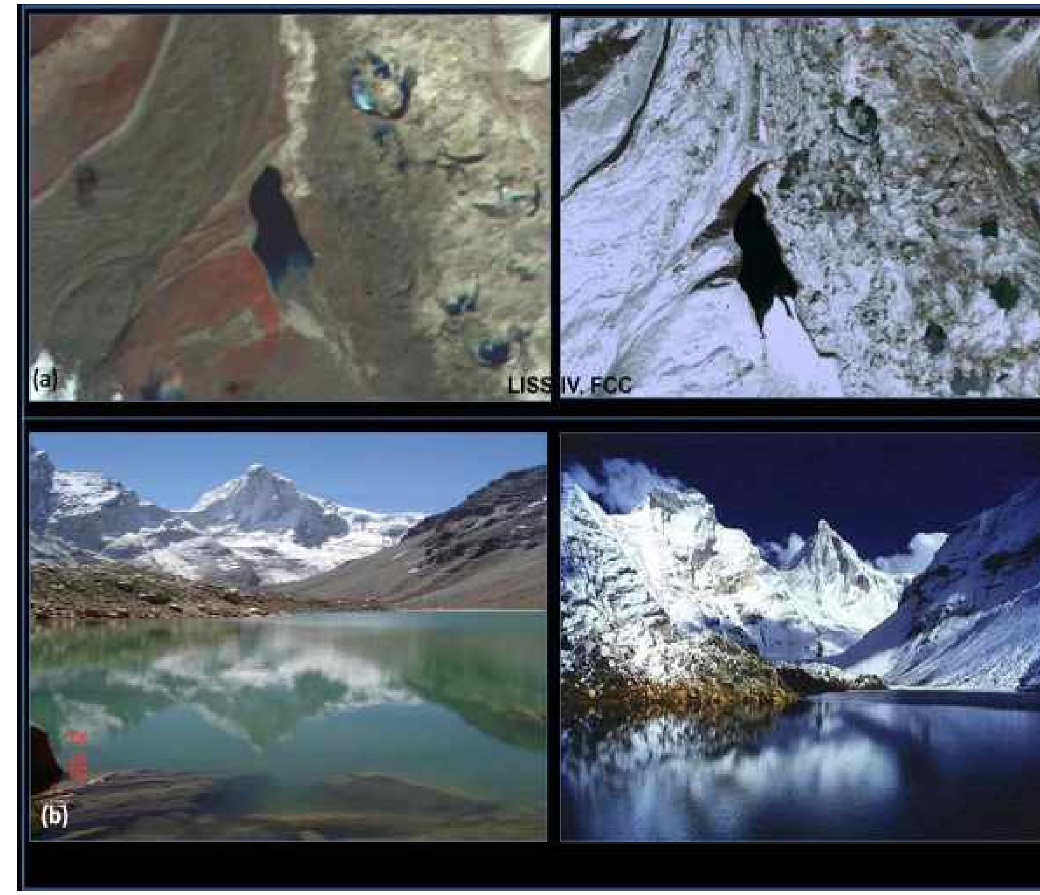
Besides the work of international researchers and that of institutions like the International Centre for Integrated Mountain Development *(ICIMOD)*, a comprehensive assessment of glacial lakes in India was conducted by the Indian Space Research organization, Ahmedabad (ISRO) under the aegis of Ministry of Environment and Forest *(MoEF, GOI)*. The project was meant for creating a National Wetlands Atlas, under which a specific task was to study the 'High Altitude Lakes of India' which was published in September, 2012. Accordingly, High Altitude Glacial Lakes are a subsection of Wetlands. This publication contains an assessment of all glacial lakes in India, lying mainly in the Indus and the Ganga River Basins and has been prepared at a scale of 1:50000 using IRS P6 data for the period 2006 – 2008.

'The National Wetland Atlas: High Altitude Lakes of India' has identified a total of 4,699 Glacial Lakes; this includes 1,966 lakes mapped as point features. The smallest sized lakes, i.e., less than 2.25 hectares are the largest in number. The important implication is that a majority of the glacial lakes are in the Indus basin, while there are only 164 glacial lakes in the Ganga Basin within India, since a majority of the remaining lakes are in Nepal and Tibet. Nepal has approximately 383,000 ha. of wetlands, which constitutes 1.14 % of its total geographical area. Further, according to this study, Uttarakhand has a total of 118 high altitude lakes constituting an area of 231 hectares and accounting for less than 1 % of the total wetland area of the state. Of these, the Chamoli district has the maximum number i.e. 60 high altitude lakes with an area of 112 ha, Pithoragad has 25 HALs occupying 76 ha *(Panigrahy et al., 2011)*.

The Glacial Lakes in India described above refer to those which are equal to or greater than 0.3 hectares in area. Almost all are located within an altitudinal range of 2400 m and 6000 m. amsl. Another interesting feature about these glacial lakes is that about 40% of them are located within a distance of 0.5 km to 2 km from the glaciers, while there are 474 lakes i.e. about 8%, which are located within the glaciers themselves. Further, 1.95 % i.e. 80 lakes are directly in contact with the glaciers but do not lie within them.

Over the last few years i.e. towards the end of 2020, a detailed study of 477 glacial lakes greater than 50 ha each was taken up by Morphology & Climate Change Directorate, Central Water Commission titled 'Monitoring of Glacial Lakes & Water Bodies in the Himalayan Region of Indian River Basins for the Year 2020 (June to October)' *(CWC, 2020)*. This is a welcome step taken by the CWC which has seriously started looking at the behaviour of high altitude glacial lakes. These studies will help in predicting the potential danger from such lakes; and the result of such studies can then be dovetailed to generate centralized data necessary for predicting floods; it will help in evading loss of life and property, if proper lake and river zoning maps are prepared and kept in public domain.

Since these lakes are located in highly unstable and dynamic glacial areas they are vulnerable to the risk of outbursts which cause sudden unexpected floods. These phenomena, known as Glacial Lake Outburst Floods (GLOFs), usually occur when the lakes expand beyond the strength and holding capacity of the frontal moraine walls which are merely a



Sacred Kedar Tal In Uttarakhand (4425 mamsl) Feeds The Kedar Ganga, A Tributary Of Bhagirathi River. Satellite Images Are Supplemented By Photographs
(Panigrahy et al., 2011)

mixture of rocks, ice and moraine loosely heaped together. The walls give way and cause a sudden release of enormous quantities of water, leading to flash floods which cause death and destruction. The early studies were conducted in the 1980s *(Vuichard & Zimmermann, 1987)*. Different studies have so far recorded well over 50 GLOFs, but records are available only for a small part of Tibet, Nepal, Pakistan and Bhutan. There were many more, which may have gone undocumented, especially in India. (For more details see Chapter 11).

3.8.4 Snowbound Areas

The name Himalaya means 'the abode of snow' in Sanskrit. These areas which receive seasonal snowfall form a part of the annual hydrological cycle. The boundary of this region keeps varying based on different seasons and altitudes, thus changing volume and area covered. Different forms of snow are found in the region - wet snow (moist and dense), powdery snow (dry and smaller particles), light snow (lighter snowflakes), spring snow (snowfall during spring conditions (Feb-March) and graupel (snow pellets or crystals). Spring snows can create floods, because warming temperatures cause rapid melting after a storm, as was seen during the recent Rishiganga floods on 7th February, 2021 (*World Meteorological Organization, 2021)*. Compressed hard snow, distinct from permanent glaciers, occurs on mountains which melt annually and expose earth and rock during the summer season, also forms a part of this component. Due to the seasonal and annual variability this component is the most dynamic aspect of the cryosphere.

3.8.5 Permafrost

Permafrost is permanently frozen ground that remains at or below 0° Celsius for two or more years *(ICIMOD, 2022)*. It may be described as a sub-surface layer of land which remains below freezing point throughout the year. Mostly, the entire region below glaciers which does not melt or recede due to changing temperatures can be considered as permafrost. In other words, it could be said that the boundaries of the cryosphere during its waning stage roughly coincides with the boundary of permafrost. All water within its pores and cavities is frozen. Permafrost is typically found in the Himalaya at 2500 m altitude and above. Such a layer includes rocks or soil whose temperature remains below the freezing point of water, i.e. 0^0 (32°F) for two or more successive years. The top layer of the permafrost is called the 'active layer', because it thaws and freezes seasonally (every year), while the area under the active layer is permanently frozen. Therefore, permafrost is not part of the annual hydrological cycle.

The Himalayan permafrost belt represents three main characteristics: (1) it develops in a geo-dynamically active mountain, which means that the controlling factors are not only temperature but also seismo-tectonic activity; (2) due to the steepness of the southern flank of the Greater Himalaya and potential large scale rock failures, permafrost evidence manifests itself best in the inner valleys and on the northern arid side of the Himalayan ranges (elevations >4000 m); (3) the east-west strike of the mountain range creates large spatial discontinuity in the 'cold' belt, mostly related to the nature of precipitation and availability *(Fort, 2015)*.

However, since permafrost cannot be visually seen, and since its dynamics are not well known, this important area of the Cryosphere is probably the most neglected and least understood. The precise altitudinal zonation of permafrost belt (specifying potential permafrost, probable permafrost, observed permafrost belts) still requires careful investigations in Ganga's cryosphere. Although it is a neglected aspect of the cryosphere, the importance of permafrost is revealed when we observe that the area under permafrost (1000,000 sq. km) is well over ten times greater than the area under glaciers in the HKH which extend over 90,000 sq. km.

3.8.6 Thermokarst Lakes

Thermokarst Lakes are a special category of High Altitude Lakes, which emerge in topographic depressions when permafrost melts, causing the land surface to collapse and to form marshy hollows or ponds. Their surfaces resemble clusters of small lakes formed by dissolution of limestone in some karst areas.43 Therefore, they are termed as thermokarst lakes, even though there is no presence of limestone. As per recent studies the water in the ponds or lakes speeds up as the thawing process expands the lakes' size and depth. They form and disappear with changing temperatures, but if the thawing continues for a longer duration it can lead to drainage of the lake area and eventual disappearance of the lake.

Some of the thermokarst lakes are below the surface, therefore invisible from the top, similar to frozen aquifers. Like the surface components, these lakes also wax and wane due to varying temperatures. At the shoreline, the microbes release green-house gases i.e. carbon dioxide and methane, therefore forming a positive feedback loop for climate warming. A study by Anthony K. W. states that permafrost thawing is likely to speed up during the current century, thus increasing the number of thermokarst lakes *(Anthony et al., 2014)*.

Very few studies on thermokarst lakes have been conducted in the Upper Ganga Basin. In many of these cases, the glacial areas have simply not been studied or mapped and consequently even if many of these formations are known to exist in some pockets, our basic inference is that there is simply no data available. Detailed studies of this phenomenon need to be conducted immediately to fill this important lacuna.

3.8.7 Verglas, Snow dust, Meadows and other Components

Apart from these major components, many other minor components also form a part of the cryosphere. Frozen layers of ice formed over rocky outcrops at high altitudes, especially during low temperatures at night, form 'verglas'. Scree and water droplets mix and form a layer of ice which melts away during the day time. Ice or snow fed meadows, locally known as bugyals are formed due to melting ice or snow. These meadows are formed during the summer season where pastoralists bring their animals to feed on the rich grasslands created in these regions. With incoming winter, these regions are again covered by snow and/or ice.

Another rare phenomenon formed due to the process of sublimation[44] is formation of snow dust which is neither ice nor snow. This forms a very miniscule part of the cryosphere, mostly present on very high peaks where the snow gets transformed into snow dust due to wind. When the ambient temperature falls, snow gets carried away by wind forming snow plumes at high altitudes.

3.9 CONCLUSIONS AND RECOMMENDATIONS

1. The Cryosphere is vulnerable to extreme variability as some components are part of the annual hydrological cycle while some are part of the longer geological time frames such as glaciers and permafrost. But the underlying fact is that all the components - glaciers, glacial lakes, snowbound areas, permafrost, thermokarst lakes and other features are interrelated, and any change in one component leads to a succession of events in the other components.

Therefore, this interconnected nature of the Cryosphere has to be recognised while planning studies and preparing management plans for the region in future.

2. Based on different criteria of size, length, seasons, etc., applied by different agencies there are different values of the number of glaciers and glacial lakes found in the region. In a temporal (2004-2007) IRS LISS III based study, the Indian Space Research Organization (ISRO) mapped a total of 6,237 glaciers in Ganga basin with the glaciated areas in this basin estimated as 18,393 km² *(ISRO report, 2010)*. The International Centre for Integrated Mountain Development (ICIMOD) estimated a total of 7,963 glaciers covering an area of about 9,012 sq.km and with a total ice reserve of 793.53 km³ for the Ganga river system *(Bajracharya SR, 2011)*. Based on the values provided by Gangakosh (NIH, Roorkee), the Nepal Himalaya has 3,252 glaciers at and above 3,500 m above mean sea level. According to another estimate by ICIMOD, the cryosphere of all the rivers in Nepal contain a total of 3,808 glaciers and covers an area of 30,902 sq. km *(Bajracharya et al., 2014)*.The three organizations mentioned above are nationally and internationally well known, and may have understandably arrived at the correct results based on diverging sets of criteria.

It is therefore recommended that there is co-ordination and co-operation between these organizations order to arrive at common criteria, and reliable definitive results.

3. The Atlas of Glacial Lakes in Ganga Basin, prepared under the National Hydrology Project, published by Bhuvan, which is the Indian geo-platform for ISRO (June, 2021), states that there are around 4707 glacial lakes (of size greater than 0.25 ha) in the Ganga basin (catchment area of 2,47,109 sq. km) in the Himalaya. Another atlas, i.e. The National Wetland Atlas *(MOEF, GoI, 2012)* has identified a total of 4699 glacial lakes.

It is recommended that since both the publications make important observations and recommendations, these need to be discussed in the public domain, so that policy decisions are taken in an integrated and holistic manner.

4. The recent meteorological statistics and various studies show increasing variability in temperature, precipitation as well as snowfall patterns which needs to be understood seriously, both in the government establishment and civil society. The rising temperatures will in fact increase the rate of recession of glaciers.

It is therefore recommended that Policies on infrastructure / development-projects acknowledge and incorporate these findings in their reports and action-plans.

5. Receding glaciers will lead to excessive flooding in a short period of time and also reduce the utilisable share of water in our rivers. Melting of glaciers due to increasing global temperatures will drastically alter water flows in the Ganga River and its tributaries during the summer season. All this will ultimately affect not only irrigation and cropping pattern, but also drinking, domestic and other uses.

It is recommended that the Draft National Water Policy, 2020 be revised before finalization since a large amount of definitive data on climate change and cryosphere has emerged in the last ten years, which require not just the NWP, but also other related / concerned Acts to be revised so as to align the policy and law framework with the emerging realities.

6. The Cryosphere is part of a contiguous geo-morphological zone, which is spread over different states and/or countries.

It is therefore recommended that in order to examine, understand and formulate an Action Plan for the restoration and sustainable development of the Ganga River, this area be considered as a single management zone, which, while recognizing the administrative boundaries of the existing nation states, also accounts for and includes the entire data on GBM Basin for planning and management purposes.

7. Towards the end of 2020, a detailed study of 477 glacial lakes greater than 50 ha each-was taken up by Morphology & Climate Change Directorate, Central Water Commission titled 'Monitoring of Glacial Lakes & Water Bodies in the Himalayan Region of Indian River Basins for the Year 2020 (June to October)' *(CWC, 2020)*. This is a welcome step taken by the CWC which has seriously started looking at the behaviour of high altitude glacial lakes.

It is recommended that updation and monitoring of such studies be undertaken on a continuous and regular basis and the data be made available in the public domain.

ENDNOTES :-

31. The word "cryosphere" comes from the Greek word "kryos" literally meaning cold (National Snow and Ice Data Center, 2021), University of Colorado, USA. The areas or places where water is in its solid form, where low temperatures freeze water and turn it into ice, are called the cryosphere of the earth. The cryosphere consists of mountain glaciers and continental ice sheets, seasonal snow, and ice cover on land as well as sea ice.

32. HKH consists of around 30 mountain peaks higher than 7,300 m. above mean sea level (amsl), (i.e. above 24,000 ft amsl), and covers a geographical area of 5,94,400 sq.km., and contains the origins of ten major river-basins of the world *(Wester et al., 2019)*.

33. Temperatures below 4000 ft might also be less than 0°C but they remain low for a short period, therefore they cannot be easily classified under the category of cryosphere.

34. Parts of Sikkim are included in this section as water from the eastern side of the ridgeline of theKangchenjunga peak flows into the Tamor River. Three rivers Yangma, Ghunsa and Simbua join the Tamor River. The origin of the Simbua River is the Yalang glacier which lies at the foot of Mt. Kangchenjunga (Based on discussions with Dr. Chiranjibi Bhattaria, Nepal).

35. Rabi crop: Rabi crops are known as winter crops. They are grown in October or November

and harvested in spring

36. Kharif crop: Kharif crops are the crops which are sown at the beginning of the rainy season, e.g., between April and May.

37. According to the same study, there are around 16,049 and 10,106 glaciers in Indus and Brahmaputra, with the glaciated areas in the basins estimated to be 32,346 and 20,542 km² respectively. These estimates lead to total glaciated area in these three basins to be 71,182 km² for 32,392 glaciers.

38. In the epic Ramayana, there is a mention of Banderpoonch (Monkey's tail) and Mahalangoor mountain ranges, indicating that when the epic was written this mountain range was one continuous area without borders, since the state or national boundaries as we know them did not exist.

39. Other most commonly used vernacular terms in Garhwali language are: Khaal = Pass/Saddle and Bugyal = High altitude meadow often covered with snow during winter. Bamak = glacier

40. For details of the geomorphology of the Gangotri Valley, see 1. Singh 2004, 2. Singh, Dutta 2004, 3. Tiwari 2004, and 4. Puri 2004.

41. The author successfully led an expedition to Kalindi peak in 1976, and also participated in an expedition to the Shivling peak (1975) which unfortunately could not be summited due to inclement weather. Since then, the author had made four more visits to the Gangotri glacier upto Thalay Sagar and Nandanban.

42. Cedrus deodara, the deodar cedar is a species native to western Himalaya in India, Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, the Darjeeling region of West Bengal and western Nepal. These ancient trees occur within the altitudinal range of 1500 to 3200 meters (about 5000 feet to 10500 feet). It is a large evergreen coniferous tree which can reach to a height of 50 meters and in certain exceptional cases up to 60 meters. It has a huge trunk which can reach a width of 3 meters in diameter.

43. Karst areas: an irregular limestone region with sinkholes, underground streams, and caverns.

44. Sublimation is the transition between the solid and the gaseous phases of matter, with no intermediate liquid stage. In the context mentioned above, the term sublimation is used to describe the process of snow and ice converting into water vapourin the air, without first melting into water.

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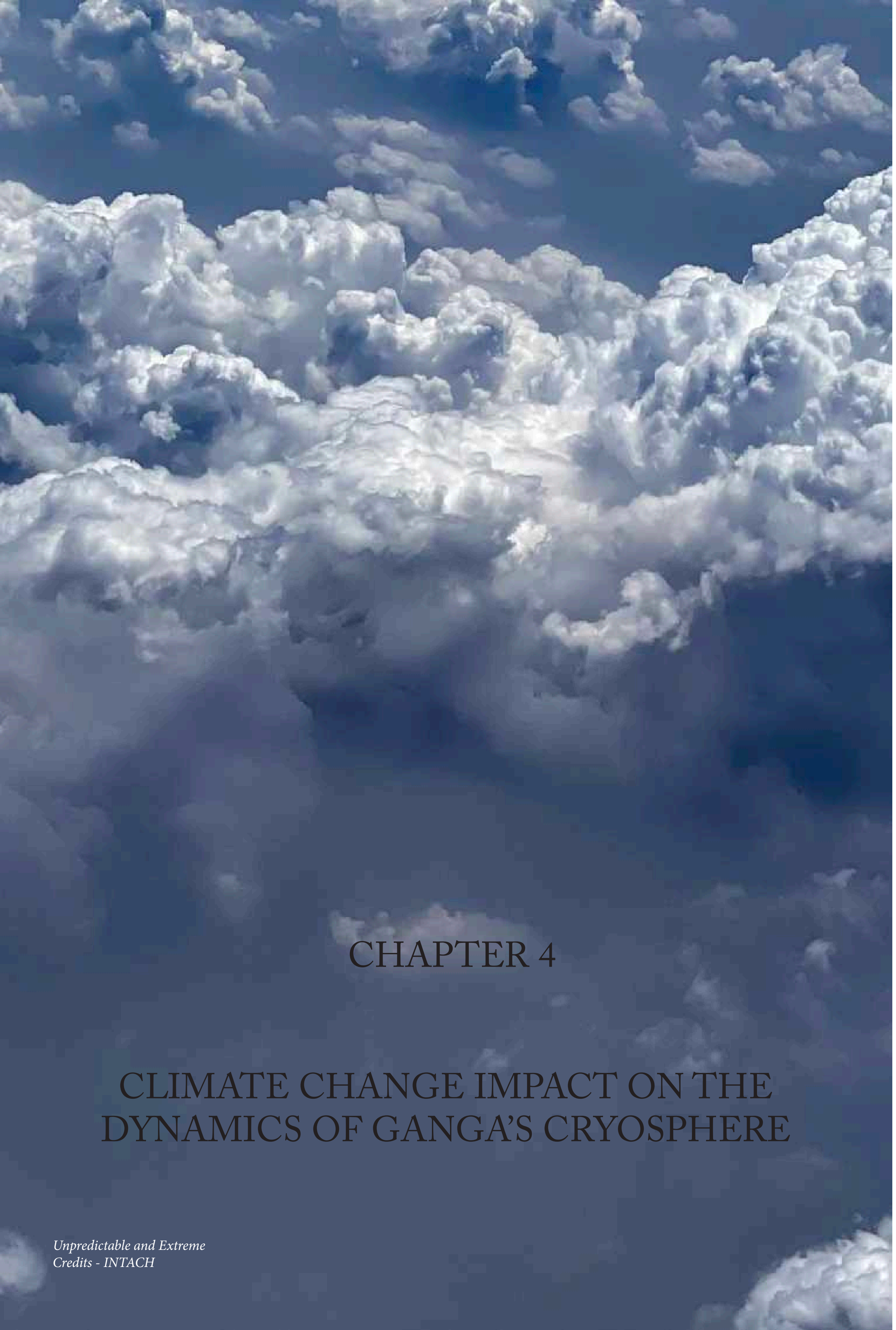
Deoriatal with Chaukhamba Peaks in Background



CHAPTER 4

CLIMATE CHANGE IMPACT ON THE DYNAMICS OF GANGA'S CRYOSPHERE

Unpredictable and Extreme
Credits - INTACH

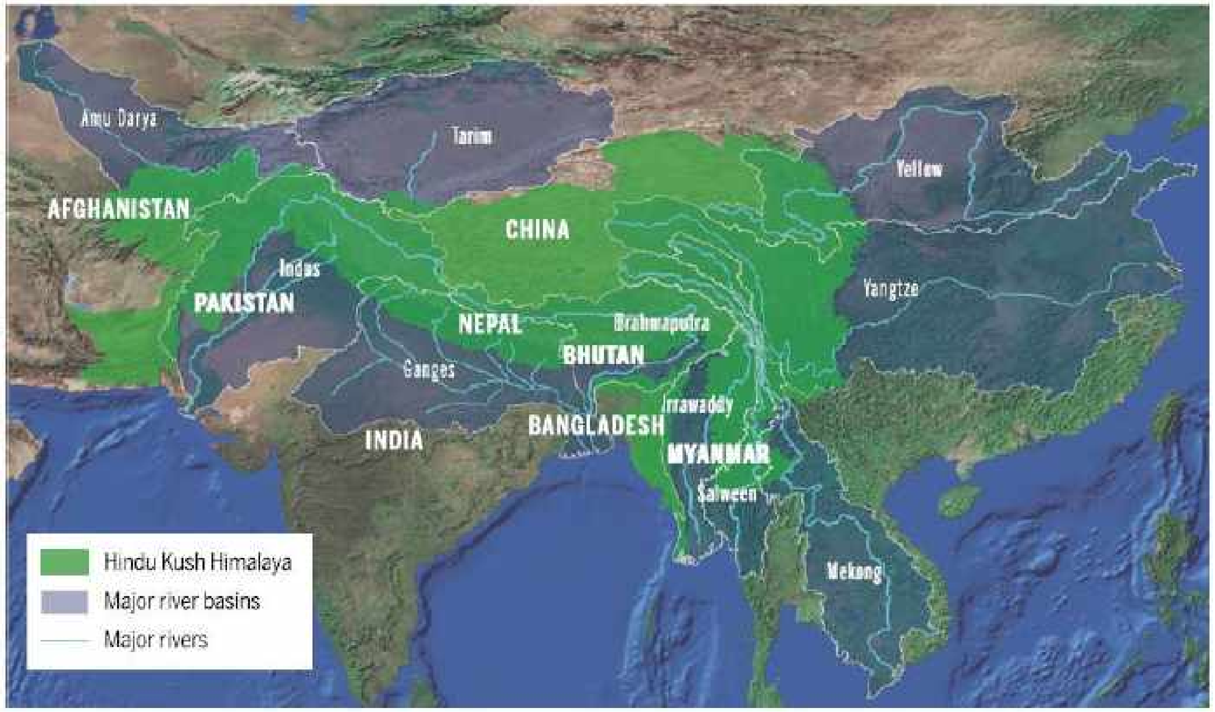
4.1 CLIMATE CHANGE DISCOURSE AND ITS RELATIONSHIP WITH THE CRYOSPHERE

The Climate Change discourse during the last few decades of the 20th century was rather contentious, among scientists on the one hand, and among politicians and lawmakers on the other. In fact, it was the lack of unequivocal agreement among scientists that led to the naysayers among the politicians to avoid taking important investment decisions regarding emission control, adaptation and change in technology. No attempt was made to increase the resilience of sections of the society, vulnerable to the adverse impacts of climate change. They also avoided making policy interventions regarding consumption patterns, disincentives related to fossil fuel use and incentives for renewable energy. The discourse was mainly centered on the share of the responsibility for what had already gone wrong, and the duties of the sovereign nations, both industrialized as well as developing, to accept responsibilities regarding production, consumption and trade in products and services that were not climate change compliant.

However, at the turn of the 20th century, when the 4th Assessment Report of the IPCC (2007) was published, world leaders started gravitating towards the inevitability of climate change and the severity of its impacts. The societal perception at the global level had accepted the reality of climate change and the inevitability of disasters (i.e. melting of the polar regions, receding of glaciers, rise in the sea level, unusually erratic weather and rainfall conditions and climate change refugees). Several Conferences of Parties (COPs) held during the last two decades have not brought about a significant change in national policies of most nations and the blame game has continued. Therefore, until the publication of the 4th Assessment Report of IPCC in 2007, there was little unanimity among global leaders regarding the reality of climate change and the potential severity of its impacts. However, the period post-2007, brought about a change in perception and there was a general agreement on the need to act swiftly in order to prevent the impending crisis.

In the midst of these controversies and confusion, the International Centre for Integrated Mountain Development (ICIMOD) decided to conduct an assessment (2011-2019) of the entire body of scientific evidence generated so far, related to one of the key issues in the climate change discourse, namely, its impact on the Hindu Kush Himalaya (HKH). This study was conducted across eight countries constituting ten major river basins located in south and central Asia. This was also the area which together contained about one - third of the global population and more than half of the global poor. In the following sections, an attempt has been made to draw out the key findings and conclusions which are compelling enough to change the political and societal perception of climate change from being just a distant threat to being an emergency situation requiring immediate action. The ICIMOD Assessment of HKH has made it abundantly clear that the crisis is already upon us, and that we need to move from crisis perception to emergency action.

Today, scientists working on Climate Change warn us that the Himalaya is getting warmer considerably faster than the rest of the earth, and that its greatest physical impact will



Map 4.1 Hindu Kush Himalayan Region and Ten Major River Basins *(Wester et al., 2017)*

be on the Cryosphere located in the altitudinal range of 3000 m. to 8000 m. Around the world, mountain glaciers are retreating due to rising snowlines as warmer air is rising to higher elevations, promoting more melting and less snow accumulation. In some places, it also means more rain.

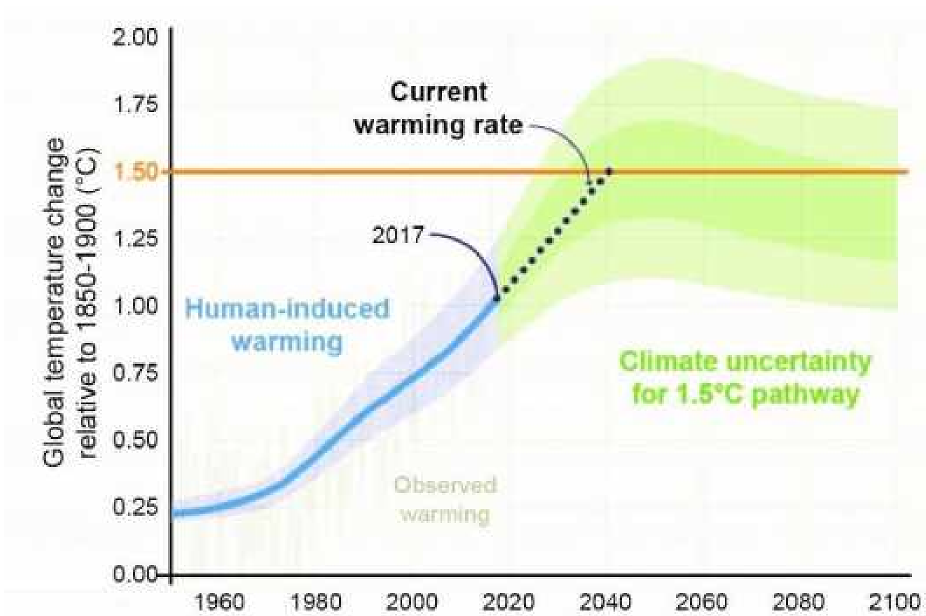


Diagram 4.1 Human-Induced Warming (Blue Shading) Reached Approximately 1°C Above Pre-Industrial Levels In 2017. At The Present Rate, Global Temperature Rise Would Reach 1.5°C (Above The Global Average Land And Ocean Temperature Recorded During Pre-Industrial Period) By Around 2040. The Stylized 1.5°C Pathway Shown Here (Green Shading) Involves Emission Reductions Beginning Immediately, And Co2 Emissions Reaching Zero By 2055 *(World Climate Research Programme, 2018)*

That has been the consistent observation around the world's tallest and coldest mountains over the past few decades. The global average land and ocean temperature during the 20th century was 13.9ºC (or 57.0°F). However, by the year 2017 it had risen by 0.84ºC (1.51°F), i.e., 13.9ºC + 0.84ºC =14.74ºC. By implication, this alarming rise of almost 6% has led to a negative climate change impact which is discernible at the decadal scale. The global land and ocean temperature for January, 2020 was the highest recorded during the last 141 years, with a temperature departure of 1.4ºC or (2.05°F) above the 20th century average. Further, the four warmest January months on record have occurred during the past 4 years, i.e., 2016-2020. During 2016, it was even higher, at +0.94ºC (+1.69°F). This peaking was attributed by some scientists to a strong El Nino event. Further, international research since 1850 indicates that even if the global community manages to keep the level of warming at 1.5ºC (the target broadly agreed upon by the international community), the level of warming will still be at least 0.3ºC higher in the entire HKH region, while in the North-West Himalaya it will be at least 0.7ºC higher than the global average.

4.1.1 Impact of Climate Change on Cryosphere of the Ganga River Basin

During the last four decades, rising temperatures have led to a widespread shrinking of the cryosphere, including the uppermost sub-basins of Ganga, i.e., glaciers near the origins of Ganga, Yamuna, Mahakali (Sharada in India), Karnali, Gandaki, Sapta Koshi, Mechi, Mahananda, etc. Further, permafrost temperatures have increased since the levels recorded in 1980. The increase in temperature has been especially great during the period 2007 to 2016 (0.29ºC - ± 0.12), in just nine years! Such a permafrost thaw and glacial retreat have decreased the stability of high altitude mountain slopes, which can potentially increase the incidence of avalanches and rock/ land-slides *(Special Report on the Ocean and Cryosphere in a Changing Climate, IPCC 25th Sept 2019)(Portner et al., 2019)*. In exceptional years, the highest thinning rates for the Gangotri glacier have been reported at ~1.5 m per year. The ice thickness of Gangotri Glacier varies from around 20 to 40 m. near the snout, to a maximum of ~500 m in the middle reaches. The thickness range in the upper reaches is around 200 to 400 m. but is typically lower near the head of the glacier owing to the lower velocity and steeper slope. In the case of tributary glaciers, thickness along the main trunk varies between 150 and 300 m. for the western tributaries compared to 100 and 200 m for eastern tributaries, which are also located at lower altitudes in comparison to those in the west *(Bhushan et al., 2017).*

4.1.2 Loss in Area of Glaciers

Across all sub-basins of Ganga, the smaller glaciers (in terms of length, width, and depth) are receding faster than the longer/larger ones. Further, the ones at lower altitudes are also melting faster than those at higher altitudes. Glaciers which are heavily covered with rock, debris or moraine and are the cleaner whiter ones reflect more solar radiation and have relatively lower rates of melting, whereas the debris-covered ones absorb more heat and melt relatively faster.

While all glaciers are receding, the rate of shrinkage is faster in the case of the eastern sub-basins, whereas it is slower in the case of the central sub-basins of Ganga. This is consistent with the altitudinal factor, since several large ones that are well above 6000 m. in altitude are known to be receding at a much slower rate. These findings have been especially evident during the last six decades, i.e. from 1960 to 2015 (*Chand & Sharma, 2015; Thakuri et al., 2014).*

4.1.3 Loss in Mass of Glaciers

Studies conducted after 2001 indicate that glaciers in the eastern sub-basin of Sapta-Kosi have suffered a relatively higher rate of mass-loss than the glaciers in the western region. Debris-covered glaciers in the Langtang and Khumbu Glaciers have lost mass in recent years, although at a lower rate than debris-free glaciers *(Immerzeel et al., 2014)*. It appears that if there is a thick enough layer of debris, then it protects the ice from the sunlight and reduces the rate of ice-melt. A clean glacier, on the other hand, is vulnerable to bright sunshine which accelerates the snow and ice melt.

Ice Snout of Khumbu Glacier, Nepal Himalaya, with thick (5 to 6 m) debris layer on top of white ice wall *(Wester et al., 2019)*

As stated earlier, Nepal contains a total of 3,808 glaciers and covers an area of 30,902 sq. km. During the last three decades, Nepal has lost more than a quarter of its glacial mass. The rate of loss has been accelerating and the total glacier area has reduced by 24% between the years 1977 and 2020. On an average, glaciers have receded by 0.38 km every year and such a retreat could destabilize the adjoining ice sheets, thereby triggering frequent avalanches (*Bajracharya et al., 2014)*. While such aggregative inferences sound dramatic, they are based on detailed assessment and measurements of glacial volumes by conducting

mass-balance studies over several years. Note that very few such 'mass-balance studies' have been conducted in the Indian part of the Himalaya. Without such studies of glacierized areas, a water balance study of Ganga would be unrealistic and incomplete.

It has been projected that by 2050, the loss in area and mass of glaciers in the Ganga Sub-basin could be between 25% and 50%, while in the Karakoram-Kunlun Shan region, the loss in area and mass is projected to be much lower, i.e., in the range of 18.6% and 30.3%. In fact, in the Karakoram area, there are a few glaciers which are actually expanding and have a larger accumulation rate, which somewhat compensates for the overall loss in area and mass, due to which it is lower than that found in the Ganga sub-basin. Since this phenomenon of expanding glaciers is contrary to what is happening elsewhere, it is generally referred to as 'the Karakoram Anomaly' by glaciologists, and was first noticed by Hewitt in 2005, before being confirmed by subsequent geodetic studies. Glacier behavior in the Karakoram is highly heterogeneous, both spatially and temporally, and its drivers are not yet fully understood *(Bolch et al., 2012; Brun et al., 2017; Gardelle et al., 2012; Jacob et al., 2012; Kääb et al., 2015).* The HKH Assessment, 2019 (ICIMOD) mentions that in the case of Chhota-Shigri Glacier in the Lahaul-Spiti region (Indus-Basin) there is evidence of 'balanced conditions' during the period 1988 to 2002 in the case of some glaciers (i.e. the rate of ablation was more or less the same as the rate of accumulation). This is in contrast to the Ganga basin where there is no evidence of glacier-balance or of expanding glaciers in any of the sub-basins.

4.1.4 Significance Of Permafrost In Ganga Basin : Out Of Sight, Out Of Mind!

Permafrost is typically found in the Himalaya at 2500 m and above. Permafrost acts as a binder with soil humus and rock particles. So, when permafrost melts, it starts off a debris flow which can negatively affect hydro-power plants located downstream. Usually, the process is slow, but during Extreme Point Rainfall Events (EPRE), or cloud bursts, the permafrost thawing will be triggered and accelerated. Another known phenomenon is that of 'abrupt thawing', and is generally attributed to microbes within humus and soil, that become active if the period of thawing continues for a sufficiently long period of time. The current prediction is that the thickness of the active layer will increase over the next few decades. The layer of permafrost in Himalaya has been thawing at a noticeable rate during the last three decades. The area under permafrost may decrease between 24% and 69%. The impact of permafrost thawing will bring about morphological changes that will affect the Ganga River Basin in the very near future.

In India, permafrost temperatures have increased since the levels recorded in 1980.The Special Report on the Ocean and Cryosphere in a Changing Climate, 2019 by IPCC states that the increase in temperature has been especially great during the period 2007 to 2016 (0.29ºC - ± 0.12), almost half a degree in just nine years *(Portner et al., 2019)*! Such permafrost degradation will destabilize mountain slopes, and threaten transportation networks and infrastructure projects (roads, hydropower stations, urban settlements). The occurrence of landslides is also expected to increase rapidly.

Further, permafrost thawing releases greenhouse emissions. Notably, thawing of permafrost also releases billions of tons of carbon dioxide (CO_2) and methane (CH_4) into the atmosphere. A study reveals that permafrost soils from the North pole would generate one gigatonne[45] or 1000 million tons of methane by 2100 *(Knoblauch et al., 2018)*. Similar studies need to be conducted in the Himalayan region as well.

The first ever workshop on 'Himalayan Permafrost under the Changing Climate" was organized in New Delhi on 12th August, 2016 with the aim to promote permafrost research and knowledge generation in the Indian Himalayan Region (IHR). The main objectives of the workshop were:

a. Sensitize the local government, funding agencies, research institutions, universities and other stakeholders on various issues related to the permafrost thaw/ ground ice in the Himalaya,

b. Explore research collaborations with experts in the field who can help in fostering permafrost research in India.

Key problem areas identified:

i. Lack of research background in Indian institutions and universities

ii. Lack of funding opportunities for permafrost/frozen ground research.

Following this, the Indian Permafrost Network (IPN) was created in 2017 with the National Institute of Hydrology, Roorkee, as the lead organization in collaboration with ICIMOD and Carleton University, and Canada to promote permafrost research in the country. Since then, there have been an increasing number of research projects on permafrost in the Indian Himalayan Region, however, not many of them focus on the Cryosphere in the Ganga River Basin. A study to map permafrost for more than two consecutive years in the Kullu district in Himachal Pradesh to find out the impacts of global warming was conducted under the Indo-Swiss Indian Himalayas Climate Adaptation Programme (IHCAP) in 2016. Another study conducted in Sikkim stated that there is an abundance of permafrost in Sikkim Himalayas suggesting increased risks of thawing permafrost under the influence of climate warming in future *(Haq & Baral, 2019)*.

A study by Schuster states that permafrost soils store nearly twice as much Mercury (Hg) as all other soils, the ocean, and the atmosphere combined, and this element is prone to being released, as permafrost thaws over the next century *(Schuster et al., 2018*). Similar such studies need to be conducted in the Cryosphere of the Ganga River basin as they will have significant impact on the water quantity and quality downstream.

Since it cannot be visually seen, and since its dynamics are not known, this important area of the Cryosphere has probably been the most neglected. Glaciers and snow are spectacular, and hence have an aura around them, because of which they have been studied for a relatively longer period, i.e., for a decade or so in Nepal. Permafrost, therefore, has been largely neglected, and is the least understood fraction of the cryosphere. Therefore, although permafrost has been such a significant component of the cryosphere, studies, and research in the Himalayan Cryosphere and more particularly in Ganga Cryosphere is still in its nascent stages.

4.1.5 Impact of Climate Change on Thermokarst Lakes

Thermokarst lakes are suitable for climate reconstruction studies as they are unique local "sediment sinks" that can collect useful environmental data and serve as 'archives' over their deposition/life span. As there is very little information about thermokarst lakes with regard to the status of permafrost thawing in the region and comprehensive analysis of emission of carbon gases, there is a need to focus on the following aspects given below *(Pandey et al., 2020)*.

1. The state of permafrost and thermokarst lakes across the Himalaya.

2. The pattern of the evolution of the thermokarst lakes due to climate change.

3. The influence of the thermokarst lakes and changes on the local ecosystem(flora and fauna), and consequent impact on human settlements in its vicinity.

4. Estimate/quantify the emission of the CO_2, CH_4 from these lakes,

5. Evaluate the potential impact of these lakes on the global climate due to carbon Emission and the Paleo-ecology and Paleo-climate of the area using different biotic and abiotic proxies.

Such studies need to be conducted in Ganga River Basin with a focus on understanding their influence on the river regimes. The studies may also throw up new areas of concern currently unknown to us.

4.2 GANGA'S CRYOSPHERE: CURRENT STATE OF KNOWLEDGE

Due to the ever-increasing and overwhelming demands for water in the Indo-Gangetic plains and its inappropriate use, practically all attention and corrective actions have been focused on regions surrounding the river-stretch between Haridwar, Rishikesh and Farakka Barrage. This is also the area where most studies, research, and spiritual energies have been dovetailed along with financial investments. While the importance of the Cryosphere is universally accepted, there are very few studies and research conducted on these aspects. This section gives an elaborate review of the studies done so far on the Cryosphere in India and Nepal, different research methods that have been used, and the outcomes so far.
As mentioned earlier, global warming and climate change are not new phenomena, but

their entrance into the center-stage of global discourse occurred only around 1988 when the Inter- governmental Panel on Climate Change (IPCC) was jointly established by the UN and the World Meteorological Organization. The IPCC's mandate is to contribute to the knowledge base of the UN Framework Convention on Climate Change (UNFCC). The objective of the UNFCC in turn is to bring about stabilization in the emission of greenhouse gases in the atmosphere and contain global atmospheric warming to the extent possible. The IPCC has produced and submitted six full-fledged reports until 2021. The second part of the sixth report has been released in 2022 and is now available in the public domain.

Besides these reports for the policy makers, it has also been publishing special reports on certain important topics. Two such reports were published in September 2019, namely, 'The Special Report on Climate Change and Land' and 'Special Report on Oceans and Cryosphere in a Changing Climate'. An earlier special report on 'Extreme Events and Disaster' was published in 2012. These three reports, inter alia, form the basis of our assessment of the Hindu Kush Himalayan cryosphere. These reports are in addition to the 'Hindu Kush Himalaya Assessment', 2019, prepared by the International Center for Integrated Mountain Development (ICIMOD).

At the global level, the World Glacier Monitoring Services (WGMS), in collaboration with an American agency, has been studying and assessing the glaciers and snow-covered areas. Their inventory contains 130000 glaciers and it provides location, area, length, orientation, elevation and classification, but gives only one entry for most glaciers. These entries are based on aerial photographs and maps, and therefore they only provide a snap-shot of the glaciers. Most photographs are of a post-1950 vintage. The first such inventory was made in 1989.

In a recent study, glaciologists Oxana Suvoskul and Vladimir Smaktin of the International Water Management Institute (IWMI) have described and assessed the 'Glacier System and Seasonal Snow Cover in Six Major Asian River Basins', (2013), which includes the Ganga River Basin. Their study contains data till 2011. As per their assessment, there were only 64 Snow / Ice Weather Stations above an altitude of 3000 m. and 38 Weather Stations above 4000 m. in the six Asian river basins, which cover practically the entire Hindu Kush Himalaya relevant to our study *(Savoskul & Smakhtin, 2013)*. Not surprisingly, there are only six weather stations above 3000 m. altitude in the Indian part of the Ganga River Basin. Of these, there are three Meteorological / Snow stations in the Yamuna sub-basin and three in the Bhagirathi sub-basin above 3000 m. Idiomatically speaking, we are 'very much in the dark' in terms of sufficient weather/ climate data throughout the Ganga River Basin.

Further, just about a dozen scientists have actually conducted direct measurements in a few relatively small glaciers and even these studies / assessments have several limitations. In other words, glaciology in India is a very young and uncertain science with very little empirical data. On the other hand, in Nepal, where the International Center for Integrated Mountain Development (ICIMOD) is situated, a relatively larger number of studies of the Himalayan Cryosphere have been conducted.

A comprehensive assessment, of the Hindu Kush Himalaya was carried out over the last twelve years by ICIMOD, with inputs from over 350 researchers, and with financial support from 14 countries - Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Sweden, Switzerland and the U.K. This magnum opus entitled 'The Hindu Kush Himalaya Assessment' was edited by Philippus Wester et al. and published in 2019. For the following sections on the cryosphere of Ganga basin we have drawn heavily on the ICIMOD Assessment, as it has encapsulated all the research that has taken place on this subject so far. In addition, we have reviewed other research work carried out by the IWMI, Sri Lanka, The Glacial Lake Atlas of Ganga River Basin, National Remote Sensing Centre (ISRO), and The National Wetland Atlas, MoEF, GoI, 2012. The importance of the cryosphere for the GRB notwithstanding, the concern has mainly been about the impact of climate change on this unique entity.

4.2.1 Studies of Cryosphere of Ganga River Basin in India and Nepal

A. Run-off and Mass-balance studies from Gangotri Glacier

An important mass balance (MB) study of Gangotri glacier carried out during recent years was by Anubha Agrawal (Delhi Technological University), Renoj Thayyen (National Institute of Hydrology), and A. P. Dimri (Jawaharlal Nehru University), for the period 1985 to 2014. Their work has taken on the issue of impact of global warming and climate change on the mass balance of the Gangotri glacier. While they do admit that the monitoring of a glacier system requires long- term mass balance observations, they also accept that such observations are not consistently available since large glaciers like the Gangotri have not been monitored due to logistical challenges. The authors have used three different methods viz.

(a) Ice Flow Velocity method,
(b) The Energy Balance Modeling Method, using Regional Model (REMO) outputs, and
(c) Data from in-situ automatic weather stations (AWS)

The researchers also used the geodetic method for conducting a MB calculation for another small glacier called Dokriani located a few kilometers from Gangotri glacier, but within the Bhagirathi basin, in order to compare relative impacts of global warming (GW) on small and large glaciers.

Their study has produced some interesting results which may prove to be very useful for conducting an extensive, long term MB study of the Gangotri glacier. Their primary conclusion is that the Mass-Balance for Gangotri glacier estimated for the period 2001–2014 using the Ice Flow Velocity method is -0.92 +/- 0.36 m w.e.a-1(w.e.a-1: Water Equivalent per Annum). Then, by using the AWS data and Tropical Rainfall Monitoring Mission (TRMM) for the year 2006 – 2007, the MB is -0.82 m w.e.a-1 and finally using the REMO[46] data the MB is -0.98 m w.e.a-1. Further, they state that using the surface velocity method, the glacier has lost about 9% of its volume during the period 2001 to 2014 and vacated an

area of 0.152 sq. kms from the snout region; and that it has retreated by 200 meters in the last 14 years *(Agarwal et al., 2017)*.
In conclusion, one may state that this study has provided a first-order-estimate of the mass-balance of the Gangotri Glacier based on short duration physical evidence, and that the results from three different methods used are not just remarkably similar but also heartening. Secondly, the loss in volume (9% in fourteen years) suggests the need to urgently study the regional climate, and install adequate instrumentation for collecting continuous data in future.

Another recent study conducted by researchers of the Indian Institute of Science, Bangalore in the Chandra basin of the Yamuna River, has found that during the period 1984-2012 i.e. in 28 years, 146 glaciers have lost 20% of their ice cover and a corresponding volume of water. The study has used a combination of satellite data on snow-lines, Temperature Index-Melt-Model and Accumulation Area Ratio Method to estimate the Annual Mass balance for glaciers in the Lahaul- Spiti region of Himachal Pradesh*(Tawde et al., 2016)*. Such studies will have to be replicated on a much larger scale in Uttarakhand and Nepal, and also in southern Tibet.

B. Estimation and Measurement of Snow Cover Area

Snow-cover estimation and measurement is based on a set of variable components such as snow-cover, ice-depth and permafrost. Quantifying snow is done by carrying out in-situ measurements of snow depth, and then converting it into a Snow-Water-Equivalent. The rate of annual accumulation is estimated from glacier mass-balance records, or it can be based on ice-core measurements. Further, Snow-Line-Elevations (SLEs) and their increase or decrease also represents an important indicator/variable of climate change, and are known to be highly correlated to Glacier Equilibrium Line Altitude (GELA).

The average snow-covered area of the extended HKH ranges between 10% 'mean-minimum' and 18% 'mean-maximum'. The challenges related to calculating the area under snow-cover notwithstanding, glaciologists estimate that, at the river-basin scale, the Ganga basin as a whole is expected to experience a 50% to 60% decrease in area covered by snow during the period 2070 to 2100 *(Viste & Sorteberg, 2015)*. Studies point out that once large glaciers begin to recede, their rate of mass reduction accelerates.

Glacier volumes are normally measured using two methods :

a. 'Upscaling of volume / area' is a method where volume is calculated using an empirical formula, assuming that glaciers get thicker as one moves upstream from the snout / tip of the glacier towards the peak / summit.

b. 'Distributed Estimates' of glacier thickness is carried out by taking a dispersed set of readings along and across the glacier*(Farinotti et al., 2017; Linsbauer et al., 2012)*.

Table 4.4: Different Estimates Of Area Under Glaciers In Ganga River Basin

Note: The Estimates Given Above Indicate That The Average Glacier Area Estimated May Be Taken As The Average Between Reference Work 1, 2, 3 And 5; It May Be Assumed That Reference Work No.4, I.e., Rgi 3.2, Is An Outlier (Wester et al., 2019)

Sr. No.	Reference	Area in sq. km
1	Cogley 2011	21973
2	Bolch et al 2012	22829
3	Nuimura et la 2015	19991
4	RGI 3.2 (Year?)	26688
5	RGI 5.0 (Year?)	20070

Since the former method is said to be potentially misleading, especially for composite glaciers as found in the Himalaya, the latter is being used for Himalayan glaciers. In the Kosi Basin for example, the Yala glacier in the Langtang valley of Nepal, Rikha Samba glacier in the Hidden Valley, and West Changri Nup Glacier in the Doodh Kosi Basin have all been carried out by using the 'Distributed Estimates Method'. These were carried out after 2007. In addition, some other studies were also initiated, e.g., Dokriani, Kangware, Rikha Samba etc., but the data collected was discontinuous and therefore not of great value for a comparative analysis. So far only about 30 glaciers covering an area of 120 sq. km (out of a total area of about 1,00,000 sq. km) have been studied.

C. Projected Changes in Glaciers

Projected Glacier changes in the long term i.e., by 2080 to 2100 are a matter of serious concern. The Equilibrium Line Altitude (ELA) in central and eastern parts of Ganga Basin is projected to rise up to 800 m by the year 2100. These changes will lead to unsustainable mass-balances and a gradual disappearance of low altitude glaciers. Recent studies *(Kääb et al., 2015)* and *(Brun et al., 2017)* are very convincing, and the ICIMOD assessment also arrives at important recommendations, which, for India and Nepal, have important implications.

It is now evident that there is an urgent need for institutions like Geological Survey of India and National Institute of Hydrology and several others to initiate studies for developing estimates of 'glacier mass change' for key glaciers, starting with Yamuna and Bhagirathi sub-basins and Mahakali on the Indo-Nepal border, and then follow this up with collaborative studies on glaciers in Karnali and Gandaki basins. In the case of Saptakoshi, studies are already in an advanced stage, since such work has been going on for about 20 years at ICIMOD and Kathmandu University. Further, satellite data for the period prior to the year 2000 has now been declassified, and can now be used for such studies. The objective of such studies will be to reduce uncertainties, and compel policy makers to take immediate action. It may be noted that our understanding has improved during the last 20 years mainly because of the de-classification of satellite imagery and its subsequent analysis, for the decades prior to the year 2000 *(Lin et al.,2017; Zhou et al., 2017)*. If a similar declassification is done for flow data on the Ganga, the quality of research results and policy making would take a quantum leap.

D. Limitations and Variations in Study Methods and Techniques

Besides the methods mentioned above, Remote Sensing techniques have also been used for procuring information on 'Snow-Level-Elevation' lines, and therefore on overall snow-cover as well. In addition, Remote Sensing can provide information for identifying changes in 'Glacier Mass-Balance', etc. This technique has the advantage of being able to cover vast areas that are practically inaccessible from the ground *(Immerzeel et al., 2009)*.

However, it is important to note the limitations of remote sensing technology. The study to measure change in the area of the Gangotri glacier reported that the Gangotri glacier shrank by 4.4 sq. km between 1968 and 2006 i.e. in 38 years *(Bhambri & Bolch, 2009)*. According to another study, the glacier area reduced by 15.5 sq. kms between 1976 and 2006 *(Rao & Yogesh, 2016)*. Bhambri has suggested that this discrepancy may be due to the fact that the terminus of the glacier is debris-covered which obscures the snout retreat which would be difficult to assess through a remote sensing technique. Further, the area under snow-cover in the upper-most watersheds of Ganga varies from 10% in summer (ablation period) to 85% in winter (accumulation period). The figures indicate that the 'inter-annual' and 'intra-annual' variability is also so high that identifying one discrete value for reflecting the area under snow cover would be meaningless.

These discrepancies highlight the fact that arriving at results using only satellite imagery is unreliable and can lead to incorrect or misguided policy recommendations. The recent studies based on satellite imagery do give us a continuous and photographic rate and nature of change in different glaciers, but this interpretation is also not adequate for prediction because the data has thrown up results and observations that are quite contrary to the belief that all glaciers around the world are melting and receding rapidly. Further, using the results of such studies of the second largest glacier in India and extrapolating them to the entire Cryosphere in India for arriving at policy recommendations regarding management of land and water resources will not only be unscientific but also misleading. Further, estimating snow-cover based on remote-sensing data would also not be realistic, since it does not adequately capture the third dimension, namely depth. Taking direct field measurements is also a very challenging task. Field measurements are often inaccurate because of the wind factor, which can make it drift leading to an 'under-catch'. Establishing weather stations at elevations above 5000 m is physically and practically a very daunting task, and even when placed there, they are vulnerable to avalanches and land/rock- falls.

Therefore, relatively speaking, 'ice-cores' and 'shallow firm cores' provide an important method for calculating snow accumulation rates, that can yield Century-Scale Series of Climate Data at High Elevations. However, currently, except for the scientists at Nagoya University, Japan, who started collecting core samples way back in 1962, no other agency/country is known to be studying 'ice-cores'. Changes in seasonal snow-cover will directly impact the availability and seasonal distribution of freshwater in mountain river basins, including the Ganga River basin. Such changes also impact permafrost via alterations in thermal coupling between the atmosphere and subsurface soil and ice. Elsewhere in the HKH area, the climate reconstruction scenarios have currently been based on ice-cores taken from the Mt. Everest region *(Kaspari et al., 2008)*, the Pamirs and the Tibetan Plateau. Such estimates may therefore be taken only as proxies.

A mass balance study of a glacier has been internationally accepted as the most reliable and accurate way of understanding glacial dynamics. But sadly enough, barring a few glaciers, such as Gangotri, Chandra, Dokriani and a few other smaller ones, no major glacier has been taken up so far for conducting a mass balance study in the Indian part of the Ganga Cryosphere. None of the other glaciers have been systematically researched by glaciologists, geologists or hydrologists. Perhaps the maximum amount of scientific work done so far is on the Gangotri Glacier. However, almost all the work undertaken so far has focused its attention on Gomukh, i.e., the snout of the Gangotri glacier and an area of just about 2 km around it. The emphasis was on snout monitoring and the geomorphology of the surrounding areas and palaeo-glaciation of the vacated bed of the glacier. Consequently, the changing dynamics of the Gangotri glacier beyond the snout remain largely unstudied.

Similarly, practically none of the studies reviewed by us were carried out by investigators who physically visited the glaciers or traveled on them extensively. In other words, the studies were based on maps of the Survey of India (SoI) and the satellite images superimposed on them. Consequently, there is not a single study which fully describes the Gangotri Glacier from its origin to the snout, or any of its major tributary glaciers like Chaturangi, Raktavarna, etc. The Raktavarna Glacier for example which extended right up to the main trunk in the recent past has now receded and become an independent entity. But this phenomenon has not been studied in detail. Chaturangi Glacier is about to suffer the same fate as Raktavarna Glacier since there appear to be no research projects in the pipeline for studying this glacier in the near future.

Studies carried out so far have not clearly demarcated the accumulation zone and the ablation zone either on a map or on the ground. There are no markers or cairns to identify such zones which could be used later by researchers and investigators in future. The only physical markers are the ones placed by Auden in 1935. In fact, the first map of the snout area was also prepared by Auden in 1935 on a scale of 1:4800, and all later investigations by the Geological Survey of India (GSI) are based on the cairns erected by Auden. Similar morphological studies were carried out in 1956, 1971, 1975, 1977 and 1996. However no major study has been carried out so far by GSI to extensively study the Gangotri Glacier, even though it is the best equipped government agency for conducting such a study.

Currently, there are two institutions, the Survey of India (SoI) and the Geological Survey of India (GSI) which maintain and update records of several physical characteristics of the glacier, but they both arrive at grossly differing results. For example, as per SoI the area of Gangotri glacier is 75 sq. km, while the GSI has calculated a figure of 143.58 sq. km!

Independent research estimates the area of Gangotri glacier to be 258.56 sq. km! *(Agarwal et al., 2017).*

Note: The SoI, the oldest national institution working on topographic mapping, does not appear to have given any formal clarification or counter statements on discrepancies regarding fundamental values such as the area of the Gangotri Glacier.

This divergence in values needs to be scientifically reconciled if we wish to take policy decisions regarding its impact on the downstream hydrological regime. A commonly accepted value would also help in conducting comparative assessment of the most important glacier system in the Upper Ganga Basin within Indian borders. Subsequently or simultaneously the group of institutions working on the cryosphere should immediately study the Nanda Devi glacier system, and other lesser-known glaciers in Uttarakhand which continue to remain a blind spot.

Such variance in conclusions can be observed between government institutions and private institutions as well. While the GSI expects the rate of recession to be about 18 meters to 20 meters per year for several decades in future, the Glacier Research Group (GRG) in Delhi headed by Dr. Syed Iqbal Hasnain has predicted that the rate of recession may rapidly increase to 100 meters per year! Therefore, an internationally accepted validation of results based on the best scientific practices is urgently required.

Similarly, the GSI has calculated the area vacated by glacial recession and arrived at a figure of 0.21 sq. km as the area vacated during the period 1985 to 1996. There are different results drawn by different independent researchers regarding the area vacated by glacial recession. All such deviations and variations notwithstanding, experts from government and non- government agencies agree on the fact that in the absence of real time standardized data gathered directly from the field for a significant period of time-estimates, all conclusions will continue to be conjectural and highly suspect.

Measurement of water discharged at Gomukh has been carried out for the last 18 years. However, different agencies have arrived at different discharge results, probably because they have followed different methods based on divergent assumptions, which lead to results that vary so much that they cannot be relied upon. None of the studies reviewed so far have had the quantification of climate change impact as an important objective of their study. Besides the variance in the results regarding quantification studies, there is an additional problem related to the distinction between snow melt and glacial melt. Without knowing the share of these two fractions, making policy decisions regarding the management of water resources would not be very meaningful. In order to sort out this problem isotope studies will need to be conducted (within the larger mass balance study) in order to quantify different fractions from different tributary glaciers and the main trunk glacier.

Therefore, selecting statistically significant samples of locations for conducting ground-truth verification exercises and verifying these with the data from gauging stations would make the assessment more realistic.

E. Need for Automated Gauging Stations

As per the Central Water Commission (CWC, 2012) there are three snow and ice measuring/ gauging stations in the Yamuna snow-covered areas and three stations in the Bhagirathi sub-basin. The Geological Survey of India also conducts snow-gauging by placing 'stakes', but we do not have enough data or studies which could be used for measuring changes in the cryosphere consequent to climate change, or for understanding its impact on the basin hydrology. In the Nepalese segment i.e. Mahakali to Sapta Koshi as well, there is a paucity of real time data *(Kirkham et al., 2019)*.

Unlike the conventional snow and ice measuring stations which are basically mechanical in nature and attached to a digitized computer system, studies by Kirkham and others of the Cambridge University have used a novel technique, where a passive Gama Ray Sensor measures the Snow-Water Equivalent (SWE) of a particular area. The study was carried out by using the above-mentioned technology over a period of two years. The instruments were installed at an altitude of 4962 m. Kirkham claims that 'precipitation gauges' currently used at different locations significantly under-represent the solid fraction of precipitation by almost 40%, as compared to the 'Gama Ray Sensors' technology. Therefore, Kirkham recommends the installation of such devices in other parts of the Ganga's cryosphere as well. Currently, these stations have been installed by ICIMOD, and are located at Ganja-la, Langtang Glacier, Yala Glacier and Langshisha Glacier in Nepal. The stations have started yielding data on 'Snow-Water- Equivalent' (SWE) values. However, it will be several years if not decades before we can get basin-level data for a full hydrological assessment.

F. Need For Creating A Centre For Integrating Data On The Himalayan Cryosphere

Considering the large variability in study methods and results, it is necessary that cryosphere studies need an integrated approach. It appears that in order to conduct a mass balance study of Gangotri glacier in particular and the Himalayan Cryosphere in general, practically all the institutions mentioned above would have to work together on a common 'National Program for Studying the Himalayan Cryosphere'. There is an urgent need to create such a framework. The Indian government has recently announced that it will soon establish a 'National Centre for Field Operations and Research in Himalayan Glaciology'. But this has not yet materialized!

In order to make an assessment of snow cover, and its seasonal or long-term increase or decrease, one would require extensive measurement of precipitation/snowfall over a fairly long period of time, say a time series of 40-60 years. But unfortunately, we do not have the requisite number of Automated-Weather-Stations (AWS) for conducting meteorological studies or for modeling the glacier processes. In addition, the location and frequency of such data collection needs to coincide with the dates/data taken from satellite images in order to enable reliable comparisons. Such studies can be conducted only by national institutions or organizations like National Institute of Hydrology (NIH), Indian Institute of Remote Sensing (IIRS), India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM) and the Wadia Institute of Himalayan Geology (WIHG) which has a separate Centre for Glaciology. More importantly, a Centre that coordinates the research done by all these institutions is urgently needed. Such a centre then needs to be adequately funded for running a long-term program.

The Department of Science and Technology (DST) has supported a program on Himalayan glaciology but this has been in the 'project-mode' which is for a limited timeframe. Further, since the institutes and universities concerned were constrained by time and finances, they restricted their work to hydro-geo-chemistry, remote sensing data, hydrometrics, lichenometry, suspended sediment measurements, and snowmelt runoff modeling. Besides the obvious shortage of funds, all the above-mentioned organizations have pointed out logistic difficulties such as absence of accommodation facilities, equipment and instrumentation, scientists and field investigators who are willing to work at high altitudes, large enough teams of scientists who can operate in tandem and in rotation. All these seem to be mere excuses for national institutions that have been in existence for several decades or even a whole century. (e.g., SoI was established in 1767, GSI in 1851, and WIHG in 1968!)

Both Nepal and India need to initiate a long-term program where such advanced technology is widely used across Ganga's cryosphere. Automated Weather Stations having Gama Ray Sensors for measuring snow and ice would need to be installed at all major glaciers, so that 'time-series' data can be constructed in order to interpret trends regarding the contribution of non-renewable waters from the cryosphere. India and Nepal can also collaborate on long-term studies where ice-core measurements/assessments can be conducted.

Only when such data is available for all major tributaries of Ganga, will it be possible to draw definitive conclusions for making evidence-based recommendations. Although such instrumentation is maintenance free, it entails major capital investment, which does not appear to be forthcoming. Such studies need to be given priority if we wish to understand the impact of climate change on the Himalayan cryosphere. It would also enable hydrological forecasting, and help to predict avalanche threats. Efforts towards this were made, but they have not yet materialized. It was way back in 1948 that the Indian Meteorological Department (IMD) introduced the idea of setting up a 'High Altitude Research Center for Multidisciplinary Research in Himalaya'. However, this idea was not taken up seriously during subsequent decades and unfortunately, such an institution still does not exist in India. Today, many new but highly specialized research institutions have mushroomed, but none of them satisfy the objectives of multidisciplinary research. Later, during a National Seminar on Resources, Development and Environment (NSRDE) in the Himalayan region, delegates emphasized the existence of policy gaps. One of the important recommendations was that a high-level multidisciplinary group be set up to identify and bridge gaps in the ongoing research pertaining to the Himalayan region and to identify financial arrangements for supporting such work. This recommendation only reiterates the urgency of establishing a national institution for studying the Himalayan cryosphere.

In 1989, Ives J. D and Misserli B. presented the theory of 'Himalayan Environmental Degradation' popularly known as EDT (Environmental Degradation Theory)*(Ives, 1987)*. Briefly it concluded that the population explosion in the Himalayan region, the reduction of land per family, the deepening of poverty, and massive deforestation had together created the problem of sustainably developing the mountain societies. Later, in 1993, the Planning Commission appointed an expert group to formulate a National Policy on the Integrated Development of Himalaya and recommended the establishment of Himalayan Development Authority (HDA) under the chairmanship of the Prime Minister and also to create a National Himalayan Environment and Development Fund (NHEDF). The objective was to promote the integration of natural sciences and social sciences*(Bahadur, 2003; Sharma et al., 2015)*. However, all these efforts have not yet materialized.

G. Status of Institutional Structure for Himalayan Studies in Nepal

The Government of Nepal started conducting its hydro-meteorological activities in 1962 under the Department of Electricity, and then transferred it to the Department of Irrigation. Later the activity was upgraded to an independent department in 1987, and was called 'Snow and Glaciers Hydrology Unit' (SGHU). It has established 15 stations at Langtang (Rasuwa), Solukhumbu, Koshi (near Mt. Annapurna), Malkala Glacier in Sankhuwasabha, Dolpa-Kanjiroba, Humla, Tsho Rolpa, Dalfe Lek-Jumla, and Dharapani in Manang and other locations. Although the existence of 15 high altitude snow/ice measuring meteorological stations is a good start, it is not adequate or representative enough to give us data that could be used for taking timely actions, or formulating national and/or regional policies. India should take a cue from the Nepalese experience and establish a special department for 'Snow and Glacier Hydrology', which can directly feed into Basin Level Studies being conducted by the Central Water Commission. Studies of the cryosphere within the Indian Himalaya began in 2015, when the Government of India commissioned studies through the Indian Himalayas Climate Adaptation Program (IHCAP), but these are still not integrated and holistic. Several studies have been done (as discussed above) but they are fragmented and therefore there is a need to establish a nodal agency which centralizes this data for policy formulation.

4.3 CIVIL SOCIETY CONTRIBUTION

The local and traditional knowledge systems of communities inhabiting these regions will be a great source for historical documentation of changes in the cryosphere region. The local communities might not have scientific understanding but they have certainly experienced the correlations between the floral and faunal behavior patterns and changes in the different elements of the cryosphere. Therefore, the bureaucracy and technocracy should solicit the knowledge and wisdom of the pastoral (transhumance) community and the agriculturalists with regard to understanding physical phenomena and the relationship of the cryosphere with the behavior of floral and faunal species, as a basis for building resilience to impacts of climate change.

As discussed above, studying, and understanding the cryosphere is a mammoth task. Civil society can also chip in by carrying out 'ground-truthing' expeditions by high altitude trekkers and mountaineers. Further, travelogues of such groups will need to be included as extensions of pilgrimages for those who wish to serve the cause of Ganga meaningfully. As a start, all major glaciers in Uttarakhand i.e. longer than 2 km should be assessed and a bench mark established for i) Gangotri Glacier- 30.2 km in length; ii) Sundardhunga -4.32 km;iii) Satopanth - 3.8 kms; iv) Pindari - 3 km; v) Nandadevi group - 19 km; vi) Namik in Pithoragarh- 3 km; vii) Milam - 16 km; viii) Maiktoli - 5 km;ix) Kaphni in Bageshwar dist.- 3 km; x) Dronagiri near Ranikhet- 5.5 km; xi) Chorabari close to Kedarnath - 7km ; xii) Bandarpoonch - 12 kms and xiii) Tipra-Bamak - 6 km, amongst others, all of which are above the headwaters of Yamuna river, should be immediately taken up for assessment and benchmarking.

4.4 CONCLUSIONS AND RECOMMENDATIONS

a) Rapid Increase In Temperature

The Himalaya is getting warmer considerably faster than the rest of the earth and its greatest physical impact will be on the cryosphere The increase in temperature has been especially great during the period 2007 to 2016 (0.29^{0}C- ± 0.12), in just nine years! Hence, the Central and Eastern Himalaya is most likely to lose glacier mass in future leading to floods and EPREs.

b) Rapid Glacial Recession And Loss Of Glacial Mass

Most glaciers in the Ganga River Basin have been retreating since 1850, and have experienced a loss in glacier-mass and reduction in thickness. By the end of the 21st Century, glacier volumes are projected to decline by 90%. In the Ganga Sub-basin, the loss in area and mass of glaciers could be between 25% and 50% by 2050. This will lead to drastic reduction in contribution to river flows.

c) Elevation In Snow Line Leading To Reduction Of Natural Storage Of Water

The Snow-line Elevation is expected to rise between 400 m and 900 m by the year 2100. As a consequence, the flows from snow and ice (cryosphere) will keep increasing up to the year 2050 and after that they will reduce dramatically. This change will reduce the natural storage of water above and below the surface.

d) Insufficient Studies On Glacial Recession

So far, only about 30 glaciers covering an area of 120 sq. km (out of a total area of about 100,000 sq. km) have been studied. Out of these, only 5 glaciers are in India while the other 25 are in Nepal. This makes it impossible to predict or mitigate disasters.

e) Increase In Floods (GLOFs) Due To Glacier Melt Run-Off And Thawing Of Permafrost

Glacial Lakes have been expanding rapidly and also increasing in number due to glacial recession that is caused by snow-melt that ends up as water in glacial lakes. Such a recession of glaciers, which is causing an increase in glacier melt run-off, is also creating new glacial lakes and expanding old ones. Thawing of permafrost will increase and aggravate global warming and impact of climate change during the next 80 years. All this will adversely affect the Ganga River Basin.

f) Woefully Inadequate Number Of Snow And Ice Measuring/ Gauging Stations

Currently there are only three snow and ice measuring/ gauging stations in the Yamuna snow-covered areas and three stations in the Bhagirathi sub-basin. When a significant amount of data is collected at such climate stations it will yield reliable information for taking decisions regarding the location of infrastructure projects such as small and medium scale hydro-power projects, roads, mountain-slope-stabilization-programs, etc.

4.4.1 Recommendations

Need for more in-depth and long-term studies:

- The 'National Centre for Field Operations and Research in Himalayan Glaciology' should be established and adequately funded without further delay.
- There is an urgent need for collecting statistically adequate data so as to put together the full picture of Ganga's hydrology.
- A minimum number of 10% of all glaciers of different sizes need to be studied.
- These studies can form the baseline data which could then be expanded to other glaciers so that the rates of recession can be documented accurately.
- Further, mass balance studies need to be taken up in collaboration with scientists from Japan and other countries who have already conducted such studies based on ice-core measurements/assessments, in order to make predictive studies of glacial recession.
- Need for detailed analysis of glacial lakes and periodical updating of the Atlas of Glacial Lakes in Ganga Basin.
- It is recommended that many more snow and ice measuring/ gauging stations need to be installed and extensive data needs to be collected for enabling a time- series analysis. An adequate number of Automated Weather Stations and Ice/Snow Research Stations above 4000 m in India, Nepal and Tibet must be installed. Automated weath-

er stations having Gama Rays Sensors for measuring snow and ice would need to be installed on all major glaciers, so that 'time-series' data can be constructed for making evidence-based recommendations.

- It is recommended that an Integrated/Comprehensive Sustainable Development and Management Plan for the Ganga River Basin which includes the Himalayan cryosphere as an important factor while assessing and calculating the hydrology of the basin be prepared at the earliest Further, it is recommended that a trans-boundary perspective, which includes India, Nepal, Tibet, and Bangladesh be included in this Plan.

- It is recommended that the local and traditional knowledge systems of communities inhabiting these regions be included in such a Plan. This will also be an important source of historical documentation for recording changes in the cryosphere region. The knowledge, experiences and wisdom of the pastoral (transhumance) community with regard to understanding physical phenomena and the relationship of the cryosphere with the behavior of floral and faunal species, would need to be used as a basis for building resilience to impacts of climate change.

- It is recommended that Civil Society be involved in the River Basin Planning process by carrying out 'ground-truthing' expeditions with the help of high altitude trekkers and mountaineers. Further, travelogues of such groups could be included as extensions of pilgrimages.

- It is recommended substantial increases in funding be made in order to support-long-term research programs rather than supporting short-term project-based studies.

ENDNOTES :-

45. Gigatonne: a unit of explosive power equivalent to one (109) billion tons of TNT.

46. REMO: Regional Climate Model; and Distributed Glacier Mass Balance Model (DGMBM) are the two commonly approaches used for studying Climate-Change impact on mass balance of glaciers.

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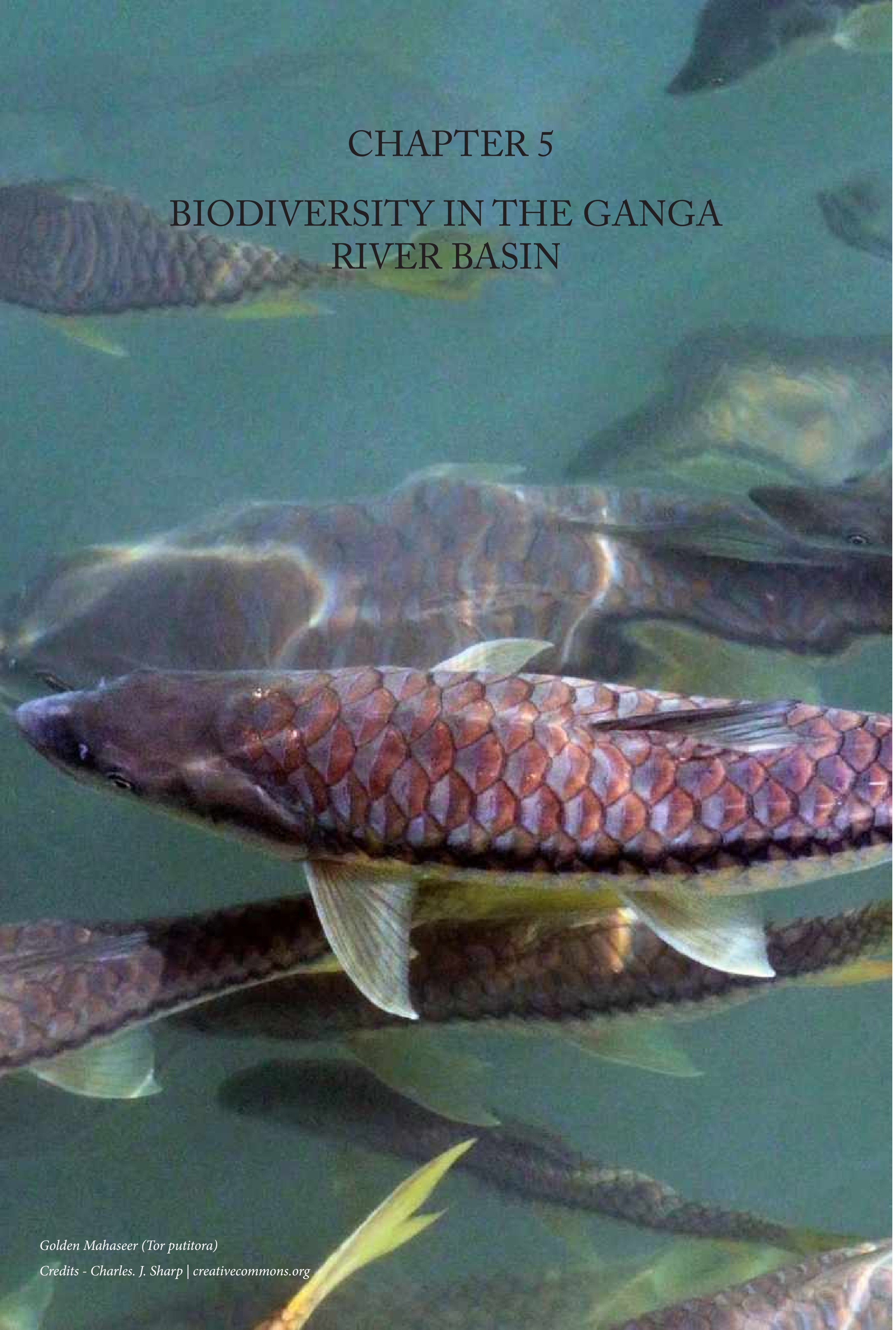
CHAPTER 5

BIODIVERSITY IN THE GANGA RIVER BASIN



Golden Mahaseer (Tor putitora)

Credits - Charles. J. Sharp | creativecommons.org

5.1 IMPACT OF CRYOSPHERE ON BIODIVERSITY

Understanding the cryosphere and the impact of climate change is crucial because it forms the basis of biological diversity of the Ganga River Basin. The cryosphere is an all- encompassing term for those portions of Earth's surface where water is in solid form, including sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground. Thus, there is a wide overlap with the hydrosphere. The climatic variations in the different regions of the Cryosphere impact the local geomorphology and also the biodiversity. The moraines, glacial lakes and permafrost are home to unique flora and fauna, which can survive in very harsh, cold temperatures. Further, as mentioned in previous chapters, the important function of regulating environmental flows during lean periods is one of the ways in which the cryosphere affects the biodiversity. The cryosphere is therefore indispensable in terms of its ability to conserve and maintain various sub-ecosystems, which provide social, economic, and cultural services as well as other tangible values.

5.2 VERTICAL AND HORIZONTAL RIVER SYSTEM INTEGRATION OF BIODIVERSITY

The biodiversity of Ganga River Basin follows a vertical (along the elevation gradient) and horizontal (across the river-stream) structure of habitats. These principles of ecological as well as hydrological synergy between the biotic and abiotic factors (such as geology, hydrology, meteorology, etc.) determine the biological diversity of the region. In case of the Ganga, elevation has a great influence on the biodiversity because the basin hosts the highest altitudes in the world. Globally, very few rivers in the world encounter this unique aspect. In addition to altitude, the topographic index, slope direction, slope position, slope shape, determine the biodiversity in this sub-ecosystem *(B. Liu et al., 2009)*.

The Ganga River Basin is a unique ecosystem which contains a consortium of species specifically evolved within the atmospheric, lithospheric[47], hydrospheric and cryospheric conditions, thus forming a unique biosphere. This ecosystem is further divided into sub-eco- systems like the glacial ecosystems, glacial lakes, river and spring ecosystems, meadows/grasslands, forests, flood plains, agrarian ecosystems and the delta ecosystem, each containing separate sets of species. The borders of these ecosystems are not discrete, but have an interface that holds a mix of two or more sub-ecosystems and tend to have a larger number of species than either of the individual sub-systems: for example, the periphery of the glacial lakes in Gangotri, Nanda Devi glaciers, or the periphery of large forest patches like the Chirbasa, Bhojbasa forests near Gomukh, forests around the Lata Pass North of Rishi gorge and Dharansi forest in Outer Nanda Devi Sanctuary. At higher altitudes, meadows or *bugyals* like Nandanban, which are formed seasonally also have an overlap between two or more sub-ecosystems. The rocky terrain or outcrops are an exception because they end precipitously and abruptly, thus creating a relatively tiny interface at the very edge of a mountain landscape.

Further, the changing snow-lines, temperature, moisture content, wind speed, and sun direction in the Cryosphere and global events related to monsoonal shifts or loss of soil carbon also influence the ecosystem boundary shifts such as tree-line movements and high-elevation ecosystem changes. The vegetation pattern on mountain slopes changes with changing altitude and snow lines. The fish composition and species richness in river tributaries varies greatly from upstream to downstream with changing snow melt, temperatures and environmental flows. Himalayan Mahseer (*Tor putitora*), brown trout (*Salmo trutta*), common carp (*Cyprinus carpio*) and katla (*Catla catla*) are typical examples of fish species directly dependent on the extra-low temperatures of the glacial streams *(Sehgal, 1999)*.

While the vertical distribution and temperature gradients affect the species richness, horizontal distribution of a river basin can show regional variation due to changing precipitation patterns occasionally leading to formation of sub-ecosystems within a larger river basin. Based on this principle of vertical and horizontal integration, we will try to understand the biodiversity of the Ganga River Basin through categorization of different sub ecosystems which include the systemic diversity of intra and inter species.

5.3 SUB-ECOSYSTEMS

a) Cryosphere Ecosystem

The upper regime of the Ganga River Basin comprises of the fragile Himalayan ecosystem which is an important biodiversity hotspot and includes the Cryosphere of Tibet Autonomous Region (China), Nepal and the states of Uttarakhand and Himachal Pradesh in India. The Himalayan range supports about 25% of the world's terrestrial biodiversity and 50% of the biodiversity hotspots as identified by the United Nations Environment Program. Therefore, the Himalayan Mountain ranges are the most bio-diverse regions in the world – some of them still undiscovered. About 35 new species were found every year in the Eastern Himalayas between 1998-2008 *(Walker, 2019)*.

The biological diversity in the Cryosphere of Ganga River Basin is the result of adaptation to the specific environment and the mutation and adaptation of various species of flora and fauna over millennia. This diversity has occurred due to a combination of favourable or unfavourable abiotic conditions, which differ in different altitudes, such as temperature, rocky terrains or alluvial plains, strong winds, snowfall in higher altitudes, increasing rainfall patterns from west to east mainly dominated by the monsoons from June to September. The monsoon is followed by near arid conditions during the winter and early mid-summer. Further, the biodiversity varies greatly with changing altitudes as well as the degree of exposure to solar radiation. For example, the southern slopes of Himalaya have different biodiversity as compared to the northern slopes due to the difference in solar radiation, which has a direct bearing on the temperatures and snowlines. Varying snowlines during different seasons result in the creation of unique ecosystems such as glacial lakes, meadows or pasture-lands as a response to the unique abiotic factors. As the species herein are extremely sensitive to their unique environment, the behaviour of different species in these ecosystems needs to be understood holistically if they are be saved from becoming rare or extinct.

In Tibet, (Jadhganga, uppermost Karnali and Saptakoshi region) which is a cold, dry desert area, the flora is mostly xerophytic (drought resistant) e.g., shrubs and grasses. In addition, this region is also home to endemic medicinal plants such as Keera Jhar (*Cordyceps sinensis*), saffron (*Crocus sativus*), and snow lotus (*Saussurea laniceps*). This unique bio-geographic zone is home to fauna which has adapted itself to the cold temperatures and dry weather conditions on the northern slopes of the Himalaya. Woolly Hare, Tibetan Gazelle, Snow Leopard, Himalayan Black Bear, Himalayan Brown Bear, Red Fox, Tibetan Wolf, Himalayan Ibex, Himalayan Marmot, Himalayan Blue Sheep, Red Billed and Yellow Billed Chough, Chukar Partridge, Snow Partridge, Blue Rock Pigeon, Snow Pigeon, Himalayan Snowcock, Lammergeier, Himalayan Griffon, Golden Eagle, Rosefinch, etc. are found in the area *(Hays, 2015)*.

In Uttarakhand and Nepal, there are well over 5,400 species of plants of which 750 are specially known for their medicinal value. Nepal also has a rich faunal diversity with 175 species of mammals, 850 species of birds, 650 species of butterflies and 170 species of freshwater fish. The Department of Forest, Government of Nepal, acknowledges that with just 0.15% of forest- land in the entire world, Nepal harbours 9.4% of all bird-species, 2.2% of all known plants, and a considerable number of these species are in Protected Areas (PAs), which form about 16% of the geographic area of Nepal. Similarly, the birch tree (Betula) and the juniper shrubs (Juniperus) are important species which need to be studied for understanding the correlation between climate change and its impact on the Himalayan Cryosphere. They thrive in the snow-line areas which harbour forest tree species as well as cold desert species.

Of the ten basic bio-geographic zones identified in India, Zone I (Trans-Himalaya) and Zone II (Himalaya), are relevant to the Cryosphere of the Ganga Basin. These have been further divided into I-a, I-b, I-c, and II-a, II-b, II-c, II-d. Of these seven sub-zones the Ganga Basin largely constitutes II-b and II-c, which together cover 1.8% of India. Even though the Himalaya as a whole, including the Brahmaputra and Indus cover an area of 12% of the country, the Himalaya harbours 30% of the faunal diversity. The Zoological Survey of India in its recent publication entitled 'Faunal Diversity of Indian Himalaya, 2018', has identified a total number of 30,377 species/subspecies, of which 372 are Protozoa, and the rest 30,005 are Animalia.

Due to a great variety of physiographic conditions the Himalaya supports a very large variety of vegetation with close to 8000 angiosperms, 44 gymnosperms (about 40% of them being endemic to the Himalaya), about 2900 bryophytes (lichens, mosses and liverworts) and 6900 species of fungi *(Singh & Hajra, 1996)*. The Brahmakamal (*Saussurea obvallata*) is one of the rare flowers that bloom only after sunset in these mountain ranges at altitudes of around 3000-4500 m from August to mid-September. Due to its beauty, it has acquired the title of the state flower of Uttarakhand. (not to be confused with Brahma Kamal or

Night-blooming Cereus (*Epiphyllum oxypetalum*), native to Sri Lanka and now a popular garden plant in homes in peninsular India).

Rare Himalayan Flower Brahmakamal in Uttarakhand's Chamoli District *(S. Pal, 2020)*

Bhojpatra Tree (*Betula utilis*) **at Bhojbasa, an indicator species broadly identifying the lower end of the snowline up to 4500 meters** *(Field Visit, May 2019)*

Bhojpatra Tree with whitish bark and green pines, between Chirbasa and Bhojbasa (*Field visit, May 2019*)

Bharal, Himalayan blue-sheep (*Pseudois nayaur*) *(Courtesy:iNaturalist, n.d.)*

Alpine Yellow Billed Chough (*Pyrrhocorax graculus*)
(*Field visit, May 2019*)

Pied Bushchat *(Saxicola caprata)*
(*Field visit, May 2019*)

Rock Bunting (*Emberiza cia*) (*Field Visit, May 2019*)

Radde's Warbler *(Phylloscopus schwarzi),* **at Bhojbasa (Gomukh)** (*Field Visit, May 2019*)

Rufous-bellied Niltava *(Niltavasundara)*
(*Field visit, May 2019*)

Pallid Harrier *(Circus macrourus)*
(*Field Visit, May 2019*)JJ

The faunal diversity also shows a great adaptability to the harsh physical and climatic conditions characterized by low temperatures e.g., the bharal also known as Himalayan blue-sheep (*Pseudois nayaur*), ibex (*Capra ibex*), yak (*Bos grunniens*), musk deer (*Moschus leucogaster*) and tahr (*Hemitragus jemlahicus*) can be frequently seen from 4000 meters up to 6000 meters. At the apex of these mammals, lives the snow leopard (*Panthera uncia*). At lower altitudes from 2000 meters to about 5000 meters one can see the Himalayan black bear (*Ursus thibetanus laniger*), marmots (*Marmota himalayana*) and other rodents. The western and Central Himalaya together harbour 35 different species of amphibians, and 200 species of fish which inhabit lakes, streams, and rivers.

Himalayan Golden Eagle and Himalayan Black Eagle *(Animal Database, n.d.; Animalia, 2021)*

The birds of prey or raptors e.g. Himalayan Golden Eagle (*Aquila chrysaetos*)[48] and the Himalayan Black Eagle (*Ictinaetus malaiensis*)[49] are at the avifaunal apex of the ecological ladder. As their health and population depends directly on the population of smaller birds, marmots in the higher altitudes and rodents and reptiles in the lower hills, the Golden and Black Eagle are an important indicator of the impact of climate change on the Himalayan ecosystem.

Marmot *(Marmota himalayana)*
(Field Visit, May 2019)

b) Glacial Ecosystems

Ice sheets and glaciers are host to significant biodiversity despite cold temperatures, limited water availability, and low nutrient availability. Essentially, the physical properties of glaciers influence the microbial communities that reside within them, and these communities drive ecosystem-services. The ecology and productivity of microbial life on, in, and beneath mountain glaciers is largely dictated by a combination of proximity to sources of organic matter and nutrients. There is a complex series of interconnections between the upper layers and bottom layers of the glacier which support micro species (snow algae, ice algae, supra-glacial cyanobacteria, bacteriophages and others) adapted to different temperatures and locations within the glacier *(Hotaling et al., 2017)*.

At the bottom of the Gangotri Glacier, the ice melt converts itself into a pro-glacial stream which flows practically throughout the length of the glacier, i.e. from the top-end of the glacier to the snout.[50] A specialised cold-water invertebrate community persists in these cold, pro-glacial streams primarily below glaciers, but also on snowfield and groundwater springs *(Muhlfeld et al.,2020)*.There is a difference in the microbial diversity and abundance in surface snow at different altitudes (5300 and 5504 m above sea level), a moraine lake and a glacial stream. Microbial communities in the snow are significantly different from those in the moraine lakes and streams, although they are similar within snow and within the aquatic habitats. It is found that the snow habitat is easily affected by various environmental factors, while the aquatic habitats were comparatively stable in different glaciers *(Y. Liu et al., 2011)*.

Different organisms have different ways of coping with the low temperatures at different altitudes. One such mechanism is hibernation[51]. When permafrost melts, hibernating creatures such as microorganisms, which were frozen during different time periods, can come back to life. The Cryosphere of Ganga River has several species of frozen biota which have remained dormant over millennia. This has been the case since the uplift of the Sea of Tethys, during the Mesozoic Era from around 252 to 45 million years ago. These species can come back to life, due to melting with increasing glacial recession, and be released into the streams.

These life forms could either be benign or harmful to humans or the rest of the ecosystem, with varying degrees of magnitude. Since they might not have any natural predators in the evolved food web, their populations could suddenly boom or collapse. For example, a giant 30,000-year- old frozen virus was discovered deep in the Siberian permafrost and when it was revived it was still infectious. Other such examples have been found in the Antarctic dry valley environment which acts against psychro-bacteria (cold). And so, there is a need for continuous monitoring and assessment of such life forms in these areas in order to be able to take precautionary measures against their ill effects, if any. Therefore, beyond immediate connections between the biodiversitywithin glaciers in a Cryosphere, the geo-microbiological and ecological activity anywhere on, within, or beneath a glacier can directly influence stream and lake ecosystem-function in downstream regions *(Khairnar, 2016)*.

c) Glacial Lakes and Wetlands Ecosystems

The aquatic biodiversity and productivity tends to be lower in glacial lakes as only cold-tolerant and cold-adapted species can withstand their harsh conditions. Glacial rock floor and low nutrient levels create an oligotrophic (low level of nutrients) environment where few species of plankton, fish and benthic organisms reside *(Netto et al., 2012)*. Fishes, when present, are the dominant predator of worm-like organisms (e.g., nematodes, rotifers, nematomorpha, and insect larvae), crustaceans, diminutive molluscs, bacteria, algae, and a few aquatic vascular plants *(Gobbi & Lencioni, 2020)*.

The 'High Altitude Wetlands in the Indian Himalaya - Conservation & Management' report by G. B. Pant National Institute of Himalayan Environment, 2020 states that an assessment of 62 plant species from Devikund in Uttarakhand reveals the occurrence of 14 species falling in different threat categories of IUCN *(Bagchi et al., 2017)*. One new species *Saxifraga minutissimahas* been added with two small populations in wetland complex of Vasuki Tal in Uttarakhand *(Chatterjee et al., 2010)*. A niche-specific microbe Sanguibacter has been reported from Roopkund Lake *(Yadav & Kour, 2018)*.

These lakes provide important breeding grounds for terrestrial and arboreal fauna. They are also important breeding grounds for continental migratory birds, especially for the globally threatened Black-necked crane (*Grus nigricollis*) (Vulnerable, IUCN Category). These landscapes are also home to unique big animals for example, the near threatened Argali (*Ovis ammonhodgsoni*), the vulnerable Urial (*Ovis orientalisvignei*), the low risk Bharal (*Pseudois nayaur*), the Wild Ass (*Equus kiang*) and Snow Leopard (*Panthera uncia*).

d) Meadows or Pastureland Ecosystems

Meadows / pastures / grasslands exist in practically all areas within Indian as well as Nepal borders and these are sprinkled with grasses, ferns, shrubs, wildflowers, lichens, mushrooms, fungi, mosses, liverworts, herbs, sedges[52] and forbs[53]. These grasslands where shepherds and herders take their animals during summer months (May to September) are called ' Bugyals' and can be found in areas around glaciers and at the foot of very high mountains as well. Such alpine grasslands account for an area of 114,250 sq. km in the Indian Himalaya. Such meadows remain snow bound from November to April.

A fairly large portion of northern Nepal (19.36%) is covered with snow, ice-glaciers and very high altitude, rocky terrain which is neither habitable nor productive in the conventional sense. This fairly broad band in the north holds a large number of permanent pastures and meadows/grasslands and natural lakes/wetlands, which not only support a large biological diversity of wild flora and fauna, but also support livestock, thus providing a niche occupation for pastoralist communities/transhumance (Elaborated in Chapter 6).

e) Forest Ecosystems

The recorded forest area of the state of Uttarakhand is 34650.56 km², which is 64.8 % of its total geographical area and 4.5% of the national forest area. Its forest cover is 24,465 km² which represents 45.74% of the state's total geographical area and 3.61% of the forest cover of the country.

Nepal is situated in the Indo-Malayan and Palaeo-Arctic bio-geographic realms. From the Terai forest in the Southern plains to the highland plateau of Tibet, the landscape rises from 100 m to 8,848 m amsl. This dramatic rise takes place within a distance of 150 kms and covers practically all types of vegetation and forest including the swamps in Terai and cold desert forests in Tibetan region. The total area under forest is about 39.6% of the geographic area i.e., about 55,180 sq.km of which about 10% is degraded scrubland. Just below the high altitude mountainous areas there are several types of forests and scrub-lands like, tropical, subtropical, temperate, sub-alpine forests and tropical, subtropical, temperate, and alpine scrublands.

f) Aquatic Ecosystems

The aquatic ecosystems in the Ganga River Basin which include springs, rivers, lakes and wetlands are different in character and exhibit various degrees of trophic evolution. A myriad of factors including air and water temperature, water flow, turbidity fluctuation, substrates, aquatic and riparian vegetation, dissolved substances, oxygen availability and food affect the biotic interactions which take place in these aquatic ecosystems. The biotic components in such ecosystems consist of phytoplankton, zooplankton, macro-benthos, and fish species as well as floral diversity. There are sub-ecosystems within aquatic ecosystems such as riverine and spring ecosystems, as elaborated below.

Riverine Ecosystems

Fishes are abundant in all the tributaries, especially in the delta area, where they form an important part of the diet of surrounding communities. In the Bengal area common fish include feather backs (Notopteridae family), barbs (Cyprinidae),walking catfish, gouramis (Anabantidae), and milkfish (Chanidae) *(Lodrick & Nafis, 2021)*.

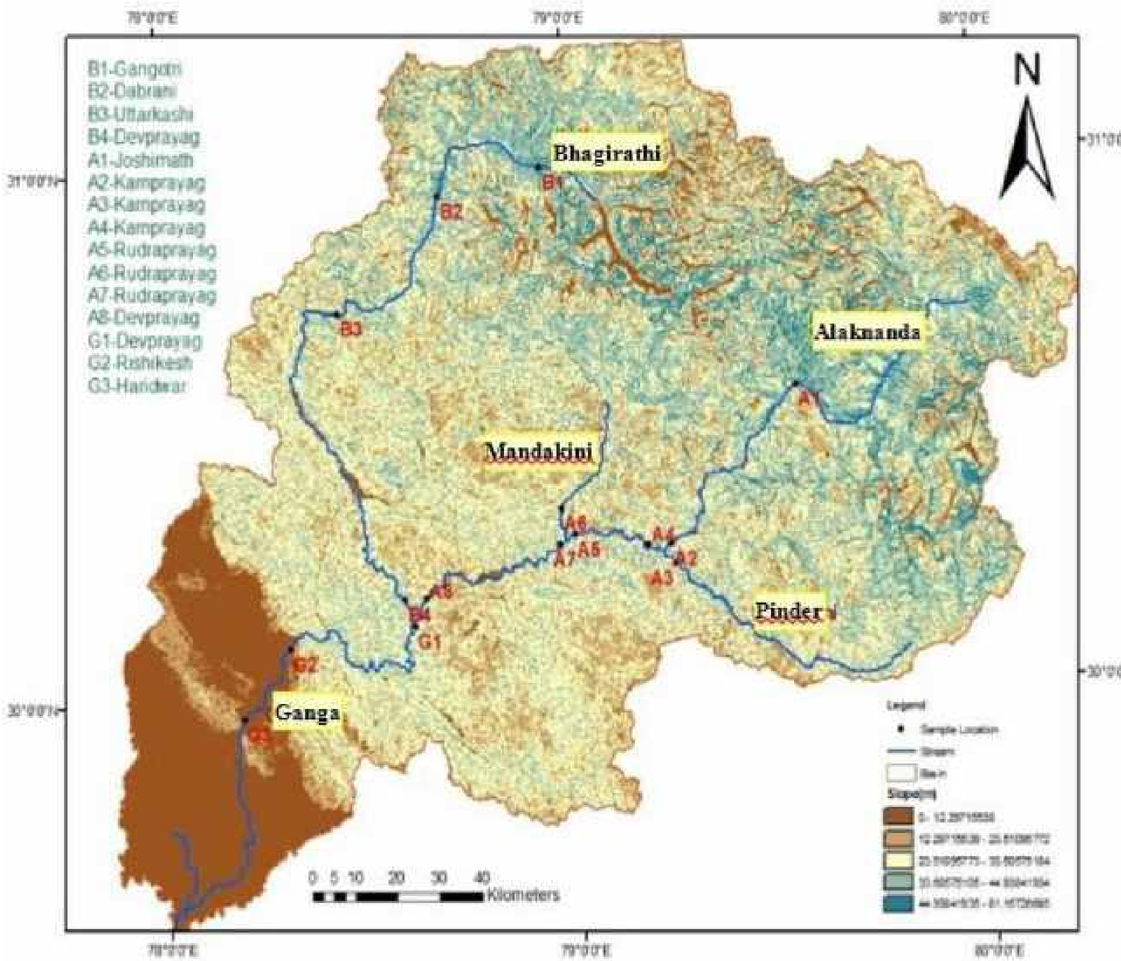
Ganga River Dolphin, or Susu *(Platanista gangetica)*
(Photo:J. Gupta, 2012)

The Ganges River Dolphin or susu (*Platanista gangetica*), a nearly sightless aquatic mammal with highly developed sonar capabilities can be found throughout the Ganga-Brahmaputra basin, but it is considered endangered because of encroaching human activity. These large freshwater mammals are found only in the Indian subcontinent and survive at the upstream range limit. The Karnali basin provides the upper range for the Gangetic River Dolphin. The lower reach, where it is called Ghaghara, supports the last potentially practical population of the Ganga River dolphin in Nepal. These dolphins are at their farthest upstream range and inaccessible due to the Girijapur Barrage, located about 16 km downstream of the Nepal-India border.

A study 'Environmental Assessment of the Aquatic Ecosystem of Upper Ganga Basin' conducted under the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) by National Institute of Hydrology in fifteen sampling sites (Refer Map 5.1) in the Bhagirathi and Alakananda River systems gives the following observations:

Maximum density of zooplankton[55] was recorded during summer and minimum during monsoon. It was observed that during summer zooplankton population increases due to higher biological integration activity in aquatic ecosystems. Aquatic macrobenthos[56] are an extremely diverse group of animals dwelling in bottom substrate and sediments of rivers. The increase in macrobenthos indicates higher levels of pollution and vice versa.

In Ganga River, a total of 26 fish species belonging to 7 families were recorded, in which 14 species belong to Cyprinidae followed by Sisoridae (3 species), Balitoridae (4 species),



Map 5.1: Location of Sampling Points in the Upper Ganga Basin
(National Institute of Hydrology, n.d.)

Cobitidae (2 species), Mastacembelidae (1 species), Schilbidae (1 species) and Salmonidae (1 species). There is a negative correlation between stream altitude and species diversity as well as relative abundance. Shannon index (H) value of fishes at all the sampling zones ranged within 1.57 to 3.97, which indicates a good level of fish community in upper riverine zones of Bhagirathi and Bhilangana Rivers but low index shows that the fish species richness is decreasing in down streams after the installation of hydropower projects.

Degree of Sensitivity in Aquatic Ecosystems
The physical and biological factors within the biosphere are always in a state of flux, as they try to reach a state of equilibrium. Thus, at any specific time an ecosystem may be moving from a lower level of equilibrium to a higher level, aiming at reaching a climax or a near climax state (i.e. where the maximum possible biodiversity is reached, and the tendency of the system to bring about changes is minimal). In such a situation any change in the biotic or abiotic factors will lead to a further series of adjustments. Therefore, the degree and quality of response of abiotic and biotic factors to the external stimuli, decides the eco-sensitivity of the region. Based on this degree of sensitivity, different species have different response rates and coping mechanisms to changing biotic as well as abiotic factors which

need to be considered while formulating Management Plans for the Ganga River Basin.

Out of different abiotic factors which impact the degree of sensitivity of species, Dissolved Oxygen level is one such parameter. The threshold requirement of Dissolved Oxygen (DO) of different species in the Ganga River system is different. The species living at the bottom of the river or which feed at the bottom like crabs and oysters might require 1-5 mg/litre DO. Those which reside in shallow but rapid waters require higher DO levels around 4-15 mg/litre DO. Trout, a fish species, needs at least 4 times as much DO if the water temperature reaches up to 24 degrees and above, but much less when it is at lower temperatures. Thus, there is a direct relationship between fish species found in higher Himalayas to the levels of DO. When the water is stagnant the DO levels fall because the aeration levels fall.[57]

A unique characteristic of Ganga waters, apart from the fact that it contains bacteriophages and marine fossils of plants and fauna is, that it records exceptionally high suspended dissolved oxygen (DO) (around 14-15 mg/litre) in certain stretches. As a general rule, rivers having 5mg/litre to10 mg/litre support more species and larger population concentrations. In areas where the river streams flow through national parks and other conserved areas, the DO levels are generally in a beneficial range for the biodiversity to flourish as against the river stretches which flow through a city or industrial area.

Studies such as the 'Effect of Time and Temperature on DO Levels in River Waters, 2019' conducted by CWC and the inferences derived from such studies need to be used for the management of Himalayan rivers *(Central Water Commission, 2019)*.

In 2020, a study by Chakraborty, Sondipon and others entitled 'Scanning the water quality of lower Gangetic delta during COVID-19 lockdown phase 'using Dissolved Oxygen (DO) as proxy' measured DO levels in the Bhagirathi-Hooghly river at various locations (*Chakraborty et al., 2020*). Samples were collected between 2nd April and 23rd April at polluted locations like Diamond harbour, Namkhana and Ajmalmari. The samples contained higher levels of DO i.e., 38.54% higher than the normal DO found at Diamond Harbour, 31.7% higher at Namkhana and 12.4% at Ajmalmari. Consequently, having a positive impact on fish and other species in the Bhagirathi-Hooghly River at these locations. Such studies would help in better establishing the interrelationship between biological factors and abiotic factors and better management of the riverine ecosystems. (Note that the average DO level (for pre COVID lockdown period) varied between 5.79 mg/lit at Ajmalmari to 4.5 mg/ lit Diamond Harbour)

g) Spring Ecosystems
In Nepal, almost 80% of the 13 million hill and mountain people rely on springs as their primary source of water *(Poudel & Duex, 2017)*. Mineralogists estimate having at least 50 hot water springs in the land belt stretching between the Himalaya and foothill regions in Nepal. These hot-water-springs are locally known as *tatopani* simply meaning 'hot water'. The Indian Himalayan Region is host to almost 3 million springs. Over 200 million people in India depend on springs, out of which 50 million people are in the 12 states of the Hima-

layan region (*A. Gupta & Kulkarni, 2018*). It is because of these springs that these regions are dotted with '*kunds*' - hot water springs such as Gauri kund, Gangnani, Tapovan, Joshimath, Taptakund, Tatopani, Annapurna and others which are revered due to the medical and healing properties in the water.

According to research conducted by H.T. Odum in 1953 and further expansion of the theory by Whitford in 1956, springs are highly productive in their natural state as compared to other aquatic ecosystems. This is due to stable environments in terms of spring structure and function, and lesser external forcing conditions as compared to other aquatic ecosystems (*Knight & Notestein, 2008*). Thus, as spring ecosystems are rich in minerals, nutrients and dissolved gases, the springs nurture and nourish a wide variety of flora and fauna - including macrophytes, algae, natural detritus, and complex food web of herbivores, omnivores and carnivores, as well as support wide range of microbial diversity.

Because of steady discharge rates, perennial springs provide water to numerous streams, lakes, wetlands, and rivers, thus forming the terrestrial origin of all flowing water of the hydrological cycle of Ganga. Contributing to the base flows, most of the rivers in the Himalayan region are spring derived. In fact, these springs, while flowing downhill from their origins, have formed their own narrow riparian zones on either side of their flowpaths. These riparian zones usually have rich vegetative growth, which support numerous organisms.

h) Ecosystem in The Indo-Gangetic Plains

The middle regime of the Ganga River basin comprises the vast Indo-Gangetic plains formed by the tributaries of Ganga, Yamuna and rivers flowing from Nepal. The Indo-Gangetic plains lie in the Indian border covering the states of Rajasthan, Uttar Pradesh, Madhya Pradesh, Bihar, Jharkhand, Assam, and West Bengal. Historically, these plains were once densely forested. Historical writings indicate that in the 16th and 17th century wild elephants, buffalo, bison, rhinoceroses, lions, and tigers were hunted there. However, most of the original natural vegetation has disappeared from these plains and the land is now intensely cultivated to meet the needs of an ever-growing population. Large wild animals are rare, except for deer, boars, and wildcats and some wolves, jackals, and foxes.

The river stretches adjoining protected areas or national parks have healthy biodiversity and these areas practically form almost 10% of the middle regime. Biota form their own smaller sanctuaries in stretches where the river is less disturbed, and this is coterminous with the levels of pollution. Therefore, deteriorated stretches are mostly near cities such as Delhi, Kanpur, Allahabad, Varanasi and others where DO levels are low due to agrochemicals, industrial effluents and urban sewage.

i) Delta sub-ecosystem

The lower river regime comprises the delta region which mainly falls in the West Bengal state, a small part of Assam and the whole of Bangladesh. The delta formed by various con - tributaries and distributaries of the GBM river system is host to a variety of flora and fauna and is dynamic due to constantly changing landforms and river channels. The forests of Bangladesh cover three major vegetation types occurring in three distinctly different ecosystems, that is, hill forests; Sal forests and mangroves (*Mukul et al., 2018*). The Sundarban, mangrove forests (covering well over 10,000 km²) in the deltaic region form a different sub-ecosystem with a host of different aquatic as well as terrestrial flora and fauna due to the unique ecosystem created at the peripheries of mixing of freshwater and saline water. The south-western parts of Sundarbans form a habitat for the world's largest surviving population of the Royal Bengal Tiger (*Panthera tigris*). The delta region is home to about 138 mammal species, more than 566 species of birds, 167 species of reptiles, 49 species of amphibians(*IUCN, 2015*) (For details see Chapter 13)

5.4 POLICIES AND LAWS RELATED TO BIODIVERSITY

Considering the significance of biodiversity, India, Nepal and Bangladesh have promulgated different laws and policies with the aim of conserving these natural resources. Based on the Acts and Laws shown in Table 5.1 below, various biodiversity management policies and notifications have come into existence, e.g. the Bhagirathi Eco sensitive Zone and the Nanda Devi National Park in the Indian part of the Cryosphere and the Community Forestry Program in Nepal (For laws and policies in Bangladesh see Chapter 13).

Since 1974, at the behest of UNESCO's Man and Biosphere program, biodiversity reserves have been identified and declared by the Indian Ministry of Environment and Forests. There are several National Parks, Sanctuaries and Biosphere Reserves notified in the Himalaya but the most significant for the Cryosphere in Ganga Basin is the Nanda Devi Biosphere Reserve. The Nanda Devi region was notified and declared as a biosphere reserve and a National Park in 1982. Later UNESCO declared the Nanda Devi National Park as a World Heritage Site in 1988.

Consequently, all treks, expeditions, and grazing have been banned in the core area. Similarly, mountaineering expeditions to the Nanda Devi main peak, and all other human presence, have also been banned in the core areas. There are two routes for entering the Nanda Devi sanctuary. One passes right through the Rishi Gorge, and the other goes through the Lata pass. The one through the Rishi Gorge is more difficult to negotiate than the one through Lata pass. However, surveillance at the Lata pass and at the entrance of the Rishi-Gorge needs to be tightened. The Forest Department as well as the Police Department need to coordinate their functions. Further, the area comprising of Valley of Flowers has also been declared as a National Park and the total area of Nanda Devi National Park now adds up to 2,236.74 sq. km., surrounded by a buffer zone of 5,148.57 sq. km, where environmentally sustainable activities are permitted.

Table 5.1: A Brief Description Of Major Legal Tools In The Three Riparian Countries

Countries	Environment (General)	Forest	Rangeland	Water
India	Environment Protection Act; and Rules (1986) The Biological Diversity Act, 2002	The Indian Forest Act – 1927 Wildlife (Protection Act - 1972 Forest (Conservation) Act, 1980 National Forest Policy in 1988	N.A.	The Water (Prevention and Pollution Control) Act - 1974 National Water Policy
Nepal	Environment Protection Act - 1997	Forest Act - 1993 Forest Regulations - 1995	Rangeland Policy - 2012	Water Resources Act - 1992 The Ramsar Convention on Wetlands (Iran 1971)
Bangladesh	Bangladesh Environment Conservation Act 2010; National Environment Policy 1992, and Bangladesh Environmental Conservation Rules 1997	Forest Act - 1927 and Amendment	N.A.	Bangladesh Water Act - 2013

The Govind Pashu Vihar (GPV) National Park was established on 1st March 1955, and is situated in Uttarkashi district in the Indian state of Uttarakhand. The park lies in the higher reaches of the Garhwal Himalayas. The total area of Govind Pashu Vihar National Park and Wildlife Sanctuary is 958 km^2. The Snow Leopard Project started by the Government of India is being managed at this sanctuary. The GPV National Park is one of the few remaining strongholds of the bearded vulture in the Himalaya.

5.4.1 Bhagirathi Eco Sensitive Zone (BESZ)

The BESZ notification was published on 18th December, 2012 by Ministry of Environment and Forest spread across the entire Bhagirathi basin from Gomukh to Uttarkashi constituting an area of 4179.59 sq.km., covering the entire watershed of a 100 km stretch of the Bhagirathi River. The notification admits that a number of hydro-power projects have been commissioned or are under implementation, or have been proposed; and that anthropogenic pressure on ecosystems has increased tremendously, causing irreparable damage to the fragile mountain ecosystems, and also affecting the flow and character of the river. (Note: the Gangotri National Park lies contiguously upstream of Gomukh, right up to the origin of the glacier starting from the Chaukhamba peak. Similarly, the Govind National Park also lies in the vicinity of the ESZ.)

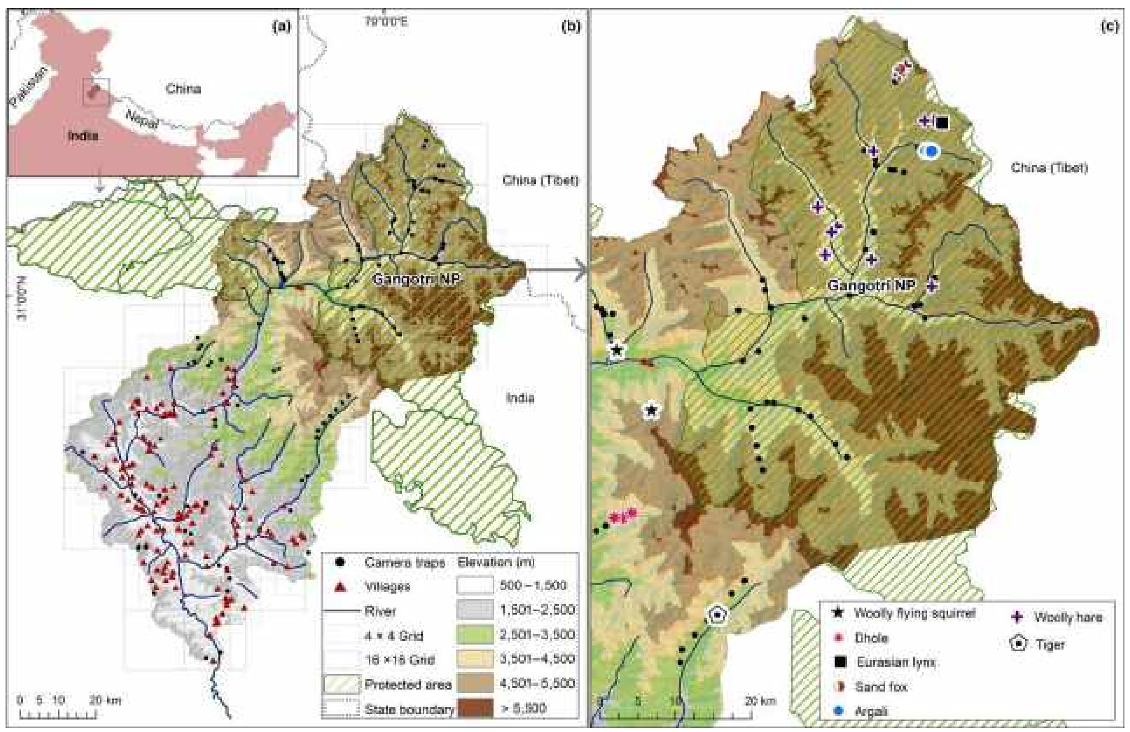
The notification requires the preparation and implementation of a Zonal Master Plan (ZMP) for the entire area which involves the Departments of Environment, Forest, Urban Development, Tourism, Revenue, Public Works, Pollution Control Board, Water Resources, Panchayat Raj Institutions (PRIs), Rural Development, etc. The Border Area Development Plan and other Central Government plans are all expected to be a part of ZMP, and provides for a) restoration of denuded forest areas b) conservation of water bodies, catchment areas, and watershed management c) groundwater management, soil and water conservation, in order to fulfil the needs of the local communities. It is expected to ensure that the natural boundaries of the river and its tributaries will not be tampered with due to any kind of structure or construction on the banks of the river.

A High-Level Monitoring Committee was to be appointed for monitoring the implementation of ZMP and to ensure that there is no change in the existing land use especially the green uses. Tourist resorts and commercial complexes were to be located only in areas with surplus water and electricity so that the rights of the local community are not disturbed. All natural springs were to be identified and listed and plans for their conservation and rejuvenation prepared. Developmental activities have been banned at or near such springs.

The ZMP is expected to include a separate Tourism Master Plan and a Carrying Capacity Study of the ESZ. A clear set of guidelines has been framed for the construction and maintenance of hill roads (tarred or un-tarred). It further provides for placing signage / notices about all fault zones and landslides zones indicating the start and end of such an area.

All sites and locations which are important from the point of Natural Heritage and Man-made Heritage are to be listed in the ZMP and protected. These include confluence points of rivers, waterfalls, pools, springs, gorges, sacred groves, caves, points, walks, rides, bridle paths and all temples, buildings and structures and their precincts which have historical architectural or aesthetic values. All River Valley Projects like dams, tunnels, construction of reservoirs, etc. have been prohibited, and abstraction of river water for new industrial purposes has been prohibited. Similarly, mining, minerals and stone quarrying has been prohibited except for local household purposes. Micro or mini power projects which serve the needs of local communities have been permitted.

A study conducted in 2020 entitled 'Mammals of the Bhagirathi basin, Western Himalaya: understanding distribution along spatial gradients of habitats and disturbances' states that the Bhagirathi basin has the potential to remain a stronghold for conservation of several threatened and rare mammal species. Based on a methodology of using camera traps (the total number of camera-trap days were 33,057, with a mean of 108 trap days per camera), the study was able to record nine mammal species which are categorised as threatened (four Vulnerable, five Endangered), four as Near Threatened and 26 as Least Concern on the IUCN Red List in this region.



Map 5.2 Camera-Trap Locations And Permanent Human Settlements Along An Elevation Gradient In The Bhagirathi Basin And Location Of Some Of The New Species Recorded
(R. Pal et al., 2020).

5.5 GEOMORPHOLOGY OF NEPAL

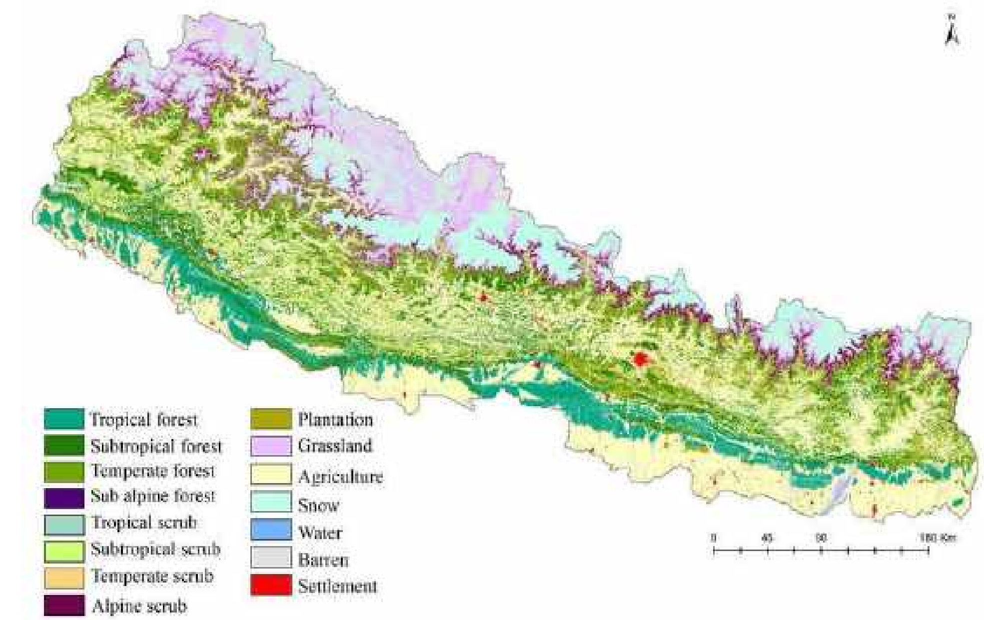
Bio-geographically, the Himalaya is a complex region with a very warm and humid climate along the southern border and extremely cold and arid conditions at the northern border. Practically all the bio-geographic zones from 'moist tropical' to 'cold arid deserts' are encountered in these mountain ranges. There are four basic biotic provinces in the Ganga Basin in India i.e.,

1. Trans-Himalaya (Himachal Pradesh and West Garhwal)

2. North-West Himalaya (Himachal Pradesh)

3. West Himalaya (Kumaon and Garhwal)

4. Central Himalaya (Nepal and extreme west Sikkim)



Map 5.3 Land Use and Land Cover Map of Nepal
(Sudhakar Reddy et al., 2018).

The forests in particular, and biodiversity in general, acquire a special importance in the Himalaya, because of the extremely fragile and sensitive character of the physical environment reaching extraordinarily high altitudes. The Himachal Pradesh and Uttarakhand areas are dominated by coniferous forests, chir pine, blue pine, deodar (Douglas fir), fir, and the floor is covered by legumes, grasses, and other herbs. Although there is no clear-cut division between eastern and western parts of the Himalaya, the eastern flanks especially in the lower altitudes support subtropical vegetation which includes magnolias, oaks, laurels, and rhododendrons of different colours, orchids, ferns and epiphytes.[58]

5.5.1 Community Management of Forests in Nepal

Forests in Nepal are under a mixed-management regime viz., Government-Managed Forests (GMF), Community-Managed Forests (CMF), Leasehold Forests (LF), forests managed by Religious Trusts (R.F.) and the National Parks and Reserves (NPR). The Terai forests near the Indian border have been developed as productive forests and are managed under the Operational Forest Management Plan (OFMP) in the 18 districts of Terai.

The hill forests are managed under a unique Community Forestry Program (CFP) which commenced in 1978 and is currently in operation. This was an ambitious national initiative to devolve forest rights to forest-dependent communities, especially since historically all forest rights were vested in the state. The (Nepal) National Forestry Plan of 1976 and the Forestry Rules of 1978 were introduced to correct the negative impact of the Private Forest Nationalisation Act of 1957, which had led to heavy deforestation during the ensuing 20 years (1957 to 1976).

The CMF Experience from July 2003 onwards
A total of 12,584 Forest User Groups (FUGs) had been established, and they were managing almost one million hectares of forests through active community participation. Admirably, there are about 1.5 million households estimated to be registered under this program. The FUG members have the right to protect, manage and harvest the forest after it is handed over to them by the government. There are common guidelines and regulations which also allow them to take technical support from NGOs, foreign experts, donors etc. Nepal is one of the first developing countries to adopt the Community Forest Management paradigm under a modern governance system. Recent studies have concluded that the impact has been largely pro-poor. Many FUGs have depended on the Sal (*Shorea robusta*) tree species for making the activity economically viable.

One of the main drivers of the program was reduction of the ill-effects of environmental degradation. A recent Community Forest study at Kumrose, Nepal indicates that the biodiversity in Community Managed Forests is greater, especially in the Terai region. Further it was expected that the area under forest cover would also rise. The recently conducted Forest Resources Assessment of 2015 has recorded an increase in forest cover of about 13% between 1990 and 2014. By 2008, the forestry sector was considered to be an important economic sector contributing 9.5% to the GDP Timber and Non-Timber Forest Produce (NTFP). Currently, 2.8 million hectares of forest, i.e., 30.5% of all forests in Nepal are under the community forest system and give benefits to 3.8 million households.

Glacial Lake on Bhagirathi Glacier
(Field visit, May 2019)

5.6 CONVENTIONS, POLICIES AND LAWS FOR WETLAND CONSERVATION

India ratified the Ramsar Convention on Wetlands[59] and became a member in February, 1982, and Nepal also became a member in 1988. In the National Water Policy (2012), Government of India has a special provision namely, Section 8, entitled 'Conservation of River Corridors, Water Bodies and Infrastructure' which includes wetland conservation. Therefore, some wetlands are protected after the promulgation of the Wildlife Protection Act, 1972 in India, and some are managed under a Ramsar Convention. It is now being appreciated that wetlands are an important natural element which maintains the integrity of the geo-morphological landscape as a whole. Therefore, modern land-use policies have been emphasizing on maintaining the wetlands intact and restoring the original natural status of such lands that have been drained or reclaimed for other purposes.

5.7 WHAT IS REALLY HAPPENING TO BIODIVERSITY, OUR NATURAL HERITAGE?

In spite of so many laws and other provisions, there has been consistent degradation of biodiversity in the entire Ganga River Basin.

5.7.1 Fragmentation of River Stretches

The vertical and horizontal integration of the river system enables local migration of different species in order to protect them from changing biotic and abiotic factors such as temperature, pollution levels or invasion of predatory species in the aquatic ecosystem. Therefore, a network of contributaries and distributaries offers corridors for movement or escape routes to different species either large or small. Such processes are crucial for ecosystem stability. For example, indicative species such as Gangetic dolphins, crocodiles or even smaller species such as mosses or lichens tend to move upstream or downstream to cleaner habitats. Certain fish species such as hilsa (*Tenualosa ilisha*) migrate upstream from sea waters into the freshwater river streams for spawning. However, after the construction of Farakka barrage this migration of the fish to reach its natural breeding ground was obstructed. This phenomenon is witnessed almost in all river stretches which have been dammed or polluted, especially in dry patches where the water levels in river streams are almost negligible. NMCG has recently tried to solve this issue by asking all the new construction agencies to include fish ladders in their engineering projects wherever possible but their implementation and efficacy still remains doubtful.

5.7.2 Pollution in Aquatic Ecosystems

Rising levels of pollution in the Ganga River system has been a commonly known phenomenon. Agro-chemicals, effluents from industries, untreated urban sewage and religious offerings have reduced the DO levels of water in many river stretches, completely killing the biodiversity in the region. With regards to lack of proper solid waste management, the river has been polluted with different kinds of plastics and non-degradable waste which is toxic to biodiversity. In 2020, a study entitled 'Quantitative analysis of Micro-plastics along River Ganga' conducted by Toxics Link studied water samples from Haridwar, Kanpur and Varanasi. Apart from micro-plastics, there were other kinds of plastics as well such as single-use plastic and secondary plastic products. Of the samples collected, those taken at Varanasi had the highest concentration of plastic pollution. The study further stated that more than 663 marine species are affected by marine debris and 11 percent of them are said to be related to micro-plastics ingestion *(Saha et al., 2020)*. (See Chapter 10 for more details)

Table 5.6: Relative Average Concentration of Micro-plastics

(Saha et al., 2020)

Location	Fragment	Fibre	Film	Bead
Haridwar	72.00 +/- 36.572	13.20 +/- 3.421	17.2 +/- 12.677	0
Kanpur	71.00 +/- 5.00	23.00 +/- 8.456	15.00 +/-2.2236	0.60 +/- 1.342
Varanasi	91.20 +/-25.024	14.80 +/- 2.049	18.40 +/- 7.635	2.20 +/- 2.049

5.7.3 Encroachment of River Beds

Riverbeds which have been completely dried off or seasonally dry off have been converted into agricultural lands or industrial zones. These seasonal or perennial river beds, also known as sand beds, are breeding grounds for turtles and other flora and fauna. Therefore due to human encroachment these sand beds, which are nesting grounds, are being lost, causing a disastrous impact on biodiversity. There is a need to demarcate such sensitive areas and strictly restrict private farming companies, industries, local farmers, etc. in these regions. Further, there is a need to encourage fisher folk and other local communities to practice sustainable livelihood practices. Therefore, campaigns for restoration of biodiversity should not just be limited to cleaning up the river, but also address livelihood related problems. There are some local organizations working with local communities in this region. Such work needs to be strengthened and advocated further.

5.7.4 Degraded Status of Forests

The implementation and enforcement of forests related legislation right across the central Himalaya i.e. from east Himachal to west Sikkim is very weak and ineffective and has had little impact on preventing the rampant trade in the endangered species of the forests. In case of the Bhojpatra trees or the Himalayan Birch (*Betula utilis*), the tree has suffered the most in the Gangotri region as the bark is collected for sale to the pilgrims since it fetches a high price. The peeling and ringing of Bhojpatra leads to the inevitable death of these trees. The *Kasturi Mriga* or Himalayan Musk Deer (*Moschus leucogaster*) is suffering a similar fate, as it is being rampantly poached not only in Himachal Pradesh, Uttarakhand and Sikkim but also in Jammu and Kashmir and Arunachal Pradesh.

5.7.5 Problems related to Livelihoods

Due to indiscriminate fishing practices, which do not abide by the natural or seasonal cycles of different fish species, the local aquatic biodiversity is getting routinely destroyed. The noise pollution caused by big vessels has been affecting the communication ability of mammals such as Ganga Dolphins which depend on their high-frequency echolocation clicks (as they are almost blind, a condition believed to have been adapted to survive in muddy waters) to sense their environment, navigate, and locate prey in the muddy waters.

Apart from increasing water pollution levels, a research paper 'Interacting Effects Of Vessel Noise And Shallow River Depth Elevate Metabolic Stress In Ganges River Dolphins', published in 2019 illustrated that noise can trigger responses ranging from avoidance to chronic stress, to permanent hearing loss and sometimes even stranding, injury, and mortality in these aquatic beings *(Dey et al., 2019; Kelkar, 2019)*. These impacts on biodiversity are some of the major concerns against the creation of proposed 106 new waterways under the Inland Waterways Project based on the National Waterways Act, 2016, by the Government of India. This project, which will increase large-scale commercial shipping and navigation in these river systems (including waterways on the Gandaki, Ghaghara and Kosi rivers from Nepal and Padma, Brahmaputra and Teesta rivers in Bangladesh), is causing growing concerns about the well-being of biodiversity. Developing waterways by dredging and the movement of barges with dirty cargo such as coal, fly ash and iron ore has many serious adverse ecological impacts (*Dharmadhikary & Verma, 2021*). Gill nets and mosquito nets used by fisher communities also lead to entrapment of fishes of all sizes in the synthetic material. Such livelihood-nature conflict needs to be addressed by conducting awareness campaigns, and by providing necessary equipment such as better quality nets and boats to local fishermen.

The species composition of fish is changing in favour of exotic and invasive species such as catfish which are now dominant as compared to the native species resulting in loss of biodiversity richness and adverse impact on the food web.

5.8 IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

The increase in temperature has also impacted terrestrial and freshwater species in particular, and the mountain ecosystems in general, because lands and rocky outcrops, which were previously covered by snow and ice, have now been exposed. This has led to changing seasonal activities of species, especially plants and animals which may be seasonally abundant in such areas. In the case of economically useful plants and animals, this can cause a positive result, especially for the transhumance population, as new meadows (*bugyals*) get created. Species adapted to cold have been observed to decline in the high altitudes. This may ultimately lead to their extinction (e.g. snow leopard, ibex, marmots, etc.).

In other words, the changes in the cryosphere not only cause the changes in the climate but are also affected by it. It is a two-way relationship and therefore studies are important, as the water yield assessments being carried out for hydro-power projects depend on such studies for their reliability. In fact, they must be made mandatory for all proponents of hydro-power projects, especially the run-of-the-river projects whose viability is entirely dependent upon the lean season flow resulting from snow and ice melt. More importantly, ensuring the security of 'environmental-flows' can then be based on realistic projections instead of assumptions and wishful thinking.

5.9 PROBLEMS IN THE DELTA

Apart from the problem of polluted waters which are drained off from the upper Riparian states, the Delta faces increasing disturbances due to global warming with increasing threats for food security and biodiversity in the coastal regions. Reduction in siltation and increasing salinity due to changes in water flows due to multiple dams and barrages upstream has been impacting the aquatic flora and fauna. Biodiversity issues related to the delta have been discussed in Chapter 13.

The dominant species of Sundari (*Heritiera fomes*) and Goran (*Ceriops decandra*) are affected by top-dying disease. According to fish landing data, the Hilsa catch in the river Ganga has been reduced by more than 50% within the last 15 years. Local people have also started catching juvenile Hilsa which are hardly 3-4 inches in length (*Behera & Haider, 2012*). A number of species like the Javan rhinoceros (*Rhinoceros sondaicus*), water buffalo (*Bubalus bubalis*), swamp deer (*Cervus duvauceli*), Gaur (*Bos gaurus*), hog deer (*Axis porcinus*) and became extinct during the last 100 years in the Sundarban. Oil spills are another recent potential threat and could cause immense damage, especially to aquatic fauna and seabirds and also to the mangrove forest biodiversity (*Islam, 2016*). (See Chapter 13).

5.10 THE QUESTION IS - WHAT CAUSED ALL THESE CHANGES?

5.10.1 Changing Nature of Human Dependence on Biological Resources

Traditionally, forests provided timber for construction of houses, fuel, fibre, food (fruits, berries, and wild vegetables), herbs and medicinal plants, etc. to the rural communities.

However, human exploitation of these forests and clearance for cultivation has increased rapidly in the past few decades. The area under forests has fallen during the same period from 43% to 29% by 2000 and about one-third of it stands degraded (*Forest Survey of India, 2017*). This increasingly negative inverse ratio between demand and availability of biotic resources has been the main cause of deterioration in biodiversity.

Traditional use of forest produce has been one of the reasons for this degradation but practices such as commercial tree felling, illegal logging and encroachment and submergence of forest lands in and around reservoirs has been a more serious cause of forest depletion. The main reason for this is because the traditional communities practised lopping of branches rather than clear felling. The commercial contractors however practices clear felling which has resulted in far more destructive consequences. Important commercial species of trees e.g. *Shorea robusta, Dalbergia latifolia, Dalbergia sissoo, Pterocarpus marsupium, Azadiracta indica* and T*axus baccata*, which were found abundantly a few decades ago, are now facing extinction. Most of the faunal species – apart from the Tibetan Antelope and Giant Panda, of which numbers have rebounded in the past decade, are being driven to extinction. Rhododendrons, orchids, rare medicinal and wild edible plants are also under threat (*Walker, 2019*).

The Zoological Survey of India, in its recent report entitled 'Faunal Diversity of Indian Himalaya' has identified the following threats to the mammalian species : habitat loss due to land use change, unsustainable livestock grazing, illegal wildlife trade and climate change (*Kailash et al., 2018*). The man-made threats to bird species are also identified by Krishnendu Mandal, Kamalika Bhattacharya et al., ZSI, as follows: hunting pressure, poaching, forest and land encroachment, solid and chemical waste dumping, grazing, habitat destruction due to tourism, deforestation, change in water quality, chemical discharge from industries, fertilizer spills from agricultural land and eutrophication of some water-bodies (*Mandal et al., 2018; Nautiyal, 2013*)(*Mandal et al., 2018*). Threats to the reptiles identified by Varadraju and Dipak C. K. are as follows: introduction of invasive species, diseases, habitat loss, fragmentation of reptile population, and construction of dams across rivers.

Identified threats to Himalayan amphibians include deforestation and habitat destruction, damming of rivers, overfishing and pollution by pesticide and detergents, stone-quarrying, acidification of water bodies, the capture of frogs for human consumption, climate change and global warming and increase in UV-B radiation at higher altitudes. The concept of maintaining environmental flows has been widely used as an answer to all biodiversity related problems in these river streams, however, it has not been really addressed (This aspect is further elaborated in Chapter 9 and 10). This degradation is not just a result of increasing human dependence and inadequate laws but because implementation and enforcement is very poor. Although traditional systems of forest management had their lacunae, the present invasive and commercial interventions have taken a quantum jump in degradation.

These lacunae are seen across the management of Ganga River basin in Nepal, as well as in India, in different magnitudes and combination of factors. The following section provides a brief analysis of some of the stumbling blocks and flawed perceptions by taking the example of lessons learnt while implementing rules and regulations in the 'Bhagirathi Eco-sensitive Zone':

1. Conflict of Interest between government's perception and actual need :

a. Practically all political leaders, irrespective of their party affiliations, have branded the Bhagirathi ZMP as being anti-development. In our current political scenario this does not seem to be surprising because all political parties appear to be using double standards, i.e., one for drafting and declaring laws and policies, and exactly the opposite view when it comes to public-posturing, implementation or enforcement. It is not as if they are unaware of the disasters and dangers of non-sustainable development projects, but their direct political and economic interests do not permit them to accept or insist on the enforcement of the 'rule of law'. It must be stated however that the ESZ notification and the structure of the BESZ is quite adequate for the purpose of conservation, but only if it is implemented and enforced in letter and spirit.

b. The cancellation of large-scale hydropower projects is being perceived as a loss of investment by the government of Uttarakhand, which feels that an investment opportunity of Rs.17,000 Crores and annual revenue of Rs.2000 crores has been lost. The government also believes that about ten small-scale hydro projects below 25 MW each, having a cumulative capacity of 82 MW should have been permitted, since they are based on Trench Weir Technology, and since the tunnels are also very small (2 x 2 x 2.5 meters) and cause no obstruction to the river flow (the issues related to such tunnel-based projects are discussed briefly in chapter river valley project). Uttarakhand State Government also feels unfairly treated because such small-scale HEPs are being permitted in Himachal Pradesh. This apparently logical argument is misconceived, because in reality, small-scale hydro projects have created dry stretches in river channels, thereby damaging the riverine ecosystem and depleting the diversity. The short-term financial benefits lead to irreversible loss of biodiversity.

2. Imbalances created in Ganga water regime & springs-network :

The experience of the last seven years clearly indicates that most of the norms and rules are being openly flouted under the pretext of calling them anti-development. For example, when the construction work on Pala-Maneri and Loharinag-Pala hydro-electric projects was in progress, several springs and water sources either completely or partially dried up. The ZMP has not been able to effectively check such negative actions. Similarly, Maneri Bhali–II has led to not only drying up of springs but also periodic drying up of entire stretches of the river. Therefore, a detailed hydrological study is needed for the area in order to understand the complex network of aquifers. Such a detailed study alone will enable the planning and protection of springs and groundwater sources.

3. Communities are deliberately misguided about BESZ norms :

a. The major problem about such notifications and Master Plans is that the State level politicians, Urban Local Bodies (ULBs) or Panchayat Raj Institutions simply do not believe in making their constituencies aware or oriented about the importance of such regulations. In fact they appear to be openly defying such notifications and turning public opinion against ecological zoning and developmental practices which are sustainable.

b. Another important reason for failure of such ESZs and ZMPs is that the local leaders have also not advocated the merits of the schemes and programs which are of significant benefit to the local residents, and which also protect the fragile ecosystem of the area. Since the local population is kept deprived of benefits of such schemes, they naturally feel inclined to oppose and reject provisions of the BESZ.

4. Lack of financial benefits to the local population :

The State of Uttarakhand has one of the highest degrees of forest cover in the country, since forest areas, national parks, wildlife sanctuaries and the BESZ together constitute almost 98% of the total area of the State. The urban and rural settlements on the other hand cover barely 2% and the total area. The total population of the region is 66,680 (year 2011) or about 41 persons per square kilometre and therefore, the anthropogenic pressure per se is very low. In fact, about 14 villages identified in the last census report were declared as abandoned, i.e., having no population at all. Such 'ghost villages' indicate that livelihood options have not been provided through government schemes, and the harsh natural conditions and market conditions have made conventional farming and pastoralism completely non-viable. In the higher reaches near the glacier such abandonment of villages has become more frequent. (See Chapter 6)

5.11 GOVERNANCE OF NATURAL RESOURCES IN GANGA RIVER BASIN

The current discourse on sustainable river basin development and management broadly accepts that an internally consistent set of laws, policies and institutions are crucial for arriving at the desired outcomes. In the case of Ganga river basin, such governance structure would need to ensure that laws and policies on natural resources are consistent at the local level, i.e. at the district and state levels, at the national and international level as well. Since large parts of Ganga lie in Nepal, China and Bangladesh laws and policies related to agricultural lands, pasture lands (also known as rangelands in China and Nepal), forest lands, wet-lands, and urban/industrial lands, need to be consistent with each other.

Similarly, policies related to tourism, infrastructure development have to be complementary to each other. In addition, the institutional framework, research and data collection centres, implementation and enforcement mechanisms have to be in place and continuously monitored and fine-tuned so that they produce the best results. Currently it appears that China, India and Nepal do not have an adequate regional perspective, and they also do not have multilateral conventions or agreements or a formal procedure through which they can discuss common issues, research programs, institutions for centralized data collection and interpretation.

This situation has been further hampered by geo-political border disputes and ideological disagreements on how to work towards mutually beneficial development access and management of natural resources. This is true not only between India and China but also between India and Nepal, and China and Nepal as well. In some cases, there is inadequate decentralization of laws and policies and in some cases there is inadequate envisioning at the national or international level. Similarly, there is a lack of institutions which can link the upstream and downstream communities, especially in the mountainous landscapes. In the cryosphere there is a complete absence of such institutions.

The Indian experience suggests that one can start moving towards a basin level governance structure only if a process of initiating the preparation and implementation of a trans-national Ganga River Basin plan is envisaged, which includes India, China, Nepal and Bangladesh. It is only through such a long-term process that we will move towards trans-boundary cooperation for managing connected landscapes, wetlands and lakes, forests and pastures. It is in this context that we will look at the governance framework as it exists, and how it needs to be developed in the future.

5.12 SIGNIFICANCE OF THE NEED TO PROTECT THE CRYOSPHERE AND BIODIVERSITY

According to data cited in the ICIMOD Assessment Report, 70–80% of the region's original habitat has already been lost and that loss may increase to 80–87% by 2100. A quarter of endemic species in the Indian Himalayas alone could be wiped out by 2100 (*Wester et al., 2019*). This is a great threat as extinction of species is irreversible. And this is only set to worsen with the growing impacts of climate change, along with new infrastructure development, trade routes and hydropower dams planned for the fragile region. Along with species loss and geo-morphological changes, this will mean that various dimensions or extent of the key environmental services that this region provides will be compromised – such as water and carbon storage.

Permafrost thawing due to rising temperatures can influence a broad range of systems, including hydrology, landscape evolution, vegetation, water chemistry, sediment loads in torrents and rivers, debris flows and rock fall. As permafrost under high altitude pastures can retain water in the active layer, the uppermost ground layer that freezes in the winter and thaws in the summer supports vegetation such as mosses, lichens and dwarf shrubs. But when permafrost disappears, the water can drain freely, the ground becomes drier and vegetation changes, with impacts on herding communities and the ecosystem as a whole.

As a consequence, it can strongly affect regional livelihoods and economies not only in the upstream regions but also downstream areas. Increasing glacial lakes, due to thawing, are also vulnerable to abrupt flooding events downstream during extreme rainfall events (Elaborated in Chapter 10).

Further, changing snowmelt patterns upstream will directly have an adverse impact on downstream ecosystems due to flooding, changing the land availability and environmental flows downstream. Increasing drought-like situations after the water towers have melted[60] will drastically impact the diversity of ecosystems and species. Therefore, as the cryosphere has created favourable conditions for the rich biodiversity to flourish in this region, changes in the cryosphere will have a direct impact, thus creating the need for urgent action for biodiversity conservation and management in the region.

5.13 CONCLUSIONS AND RECOMMENDATIONS

1. Retreating glaciers will expose new stream channels, sediments and bedrock, significantly altering mountain landscapes, as well as bring back to life frozen or hibernating microorganisms. Despite considerable progress in formulation of policies and laws, biodiversity in the Cryosphere remains one of the most understudied, yet arguably most imperilled and rapidly changing ecosystems in the Ganga River Basin. Retreating ice directly translates to loss of habitat and species diversity up stream as well as downstream.

Therefore, it is recommended that there should be a comprehensive documentation of the biodiversity and different functional roles of glacial micro-biota in the cycling of carbon fixation and nutrients on, within, and beneath glaciers, as well as how shifts in the release of these resources from glaciers may affect downstream ecosystems.

2. Bacteriophages, which give its unique character to Ganga waters, are found all across the rivers, but become much less effective in highly polluted areas. More research needs to be conducted on such aspects. As 42% of Ganga water is contributed by Nepali rivers such as Gandaki, Ghagara and Sapta Kosi,

Therefore, it is recommended that research with regards to bacteriophages also needs to be conducted in the origin glaciers within Tibet Autonomous Region, China, and Nepal apart from focusing only on the Gangotri glacier.

3. Aquatic ecosystems especially those formed at interfaces between two riverine ecosystems, such as confluences, also need special protection. Unfortunately, as a matter of policy, within India, such ecosystems or landscapes are outside the scope of MoEF& CC, and the Irrigation Department does not have a mandate to declare such areas.

It is recommended that special corridors or escape routes for aquatic species need to be conserved as riverine sanctuaries which are a rich consortium of living micro and macro flora and fauna.

It is further recommended that a new provision needs to be added under the Environmental Protection Act to reserve such aquatic areas as spawning grounds, corridor routes along with working towards preservation and conservation of the entire river network.

4. The Cryosphere of the Ganga River Basin is a combination of different sub-systems and biomes which have been determined by different dominant species and different abiotic factors which are constantly affecting and interacting with each other. The Biodiversity Assessment Framework underlines the need to go beyond conventional listing of flora and fauna and highlights the need to conduct studies related to behavioural patterns, sensitivity of species, inter and intra-species relationships, comparative studies between different time periods and other such parameters. Such an assessment could help in achieving holistic biodiversity conservation across the vertical and horizontal river system of Ganga River basin.

There is a need to de-bundle such interactions in terms of different trophic levels, sub-ecosystems, biomes or niches. Further, interspecies and intra-species relationships will need to be separately studied.

In order to carry out such a systemic assessment, a Biodiversity Assessment Framework is recommended which outlines studies and research in three phases:

Phase 1 : Independent pilot studies and creation of inventories of specific species or factors such as relative abundance, species richness, indicator species, and pattern of succession, specific niches or biomes will be included in Phase 1. This will enable the creation of time-series data amenable to periodic comparison and analysis.

Phase 2 : includes mapping and studying inter and intra-species relationships and associations, interdependence between different species and understanding associations between different categories of fauna and flora with abiotic and physical features of an ecosystem. Comparative studies between different time periods or different regions can be useful in understanding the changing behavioural patterns of different species and degrees of sensitivity due to human interventions.

Phase 3: includes orienting these studies towards conservation and management plans. Different sub ecosystems require different management plans as per specific objectives. Studies such as water use/wastewater use footprints should be conducted across the river basin. These studies need to be integrated with other scientific studies related to hydrology, climate change and changing agricultural impacts. A holistic ecological perspective will only aid towards better understanding and planning of detailed Biodiversity Conservation and Management for the region.

Studies mentioned in Phase 1 can be conducted independently while the studies mentioned in Phase 2 and 3 could be carried out simultaneously by different teams of researchers, academicians, government bodies as well as local community members and students.

All the recommendations related to Biodiversity Assessment Framework and Conservation need to be strengthened and provided adequate finances and infrastructure for immediate implementation and enforcement. Such studies will help in developing a time series analysis thus moving from benchmark studies to continuous studies, which will help in recording dynamic ecological responses. Such ecological assessment will be significant in taking management strategies from a high level of uncertainty to greater degree of certainty. This will help in moving towards the right direction and ensure optimal use of all resources including manpower, finances, and time.

There is a need for inclusion of stakeholder benefits and responsibilities in biodiversity conservation plans by creating a backward linkage with these ecosystems in order to foster symbiotic relationship between the population and the biodiversity.

All the activities of the resident population as well as the exogenous population need to be in congruence with the principles of biodiversity conservation. There is a need to create an impetus for the residents and the tourists, to not just look at the biodiversity from an aesthetic perspective but also take the responsibility of protecting the forests. Some of the measures undertaken under the Community Forestry Program in Nepal could be implemented across the river basin. Local fisher folks and farmers need to be included in such plans for developing a reciprocal relationship between humans and nature. Such livelihood-nature conflicts need to be addressed by conducting awareness campaigns, and by providing necessary equipment such as better quality nets and boats to local fishermen.

Partial and fragmented solutions either in Cryosphere or in hydrology or in biodiversity will not work. Currently, most of the research in Nepal as well as India is fragmented.

It is therefore recommended that biodiversity in the entire Cryosphere region in India as well as Nepal needs to be looked at as one bio-geological region. Such a perspective will help in better understanding and policy interventions in downstream regions as well.

5. India has provided systemic protection for forest areas by declaring them as national parks, sanctuaries, reserve areas, eco sensitive zones. However, there are no such provisions either in the Cryosphere region or for aquatic ecosystems in the upper or middle regime in the Ganga River basin.

It is therefore recommended that certain eco-tones/interfaces, corridors or escape routes for aquatic species need to be conserved as riverine sanctuaries which are a rich consortium of living micro and macro flora and fauna.

It is further recommended that a new provision be added under the Environmental Protection Act to reserve such aquatic areas as spawning grounds, corridor routes along with working towards preservation and conservation of the entire river network.

6. Certain regions within the Cryosphere are likely to disappear in the near future, af-

fecting physical morphology as well as biodiversity. Larger glaciers such as Gangotri or Nanda Devi glacier might remain for longer duration as remnants or relics of the glacial system.

It is recommended that such areas be demarcated as special 'Conservation Reserve Zones' and a ban be imposed on human activities. Pre-conditions need to be set for researchers, sadhus, mountaineers who will be allowed to go into such areas with pre-requisite permits, etc.

ENDNOTES :-

47. The rocky outer crust of the Earth is made up of the brittle crust and the top part of the upper mantle. The lithosphere is the coolest and most rigid part of the Earth.

48. Himalayan Golden Eagles are very large raptors, with the largest eyes relative to their size in the animal kingdom and eyesight which is 8 times stronger than an average human being's and can spot a rabbit at 3.2 km distance. It has a huge wingspan of 1.8m to 2.34m (5ft 11 in. to 7 ft. 8 in.). They normally inhabit at altitudes between 3000m and 5500m. They use their powerful claws and massive talons to swoop down upon their prey. While soaring in the sky, the broad wings are wide open in a V slightly above the line of the back.

49. Himalayan Black Eagles are large, forest-dwelling raptors that occur along a range that spans from Pakistan and Indochina to the Malay Peninsula. Black Eagles occupy lowland, evergreen forests, from 0-4,000 meters above sea level.

50. If a person puts his/her ear on the ice surface at the edge of any glacial crevasse, then the gurgling sound of the pro-glacial stream can be clearly heard. In the case of Gangotri glacier the sound of a flowing stream can be heard even on the smaller sub-glaciers.

51. Hibernation is a state of greatly reduced metabolic activity and lowered body temperature adopted by certain mammals as an adaptation to adverse winter conditions.

52. A grass-like plant with triangular stems and inconspicuous flowers, growing typically in wet ground. Sedges are widely distributed throughout temperate and cold regions.

53. A herbaceous flowering plant other than grass.

54. Deodaar trees have a shape similar to the shape of church spires, which symbolise the connection with the divine world; hence, the Deodaar tree is considered to be sacred. The word Daru is also associated with the word 'druid' from ancient Celtic cultures which refers to mythological creatures who are benevolent but are not treated as saints or gods, they are usually associated with trees indicating divine connection.

55. Zooplankton are an important component of the food web cycle and act as primary consumers in aquatic ecosystems.

56. Macrobenthos: macrobenthos are those organisms larger than 1 millimetre, which are dominated by polychaete worms, pelecypods, anthozoans, echinoderms, sponges, ascidians, and crustaceans

57. Oxygen dissolves into water primarily due to aeration. Aquatic flora flourishes in shallow rapids where there is exposure to sunlight due to the photosynthesis process oxygen is released as a by-product. Due to this photosynthesis process, the DO levels peak in the high altitude Gangetic Rivers during the day and fall during the night. Temperature and saturation also impact DO levels. At high altitude when stream temperature is low , the DO saturation point is close to 10 to 11 mg/litre. Biota in these regions have adapted to cold temperatures because DO levels are very high.

58. Epiphytes: Plants which grow on other plants but which are not parasitic.

59. The Ramsar Convention on Wetlands (Iran 1971) is of International Importance especially as Waterfowl Habitat is an international treaty for the conservation and sustainable use of wetlands. It is also known as the Convention on Wetlands. Every three years, representatives of the Contracting Parties meet at the Conference of Contracting Parties (COP), which is the policy-making organ of the Convention. The last three conferences were held at Punta Del Este (COP12), Uruguay 2015 (COP13) and the last one was held in Dubai, United Arab Emirates, in October 2018 (COP14).

60. The complete meltdown of glaciers and the permafrost has been predicted to happen in about 100 years if the current rate of temperature rise continues.

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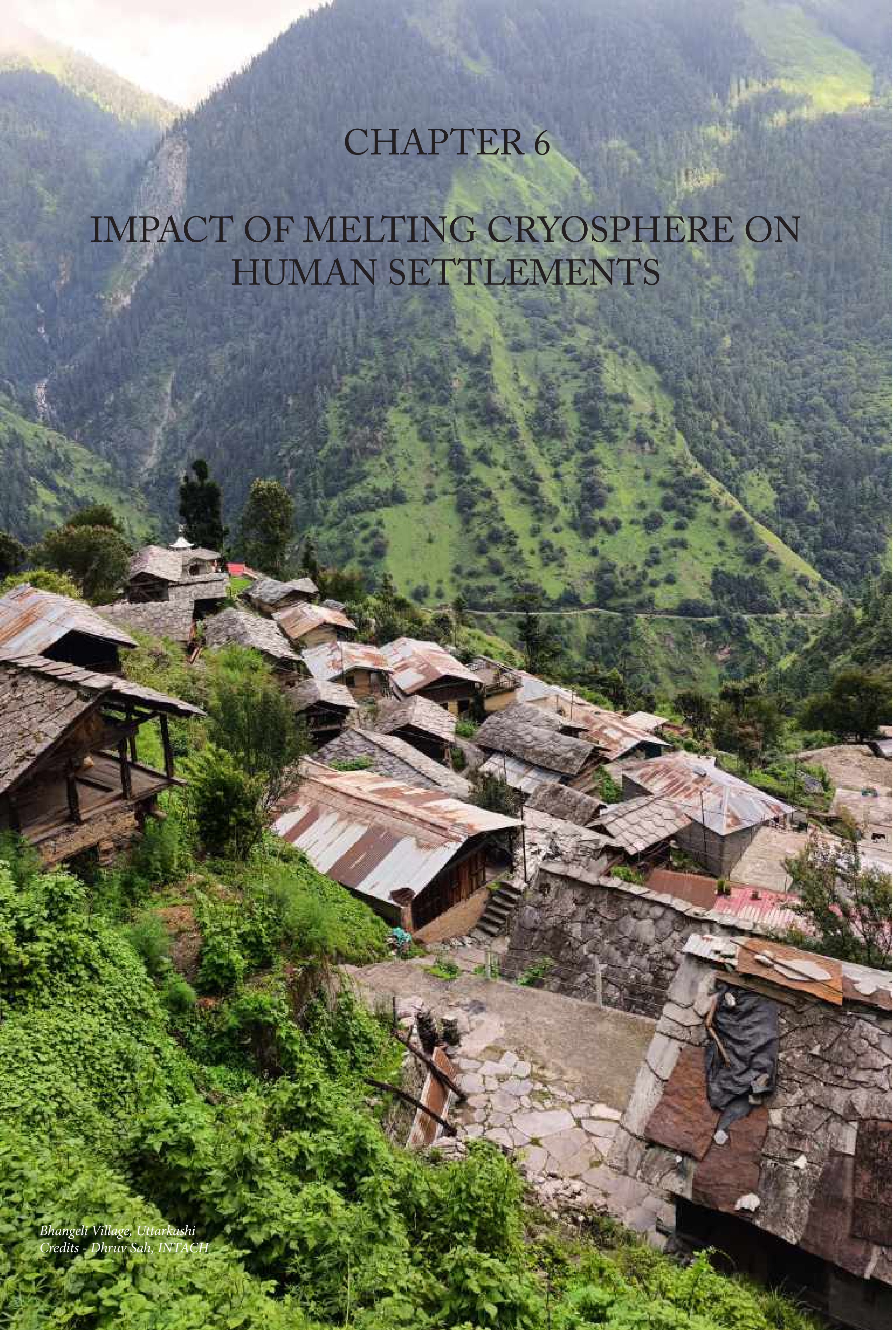
CHAPTER 6

IMPACT OF MELTING CRYOSPHERE ON HUMAN SETTLEMENTS



Bhangeli Village, Uttarkashi
Credits - Dhruv Sah, INTACH

6.1 EVOLUTION OF HUMAN COMMUNITIES IN THE CRYOSPHERE

The purpose of this chapter is to understand the impact of the shrinking cryosphere, human interventions and climate change on the local communities residing in these regions. However, before we discuss these impacts, it is important to understand the evolution and settlement patterns of communities in these areas.

The first human settlers to inhabit these hostile mountainous regions were probably the ascetics who travelled far away from civilization, around the 8th century CE in search of solitude. Gradually, other communities who could adjust to these harsh and remote surroundings, developed ways of sustaining their lifestyles which enabled them to settle down in this extreme terrain. These livelihoods were governed by the dynamics of the cryosphere and prevailing weather conditions, thus giving rise to practices such as subsistence agriculture and pastoralism. Some settled in the middle and lower hill ranges and formed smaller villages or hamlets, thus developing a lifestyle based on hill-farming. The first region to be settled was the Indo-Malay zoo-geographic zone and then the Central Himalaya. Adjusting to nature's ways and consciously recognizing the intrinsically dynamic nature of the Himalaya, guided by principles of respect and reverence led to the evolution of livelihoods and lifestyles which were resilient to natural phenomena. Their philosophy of humility towards nature was not driven just by religious sentiments but by a long legacy of practical experiences determined by the environment.

Consequently, as interactions with the plains and peninsular India and Tibet increased, trading communities prospered. Various communities which shifted to these regions, especially in Kumaon and Garhwal, adapted to the new climatic conditions, gradually discarding their original cultural traits linked to the areas in the plains from where they had come. They evolved new values based on 'environmental-determinism'[61] and a cultural lifestyle suited to the ecosystem and constantly changing physical circumstances. Rock art, found by archaeologists in Kumaon, Garhwal, Ladakh, Nubra valley (Indus basin) reveal evidence of cultural links with certain communities from Central Asia and China. Drawings of Bactrian camels[62] in rock art from 1000 CE, is one such example. Human communities, like plant and animal species also found their niche in their new environment / habitat.

Today, the Himalaya contains about 13% of the world's population, i.e., about 950 million people. However, if we take the cryosphere alone, i.e. land above the height of 4000 -5000 m. amsl approximately, then human habitation in such areas would be just about 30 million people . The population in the cryosphere regions of Ganga and Brahmaputra River basins in Tibet, Nepal, Bhutan and India is very sparse, while its density increases in the lower altitudes. Just as the cryosphere has played an important role in shaping the biodiversity of the region (elaborated in the previous chapter), it has also shaped the history of ancient human settlements, migration routes and their livelihoods. Over centuries, pastoralism, agriculture, and trade became the most common livelihood options for these communities, determined mainly by the ecological limits and ecosystem services provided by the cryosphere.

6.2 GEO-MORPHOLOGICAL STRATIFICATION LEADING TO SOCIAL STRATIFICATION

An important determinant of human settlement in earlier times was the nature and character of geo-morphological stratification of the Himalaya. It's impact of on human settlement was not homogenous, i.e., it varied in different areas in and within different communities. This was revealed by studies in the field of 'environmental archaeology' which highlight the significant impact of geological and biological factors on the choice of location of the human settlements *(Gupta, 1985)*. For the purpose of understanding this heterogeneity in human settlements it would be useful to divide the Himalayan landscapes into six zones.

Zone I : The small southern strip of land between the Indo-Gangetic Plain and Himalaya is known as 'Terai' which in most parts is covered with thick forests or swampy lands.

Zone II : Where the alluvium of the Indo-Gangetic plains end, one encounters sand and coarse gravel which is locally called 'Bhabar'. The Bhabar is a gently sloping mass which is still being formed and consists of crumbling wastes of the mountains which are swept down by numerous rivers and deposited at the bottom of the slope.

Zone III : Just above the Bhabar, mountains rise suddenly to a height ranging between 300 meters to 1000 meters. This major mountain range is known as the Shivaliks. Most of the better-known towns and hill stations lie in the Shivaliks.

Zone IV : The Lesser Himalaya, known to geologists as the 'Krol', lies above the Shivaliks. The Krol is a peculiar geological formation characterized by limestone which stretches from Kunihar in the northwest to Nainital in the southeast.

Zone V : The Greater Himalaya lies above the Lesser Himalaya, which is also called'Himadri'. This covers the region which is perennially snow covered (i.e., above the snowline) or which regularly receives snow in winter.

Zone VI : Beyond the Greater Himalaya lie the Great Tibetan Plateau, Ladakh, and the extreme northern fringes of Sikkim, Nepal, Garhwal and Himachal Pradesh.

This stratification is not discrete since there are overlaps between each of them. The moot point is that each zone has a different environment which has created niches for specific communities.

6.3 CULTURAL STRATIFICATION

Besides the geo-morphological classification which determined the settlement of communities, there were also other cultural divisions. The entire region from Yamuna and Ganga right up to the Ghagara valley on Nepal border was known, till about the 9th century, as the 'Kedarkhand' or the land of Badrinath and Kedarnath. Although there is no documentary evidence regarding the age of the Kedarnath temple and by whom it was constructed, according to the Garhwal Vikas Nigam, the temple was built by Adi Shankaracharya in the 8th century. One can deduce that it must have existed during the Little Ice Age (1420-1820 AD). The Little Ice Age, as known to geologists, was a brief period of cooling, when the Global Average Temperature changed from a long-term warming trend to an anomalous cooling trend lasting about 400 years *(Matthes, 1939)*. Vernacular literature of that period also mentions that for several years, the route to Kedarnath was intermittently closed since it was completely covered with several feet of snow.

After the 1820s, global temperatures once again rose, exposing the temples as seen in the picture below.

Images of Kedarnath Temple from the year 1882
(Indiatimes, 2013; Rare Book Society of India, 2013)

6.4 EMERGENCE OF GARHWAL REGION

It was only after the 10th century that this region acquired the name of 'Garhwal'. The state of Uttarakhand is broadly divided into two divisions, namely Garhwal and Kumaon. The Kumaon region covers the districts of Almora, Bageshwar, Champawat, Nainital, Pithoragarh and Udham Singh Nagar. The Garhwal region covers the districts of Chamoli, Dehradun, Haridwar, Pauri, Rudraprayag, Tehri Garhwal and Uttarkashi. Although the two regions are similar to each other, they can be distinguished by their sub-dialects, Kumaoni and Garhwali. Nepali is also spoken in several areas, and together these dialects are called the 'Pahadi' language.

The migration of human communities into the Himalaya can be linked with important tectonic events and related river avulsions which have taken place during the last few millennia. It is generally agreed that of the different tectonic events, there were three events (around 2000 BCE, 200 BCE and a recent one in 850 CE) which were significant for the morphology of the river system in Ganga basin and the subsequent human settlement patterns.

It may be conjectured that the tectonic movement led to displacement and shifting of rivers, mountains and valleys which have not only caused major physical upheavals, but also led to changes in the human migration routes. References to the first uplift in 2000 B.C.E, can be found in the Vedic and post-Vedic literature. It appears that the Mongoloid tribes, who, earlier, had been forced to restrict themselves to the Tibetan Plateau and regions to its north, gradually started finding passes which could enable them to travel across the Great Central Himalayan Ranges into the Central and Lower Himalaya. By the same token, the Indo-Aryan Rajputs were able to move northwards, through the valleys and passes created partly due to the faults and fissures, as a result of the tectonic uplift, and partly by the erosive power of the rivers changing their course. Thus, the latitudinal as well as longitudinal stratification of the terrain affected the lifestyle of human settlements and vice versa.

6.5 POPULATION MIGRATION IN ANCIENT TIMES

The Himalayan Mountain Ranges have been described as one of the cradles of human civilization, although recorded knowledge about prehistoric settlements is sparse and sometimes piecemeal. It is mainly found in Sanskrit literature, such as the Vedas, Puranas, etc. which were entirely an oral tradition to begin with, and have been subjected to modifications over the centuries before appearing in written form. A few inferences, which can be derived from such literary references, are given below:

The Western Himalaya was widely inhabited from about 1500 B.C.E onwards by a nomadic population known as 'Khasha', who were a part of a succession of waves of Aryan migrants from the northwest. Although they initially subjugated the local population, the Khasha gradually integrated into the local Hindu culture. In the central and eastern Himalaya, the settlers migrated from the Tibeto-Burman region, and were described in Sanskrit literature as '*Kirata*'. These tribes were highly skilled in the arts of magic and shamanism. In the central and very high Himalaya, the Bhotias entered from the north. These people were the most adapted to the harsh environment and high altitude. They mainly practiced pastoralism combined with a bit of agriculture. They took to trading when they realized that many of the products available in the southern Himalaya were unknown in valleys of northern Himalaya and the Tibetan Plateau. Trade in such products, especially different types of weapons and implements, became their principal and preferred occupation, which continues to this day.

Migration of communities has been a constant and ever-recurring theme in India's anthropological history. Similarly, the interaction between the indigenous and migrating/invading communities, and their eventual integration, has also been a hallmark of the way in which people lived and prospered on the Indian subcontinent. The upper watersheds of Ganga River Valley in India and Nepal were no exception to this phenomenon. The communities which we find today are a very complex mixture of Indo-Aryan and Tibeto-Burmese cultures. This area extends from Tons and Hindon tributaries of Yamuna in the west to the eastern-most tributary of Saptakoshi, namely, the Tamur River Valley in the east. They represent a wide range of languages, religious faiths, physical and racial characteristics ranging from people who are tall and fair with aquiline features, and those who are short with Mongoloid features. It is these people who have settled and shaped the social fabric of the lower, middle and central Himalaya. The current state of the Himalayan environment, in both its positive and negative aspects, is therefore a reflection of the way in which these communities have shaped, modified and sustainably used the lands over millennia. More importantly, they have simultaneously conserved and maintained their cultural traditions.

Just as there were migrations from the west through Persia, Central Asia and Afghanistan, there was also a considerable extent of migration of the tribes from Burma in the east (currently called Myanmar) and from Tibet in the north. Besides settling in the central valleys of Barak (Meghna as it enters Bangladesh) and Brahmaputra, they also travelled north and then northwest into and across the Himalayan Mountain ranges. Although we look at Himalaya today as a great physical barrier, in ancient times, it was the high mountain passes which enabled migration.[63] The relatively recent migration of Rajputs from north-western India into areas currently known as the states of Himachal Pradesh and Uttarakhand, and then practically into the whole of central Nepal, is also a historically well-documented fact.

Archaeological evidence dates to the prehistoric monuments of Central Himalaya - painted rock shelters and petroglyphs. The most recent remains of ancient brick-based habitations, art, and ritual structures of human settlements, however, are found to be around 600 BCE. In the present day, the Ranihat site in Tehri district (located on the right bank of the river Alaknanda, opposite to Srinagar town) dates back to 600 BCE. The archaeological remains are evidence that the people of Ranihat specialised in the smelting of iron from the locally available ore and manufactured iron tools for fishing and hunting which appear to be their main source of subsistence (Archaeological Survey of India, n.d.).The Malari (Uttarakhand) and Lipa (Himachal Pradesh) cave burial sites date back to 500 years BCE and offer glimpses into similar burial practices in the entire Central Himalayan region from Nepal to India and Tibet. This is further strengthened by the fact that Malari village lies close to the Indo-Tibetan border and was an important trade centre during the historical period *(Bist & Rawat, 2013; Madhwal, 2018)*.

Prof. Dinesh Saklani has traced the history of the ancient communities of Himalaya. His study discusses the origin of different communities, their social status, whether they are indigenous or immigrants, and covers the proto-historic[64] and historical period[65] up to 1000 CE. Although the study covers the Indian region of Kumaon, Garhwal and Himachal Pradesh, it also represents the settlement history of Western Nepal, especially in the Mahakali River Valley *(Saklani, 1998)*.

a) Khasha Tribes :

The Khashas or Khashirs were ancient 'bahliki' speaking Indo-Aryan tribes who have been mentioned in various Indian inscriptions and ancient Indian and Tibetan literature. They were originally from the Gandhara, Trigarta and Madra kingdoms in the north-western parts of the Indian sub-continent. Currently, they live in western Nepal, Garhwal, Kumaon and Himachal Pradesh. One finds references to the Khashas in Manusmriti[66] as '*kshatriya*'[67], however, since they did not adhere to the *Kshatriya* codes of chivalry, they gradually sank to lower levels of the social hierarchy and were eventually categorised as *mlechchas*[68]. In the Bhagwat Purana[69] they are said to have redeemed themselves by adopting Vaishnavism[70], and fought on the side of Kauravas[71]as stated in the Mahabharata[72]. In modern India, they are believed to be living in Punjab. In the Skanda-purana[73], the regions of Himachal Pradesh, Kumaon and Garhwal are described as *Kedare-khasha-mandala* and occupy the areas south of the Pir-Panjal / Pantanal range. This description is also corroborated in the 12th century text 'Rajatarangini' which is considered to be the most authentic history of ancient Kashmir.

b) Kirata Tribes

The other major group of ancient dwellers was the Kiratas, who, along with the Newars, were the earliest inhabitants of the Kathmandu valley in Nepal. The Rais, Gurungs, Magars, Tamangs and Limbus were also part of the Kirata tribes. These tribes live practically in all parts of west, north, and eastern Nepal. They also live in the Solo-Khumbu district of the Sagarmatha zone in Eastern Nepal. Interestingly, they now form an important segment of the Indian as well as the British army, constituting several regiments known as the Gorkha Rifles. Although they all speak Nepali at present, each one of them speaks a distinct tribal dialect as well.

c) Bhotia Tribes

The ancient history of the Bhotias is found in G.W. Traill's 'Statistical report on the Bhotia Mahala of Kumaon' (1851), and J. Strachey's work on the 'Himalaya in Kumaon and Garhwal' (1853). Currently, their largest presence is seen in Bhutan, Sikkim, and northwest Nepal. They are also closely connected with the India-Kailash and Nepal-Kailash pilgrimage routes, where they act as porters, guides, and mule or pony-trail leaders. This route passes through the Byans or Chaudans Pass and Lipulekh Pass. They are also seen in settlements near the five principal passes which cross the northern boundaries of Himalaya namely, Saraswati Pass, Mana Pass, Western Dhauli to Niti Pass, Gori Ganga Pass in Johar valley, Kungri–Bingri Pass, etc. Their living and food habits are considered unwholesome but understandable as they have to face extremely cold weather, and because they rarely live close to flowing water or, for that matter, any kind of water at all. This is especially so when they are travelling on high passes with large loads of goods for trade.

Their dwelling places are solidly built of wrought-stone with slanting roof made of slate, which is plentiful in the Himalayan region. In settlements where they practice agriculture, their houses may be two or three storeys, where the ground floor is invariably meant for cattle and other livestock, the first floor is meant for elders and the top floor for the children and young people. Even today most of them have no toilets. Those households who travel for trade and employment have become relatively well-off, and have now almost become a separate caste, albeit on the basis of their economic status. The Bhotias of Mana and Niti region are called 'Marchas', while those of Johar are known as 'Sokpas or Rawats'. In principle, the Bhotias do not accept any caste distinctions but in practice one can now see the existence of caste categories like Brahmans and Rajputs. The old generations wear their traditional clothes while the current generation has almost entirely shifted to modern clothing. They have simple dietary habits consisting of milk, ghee, meat and rice, and there is always a pot of water boiling for tea with butter and salt. Characteristically, almost all men and women and adolescent children drink *barchchyangor chchyang* which is locally fermented brew made from different millets like kodo, or cereals like rice.

The social status of women is high, but not equal to men. There is no dowry system and marriages are usually arranged within the clan. The society is monogamous, but whenever the elder brother dies, the wife is automatically married off to the younger brother. Unlike many other parts of India, this practice has saved the farmland from fragmentation, which, in other castes and social groups in India, has led to severe fragmentation and unending disputes. The problem of agrarian sustainability and that of the households was partly solved through this tradition. Another factor which positively influenced agrarian sustainability was the Gorkha invasion in 1790, and later, due to the British excursions into Bhotia-mahal in the early 19th Century. These two events completely ended the seclusion of the Bhotias, since a large number of them started being drafted into the army, police and other security services, which exposed them not only to the mainland Indian community but also to western culture *(Atkinson, 1853)*.

d) Vanraji tribes

The Vanrajis also known as Banrawats, Vanrawats or Banrajis are one of the native endangered ethnic minority groups originating and currently residing in Uttarakhand and in a small area in Uttar Pradesh and Western Nepal. Basically, nomadic hunter-gatherers, they mainly depend on forests and practise 'shifting-cultivation'. The name Vanraji means 'kings' or the 'royal people of the forests.' However, because of their dwindling population, low literacy rate, poverty and adverse impact of developmental projects, the Ministry of Tribal Affairs has classified them as a Particularly Vulnerable Tribal Group. The language that belongs to the Himalayan group of Tibeto-Burman family of languages named 'Raji' has been declared as 'severely endangered' by UNESCO *(Fortier, 2009; Naswa, 2001)*.[74]

This transhumance group and almost all high-altitude-dwelling communities are 'ecosystem people' i.e., depending more than 80% on nature for their survival. They have maintained a behavioural relationship with the river which at no point transgresses the natural laws of rivers; they have not polluted it or extracted from it. Their relationship with the river is that of respect, recognition of human limits and commitment to the laws of the river. For example, almost all the villages along Dhauliganga are at a height above the maximum probable flood-line as known to the engineers. Thus, by avoiding constructions within the flood-line of the river, there is a tacit respect for the laws of the rivers, an acknowledgement of the space of rivers, by its rise, ebb and flow and accepting human fragility while dealing with the forces of nature. In terms of resilience, these are the people who will fare the best during climate change-induced events, as they are habituated to continuous changes and their responses are an inherent part of their lifestyle. Resilience and adaptation come naturally to these communities, yet this crucial characteristic is largely disregarded and has led to their marginalization by mainstream society.

Temporary Settlements of the Van Gujjar community
(Photo: Anagha Athavle, Field Trip, November 2019)

3 Storey House of the Bhotia Tribe. The Ground Floor is for Livestock, the First Floor is for Elders and Top Floor for Young People
(Photo: Field Trip, November 2019)

Traditional Foot Pedal-Loom and Handwoven Carpet
(Photo: Vijay Paranjpye, Field Trip, May, 2019)

6.6 SUSTENANCE IN THE CRYOSPHERE

As explained earlier, the geological stratification led to social stratification which was interrelated with the livelihood options of these communities. The high-altitude pasturelands became seasonal feeding grounds for the flocks of pastoralists. The alluvial plains in Terai provided fertile grounds for agriculture to flourish. On hilly-slopes, subsistence farming was practiced, supported by trade, as explained earlier.

6.6.1 Pastoralism in the Cryosphere: Dependence on Glacial Lakes and Springs

Historically, the Himalayan pasturelands have been greatly influenced and transformed by pastoral communities (Bhotias, Lepchas, Gurungs, etc.) for over a thousand years. Today, they continue to provide a niche not only for animal species suited to these conditions, but also to communities which have adapted themselves to these conditions over millennia.

There is a close connection between glacial lakes, existence of pastures and the transhumance activity of the shepherd and cattle-herder community. As the glacial lakes expand and contract the peripheral areas of these lakes (i.e., the areas which get exposed during the contraction of lakes) convert themselves into pastures. These pastures then become the feeding grounds for the high-altitude animals like sheep, goat, yak, etc. In case of all the lakes below the snow line /tree line, a fair amount of water seeps as groundwater recharge. Such soil moisture/groundwater aquifers eventually emerge as first and second order streams, which supply water to practically all high-altitude villages located in the Himalaya. The maintenance of spring discharges during the summer months is possible mainly due to glacial lakes, as the precipitation during non-monsoon months is relatively low. In other words, the entire agrarian economy of the Bhotias and other pastoral communities depends on the existence, expansion and contraction of these High-Altitude Lakes.

Transhumance, as a tradition, refers to the seasonal migration of the pastoral communities along with their livestock, from one agro-ecological zone to other more favourable zones in terms of water availability, weather and presence of markets for the sale of products. During the summer months most of the flocks of sheep, goat and yaks are taken to the meadows and pastures in the higher altitudes, and the richest grazing areas are near the rims and flux (areas exposed during contraction of the lakes). In addition, due to relatively cooler conditions, the animals put on body weight as well as a thicker coat of wool. Practically the entire fodder supply for animal husbandry and the pastoral economy in general comes from these pastures located within the cryosphere and forest lands.

Transhumance: Herd of Sheep and Yak Grazing Around a High Altitude Lake
(South Asia Pastoral Alliance, n.d.)

Mountain communities and in fact all pastoralists have traditionally considered livestock as an indicator of hierarchic position, power, and wealth. Their lifestyle is governed by their own traditions, rules, and institutions, with their own mechanism for conflict resolution. A record, maintained by a 67 year old pastoralist, Kishan Singh from Purulia village, near Harsil (chosen for an in-depth study during the Garhwal Himalaya field trip in May, 2019) gives a brief idea of the pastoralists' lifestyle and their present status. The record states that till a couple of decades ago, at least twelve families in Purulia village used to have large herds of sheep which were annually taken to a snow/ice-fed bugyal or meadow located well above 3000 m.

Each family had a herd of at least 200 or more sheep which would be taken to Ratabitu, which was a temporary camp-site for the shepherds. Presently, only two families are engaged in this pastoral activity. They live in the village for a few months i.e., from about early November to about 10th of May. During summer they move up to the *bugyal*, where they stay through the summer months for grazing and fattening their herds of sheep. These nomadic families, along with their herds make an annual migration to Rishikesh where they stay for about two months, selling their raw wool or woollen products and some animals for meat. In the case of shepherds, each of the sheep yields about 20 kg of wool which sells at about Rs. 20 per kg. If the animal is sold for meat, it fetches them around Rs.5000/-. Muni-ki-Reti is the camping site (*adda*) for many herds. On their return journey they follow a route which passes from one hilltop to another. The shepherds of Purulia, on their return journey, travel from Rishikesh to Brahmapuri, then to Dhanuati, further to Kanda-Taal, then to Radi village, Moriyana, Uparkot, Gangori village near Uttarkashi, then to Bhatwadi, Garamkund, Gangnani, Suki-Tope and from there to the high altitude *padav* at Girdil and Hanglod and then finally to Purulia.

6.6.2 Difference between Pastoralism and Animal Husbandry

Pastoralism and animal husbandry on farmsteads differ in scale, time and space. Pastoralism is typically 'nomadic' in nature, and although it does not impact water quality in rivers per se, it needs to be looked at from the perspective of livelihoods and other important functions it performs, such as seed dispersal, maintaining the vigour of grasslands, and keeping the carbon cycle intact, all of which impact the water quality of rivers in one way or another.

Animal husbandry on the other hand implies a more sedentary, stall-fed and intensive approach and has different impacts on the environment. One must also appreciate that animal husbandry goes hand in hand with agriculture and both are highly interdependent. Worldwide, intensive animal husbandry is practiced at a very large scale and this has been a major source of soil and water pollution. However, animal husbandry in Uttarakhand and Nepal is practised on a relatively smaller scale, and is mainly for complementing agriculture and providing animal products such as milk, meat and eggs to the family.

6.6.3 Subsistence Agriculture

Uttarakhand and Nepal together constitute the bulk of the upper Ganga watershed. These two areas form one socio-cultural region, very similar in terms of their geology, topography and climate, which have shaped the agricultural practices in these regions. The agricultural farmlands in all these territories are broadly of two types: the steps carved out of mountain-slopes and converted into paddy fields, and the relatively shallow portions of valleys, e.g. Kathmandu Valley and Pokhara Valley. In addition, the largest contiguous areas under cultivation are in the plains of Terai. These cultivated areas cover approximately 12.5% of the geographical area i.e. 4.12 million hectares. Of these, approximately 1.2 million hectares are irrigable *(Ministry of Agriculture and Livestock Development, Govt. of Nepal, 2020, 2021).*

6.6.4 Aspects related to Agro-Biodiversity

As mentioned earlier, Uttarakhand, Himachal Pradesh, and Nepal, are very similar in terms of their geology, topography, and climate. However, there are several differences in terms of the ethnicity of their inhabitants, their history, governance, policies, and geo-politics; all of which impact the way in which water, land use and therefore agriculture is managed in these regions. During the field visit to Nepal in November 2019, the areas downstream of the Bhote Kosi river (near the China border) down to its confluence with the Sun Kosi River near Balefi village were surveyed. Farmers in this region were predominantly growing finger millet, rice, buckwheat, maize, potato, radish, mustard greens, tomato, cauliflower, and banana. Some farmers had also started growing coffee on a small scale, and selling it to tourists either in powder form or as a beverage in small road-side restaurants.

Due to the genetic diversity, various native varieties of crops are found in this terrain. About 2,500 species of rice have been identified in Nepal alone, and about 100 types of *basmati* rice in the Western Himalaya. Nepal is part of the 'Indo-Burma (Myanmar) Biodiversity Hotspot' designated by the United Nations. Nepal is unique, because within a short distance of 180 km north-south, the crop cultivation range varies from sub-tropical (60 m amsl) to alpine (4700 m amsl). There are three major agro-climatic zones in Nepal depending on their altitudes. The Terai, Dun (valleys), and parts of the Shivaliks (300-1000 m) have sub-tropical climate, the middle hilly region (1000-3000 m) experiences very warm to moderately cold climate, and the high-altitude mountainous region (2600 - 4200 m) experiences cool to sub-alpine climate.

Nepal has about 790 edible plant species of which 577 species are cultivated *(Joshi, 2017)*. Amongst the 577 cultivated species, 484 species are indigenous to Nepal and 93 are introduced species. About 224 wild species are closely related to cultivated crops called crop-wild-relatives[75]. Following are the list of some of the native crops grown in Nepal region:

Aromatic rice varieties : Basmati, Thapa Chini, Kalanamak, Jinuwa, Kanak Jira, Chanakchura, Tunde Masino

Local rice varieties : Ghaia, Jundi, Marshii

Local wheat varieties : Sathiya, Murali, etc.

Finger millet : Okhle, Dalle, Paundure, Jhapre, etc.

Buckwheat varieties : Bitter, Sweet, Chuchhe, Bharule, Bhate, etc.

In addition, they cultivate several native crop varieties of foxtail millet, proso millet, amaranthus, naked barley, vegetables and legumes *(Paudel et al., 2017)*.

Kodo Millets Grown in Strips or Slope of Rivers or Streams, Nepal
(Photo: Ashwin Paranjpe, Field Trip, November 2019)

Similar to Nepal, people of Uttarakhand also practice rain-fed, subsistence-based farming. The people in the region rely on agriculture as their main occupation with over 75% of the population depending on it. Based on different altitudes, agricultural crops in low-lying regions are called '*Gangarh*' and in high altitudes are called '*Danda*'. Rice is extensively cultivated along with other millets in irrigated lands known as '*talon*' in the Gangarh regions. The traditional practice of '*Barah-anaj*' is practiced in certain regions of the state with crops such as *Ramdana* (Amaranthus), *Rajma* (Common Kidney Bean), *Manduwa* (Finger Millets), *Naurangi dal* (mix of pulses), *ogal* (buckwheat), *bhat-maas* (soybean), vegetables such as *Kheera* (Cucumber), oilseeds such as *bhang* (hemp) etc. being cultivated. These agricultural practices provided maximum output, requiring minimum inputs *(Sati, 2005)*. Such a practice was beneficial not just in terms of production, but also for nutrition, as the selected crops met all the nutritional needs in different season of the year.

The other crops grown are pumpkin, beans, ginger, chilli, cucumber, leafy vegetables, and tobacco. Potatoes are seen as a major cash crop in the low-lying regions. Along with this there is an increase in commercial cultivation of horticultural crops such as apple, walnut, and apricot, etc. Other crops such as turmeric, garlic, ginger, cardamom, coriander, and fenugreek; ornamental flowers such as gladioli, gerbera, etc. are also grown in certain districts. During field visits in these areas[76], it was found that most families grow paddy and potato in the fields and also have a few trees of Apple, *Chulu* (or *Khumani*), Walnut, Almonds, *Chilgoja* on the high slopes. All of this can be categorised as 'subsistence-horticulture' and is certainly not well paying, since the landholdings are small.

The native agro-biodiversity in Himachal Pradesh is almost similar to Uttarakhand as both the states lie in the similar agro-climatic zone. However, Himachal Pradesh rapidly moved away from native crops towards heavy production of commercial crops. The process of diversification towards fruits and vegetable crops in the State started with the introduction of apples in the late 1950s and 60s in Shimla and Kullu districts. Over the years, the State has emerged as a leading producer of fruits grown in temperate regions and off-season vegetables. There has been a change in the cropping pattern at the state level, brought about by diversification into production of cash crops like ginger, potato, off-season vegetables, kiwi, cherries, and hops, and further into fields like apiculture and mushroom production. The process of crop diversification gained momentum in the 1990s and has now encompassed many new areas in the low and mid-hill districts. The area under food grain crops like rice, wheat, barley, other cereals, and pulses has witnessed a decline while the area under fruits and vegetables has increased over the period.

6.6.5 Ancient Trade Routes

The vast and vibrant trade networks along the old silk roads across the mountains facilitated the exchange of culture, knowledge, and biodiversity over centuries. This brought with it rich migration of species, different farming systems and plants.

6.6.6 Changes Post Indo-Chinese War, (1962) and Impact on the Cryosphere

The situation described above more or less continued to prevail till 1960. However, after the Indo-China war in 1962, the nature of human presence and interventions changed dramatically. Thereafter, the changing political scenario in India and Nepal, as well as the changing economic dynamics began impacting the communities, their livelihoods and ultimately the cryosphere. This section provides a brief insight into the post 1960s political, economic, and social as well as ecological scenario in the ryosphere with reference to the states of Uttarakhand and Himachal Pradesh (a portion of south-eastern Himachal Pradesh constitutes a small watershed of Yamuna sub-basin) in India and the whole of Nepal.

6.6.7 Changing Political Scenario and its Impact on the 'Ecosystem People'

Invasions and wars have not always benefited the trading occupation. The Indo-China War in 1962 completely devastated the Bhotia community who heavily relied on trade. The exception, of course was of those households which had at least one member of the family in the armed forces. This happened because practically all trade routes between India and Tibet (China) were closed after the war and trade across Himalaya, which was flourishing till then, came down to a trickle. Currently, there are armed check posts on all passes and trade routes. Many more remain closed, largely due to political tensions between India and China. In the case of Nepal on the other hand, trade has continued and even increased to a great extent.

6.6.8 Reservation for Employment to Bhotias as Scheduled Tribes

One of the significant ways in which policies or decisions of the Central Government in Delhi impacted the communities living in the Cryosphere region, was the declaration of the Bhotias as a Scheduled Tribe (ST) in 1967 under the Constitution Scheduled Tribes (Uttar Pradesh) Order, 1967 *(The Gazette of India, 1967)*. This provided an impetus for a wave of migration of the youth from the Bhotia community from the mountains into mainland India for availing of job reservations. This new employment provided an income which was considerably larger than what they earned in Nepal, Uttarakhand or in the Tibet Autonomous Region (China). Consequently, the economic disparity between the rich and poor amongst the Bhotias has increased dramatically, thus altering the economic, demographic as well as social dynamics within and between the Bhotia and other communities.

With changing dynamics, pastoralism also seems to have faced a setback. The village elder, Kishen Singh from Purulia village (mentioned above) lamented the fact that only two families still follow this nomadic trade route, as all the rest have migrated for jobs, or prefer to practice settled farming. One of the reasons for this migration towards other livelihoods is related to the need for settling down in mainstream society. The place of residence becomes an important identity for families for availing government schemes and benefits. However, as these transhumance communities do not have a permanent place of residence, they get left out of most of the schemes and benefits related to education, medical facilities, housing, and employment opportunities. The outward migration of these communities and their demographic transition was not due to climate change, which is a fairly recent phenomenon, but due to the exigencies of administrative processes. There is little doubt that in future, climate change too will aggravate the inverse relationship between population and availability of resources.

6.6.9 Impact of Hydro-power Projects on Transhumance Communities

In the post-independence period, the prevalent trend of building dams for meeting the developmental demands of a new nation spurred the Central and State governments into constructing hydroelectric projects (HEPs) on all available streams and rivers (except those which were in the National Parks, Sanctuaries or Eco Sensitive Zones). The benefits of such projects did not accrue to the local population, comprising mainly of communities which are 'keepers of the ecosystem'. The beneficiaries are almost always the contractors, agents and technical experts who do not belong to the mountainous-region (For details about dams and other river valley projects see Chapter 8).

Despite these difficulties, some people still practice their traditional occupation, primarily, out of pride and emotional connection, and secondly and most importantly, as they do not find themselves equipped to integrate in the larger society which is dominated by urban lifestyle values and which looks down upon these communities as backward, lying on the last rung of the social hierarchy. Social inequality and the inability of the mainstream society to integrate these communities have led to further marginalization of these communities.

6.7 IMPACT OF CHANGING LAWS AND POLICIES ON PASTORALISM

In recent decades, modern state laws, institutions and trans-Himalayan or international projects have threatened the existence and lifestyle of pastoralists. In 1974, all pasture-lands in Nepal were nationalized, and all ownership rights were annulled. Nationalization and privatization of range-lands therefore became a threat and an issue of concern. In addition, demographic change, especially increased longevity, migration to other occupations, shortage of labour in agriculture, has a combined impact on the day-to-day existence of pastoral communities in the region. There are fears expressed by sociologists and anthropologists that the livelihood of these communities may soon disappear, unless sound policy changes, institutional reforms and market support are systematically provided *(Wang et al., 2013)*.

Researchers state that the Nepal Pasture Act of 1974 has been largely responsible for decreasing the role of traditional institutions related to management and regulation of the grasslands. These grasslands have got incorporated into the 'Community Forests', therefore the pastoralists have lost their identity, leading to ownership/access issues, usufruct rights and ultimately resulting in a loss of grasslands.

Forest Users Groups (FUGs) in Nepal look at the pastures as assets to be owned, while the pastoralists look at them as 'commons.' The climate change impact has added to this problem. Glacial lakes have expanded and swallowed several grasslands and the livestock has had to move to either lower or sometimes higher altitudes to find foraging areas. The semi-natural and artificial grasslands are unfortunately being manipulated by shepherds during recent years by using chemical fertilisers and herbicides and non-indigenous varieties of grass seeds (e.g., ryegrass and white clover) in order to augment the growth of fodder. Natural grasslands in the lower altitudes have been extensively replaced by cultivated grasses. The ecosystem is being used unsustainably and the system poses problems to other communities, as well as to other economic or developmental activities.

This situation has also led to a class and caste/tribe conflict, with settled agriculturalists claiming a superior position in the social hierarchy. The Ghermu Village Development Committee, having a population of 1776 persons, living in 402 households in Lamjung district, surrounded by Manang, Kaski and Gorkha districts, face these problems.

In addition, other alternative solutions such as the younger generation of shepherds working as guides and offering 'shepherd routes' for trekking, may encourage at least some of the younger shepherds to continue with their profession. Further, an important source of livelihood could be provided by training mountain-guides for high altitude trekking and mountaineering expeditions. Purulia village, in Chamoli district in India boasts of about twenty men who work as high-altitude guides for trekking expeditions to glaciers, peaks and passes, earning an additional seasonal income of approximately Rs. 50,000- Rs. 60,000 during the months of May and June.

6.8 CHANGING AGRICULTURAL DYNAMICS

Currently, Nepal produces only about 2.1 million tons of food grains which satisfy about 50% of its requirement and the rest of the needs are satisfied through imports from India. Since India is already experiencing a glut in the production of food grains over the last two decades, the exports to Nepal are likely to continue as before.

About two-thirds of the people in Uttarakhand are involved in the farming business, exploiting about 21% of cultivable land for their livelihood. Average size of land holding is small (0.5 ha.), fragmented in scattered parcels, and making commercialisation of agriculture non-viable. Forty-five per cent of the farmers, having less than 0.5 ha. share only 13% of the total land. In recent years, the yields of major food crops in Uttarakhand have been lower than other South Asian countries and Uttarakhand is now dependent on food imports *(Singh, 2017)*.

6.8.1 Degradation of Agricultural Productivity in these Areas

Changes in agricultural practices including changes in crops and crop production, GMOs, use of chemical fertilizers and pesticides, which came in with changing economic dynamics due to policies of liberalisation are having major and far reaching impacts on the natural environment *(Singh, 2017)*. Until the 1950s, there were hardly any agrochemicals used in this region. However, the increased use of fertilizers and pesticides, especially in the last two decades, has been alarming. The Nepal Health Research Council has pointed out that pesticide use in Nepal is increasing by 10-20% every year, with more than 90% of the pesticides being used in vegetable farming. Since practically all major rivers in Nepal, including the Ghaghara, Gandaki, and Kosi flow in the north-south direction, it is logical to assume that they must carry significant amounts of fertilizer and pesticide run-off as they drain the Terai region and enter India, discharging their waters into the Ganga.

The 1965 Green Revolution wave in India led to a drastic increase in use of chemical pesticides and fertilizers with the aim of increasing per acre productivity. In Himachal Pradesh, consumption of fertilizers (nitrogen, phosphorus, and potassium) per hectare of gross cropped area has increased from 35.9 kg.\ha. in 1997-98 to 50.2 kg.\ha. in 2012-13. The high crop diversity as maintained by farmers in the past is now replaced by a few high yielding varieties and cash crops, which are prone to various pest attacks *(Kala, 2014)*. This change in crop patterns is also a result of changing food habits. Cereals and pulses have been replaced with rice and wheat, which now constitutes the main diet of the people in the region. A study conducted by the Dehradun-based Wildlife Institute of India (WII) shows that farming of 30 traditional crops has been abandoned in Pithoragarh district in the last decade due to climate change and migration *(Sharma, 2018)*. Over-exploitation and degradation of land has become a major threat to sustainable agricultural development in general and production in particular.

6.8.2 Impact of Climate Change

Furthermore, erratic climatic conditions have posed challenges to the economic viability of farming in these states. Along with the reasons mentioned above, climate change phenomena in the cryosphere are likely to have a negative impact on agriculture in these regions. Over the next 30 years or so, an increase in the discharge of glacial water through rivers may affect farming in the hilly and mountainous regions to a significant extent. Further, changes in the temperature regime and shifts in precipitation and snow will occur in space as well as time. Disastrous incidents triggered by very high intensity of rainfall may trigger similar incidents like the massive landslide that occurred near Sun Kosi River in August 2014, sweeping away several hundred hectares of farmland, killing 156 people and obstructing the Sun Kosi River, leading to the creation of a huge lake which led to further calamities downstream.

It is projected that the Terai region is likely to experience more floods due to increased water discharge from rivers. Rice, a crop which is grown widely in Nepal and is the mainstay of the Nepali diet, is likely to be severely affected by changes in rainfall patterns. On the other hand, crops such as wheat, maize, potatoes, and vegetables might actually benefit from the increased availability of water in the rivers, although the changes in temperature could pose a greater challenge for these crops.

Another phenomenon which needs to be understood better is the melting of sub-surface frozen water (permafrost). As the sub-surface ice melts, it expands and can trigger landslides. This is followed by 'frost-shattering' observed due to the freeze and thaw action operating mainly in the peri-glacial areas *(Anand & Pawar, 2015)*. Such events can be disastrous for agriculture, and we know very little about this phenomenon.

6.8.3 Inconsistent Rainfall Patterns

The inconsistent rainfall pattern with higher intensities of rain and fewer number of rainy days have become a frequent phenomenon in the Himalaya. The plains (Terai) of Uttarakhand faced a problem of rain deficit during 2005 and 2006 due to early monsoon, which led to reduction in crop production. Increasing flooding due to Extreme Point Rainfall Events (EPRE) will have unprecedented impacts on agriculture in mid-western Terai, leading to crop damage. Such events are likely to increase in coming years.

For these reasons, farmers are shifting away from the agricultural profession, leaving the land uncultivated. As a consequence, a significant portion of farmland has been abandoned. This has led to land degradation. Increased migration and reduced availability of farm labour pose significant challenges for the farm sector in Nepal as well as in these two states in India. Due to small land holdings and extremely hilly terrain, the government's farm mechanization policy has failed. Hence, agricultural productivity in Nepal has stagnated and the demand for food is increasingly being met by imports from India. Thus, Nepali farmers are losing interest in agriculture since other non-farm livelihood opportunities seem to be much more lucrative, at least for now. As economist Keshav Acharya puts it: 'Land has become a 'store of value' – an asset that can be traded at a high price, which is way above the value of crop production' *(Prasain, 2018)*.

As explained by Nehru Prabakaran, faculty at Wildlife Institute of India (WII), Dehradun, "The major reason for such decline is that farmers no longer perceive traditional agriculture in the hills as profitable. The outcome of climate change such as delayed monsoon, erratic rainfall, low snowfall, monsoon failure are further adding to the crop failures and discouraging farmers to continue investing in agriculture. Migration of the young generation in search of better economic options has reduced the human workforce required for the arduous agricultural operations in the hilly terrain. *(Sharma, 2018)*

While the preceding discussion may paint a grim picture of the agricultural sector in Nepal, Uttarakhand and Himachal Pradesh, the situation could be turned around in favour of farmers if these regions were to take a leaf out of Sikkim's success story with organic high-value agriculture and agro-tourism. The inconsistent rainfall pattern with higher intensities of rain and fewer number of rainy days have become a frequent phenomenon in the Himalaya. The plains (Terai) of Uttarakhand faced a problem of rain deficit during 2005 and 2006 due to early monsoon, which led to reduction in crop production. Increasing flooding due to Extreme Point Rainfall Events (EPRE) will have unprecedented impacts on agriculture in mid-western Terai, leading to crop damage. Such events are likely to increase in coming years.

For these reasons, farmers are shifting away from the agricultural profession, leaving the land uncultivated. Also, the increased incidents of crop depredation by wildlife, mainly due to abandoning of traditional wildlife management practices, have contributed to further decline in the farming sector." The following section outlines some ideas which could not only sustain the agriculture sector in these regions, but also provide India with an opportunity for a different kind of north-south cooperation by soliciting better cooperation from Nepal with regard to water resource management. This in turn, will have direct implications on the fate of the Ganga River.

6.9 CAN THE SIKKIM EXAMPLE OF ORGANIC FARMING BE REPLICATED?

In 2003, in a bold and unprecedented move, the Sikkim government banned the import, manufacture, sale and use of all chemical fertilizers and pesticides. This decision was especially significant for India, a country whose food security and increase in agricultural productivity is largely attributed to the introduction of hybrid seeds, chemical fertilizers, and pesticides in the early 1970s. In January 2016, Sikkim became the first and only Indian state to be declared as '100% certified organic', thanks to the committed efforts by its former chief minister Mr. Pawan Kumar Chamling, the support from Sikkim's Agriculture Department and most importantly, the courage and conviction of the farmers of Sikkim.

However, this path-breaking transition has not been without its share of challenges. Sikkim farmers have been finding it difficult to cope with pests and diseases and there is a considerable time lag in finding appropriate markets for their organic produce. But the government is now trying to overcome these challenges by providing better information and training to its farmers, focusing on value addition, branding, and global marketing of its high-quality organic products such as red cardamom, ginger, rice, buckwheat, and tea. Eliminating chemical fertilizers and pesticides has also helped local wildlife.

Therefore, it is strongly recommended that organic farming be introduced since it lends itself naturally to the conservation of genetic diversity by giving preference to native crop varieties. These are highly nutritious and resilient to adverse impacts of climate change, since they can tolerate drought conditions as well as heavy rainfall. Conserving native crop varieties by establishing seed banks and promoting native varieties amongst consumers will not only help conserve rich agro-biodiversity but also boost incomes of small farmers and improve public health. Simultaneously, there is a need to put in place policies that require detailed risk assessments of GMO crops before approving them for commercial cultivation, in order to preserve and protect its rich agro-biodiversity, and to gain credibility in the global organic food market. Farmers and breeders can use the crop-wild-relatives for producing new varieties with such traits by crossing them with cultivated varieties.

In terms of its climate and topography, Sikkim and the regions mentioned above are biogeographically contiguous. Their ethnicity, cuisine, and agricultural history are very similar. These regions already have a flourishing tourism industry thanks to their majestic snow peaks and rich biodiversity. better information and training to its farmers, focusing on value addition, branding, and global marketing of its high-quality organic products such as red cardamom, ginger, rice, buckwheat, and tea.

The fact that Nepal, Uttarakhand, and Himachal Pradesh have significant fiscal as well as geo-political challenges could be a problem to make the transition to organic. This is a golden opportunity for Sikkim to lead by example and help its neighbouring regions during its transition to organic farming. Herbs, medicinal plants, honey, resins etc., give more value than conventional or ‘husbanded’ crops. Nepal, Uttarakhand, and Himachal Pradesh could focus more on these non-timber forest products which have much higher rate of returns to investment than conventional crops.

There are some proactive actions being taken by governments and civil society organizations, such as promoting balanced use of fertilisers, production of organic manures through vermiculture, effective plant protection measures, soil and water conservation, diversification of agriculture through micro-irrigation and other related infrastructure, promotion of organic farming, precision farming and diversification of agriculture. They need to be strengthened by solving the issues related to lack of financial and technical aid, knowledge gap and inconsistent policies. These weaknesses need to be identified and addressed in order to make these regions self-reliant not only in terms of agricultural production but also for providing employment to the rural population. Therefore, India must prioritize cooperation with Nepal by offering help to Nepali farmers in the Terai region

to make the transition from chemical agriculture to organic farming. It can also make efforts for enhancing profitability from organic farming by assisting with training in organic practices, organic certification, and branding, marketing, and even import of organic farm products from Nepal. That said, it cannot be forgotten that Uttar Pradesh and Bihar would have to substantially reduce their usage of chemical pesticides and fertilizers if the benefits of shifting to organic farming in Nepal, Uttarakhand and Himachal Pradesh are to cascade into pollution abatement in mainstream Ganga.

6.10 CONCLUSIONS AND RECOMMENDATIONS

1. As a consequence of Climate Change leading to drying of springs, disappearance of *bugyals* (pasturelands), and non-viability of agriculture/horticulture, there has been a continuous migration of youth to the plains and a significant portion of farmlands have been abandoned. This has also led to land degradation. A large portion of women, children and elderly who are left behind, are unable to look after the cropland, disrupting the economic and traditional social structure in Uttarakhand and large parts of Nepal.

It is recommended that the ecosystem people who are the ‘keepers of the mountains’ are provided with supportive measures so as to sustain their lifestyle and livelihood options. In this regard, the development of health and educational facilities can go a long way to discourage migration.

2. The wool market of the pastoral communities has, until recent times, been largely informal.

Therefore, it is recommended that market linkages such as establishing cooperative systems of purchase and sale. Initiatives such as providing looms, training centres for new designs and innovation need to be taken up in order to provide employment to women and elders.

3. Organic farming also aids in the conservation of genetic diversity by giving preference to native crop varieties which are not only nutritious, but also resilient to adverse impacts of climate change since they can tolerate drought conditions as well as heavy rainfall. Therefore, it is strongly recommended that a mechanism be created for conserving native crop varieties by establishing seed banks and promoting native varieties. It is imperative to take lessons from Sikkim’s model of organic farming.

Further, it is recommended that detailed risk assessments of GMO crops be conducted as part of routine policy matter, before approving them for commercial cultivation, in order to preserve and protect its rich agro-biodiversity, and to gain credibility in the global organic food market.

4. The genetic diversity of the HKH also has global significance. The variety of crops grown by farmers could serve as potential genetic resources for improving crop yield

and pest resistance. This will be essential to support global food security in a world where shrinking crop diversity has left us vulnerable to climate change.

Therefore, it is strongly recommended that organic farming be introduced since it lends itself naturally to the conservation of genetic diversity by giving preference to native crop varieties. Quality seeds and mixed agricultural practices suited to hill agriculture have to be developed for accessibility and affordability to small and marginal farmers.

5. There is a good potential for promoting cultivation and sale of aromatic and medicinal plants in the region.

It is recommended that proper financial support, training and infrastructure be provided to support this activity.

6. Providing basic amenities such as medicine, education, shelter, electricity is essential. But this cannot be used as a justification to further promulgate destructive river valley projects.

Therefore, it is recommended to explore and focus on alternative livelihood and support options such as eco-friendly tourism, home stays, etc. which are well tuned with the natural ecosystems and its seasonal cycles. Young shepherds could be encouraged to use their knowledge about mountain routes in guiding trekking expeditions, etc. while at the same time being able to practise their traditional pastoral livelihood.

7. The inconsistent rainfall pattern with higher intensities of rain and fewer number of rainy days have become a frequent phenomenon in the Himalaya. Increasing flooding due to Extreme Point Rainfall Events (EPRE) will have unprecedented impacts on agriculture in mid-western Terai, leading to crop damage. Such events are likely to increase in coming years. For these reasons, farmers are shifting away from the agricultural profession, leaving the land uncultivated.

It is recommended that, in order to respond to the depleting agro-biodiversity, gene bank be established for the entire area of Uttarakhand and Nepal in order to preserve the traditional crops. Such crops could be incentivized by providing a Minimum Support Price (MSP) and agricultural extension services for shifting them to 'organic farming'. In addition, financial assistance for small scale entrepreneurs, who can provide drying, bottling, preserving, packaging services, in order to tap the high-end markets for the organic produce, should be facilitated. Private small-scale units (individual farmers) or farmers'-cooperatives can both be supported as optional organizational forms.

8. This situation has also led to a class and caste/tribe conflict, with settled agriculturalists claiming a superior position in the social hierarchy. Such conflict exists in many villages where there is an overlap between pasturelands and agricultural or forest lands.

It is recommended that such conflicts be overcome through a process of iterative negotiations

if government agencies and stakeholders have the political and social will to resolve these issues.

ENDNOTES :-

61. Environmental-Determinism: A view that the physical environment pre-disposes societies and individuals towards a specific development trajectory. The 'Developmental-Trajectory' is decided primarily by the physical and environmental factors.

62. Bactrian camels are one of the very few large bovine animals (e.g., cows, buffaloes, yaks, mithun (Bos frontalis), etc.) which can survive in altitudes ranging from 12,000 ft to 17,000 ft.

63. Archaeologists and geologists acknowledge that in 2000 BCE, 200 BCE and 850 CE, great tectonic upheavals are known to have occurred, creating new faults and valleys which changed the courses of rivers.

64. Proto-historic period: the transition period between prehistory and the earliest recorded history i.e. prior to the emergence of writing. Duration of this period is circa 2500 BCE. to circa 600 BCE.

65. Historical period: information about this period is available in written records. This was a period of human civilisation and historical activities after 600 BCE are included in this period.

66. Manusmruti: The Manusmṛ iti is an ancient legal text among the many other texts which sheds light onto the societal structure of the ancient society from around 200 BCE and 200 CE.

67. Kshatriya: Kshatriya is one of the four varnas (castes) of Hindu society, associated with aristocracy.

68. Mlechchas: Mlechcha or Mleccha (from Vedic Sanskrit 'mlecchá', meaning "non-Vedic", "barbarian") is a Sanskrit term referring to foreign or barbarous peoples in ancient India.

69. Bhagwat Purana: one of the texts of ancient India.

70. Vaishnavism: a sect in Hindu society which worships Lord Vishnu.

71. Kaurava: Kaurava is a Sanskrit term which refers to descendants of Kuru, a legendary king of India who is the ancestor of many of the characters of the epic Mahabharata. Usually, the term is used for the 100 sons of King Dhritarashtra and his wife Gandhari.

72. Mahabharata: Mahabharata is one of the two major Sanskrit epics of ancient India, the other being the Rāmāyana. It narrates the struggle between two groups of cousins in the Kurukshetra War and the fates of the Kaurava and the Pāndava princes and their successors. It also contains philosophical and devotional material, such as a discussion of the four "goals of life" and purpose of life.

73. Skanda-purana is the largest Mahāpurāṛ a, a genre of eighteen Hindu religious texts.

74. Many of the observations made above emerged during interviews and discussions during our field trip to various villages in the Chamoli district, November 2019.

75. 'Crop-wild-relatives' are wild species of plants that are genetically related to cultivated crops. They continue to evolve in the wild without any intervention by humans, and develop traits such as drought tolerance, disease, and pest resistance, etc.

76. The field visit to Garhwal Himalaya was conducted from 13th to 25th May 2019. Studies were conducted in 5 villages in Uttarakhand i.e., in and around Dewal (which is a market place in district Chamoli), viz. village Lohajung near Roopkhund, village Himni about 60 kms from Dewal (all in Chamoli district), Gwaldam and Chinki village which has a Bhotia community. Asharodi and Mohond villages on the road from Dehradun to Saharanpur, which were primarily Vana-Gujjar villages. Besides these villages, information was also collected from Bedni-Bugyal and Roopkund.

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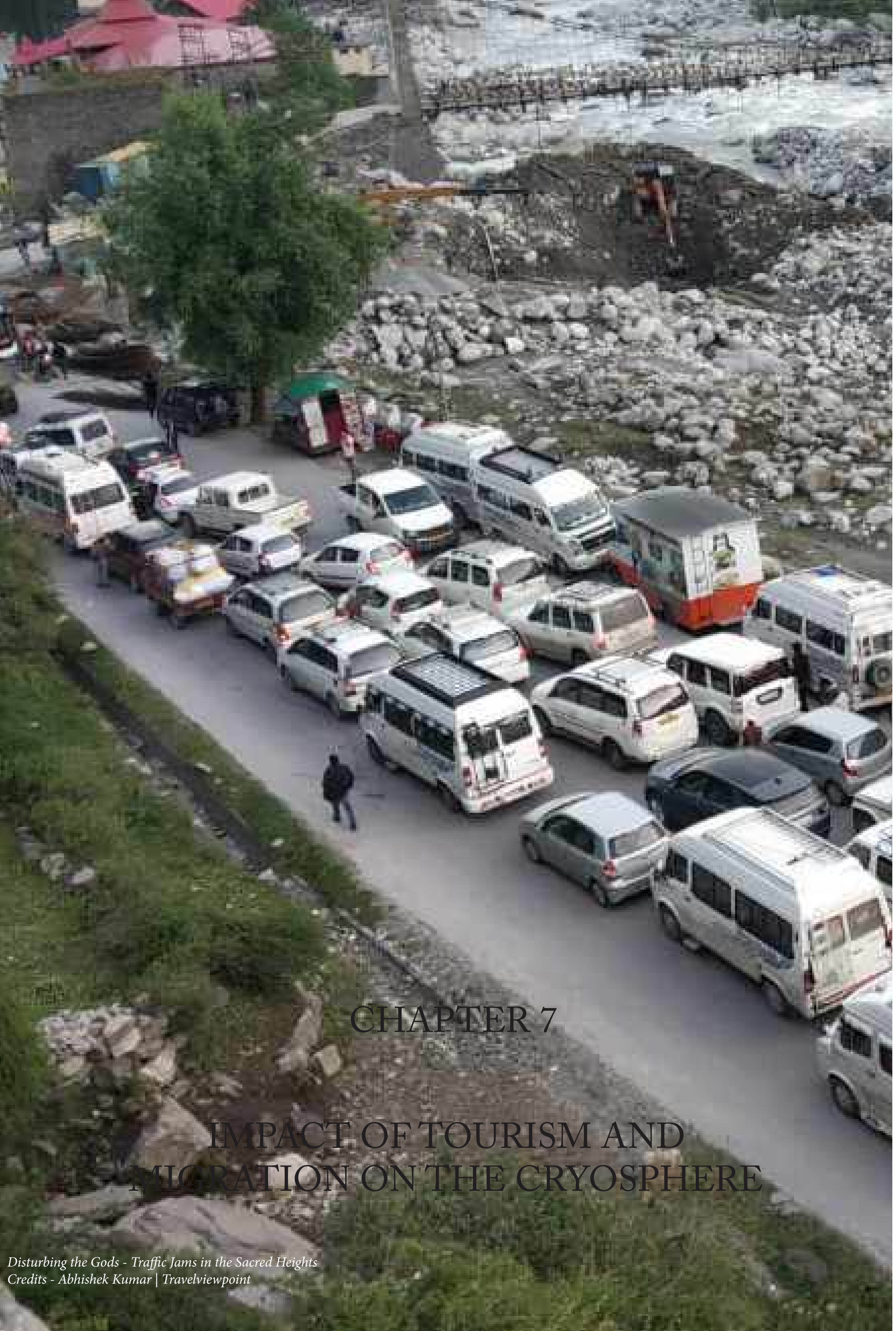


CHAPTER 7

IMPACT OF TOURISM AND MIGRATION ON THE CRYOSPHERE

Disturbing the Gods - Traffic Jams in the Sacred Heights
Credits - Abhishek Kumar | Travelviewpoint

7.1 INTRODUCTION

Although vulnerability to climate change is generally considered to be the most critical factor for advocating 'livelihood diversification', over the years, mountain communities in Nepal as well as in the Indian states of Uttarakhand, Himachal Pradesh and Sikkim have adapted to several non-climatic changes. The liberalisation of the economy in 1991 in India and its subsequent tilt towards a market-oriented economy, a major political shift from aristocracy to democracy in Nepal, and cultural changes driven by tourism resulted in diversification of livelihoods. Studies have shown that most communities do not respond to climate change risks in isolation, and we need to look at the larger socio-economic factors that are highly contextual in order to fully understand when, how, and why communities choose to change their livelihood strategies *(Dhakal, 2014; Lama et al., 2019; Parsons & Nalau, 2016).*

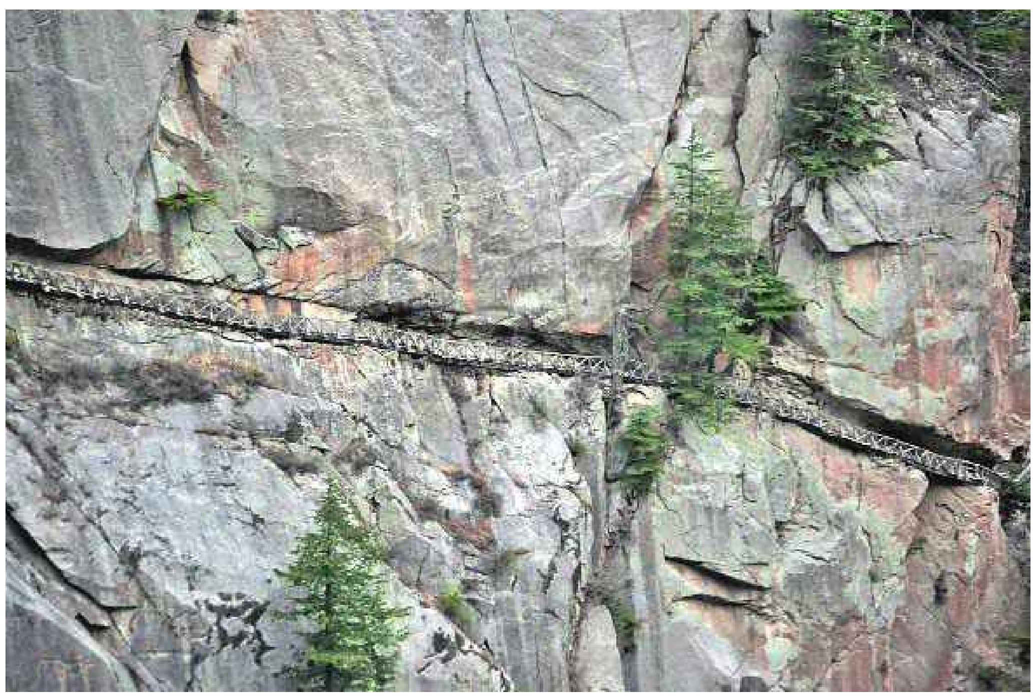
While mountains provide abundant resources to humans and other species, the communities living in the mountains have ironically been experiencing deterioration in their well-being. At the turn of the 21st century, about 30% of the mountain population was recorded as being 'below the poverty line'. While the population living in the plains had been experiencing an improvement in economic well-being by the year 2012, the percentage of population below poverty line in the rest of the Hindu Kush Himalaya increased to a phenomenal 49%. Fortunately in the case of India, Himalayan states such as Himachal Pradesh, Uttarakhand and Sikkim, the exact opposite phenomenon appears to have occurred. In these states there was a rapid reduction in the percentage of the population below the poverty line. The rate of economic growth in Uttarakhand has been well above the national average and it has ranged between 8% and 12% during the period 2005 to 2012. This could be partly explained by a huge growth in tourism and pilgrimages, as well as due to a sudden increase in remittances from internal and external migration. Both in India and Nepal, people travelling abroad for jobs, started sending home large foreign remittances.

These areas mainly attract tourists for pilgrimage, trekking, mountaineering and adventure sports, whereas, the Terai region attracts tourists to its Protected Areas and National Parks[77].Places of pilgrimage like Char Dham sites in the Indian region, Swayambhunath and Buddhist places of worship such as Lumbini in Nepal, also attract a significant number of tourists. Aside from the natural beauty, mountaineering, and adventure sports, most tourists are also interested in local food, traditions and culture. Thus, there is a rising potential for homestays and farm stays which are beginning to gain popularity. Home stays are a low-impact activity since they utilise existing infrastructure and resources, although in many cases, home owners upgrade a few rooms and toilets in order to suit the requirements of tourists.

Adventure tourism has hugely influenced the change from spiritual and agro-pastoralist socio-economic values to a more tourism-centric, economic value system, especially among the Sherpa community *(Spoon, 2011)*. While tourism brings in much needed foreign exchange and boosts the economy, its impact on the local culture and the environment needs to be understood and cautiously addressed.

7.1.1 Tourism in Uttarakhand

Prior to the 8th century, the number of *sadhus* and pilgrims visiting areas above the Shivaliks was limited. The numbers rose to a few hundred by the 18th Century, since there were no motorable roads in the Himalaya, and all travel was either on foot or on horse-back. The Chhota Chardham yatra was designed in the 8th century by the reformer and philosopher Shankaracharya (Adi Sankara). This Chhota Char Dham Yatra included representatives from all three major Hindu sectarian traditions, with two Shakti (goddess) sites, (Yamunotri and Gangotri), one Shaiva site (Kedarnath), and one Vaishnava site (Badrinath). Prior to the commencement of this Chhota Char Dham Yatra and other religious sites, the number of pilgrims visiting these regions was very small. Only *yogis* and *sadhus*, or highly devout pilgrims, who dared to brave the harsh, cold climates of the mountains with minimal facilities, visited these areas. After 1866, when the British decided to establish the town of Mussoorie, a small road was built from Dehradun to Mussoorie, and by 1901, a railway line was constructed from Dehradun to Mussoorie.



Gartang Gali, Cantilevered Walkway, Nelong Valley, Uttarkashi used by Bhotia tribesmen to go to Tibet for trade *(Ramola, 2022)*

For several centuries prior to the Indo-China War (1962), the old route from Nelong valley connected Uttarakashi with Tibet. However, this route was closed after the Indo-China War and with this closure, a major religious and cultural connection between the Buddhists in Tibet and the Hindus in Uttarkashi was ruptured.

However, post-Independence, with improved transportation, accommodation and other facilities, the number of tourists visiting the mountains increased rapidly. While this provided a considerable source of livelihood to the locals as guides, hoteliers, home-stay owners, etc, there was also a growing pressure on the natural resources. This chapter elaborates how this has simultaneously distorted the local value system as well as ecological ethics. The number of tourists and pilgrims increased so rapidly that public amenities and private accommodation could not keep up with the demand. The following section explains the changing scenario with regard to tourism in these regions, and its impact on the Cryosphere and the rivers.

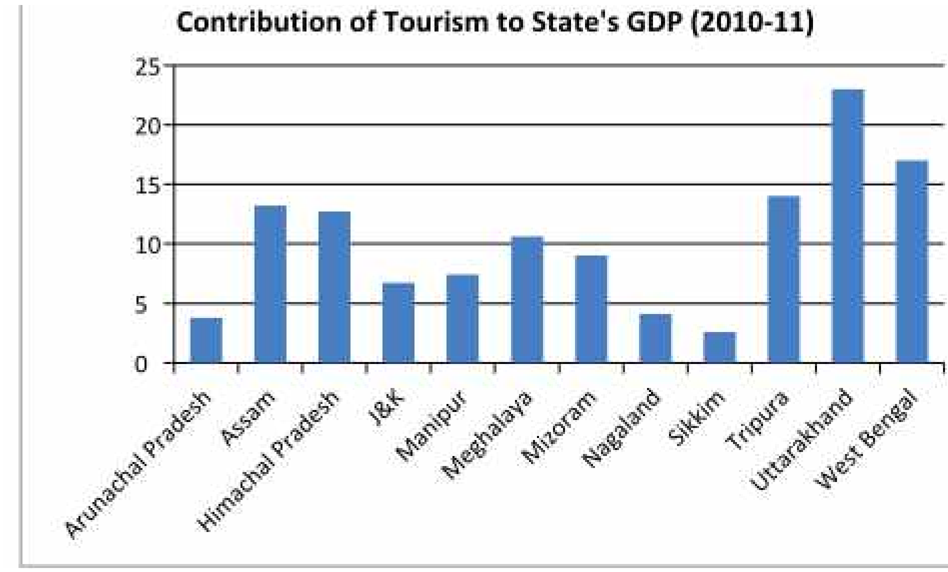


Table 7.1 Contribution of Tourism to Indian State's GDP (2010-11). Note the highest contribution in Uttarakhand state

(Gaur & Kotru, 2018).

Tourism has arguably been one of the most important sectors of the region's economy. In Uttarakhand, tourism has not only contributed to over 50% of the Gross State Domestic Product (GSDP) from 2006-07 to 2016-17 but has also provided livelihood to all the districts in the State, including the hinterlands. The number of tourists has consistently increased from around 19.45 million in 2006 to 31.78 million in 2016 *(Uttarakhand Tourism Development Board).*

7.1.2 Tourism in Nepal

Nepal is a land-locked country, but the absence of beaches and oceans is more than compensated by its majestic snow-covered peaks, glaciers, and lakes. Nepal is home to eight of the twelve tallest snow-clad mountain peaks in the world, including Mount Everest, whose height continues to increase by 4 mm. each year, consequent to the primordial tectonic movement of the Indian plate towards the Eurasian plate.

According to a report published by the World Travel and Tourism Council, in 2018, the tourism industry in Nepal generated USD 2.1 billion and created direct and indirect employment for 1 million people. In the last two decades, the number of tourists visiting

Nepal has more than doubled from 4,63,646 visitors in 2000 to 11,73,072 visitors in 2018, with a drastic decline during the Covid pandemic*(Ministry of Culture, Tourism and Civil Aviation, Govt. of Nepal, 2020)*. If these numbers are any indication, it is evident that tourism is a key factor that will determine Nepal's fortunes in terms of revenue earned and employment generated on the one hand, and its impact on Nepali society, culture, and the environment, on the other hand. The Nepal government had launched a campaign called 'Visit Nepal 2020', with the goal of attracting 2 million tourists in 2020.

7.2 TOURISM-RELATED POLICIES IN THE HIMALAYAN REGION

In India, the first Tourism Plan was laid out in 1945 by a committee set up by the Government under the leadership of Sir John Sargent, the then Educational Advisor to the Government of India. The tourism planning approach further evolved under the Second and Third Five-Year Plans. The Sixth Five-Year Plan emphasised tourism as an instrument for economic development, integration and maintaining social harmony. Further, after the 1980s, tourism gained momentum as an employment generator, source of income, source of foreign exchange earnings and as a leisure industry. The Tenth Five-Year Plan (2002-2007) made special provisions for promoting adventure tourism, wellness tourism which included traditional health practices like Ayurveda, shopping centres for traditional crafts and pilgrimage spots in the Himalayas.This led to a rapid increase in creating tourism related infrastructure i.e., construction of roads, accommodation facilities, etc.

In Nepal, the first Tourism Master Plan was drafted in 1972, leading to the creation of the Ministry of Tourism in 1978. Similar to India, post-1990s, tourism was regarded as a means of eradicating poverty and achieving overall economic development. The current priorities of Nepalese tourism are broadly shaped by the Tourism Policy of 2008, Nepal Tourism Year (2012), and Tourism Vision (2020). These policies aim to develop tourism infrastructure, increase tourism activities creating employment in the rural areas and sharing the benefits of tourism at the grassroots level. However, currently these are limited to the central regions of Nepal, while the western region is largely neglected.

7.3 IMPACT OF INCREASING TOURISM

While the impact of these policies has helped to increase tourism and has provided an economic boost in these regions, it has also led to environmental problems such as increasing water pollution levels in water bodies, pollution in glaciers, forests and valleys, deforestation for transport and accommodation. The waste management infrastructure has not evolved to keep pace with the influx of tourists, leading to littering and open defecation along trekking routes and glaciers *(Basumatary et al., 2019)*.

Unregulated, Unplanned Growth of Kathmandu City, Nepal
(Source: Kaspersk, 2014)

The unregulated nature of tourism is causing serious threats to the biodiversity in the region, with several species facing extinction. Hill stations like Shimla, Nainital, Mussoorie, Manali and others are already battling with a water crisis and outbreak of waterborne hepatitis because of improper sewage and garbage disposal. Thus, tourism in these areas has adversely impacted the fragile Himalayan ecology.

7.4 BHUTAN TOURISM MODEL

Bhutan, a country with a mystical culture and heritage, was historically a closed society, but opened itself to tourists in 1974. Its high-value low-impact tourism policy has been much talked about, and debated. Bhutan's King Jugme Singye Wangchuk introduced the concept of 'Gross National Happiness' (GNH) for the first time in 1972 as a paradigm for alternative development. This refreshing approach in a world fraught with violence, crime, corruption, and environmental degradation suddenly seemed to wake everyone up. The 2008 global financial crisis further raised serious questions about the sustainability of the western model of liberal capitalism. In 2012, the UN introduced the 'International Day of Happiness' which commemorates and recognises happiness as a human right. Lately though, Bhutan's ranking on the happiness index has slid to the 97th position. The youth unemployment rate rose to 13.2% in 2016, and some say the income gap and environmental degradation is also increasing. Radio host NamgayZam, championing the cause of mental health issues and GNH says that "the idea of GNH may have put Bhutan on the world map, but the concept has been hijacked by the West and quantified to a degree which makes it unrecognisable to the ordinary Bhutanese". Gross National Happiness is rooted in the tenets of Buddhism, Bhutan's state religion, with its focus on compassion, contentment and calmness. Further, she insists, 'You can't quantify Buddhism'. Yet, she says she has an abiding belief in the philosophy underlying GNH, if not the packaging *(Mccarthy, 2018)*. Let's take a closer look at Bhutan's unique tourism policy. The Policy was aimed at attracting tourists who were willing to pay more for a high-quality experience. This approach was expected to bring in greater revenue (and happiness) to Bhutan without putting unnecessary stress on its environment and at the same time maintaining its socio-cultural identity. The Bhutanese government fixed the tariff for foreign tourists at USD 250 per person per day during peak season and USD 200 per person per day during off-season. This way, the government promises a unique cultural, culinary and visual experience to every tourist while ensuring a good income to Bhutanese people and the lowest possible impact on the environment. Although there are several reports of Bhutanese tour operators undercutting the government tariffs and offering cheaper alternatives to tourists, these seem to be exceptions rather than the rule. By and large, the high-value low-impact tourism policy seems to have more benefits than pitfalls for Bhutan. But can the same strategy be implemented in Uttarakhand, Himachal Pradesh and Nepal as a whole?

Nepal has been perceived as an 'inexpensive' tourist destination, right from the beginning. While it is true that Nepal also offers high-end accommodation and travelling options, it is better known for its budget options that fit the backpackers' pocket. In recent years, rising tourism in Nepal and other popular destinations in the Himalayan regions such as Ladakh and Sikkim have prompted policy makers to re-evaluate their tourism policies for regions that are ecologically fragile and culturally unique. In Nepal there are increasing concerns over the pollution created from tourism. Ever since the first successful ascent in 1953, by Sherpa Tenzing Norgay and Sir Edmund Hillary, Mount Everest has become notorious for the human waste, garbage, and objects such as oxygen cylinders and food cans that are thrown away by mountaineering tourists. Eleven climbers died on Mount Everest in 2019 due to overcrowding and asphyxiation at the summit. Investigations revealed that this was mainly because excessive climbing permits (381) were issued. Everest climbers are charged USD 11,000 as permit fee, and equipment and other arrangements bring the total cost to about USD 45,000 per climber, and the gross revenue earned from Everest climbers every year is estimated at USD 300 million. But Nepal is paying a big price for the rapid degradation of the Himalaya, which may ultimately lead to loss of tourism and therefore loss of revenue.

Cities like Shimla, Kullu-Manali, Kathmandu have also become crowded with tourists, and pollution from tourism is becoming a growing concern. Bhutan's model would be ideal for sustainable development of tourism. However, this would be a challenging task, since tourism in these Indian states and Nepal has evolved in an ad hoc manner, without a long-term plan. Nepal and its people kept adapting and improvising to cater to tourists. In a sense, this informal nature of tourism in Nepal is also one of the reasons why it is so appealing for tourists. Ironically, many foreign tourists 'expect' to see the 'third worldness' when they travel to Nepal or even to India for that matter, and one fears that these destinations would lose their 'third world appeal' if the tourist experience was made too standardised and sanitised, not to mention the increased price tag!

Also, if Nepal implemented a tourism policy of high-value low-impact, it is possible that fewer Nepali people will be involved in the tourism sector, at least in the initial phase of this transition. Today, more than one million people in Nepal directly or indirectly earn their livelihood from tourism. If Nepal decides to follow the example of Bhutan and focuses on getting fewer but high-paying tourists, there may be a push-back from the public, especially from owners of small (budget) hotels, food stalls, rental jeeps, informal tour guides, etc.

Tourists' perception of Nepal as a budget destination, the dependence of a large number of Nepali people on the tourism industry, and the imminent degradation of the environment and increased consumption of natural resources presents a difficult challenge to the Nepal government in deciding the future direction of Nepal's tourism industry. Rather than fully adopting Bhutan's high-value low-impact policy, a more pragmatic approach would be for Nepal to continue with the existing model of tourism but with greater monitoring and control on solid waste, pollution, and other haphazard infrastructural developments, especially along rivers, mountains and ecologically sensitive areas. Home stays and agro-tourism must be promoted since these are now universally accepted as integral components of an environmentally sustainable, economically viable, and socially acceptable tourism paradigm.

The states of Uttarakhand and Himachal Pradesh have tried to include some of these principles in their latest tourism plans. For instance, the Himachal Pradesh Tourism Policy of 2019 defines the following objectives for developing tourism sector in the state: to promote Tourism

Diversification through theme-based development, to safeguard state's tourist destinations through sustainable interventions, to ensure that sustainable tourism primarily benefits host communities, to build capacity and develop quality human resources for the tourism industry, to provide safe, secure and unique "Tourism for all" and to create an enabling environment for investments for sustainable tourism (Department of Tourism and Civil Aviation, 2019).

The Uttarakhand Tourism Policy of 2018 aims to create theme-wise destinations which can lead to diversification, focusing on the unique selling proposition of the natural resources and heritage sites related to pilgrimage centres and cultural sites, adventure sites, wildlife and biodiversity landscapes, centres for health and rejuvenation combined with the principles of eco- tourism and rural tourism. The concepts of eco-tourism, rural tourism, home-stays and agro- tourism are becoming popular, though not at the rate at which the demand for tourism services is increasing. Therefore, there is a need to have a strategic and integrated intervention in changing the nature of tourism similar to Bhutan in these two states as well.

7.5 GROWTH OF REMITTANCE ECONOMY IN THE CENTRAL HIMALAYAN REGION

7.5.1 Remittance Economy: Himachal Pradesh and Uttarakhand

While the tourism industry has grown considerably, it has benefited very few people and has not led to much improvement in the quality of life of the local communities. Many villages have been abandoned due to lack of basic infrastructure facilities,. The younger generation has moved to the mainland and to larger cities in search of employment opportunities, leaving behind the older generation, women and children to look after the lands and the forests. The States of Uttarakhand and Himachal Pradesh have witnessed intense mass migrations internally and internationally for well over a century. Both these states (and the adjoining country of Nepal) are heavily dependent on remittances from internal migrants. In Pauri Garhwal district of Uttarakhand and Hamirpur district of HP, over 40% of households receive remittances, the highest from region of India. The household remittance to Net Domestic Product (NDP) ratio was higher than 20% in Uttarakhand and Himachal Pradesh reflecting higher dependency on domestic remittances in these States *(Tumbe, 2011)*. This reflects high out-migration from these states due to relatively better economic opportunities in other states during this period.

While the migration history in some districts of Uttarakhand goes back to the 1940s, it seems to be a recent phenomenon in Himachal Pradesh. Between 1993 and 2007-08, domestic (Inter-State) household remittance-dependency, as measured by the proportion of remittance- receiving households, broadly increased in rural and urban India. Many districts in these states have become remittance economies over the course of the 21st century. Most of the regions which are highly remittance-based from the 19th century onwards continue to depend on out-migration in the 21st century.

The regional histories suggest various causes for the initial waves of migration such as high population density, poverty, inequality, natural calamities, forced commercialisation and indebtedness, land tenure systems, new trade routes, better transportation, wage differentials, escape from caste barriers and better opportunities and aspirations. In addition, there is the theory of 'agricultural involution' offered by Chakravarty (1978) that attributes all the historical migrations to ecological reasons stemming from the fact that most of the 'Labour Catchment Areas' (LCAs) were rice-based economies with low productivity which kept the reserve price for labour at a low level *(Export-Import Bank of India, 2016)*.

Uttarakhand shows that out-migrations were already underway since the 1940s even though the literature suggests that it picked up in the 1980s. Pauri Garhwal's sex ratio was higher than 1,050 in 1921 itself and generally remained above 1100 in the latter half of the 20th century. Most of the migration is male-dominated, remittance-based. Two important reasons for migrations stressed in the literature are: rising aspirations for job opportunities and population pressure on a shrinking resource base. Most studies show that out-migration rates rise with education levels and are highest among the upper-caste households. Over 60% of the migration is outside the state, mainly towards Delhi and other big cities, while the rest of it is rural-urban migration within the state. A major share of the migrants are employed in jobs like domestic servants, cooks, wash boys, room boys, waiters, peons, messengers, drivers, helpers in informal manufacturing and service units, etc.

Formal sector jobs in the defence forces - for example recruitment in the Garhwal Rifles, an infantry regiment of the Indian Army, State or Central police forces and other government jobs also absorb a large number of migrants. A common recommendation is to reduce the out-migration by diversifying the agricultural base into horticultural activities, as has been done in Himachal Pradesh. However, the remittance trend shows that Himachal Pradesh itself is highly dependent on migrants' remittances and it is not clear whether agricultural diversification would help in reducing out-migration. A common theme running across the Himalayan region is that with limited scope of industrialisation and low interest in agricultural activities, migration forms the most important livelihood strategy for many households.

7.5.2 Nepal: Now a Remittance Economy

With increasing challenges in traditional livelihoods (explained in the previous chapter) and ecological non-viability of the rapidly growing tourism industry, the youth in these regions have largely moved away from these areas, looking for employment opportunities. The diagram below indicates that remittances received by Nepali families have risen from 2.5% of GDP in 2001 to almost 30% in 2018, which is a twelve-fold increase in less than two decades. Consequently, there has been a steady expansion of the middle class in Nepal. Better education opportunities and greater disposable incomes available to families from foreign remittances have resulted in a significant change in people's food choices. Thus, from an economy which was primarily based on subsistence farming, pastoralism and trade, Nepal has now transformed into a predominantly remittance-based economy with people preferring high quality food such as basmati rice which is not produced in Nepal in sufficient quantities and needs to be imported from India. The Nepalese have also started to consume more vegetables, fruits, edible oil, sugar and meat. The type of food as well as the quantity of food consumed by people in Nepal has undergone a significant change in the last decade. Moreover, the processed food industry in Nepal has also expanded, further increasing the demand for farm produce. Thus, Nepal's food import bill has gone up from USD 0.38 billion in 2010 to USD 1.30 billion in 2019, which is a three-fold increase in less than a decade *(Prasain, 2018)*.

With rising income levels, the demand for other consumer goods and merchandise has also gone up. These socio-economic changes have impacted the trade deficit from being zero in the year 2000 to USD 500 million in 2014 and reaching a staggering USD 11.3 billion in 2018. The annual rate of migration (skilled and unskilled) is about 400,000 persons per year, which is huge and this has a major impact on Nepal's own productivity. In future, as the middle class becomes more affluent and is able to afford better education, the brain drain will further increase since families prefer to send their youth abroad for further studies expecting that they will give much better returns to the family than if they had stayed in Nepal.

As per the 2011 Census in Nepal, the number of migrants increased twice as compared to the previous decade. The Department of Labour and Employment had issued an unprecedented number of 2,723587 labour permits (males mainly to Malaysia, Qatar and Saudi Arabia and females to UAE and Kuwait) within a small span of seven years, i.e., from 2008 to 2015. At the same time, migration to India has reduced from 77% in 2001 to 37.6% in 2011. These migrations increased the contribution of percentage of remittances to GDP of Nepal. It increased from 23% in 1995–1996 to 56% in 2010–2011. The World Bank 2014 report has recorded Nepal as the third highest recipient of remittances that contributed 30% to Nepal's GDP as compared to 10.9% in 2003-04.

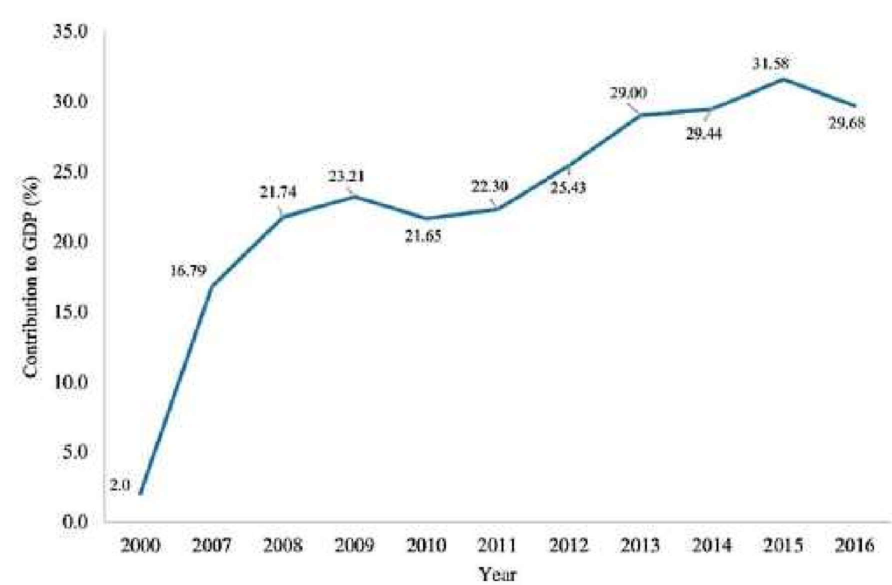


Fig. 7.1 Personal remittances received, % of GDP (Nepal)

(Source: Joshi & Khanal, 2020)

However, the trends have changed in recent times. Following the earthquake, outflows of migrants decreased as they chose to stay with their families. The slow-down in the oil industry led to a decline in demand for workers in Gulf countries. In addition, the Government of Nepal demanded a free visa and return air ticket for migrant workers while the manpower companies in Malaysia opposed the policy, which further affected remittances.

7.6 A RESPONSE TO POVERTY AND CLIMATE CHANGE

The decision to migrate is seldom influenced by one particular factor. It is influenced by

the demographic, economic, environmental, political and socio-economic situation of communities. Since farming is the only source of livelihood in most of the rural areas, and economic growth in hilly or mountainous regions is much slower as compared to urban areas, there is a tendency towards local migration to urban areas. In addition, factors such as environmental disasters due to climate change, price fluctuations, land degradation, and land-use regulations also lead to migration. Since migration to urban areas results in stable incomes, better education and employment opportunities, this is often a stepping stone to external migration for better prospects to countries like Malaysia, Middle East, etc. However, it must be kept in mind that this may not apply to all migrants and a large number end up in slums or ghettos in their own cities or in countries to which they migrate.

The relationship between climate change and migration is evident in Nepal. There are several environmental and climatic hazards that influence migration, inter alia, the important ones are, irregular rainfall, temperature rise, deforestation, river erosion, landslide, drought/lowering of groundwater level and flash floods, to name a few. These hazards have impacted the ecosystem of Nepal, resulting in the drying of mountain streams, shortage of water for irrigation and drinking, increased sedimentation, and reduction in Jhum[78] cultivation. Another case study has found that increase in time required to collect fodder and firewood, and a decline in agricultural productivity has also spurred migration *(Bohra-Mishra & Massey, 2011)*. From 2014 to 2016, Nepal has had to cope with natural as well as economic disasters. The floods in Koshi River Basin in 2014 led to a major setback to the agricultural sector. This was immediately followed by the catastrophic earthquake in April 2015 which not only destabilised the mountain slopes and the river system, but also brought a substantial part of the economy to a standstill.

7.7 THE CRIPPLING ECONOMIC BLOCKADE

Just when the economy was gradually limping back to normalcy, Nepal suffered a geo- political setback in the form of a trade blockade imposed by India. The blockade had been imposed because the new Constitution being framed by the Nepali Parliament was not quite in line with the desires of India's political establishment. Just as several major and minor tremors were physically shaking up the country, the impact of climate change was being perceived in the form of unprecedented rainfall not only within Nepal but also in the catchment areas of Sapta- Kosi in Tibet. Agricultural output was falling, there was practically no increase in employment generation and the trade blockade from September 2015 to January 2016 had dealt a crippling blow to the India-Nepal relationship. The self-esteem of people was low and their anguish against the India policies was at its highest. It is therefore no wonder that the Nepalese chose out- migration as the most preferred option for escaping the impact of climate change and economic slowdown.

7.8 NATIONAL POLICIES, LAWS AND PRACTICES RELATED TO MIGRATION

7.8.1 International Labour Migration

Most Himalayan countries have framed policies to control international labour migration. China and India, unfortunately, do not have any such mountain-specific policies either for governing internal migration or for out-migration. Migration from Nepal is governed by national, regional and international policies that govern the migration from and within HKH countries which comprise Bangladesh, India, and Nepal.

The Government of Nepal has laid down policies that will promote or facilitate migration. Establishment of a special Immigration Office which provides support and services to potential migrants has been an important institutional change. This has reduced the cost of emigration (both actual and transactional) and streamlined the remittance transfer process. This department of immigration also assists the reintegration of returnee immigrants. All these measures have proved to be very effective during the last 15 years. In pursuance of the Immigration Act 1992, the Immigration Department was established and the rules were framed in 1994. However, immigration has suddenly taken an upward direction after 2008. According to the Immigration Manual of Nepal, labour permits are issued to migrant workers. A recent report of the Department mentions that about 3.5 million labour permits were issued to migrant workers from 2008 to 2017. These were predominantly for workers travelling to Malaysia and the Gulf countries (an increase of 0.78 million permits in two years i.e., 2015 - 2017).

Further, the Government of Nepal has formulated rules and formed a Ministry to safeguard the unskilled labourers, manage recruitments, introduce restrictions on certain categories of workers etc. The promulgation of laws and policies to prevent 'human-trafficking' and their effective implementation has considerably improved the situation in the mountainous areas of Nepal. Trafficking not only includes commercial and sexual exploitation but also labour, organ trade, drug trafficking, etc. In earlier times, the protective mechanism in countries of origin as well as countries of destination remained weak. The Government of Nepal is therefore trying to introduce guidelines wherein the employer is responsible for bearing the basic cost of visa, ticket, and other expenses for the worker, whereas the migrant would pay for orientation, training, medical check-ups, the mandatory worker's welfare fund and insurance.

7.8.2 Weak and Non-Binding Regional Agreements

Regional and international instruments are important for the governance of migrants as well. Countries in the Himalayan region from where people migrate are Afghanistan, Nepal, Bangladesh, China, and India. They have come together to form 'regional consultative forums' such as the Colombo Process and Abu Dhabi Dialogues, very few of these countries have agreed upon the UN Convention, 1990 with regard to the protection of migrant workers and all members of their families, and none of them have agreed upon International Labour Organization (ILO) Conventions either. Similarly, the Domestic Workers Convention (2011), the Migrant Workers (Supplementary Provisions) Convention (1975) and Private Employees Agencies Convention (1997) which are all important for migrants, have not been ratified by several countries. It may be noted that these guidelines are not yet being fully implemented with regard to workers migrating from Nepal to India and vice versa, since there is an open border between the two countries, and has a long history of cross-migration of workers.

Internal migrants, who are relatively less educated or skilled, migrate to urban areas within Nepal. Unfortunately, they have traditionally been denied basic rights and social security, more as a matter of social and class discrimination, than as a deliberate policy. These local migrants lack access to basic education and health care. Since they do not possess identity proof, they are not allowed to buy houses and end up in informal settlements (read 'slums') that lack public amenities. These migrants however need government protection as they have to work as hawkers, domestic help, construction workers, security services, etc. Similar conditions prevail in India with regard to its internal migrants coming from rural to urban areas. The historical and socio-cultural similarities between the two countries appear to have perpetrated this phenomenon of class discrimination and injustice.

7.8.3 Remittance: Boon and Bane

It must be appreciated that migrants have contributed substantially towards the well-being of people in Nepal. Over a period of time, countries and their population have realised that migration promotes economic development, improves standard of living, as migrants earn higher wages as compared to employment in agriculture. Also, there is an increasing ratio of foreign exchange remittances as a percentage of annual GDP. A study conducted by the Nepal Institute of Development Studies and the World Bank (2009) reveals that in Nepal, migrants contributed in the form of donations for public libraries, trade schools, health care in schools, water supply in remote areas, tower clocks in village centres and computers in Nepali schools. They have also contributed to extreme catastrophes like the earthquake in 2015. The amount collected from remittances are often used to provide food and other basic needs like rebuilding shelters, livelihood and lost assets (Banerjee et al., 2011). Therefore, considering the fragility of mountainous ecosystems, depending on remittance-based economy could be helpful in providing an economic boost and at the same time, maintaining the integrity of the ecosystems.

However, sometimes, these remittances from out-migration can also lead to creation of 'ghost villages'. For instance, people in Jumla and Syangja districts in Nepal left their homes and bought land or houses in safe areas. A study in Kaski district of western Nepal found that migration led to land abandonment. Even though this resulted in an increase of forest cover in the upper part of the Harpan watershed (Jaquet et al., 2016), it had a negative impact on the lower part of the watershed, since the migration led to further denudation of the lands on the lower contours. Further, it is observed that the able-bodied working population migrates, while small children and elderly people are left behind, a common refrain among all hilly areas where the progress of the industrial economy bypasses these remote areas. Though migration and remittances provide for the daily needs of both children and elderly people, there is no one to look after the lands, forests, and streams, which are their basic life support systems.

7.9 LIVELIHOOD DIVERSIFICATION

Therefore, out-migration cannot be a solution. Sustainable long-term strategies to adapt to climate change need to be considered and implemented. However, since there are long-term solutions and require changes in societal and government perspectives, communities facing immediate hazards due to climate change inevitably opt for migration, without thinking about long term consequences. For example, an unforeseen environmental disaster in the country of adoption or a global pandemic like the recent Corona virus outbreak can completely destroy the lives of such migrants.

Further, with increasing disasters due to climate change events such as EPREs leading to landslides, floods, etc. there could be a potential reduction in the number of tourists. In such a scenario, there is a need to help the locals, dependent on tourism for livelihood, to adapt to the changing nature and demands of the tourism industry. Such adaptation strategies could range from a) increasing mobility for reducing risk (e.g. seasonal migration like the earlier communities), b) increasing production of a resource by changing land-use or pooling resources (community farming, multi-cropping patterns), diversifying income generation (creation of a livelihood portfolio from dissimilar sources e.g. farms, restaurants, provisionstores, remittances), storing and exchanging resources, or innovating new techniques to cater to livelihood needs. (e.g.exploring national and international markets for wool and handwoven fabric, as are observed in the Kutch handloom weaving sector). To understand this phenomenon, see study report entitled 'Sandhani: Weaving Transformations in Kachchh, India – Key Findings and Analysis' by *(Kothari et al., 2019)* and *(Agarwal et al., 2008; Thornton & Manasfi, 2010))*.

7.10 CONCLUSIONS AND RECOMMENDATIONS

1. Since the 1980s, tourism has evolved as one of the most important sectors providing an economic boost to the states of Uttarakhand, Himachal Pradesh as well as Nepal. While proving to be beneficial for providing livelihood options to the local communities, it has had a disastrous impact on the environment of these hilly regions because of lack of planning and monitoring. The existing trends in commercial tourism activities in the Himalayan states have direct or indirect effects such as water and solid waste pollution, over- exploitation of natural resources, food insecurity, ill-planned urbanisation, traffic congestion, loss of indigenous culture, and increase in municipal sewage impacting the Himalayan biodiversity.

It is therefore recommended that a more pragmatic approach would be for these regions to continue with the existing model of tourism but with greater monitoring and enforcement of laws (rules and guidelines) on management of solid waste, river pollution, and other haphazard infrastructural developments, especially along rivers, mountains and ecologically sensitive areas. Home-stays and agro-tourism should be promoted since these are now universally accepted as integral components of an environmentally sustainable, economically viable, and socially acceptable tourism paradigm.

2. In view of the rapidly increasing river pollution, deforestation and other forms of environmental destruction,

It is recommended that such areas be clearly demarcated and impose limits on the infrastructure development. It includes a systematic process of semi-urban and urban planning and developing tourist hubs with strict controls and legal sanctions in certain areas. For example, creation of 'no-go areas', 'no encroachment areas', clear waterways and well-preserved forested areas, would help in limiting and possibly reversing pollution and deforestation.

3. Due to increasing poverty and climate change impacts, the states of Uttarakhand and Himachal Pradesh and Nepal have witnessed intense mass migrations internally and internationally for well over a century, thus depending heavily on remittances from internal and external migrants. The relationship between climate change and migration is evident in Nepal. There are several environmental and climatic hazards that influence migration, inter alia, the important ones are, irregular rainfall, temperature rise, deforestation, river erosion, landslide, drought / lowering of groundwater level and flash floods, to name a few. These hazards have impacted the ecosystem of Nepal, resulting in the drying of mountain streams, shortage of water for irrigation and drinking, increased sedimentation and reduction in Jhum[79] cultivation.

4. Very few of these countries have agreed upon the UN Convention, 1990 with regard to the protection of migrant workers and all members of their families, and none of them have agreed upon International Labour Organization (ILO) Conventions either.

It is recommended that the national policies be modified wherever necessary in order to align them with international policies and conventions in order to protect the rights and interests of migrant female and male labour.

5. While out-migration is a short term 'resilience-option', it cannot be a permanent solution. Sustainable long-term strategies to adapt to climate change need to be considered and implemented.

It is recommended that response to climate change impacts should be in the form of focused research and policy modifications so that people are not forced to abandon their dwellings and settlements in mountainous areas due to aggravation of climate change impacts.

6. Due to increasing difficulties in the tourism industry due to climate change events and disadvantages of remittance-based economy,

It is recommended that livelihood diversification should be integrated into generation of employment opportunities, which can adapt to uncertainties in tourism trends, remittance-based migration, and climate variations Further, it is recommended that investments should be made in non-conventional avenues like high-value NTFPs, organic farming, high-end (sustainable) eco-tourism, spiritual tourism, strictly regulated pharmaceutical products, small-scale solar power plants in northwest districts like Dolpa, Humla, Jumla, Karnali, etc. In Nepal.

(These recommendations can be read along with Chapter 6 : Impact of Changing Cryosphered on Human Settlements, since the two are closely interconnected.)

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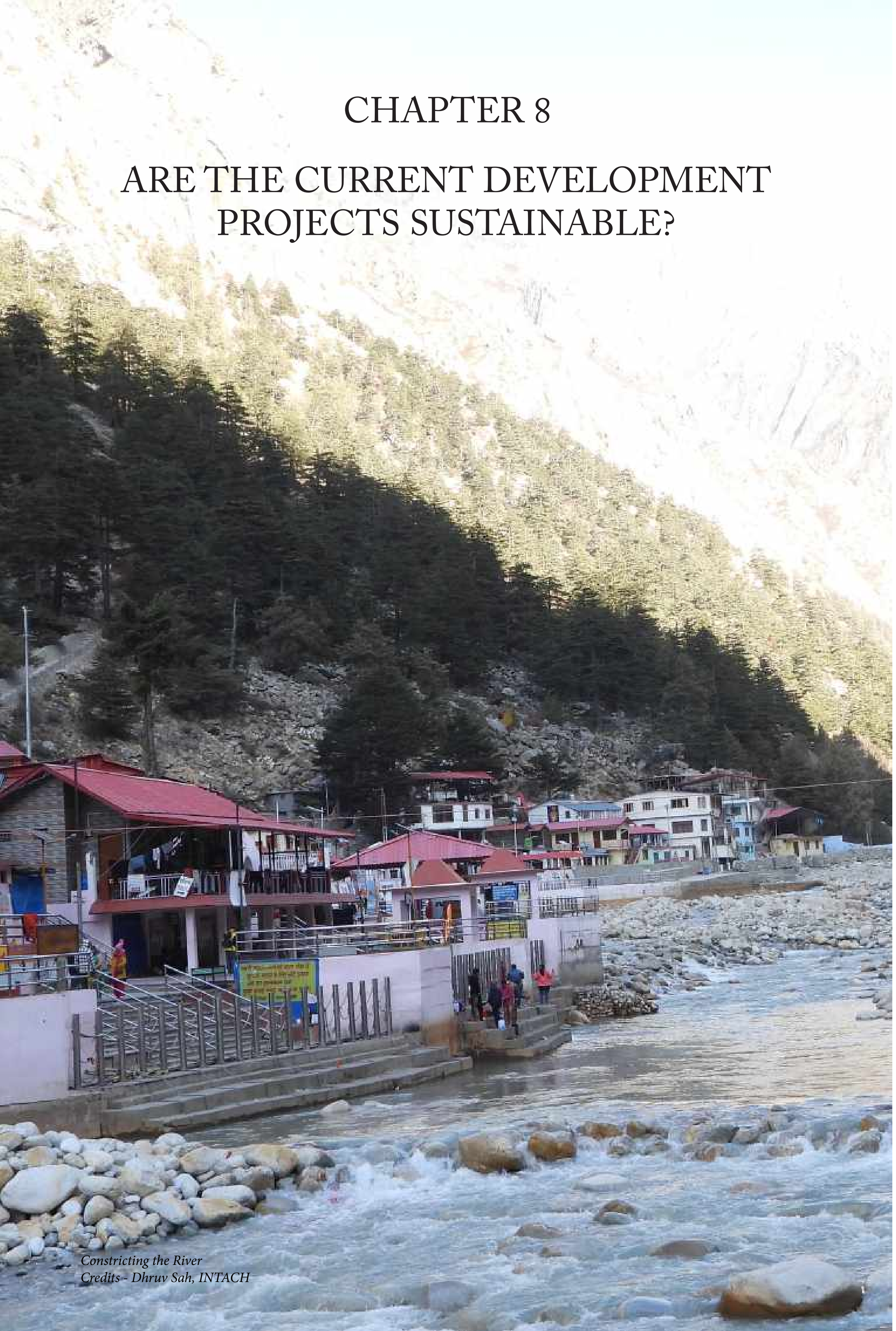
CHAPTER 8

ARE THE CURRENT DEVELOPMENT PROJECTS SUSTAINABLE?



Constricting the River
Credits - Dhruv Sah, INTACH

8.1 INTRODUCTION

When development activities on river systems first began, they were restricted to barrages and embankments. However, eventually, with progress in engineering and technology, large dams with huge storage capacities began proliferating. Further, under the facade of constructing 'run- of-river' projects (which supposedly do not alter river flows), the State departments began constructing underground tunnels which substantially diverted water from the mainstream. This fact remained sufficiently undisclosed, and therefore such projects kept proliferating under the garb of being environment friendly. Compounding the situation, the forest department transformed the Himalayan hillside by replacing the indigenous varieties of trees (broad leafed fruit and nut bearing trees) by monoculture plantations of pine trees. The emergence of border tensions across the northern frontiers created the need to deploy military power in these hilly regions, leading to an increase in roads and transport network. There were policies and Five-Year Plans for safe construction of roads with long term vision but these policies were regularly flouted for immediate returns.

While historical documentation for the mentioned period is scarce, Bhoj Taal stands out with a wealth of information and descriptions. Constructed by the Parmar Raja Bhoj of the Malwa region between 1010 and 1055, the creation of Bhopal Taal is surrounded by a vast amount of anecdotal history, succinctly captured in the proverb "*Taalo me taal Bhopal taal, baaki sab talaiya*". Undoubtedly, Bhopal Taal holds the distinction of being the first and earliest large dam artificially constructed within the Ganga River Basin. Positioned on a small tributary of the River Betwa in Madhya Pradesh, it marks the inception of major dam construction with a reservoir in the region. Throughout its existence, the structure has undergone renovations, refurbishments, and enlargements.

In 1965, the dam received reinforcement with the construction of the Bhadbhada dam, situated at the southeastern corner of Bada Talab. Presently, it plays a crucial role by supplying 140,000 cubic meters of water daily to approximately 40% of Bhopal's population. Anecdotally, Bhoj Taal's creation involved the merging and channelizing of water from 365 small streams across the entire upper catchment, resulting in the formation of a vast artificial lake. In the first half of the 14th century, Firuz Shah Tughluk, the ruler of North India, undertook the commissioning and excavation of a double system of canals. Subsequently, in 1631 and onward, Emperor Shah Jahan initiated the construction of the Eastern Yamuna Canal System. This vast canal system, of imperialistic proportions, was designed to support the plains of the Yamuna River between the Sutlej and Yamuna. Functioning for 400 years, the western Yamuna Canal System eventually fell into dilapidation.

The British imperial army, specifically the Bengal Engineering group, took up the task of rebuilding the Ganga Canals in 1817. The Yamuna Canal System, running almost parallel to the Ganga Canal System, had its water releases controlled by the well-known barrages – Dark Pathhar (commissioned on 23 May 1949, Uttarakhand), Hathani Kund (replacing the Old Taajewala Barrage in 1999, Haryana), and Taajewala Barrage. Additionally, the British initiated the construction of the Ganga Canal system from 1842 onwards. This intricate network of canals, with a total length of 6400 km, presently irrigates 9 lakh hectares of agricultural lands, standing as a testament to engineering marvel. These structures, dating back to the pre-independence period, have withstood the test of time, becoming ecologically naturalized as sustainable human interventions. Before the British era, the criterion for managing these systems was based solely on the whims of the emperors. Ancient intuitive knowledge of hydrology and engineering guided projects to completion. However, it was during the British period that advanced hydrologic engineering and architecture were deployed for the construction of public works.

Stream Flow Being Diverted Through A Channel And Water Traveling Down A Wooden Channel Generating Hydraulic Energy, Which Turns The Blades Around A Fulcrum, Which Eventually Turns The Stone Milling Wheels

The Grain Holder Hanging Above, Gradually Dropping Grains Into The Grinding Mill-Stones

(Source: Rawat, 2021)

However, in spite of there being examples of well-planned cities like Chandigarh, Himachal Pradesh and Uttarakhand saw rapid, unrestricted growth in infrastructure projects. In addition, the establishment of Uttarakhand as an independent state brought with it a new set of socio-political demands for development which basically required development of infrastructure projects which epitomize economic progress.

8.2 TRADITIONAL TECHNOLOGICAL INTERVENTIONS

Till the end of 19th century, human interventions were restricted to shaping of lands, creating of terraces, and diverting excess water flows into streams and rivulets. Bridges across streams were built out of large logs for reducing travel distance between villages. The most reliable and sustainable technology adopted on streams was the '*panchakki*' for grinding flour. Trails were marked out between villages and towns, and sometimes rock faces were cut where hard rock or dykes were encountered. Major trade routes from the Shivaliks to Tibet were created by making paths or cutting steps in soft rock; in order to ford streams and rivulets. Such technological interventions were handcrafted, cheap, replicable, and environmentally sustainable over centuries.

The best-known suspension bridge, Laxman Jhula, built using jute ropes enabling draught animals or head-loaders to go across small river gorges, is another example of the existence of sustainable traditional knowledge and technology. The 86.6 m (284 ft) long hanging bridge was built with a thick jute rope, and there are records of its existence till 1889. The jhula was said to have been built to commemorate an extraordinary feat from epic Ramayana of Laxman to cross the Ganga River with help of ropes. This bridge was later repaired and reconstructed by Raibahadur Jhunjhunwala and UPPWD. The nature of these sustainable, traditional technological interventions saw a rapid transition with the incoming imperial and colonial power, which also led to a transformation in the social structure, as elaborated below.

8.3 TRANSITION FROM AN 'ECOSYSTEM COMMUNITY' TO AN EXPLOITATIVE CULTURE

The Colonial and post-colonial period is marked by arrogant and reckless exploitation of all possible natural resources and services using inappropriate technology, and social exploitation of the traditional communities by economic and political sharks. Transport and accommodation facilities, mainly roads, enabled the non-naturalized communities to take advantage of the regional resources. Traders from the plains, commercial exploiters and technologists who were seeking hydropower and other resources settled in the lower and middle hills had a predatory mindset. These outsiders started co-opting the resident communities into exploitative practices. Such complicity led to erosion of the evolved codes of livelihood and conduct of the ecosystem people, eventually converting some of them into predators themselves. This broke off the tenuous balance and relationship between the fragile, natural ecosystem and the hill communities, conscious of limits of their own actions vis-à-vis the tipping points intrinsic to the physical and biological phenomena.

This led to a social distortion in the lifestyle of the erstwhile ecosystem communities, which started believing that they have no option but to use 'gangster logic' (i.e., a belief that the ecosystem services and resources are limited and finite, and if they don't grab them, the nexus between bureaucrats-technocrats-legislators and commercial interests will take away everything anyway). The result is that barring the really remote villages and settlements everybody joined in the process of exploitation, in spite of being conscious of the fact that it would eventually harm their own interests. This led to a large-scale migration of people who could not survive in this intense competition or were unwilling to succumb to exploitative practices, and therefore preferred to adapt to the next best options, which was to join army, police, forestry and other security services, outside their native regions. Therefore, the ecosystem people were gradually marginalized and replaced by the exploitative communities under the pretext of being the original settlers themselves.

In Nepal as well, when the first power plants were being conceived, that was the crucial time to introduce and implement good practices. Nepal had, and still has, the opportunity to learn from its neighbour's errors and lessons learnt. Sikkim and Bhutan are trying to grow in a different manner by implementing organic farming, limited tourism and a way for minimizing needs while living within the natural limitations of the environment. But Uttarakhand, Himachal Pradesh and Nepal have used their sovereign rights to make mistakes rather than learn from responsible practices of neighbouring regions.

In this process, the religious card was also played in an unethical manner. The physical and natural importance of the Himalaya and Ganga River was underplayed and unclean, unhygienic practices and blind faith was wittingly or unwittingly encouraged. Earlier, pilgrimages or yatras had stressed on the importance of cleanliness and purity of Ganga Ma, Gangotri and other such places through symbolism from various mythological stories and philosophies. This aspect of pilgrimage was substantially overruled by commercial and superstitious religious practices, which in fact have been destroying the glaciers, river system and the surrounding ecosystem.

This perversion could have been stopped with systematic planning. However, there was no foresight in the administrative processes due to which, a senseless, destructive development pattern got established. Along with increasing tourism and a changing remittance economy, river valley projects such as dams, hydropower projects, roads and other infrastructures are altering the cryosphere and demographic impact over the last few decades.

8.4 HISTORICAL OVERVIEW OF RIVER VALLEY PROJECTS IN THE UPPER GANGA BASIN

8.4.1 River Valley Projects During Colonial Period

While the Indo-Gangetic plains were dotted with canals and barrages belonging to those constructed as late as 3rd century BCE during the Mauryan empire, the history of infrastructure development in the Upper Ganga regime begins with the construction of Western and Eastern Yamuna canals and barrages built during the Tughlaq regime and Mughal era, primarily for earning revenue from land and canals. This form of hydraulic imperialism was later replicated by the British imperialists from 1842 to 1854 with the construction of Upper and Lower Ganga canals for irrigation and navigation purposes and as a solution to ward off droughts and famines in the region i.e. in the current state of Uttar Pradesh*(Wittfogel, 1981)*.

In 1907, British commissioned the first run-of-the-river hydropower plant named Galogi project in the Upper Ganga basin near Dehradun in the present state of Uttarakhand. The plant provided electricity to Mussoorie, a resort established in 1825 by Captain Young, a British military officer. The plant demonstrated the use of '*panchakki*' (water mill) technology for generating electricity. This plant is now preserved as a heritage monument and still provides some electricity to Mussoorie and Dehradun*(Azad, 2021; UJVNL, 2018)*.

The Bhimgoda barrage built at Har ki Pauri near Haridwar as the headwork of the Upper Ganga Canal in 1854 was later proposed to be restructured as a hydropower project by the British. However, the construction of this dam was met with very strong opposition from Indians, as construction of this structure meant obstructing the flow of Ganga Ma and submerging a large area of land for the first time in history. Thus, in 1905 Madan Mohan Malviya formed the 'Ganga Mahasabha' which was a conglomeration of local Teerth-Purohits, saints, local communities, public representatives, former bureaucrats, freedom fighters, scholars and several princely rulers who opposed the dam. This was the first of its kind anti-dam movement in India. In spite of the opposition, the construction of the dam began in 1912. In 1916 facing rising opposition, an agreement was entered into with the British government which was the first participatory, inclusive, negotiation process of its kind. Whatever the hidden agenda that an imperial power was ready to undertake, the occurrence of such a process was remarkable. The agreement specified that:

1. In future, the unchecked flow of Ganga will never be stopped (1916 Agreement, clause 32, para-I),

2. No decision on Ganga will be taken without the consent of the Hindu community (1916 Agreement, clause 32, para-2). This agreement is preserved today under Article 363 of the Indian Constitution *(Ganga Mahasabha, n.d.; Jansatta, 2016)*.

However, overruling this agreement, the construction of the barrage later continued in 1920. Post-Independence, in 1983 the barrage was reconstructed and replaced. Further, the Pathri, Mohanpur, Mohammadpur power plants were commissioned in 1955 and 1952 along with increasing the length of Upper Ganga canal, downstream of Bhimgoda barrage. However, these projects were built without any negotiations or participatory processes. The 1916 Agreement should have been re-negotiated through a participatory process by holding another Ganga Mahasabha. Unfortunately, hydraulic imperialism was replaced by a new Nehruvian paradigm which considered dams as 'Temples of Modern India'. The negative socio and environmental impacts of large dams had not yet been fully played out. Therefore, independent India tragically did not change the imperial 'hydrocracy' of the British.

8.4.2 River Valley Projects in India Post-1947

Thus, the growth of dams and hydropower projects which began during the imperial rule in the early 1900s (20th century) gained momentum from the 1950s onwards i.e., post-Independence period in India. At the time of Independence, the installed capacity of hydroelectric power was only 508 MW and then the number of units operating was just 51*(Singh & Gupta, 2018)*. Until then, human interventions on the Ganga were either very small or insignificant in terms of its effects on 'environmental-flows' or on the quality of water. Similarly, hydropower projects were also of a very small scale. Post-Independence, the United Provinces and Central Provinces broke up into multiple states such as Uttar Pradesh, Madhya Pradesh, Bihar and others which was followed by an increasing number of projects by independent states to acquire control over water resources for irrigation, generation of electricity, industrial use and for meeting the growing demand and aspirations in urban centers. Major barrages and dams with large scale impoundments, such as the Farakka Barrage built in 1975, and commencement of the construction of Tehri dam in 1978, accompanied by several other dams and projects were proposed and built in the 1980s and 1990s.

Formation of Uttarakhand as an independent state in 2000 completely changed the priorities of the region. Until then, the region was almost a neglected part of Uttar Pradesh in terms of infrastructure development. Establishment of a new State propelled the need for gaining economic growth and stability for self-reliance. Therefore, since 2000 there has been a rapid increase in the number of proposed hydropower projects in the state. A similar order of succession of events has been seen in Himachal Pradesh with rapid proliferation of infrastructure and hydropower projects. This was quite unlike Bhutan who have taken a different trajectory towards economic development.

8.4.3 History of River Valley Projects in Nepal

The historical and ecological successions of stages have taken place on practically the same lines in Nepal as well. The construction of the first hydropower project began on 22nd May, 1911 by installing a 500 kw electricity project at Pharping, named Chandra Jyoti. Built to light the palaces of the autocratic Rana rulers, the power station used water from two spring sources 12 km south of Kathmandu. The project has been declared as a living heritage site, but is currently dysfunctional. The water that was used for electricity generation is now used for drinking purposes in Kathmandu *(Bhushal, 2021)*.

After about 25 years, Prime Minister Dev Shamsher initiated the construction of Sundarijal hydropower plant with an installed capacity of 900 kW in 1936-39. The Sundarijal hydropower project was also meant to supply electricity to provide a luxurious lifestyle to the rulers and not for the common people. The development was stalled for decades due to political conflict. Morang Hydropower Company was established in 1939 which completed the construction of the third project - Letang hydropower plant with an installed capacity of 1800 kW in 1943 under public-private-partnership. The plant supplied electricity to Biratnagar Jute Mill and was later destroyed by a landslide *(Bhatt, 2017)*.

The establishment of hydropower projects grew by leaps and bounds, and by 2016 the production reached 782.45 MW. However, unlike India, the growth of dams and hydropower projects in Nepal has been slow due to long periods of delays in planning and execution due to political instability and a lack of technical and financial capacity. Further, domestic electricity supply for local communities has not been on the priority on Nepal's energy portfolio. In addition, there is very low demand for electricity for commercial and industrial purposes in Nepal. Therefore, despite the country's vast hydro-electric potential, the overall energy portfolio of hydropower represents a negligible portion of the overall energy profile of Nepal. Therefore, since the 1960s Nepal's liberal foreign investment policy has attracted foreign investment in the hydropower sector. In order to promote investment in industry, manufacturing, services, tourism, construction, agriculture, minerals, the Government of Nepal prioritized the hydropower sector for foreign and domestic investment. With the aid of investment from erstwhile USSR, China and India, there was been a significant proliferation in River Valley Projects in the region. However, the issue of hydropower plants has always resulted in political conflicts.The recent one was connected with the Mahakali Treaty with India regarding the Pancheshwar high dam. Within Nepal it led to contentious politics, leading to the splitting of political parties (For details see Chapter 12).

8.5 BARRAGES, DAMS AND HYDROPOWER PROJECTS IN INDIA AND NEPAL

India and Nepal have the largest population density and widespread poverty, and is also one of the fastest growing regions of the world facing growing water and energy crises. Therefore, the scope for exploring renewable energy resources (in this case hydropower projects) have been promoted. Therefore, since the 1950s and 1960s, India and Nepal respectively have seen a spurt in hydropower projects due to two primary interests, a) need for additional energy generation for meeting growing demands and b) concerns about reducing CO_2 emissions by moving away from fossil fuels for energy generation. The following table provides a brief analysis of the hydropower generation capacity of India and Nepal and the current status. The table shows that India and Nepal managed to exploit about 46.48% and 1.53% respectively, of commercially feasible capacity until the year 2011-12. This highlights the capacity for further growth in hydropower potential in both the countries, which led to the proliferation of hydropower projects and dams across the Upper Ganga River basin.

Based on size and production capacity, there are several types of hydropower projects. Micro-hydro (less than 100 kW); small-scale hydroelectric dams (1 and 10 MW); medium-scale projects (10 to 100 MW); and large-scale hydropower projects are those having an installed capacity of 100 MW capacity or more. In addition to different sizes of projects, the schemes implemented fall under two broad categories: storage projects, or run-of-the-river (ROR) dams.

Table 8.1: Status of Hydropower development in India and Nepal

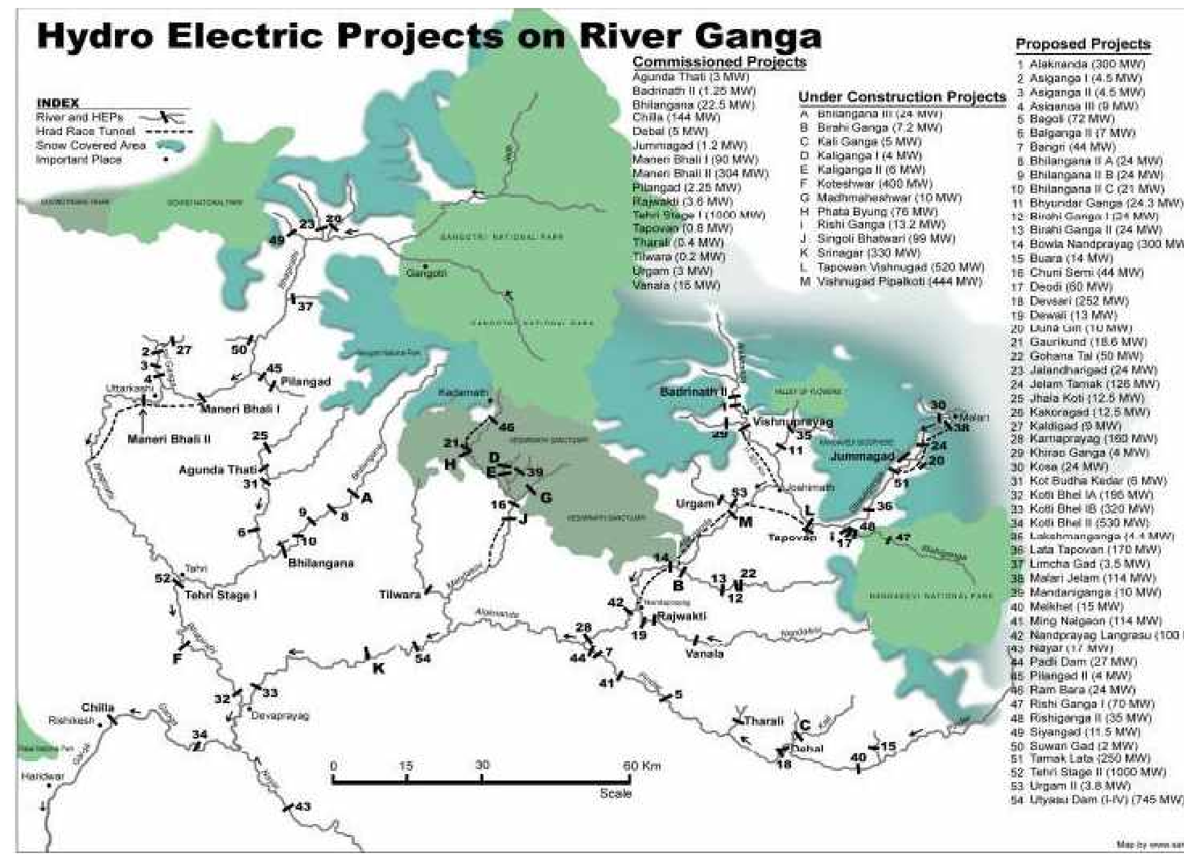
(Source: CEA (Central Electricity Authority) of India Annual Report 2010-11 and The World Bank, Project Information Document: Kali Gandaki A Hydropower Rehabilitation Project, 2012 (Bergner, 2013)

Country	Hydropower Capacity (MW)			% Harnessed of Commercially Feasible Capacity
	Gross	Commercial Feasible	Installed	
India	1,48,700	84,044	39,060	46.48
Nepal	80,000	43,000	659	1.53

Storage projects impound water during the wet season, or times of low electricity demand, and release it for quick generation during peak hours or the dry season. In contrast, ROR projects do not have storage dams, but involve construction of underground tunnels to create an artificial drop in water, in order to increase its velocity for electricity generation. In terms of cost, storage projects are typically more costly than ROR projects of a similar size, partly due a need to construct a large reservoir dam for storage. Accordingly, their environmental, social and other impacts also increase considerably *(Bergner, 2013)*.

Of the aggregate hydropower potential of India, 79% (1,17,239 MW) lies in the Himalayan region (IHR) that covers the northern and north-eastern states of the country*(S. S. Agarwal & Kansal, 2017)*. According to the Ganga Citizens' Report, there are 784 dams, 66 barrages, 92 weirs and 45 functional lift schemes i.e. total 942 projects located in the river basin with over 75% of them in the Upper Ganga river basin excluding those in Sikkim and north eastern states *(WWF & SANDRP, 2019)*. Of the ones mentioned above (in the existing 784 dams), 39 hydroelectric projects are in Ganga basin within Indian territory according to India-Water Resources Information System (WRIS). There are 27 major and 12 small hydroelectric projects in the basin. As per current information available with Namami Gange, 44 Accelerated Irrigation Benefit Programs (AIBP) have been additionally completed by May, 2021 within a period of 3-4 years in the Ganga River Basin, *(Press Information Bureau, May 2021)*.

As per recent data, there are around 17 major and 43 minor hydropower projects in operation in Uttarakhand with a cumulative capacity of around 2,595 MW. Many new projects are in different stages of planning and construction. The project with the largest installed capacity, Tehri dam (i.e., 2000 MW) by Tehri Hydro Development Corporation Limited *(THDC India Limited)*, is located in Uttarakhand in the Bhagirathi sub-basin*(Azad, 2021; SANDRP, 2013)*. However, the statistics related to installed capacity and proposed capacity in different regions or sub-basins in the state do not add up as there is a lack of consolidated data in the public domain. Several have been proposed and added during the last decade, but it is difficult to arrive at an accurate number, due to a lack of clarity and consistency in government statements.



Map 8.1 Hydro-Electric Projects In Bhagirathi And Alaknanda Basins

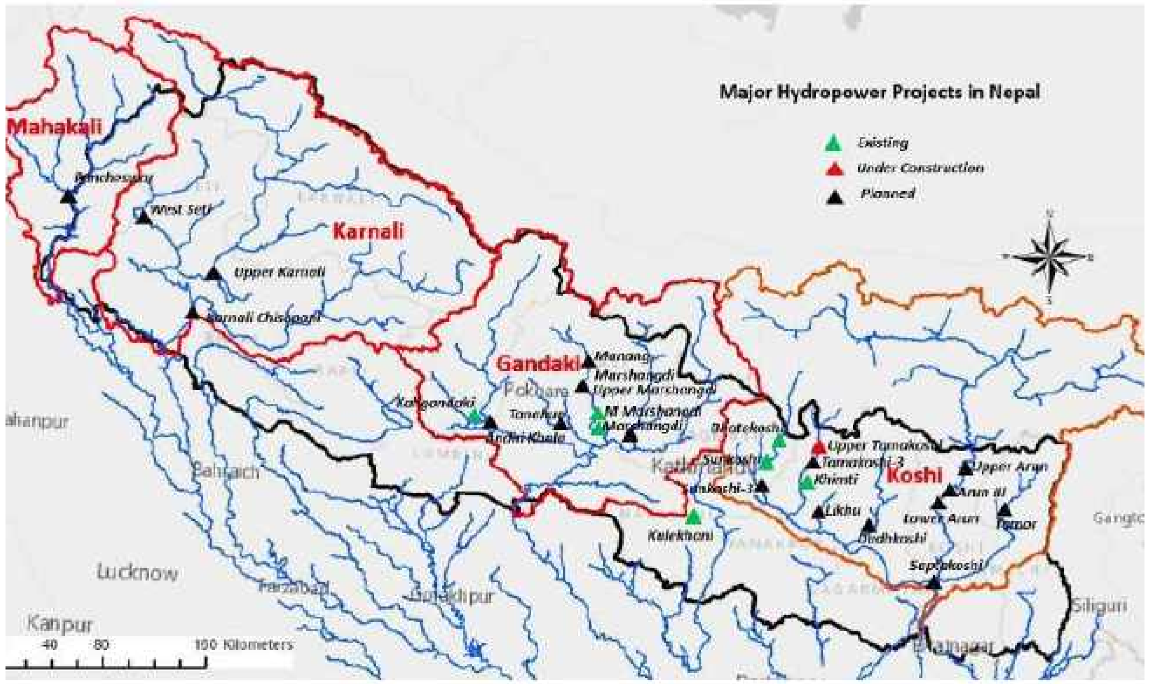
The Map Highlights That Practically The Entire Upper Regime Has Been Or Will Be Dammed With Projects Still Coming Up. The List Of Projects In Upper Stretches Of River Will Continue To Expand

(Courtesy: SANDRP, 2011)

8.6 HYDRO-ELECTRIC PROJECTS IN HIMACHAL PRADESH

Although most of the dams and hydro-power projects in Himachal Pradesh are located in the Indus River Basin, a few projects form a part of the Ganga River basin, as they lie on the tributaries of Yamuna. The Sawra-Kuddu project (1044.82 MW) a run-of-river scheme lies on the Pabbar River, a tributary of the Yamuna, in Shimla district of Himachal Pradesh. In addition, the Giri Diversion (Canal) Project is located 25 km from Paonta Sahib in Sirmaur district in Himachal Pradesh, and was commissioned in 1978.

8.6.1 Hydro-electric Projects in Nepal



Map 8.2 Major Hydropower Projects In Nepal
Mostly Seen In Sapta Kosi River Basin. The Map Shows That One Plant Is Under Construction, 6 Are Completed And 18 Are Planned
(Kaini & Annandale, 2019)

Bio-geographically similar, Nepal has also been endowed with high potential of water resources. The official Nepalese documents claim that the country has about 6000 rivers with a running length of about 45,000 km. These rivers have aneconomic potential of generating about 45,000 MW of hydroelectricity. However, in spite of the high potential, until 2018 the installed hydro capacity was just 782.45 MW, which was far below the demand and led to endemic power cuts of up to 16 hours per day *(Kaini & Annandale, 2019)*.

Currently, the hydropower system is dominated by run-of-river schemes which supply electricity to only about 12% of the population and is mostly dominated by the private sector. Almost 639.57 MW is generated by private investors who have developed around 91 hydropower projects in the country (Investopaper, Kathmandu Nepal, 2020). Therefore, despite the country's vast hydroelectric potential and the large share of electricity met by hydropower, in the overall energy portfolio, hydropower represents a negligible portion of the overall energy profile of Nepal, due to reasons discussed in the history section above and in detail in the Chapter 12.

On 4th September 2014, Nepal signed a Power Trade Agreement (PTA) with India that has enabled the exchange of power across the border. In addition, Nepal signed a power development agreement (PDA) for the 900-MW Arun III (900 MW) and Upper Karnali (900 MW) hydro projects with the developers from India. These projects will export power to India, with Nepal benefitting from the royalties and taking possession of the projects in about 25 to 30 years. The direct benefit of these two big projects to the current power shortage in Nepal is minimal, but the hope is that this type of development will attract more foreign investment to the country (For details see Chapter 12).

With this aim, in the next few years, 131 hydropower projects with a generation capacity of 2490 MW are planned to be added to the national grid in Nepal. The Government of Nepal has planned to increase access to electricity to the population from 67% to 87%, with a capacity of 1426 MW by 2022*(Bhatt, 2017)*. There are several projects under construction adding up to about 7000 MW. Its 15th Five- Year Plan envisages an increase in its installed capacity to 12,000 MW by 2030, so as to satisfy its projected demand of 11,500 MW. This increase of 1400% does not seem realistic.

8.7 GROWTH OF TRANSPORT INFRASTRUCTURE

The spread of tarred roads and railway networks began in the early 1900s mostly for connecting British communities and residences, which later grew rapidly after Independence. Until the 1900s there was no large-scale road cutting. Therefore, the occurrences of landslides were chiefly due to natural causes. The hilly regions were mostly visited by pilgrims, pastoralists, mountain tribes and mountaineers who relied on walking trails through passes, bridle rides, and kutcha[80] roads for commuting.

Road construction began with the expansion of colonial residences across the hilly regions and establishment of hill stations such as Nainital (in Uttarakhand) as the summer seat of the North Western Province, and Shimla (in Himachal Pradesh) as the Summer Capital of the East India Company, which later shifted to Kalpa in Kinnaur around the 1850s. Following the ancient Silk Route, Lord Dalhousie, the then Governor-General of India ordered the construction of the Hindustan-Tibet road also known as the Great Road*(District Administration, Nainital, 2022)*.

Post-independence, road construction and traffic movement increased with increasing tourism-related activities in the region. Increasing inflow of tourists was simultaneously combined with increasing infrastructure related to dam building in these hilly regions. While construction of roads in seismically sensitive regions is largely unadvisable (an ill advised railway line is being extended from Rishikesh to Karnaprayag, which is to be completed by 2024), another prominent reason for increasing roads was for defence or strategic purposes, considering that Uttarakhand and Himachal Pradesh share borders with Nepal and China. So, in order to establish military control, access roads to hinterlands are being constructed rapidly in these states.

During the 1962 Indo-China war, deployment of major army units on the border needed construction of tar roads and bridges across the mountain terrain. Further, increasing border disputes due to blockade tension between India and Nepal also led to construction of strategic roads across the border with Tibet. At present there are many road projects under construction in the region, some of them include the Char Dham National Highway Development Programme, Kailash Mansarovar Road, and others. These road projects are in unstable terrain with regular landslides and collapse of hill sides.

In Nepal, the first motorable road was constructed in 1924. The history of road development programs began in 1956. Linking of Kathmandu with the southern border was taken up in 1953 with Indian assistance and was opened for traffic in 1956. The Government of China constructed the Kathmandu-Kodari (Northern Border) road in 1966 *(Bastola, 2015)*. However, road construction in Nepal is not as common as seen in India. Many interior villages in the hinterlands still remain disconnected from the main city-centers, relying on *kutcha* roads and hilly trails for commuting. In recent years there has been significant proliferation of roads between Nepal and Tibet. Historical trade routes and border crossings are being reconstructed. New roads such as Arniko-Friendship Highway, the Kyirong-Rasuwa highway, and the Tibet-Mustang road are being built. Changing political dynamics, new patterns of mobility and increased access to consumer goods are both causes and effects of these regional infrastructure developments in the region *(Murton, 2016)*.

8.8 REASONS FOR PROLIFERATION OF HYDRO POWER PROJECTS

This historical overview indicates the following reasons for such rampant proliferation of river valley projects in this region.

8.8.1. Availability of Base-Flows from Cryosphere

One of the crucial requirements of hydropower projects is a continuous supply of base-flow throughout the year for consistent power generation. This crucial requirement is met by a large network of rivers with steep gradients in the Cryosphere of the Upper Ganga Basin. One of the important functions of the Cryosphere is the regulation of flow of water during the lean seasons. The availability of ice-fed and rain-fed rivers (i.e., volume) along with the natural incline (i.e. head) provides great scope for hydropower potential and has led to a proliferation of large, medium and small dams, for hydropower and irrigation.

8.8.2 Option of Generating Peaking Power

Along with the benefit of promoting renewable and clean energy, hydropower also provides the peaking power advantage, in order to meet the demands of increasing industrial complexes and metropolitan cities. There is no other conventional energy source which can instantly increase or decrease the generation of power, because of the large 'lead and lag' time required for starting and shutting down the power plant.

8.8.3 Large Hydropower Dams: Solution for Receding Glaciers

The impact of climate change on the Cryosphere and the Upper Ganga Basin which is a'snow-melt system' is well researched and documented i.e., expected increase in river flows over the next 20 years and thereafter predicted reduction in flow. The paradox of the situation is such that this very argument is used to justify further proliferation of large dams. One such argument is that "in light of climate change and melting glaciers, storage dams must be built to catch additional melt water and store it for use in the dry season when water availability is low." Further, a study suggested increasing the construction of more dams as a solution to ward off the ill-effects of increasing floods and to protect human lives and property *(Boulange et al., 2021)*.The availability of water storage in the glaciers and the assumption that these glaciers might be melting faster is motivating a push for hydropower across Uttarakhand, Himachal Pradesh, Arunachal Pradesh and Nepal.

8.8.4 Hydropower for Economic Growth

The entire justification for energy production and consumption is vexatious because the demands for energy is almost infinite (this includes conspicuous consumption, wastages, etc.) while the hydropower potential which can be harnessed without completely compromising the integrity of the Ganga River system is limited. In 2010, the report titled "Performance Audit of Hydropower Development through Private Sector Participation" by the Comptroller and Auditor General (CAG) stated that the government of Uttarakhand had pushed the state towards a major environmental catastrophe by following a highly ambitious hydropower policy.

In 2012, after the cancellation of run-of-river dam at Loharinag Pala and two in the advanced planning stage (Pala Maneri and Bhaironghati), the MoEF issued a Notification for an Eco-Fragile Zone on the Upper Bhagirathi, to protect the upper Bhagirathi and ban additional hydropower projects. This indicated that some policy makers may have realized that a threshold for altering the flow regimes in the upper reaches of the Bhagirathi may be necessary. In August 2013, the Supreme Court had ordered a moratorium on dams and had directed Uttarakhand to scrap all the hydro projects, after the Kedarnath disaster on 13th June, 2013. This order explicitly accepted that there were limits to the exploitataion of Himalayan rivers in such a fragile geology.

Declaration of Bhagirathi Eco Sensitive Zone, Gangotri National Park and Eco Sensitive Zone, Nanda Devi National Park and Govind Pashu Vihar National Park and Wildlife Sanctuary and other such promulgations were meant to essentially place limits on the uncontrolled exploitation of the upper Ganga river basin(Uttarakhand Forest Department, 2022).The River Ganga (Rejuvenation, Protection and Management) Authorities Order, 2016 under Environment (Protection) Act, 1986 laid down a new institutional structure for policy and implementation in fast track manner and in order to empower the National Mission for Clean Ganga to discharge its functions in an independent and accountable manner.

Although the government had closed the upper Bhagirathi for additional dam construction, it continued to grant permits to projects on the Mandakini, Dhauli Ganga and Pindar rivers which flow into the Alaknanda River and eventually into the Ganga. The 2012 Bhagirathi Eco Sensitive Zone Notification was amended in 2018, following the Uttarakhand government's objection that the notification was 'anti-development.' In August 2021, the Union ministries of Environment, Power and Jal Shakti departments submitted a consolidated affidavit to Supreme Court stating that seven projects: Tehri Stage 2 (1000 MW), Tapovan Vishnugadh (which was impacted by the February 2021 flashflood), Vishnugadh Pipalkoti, Singoli Bhatwari, Phata Bhuyang, Madhyamaheshwar and Kaliganga 2 have been given the green signal on grounds that they were over "50% complete". Although the affidavit says that no new projects will be allowed in the Upper Ganga region, the clearances granted to these seven projects are highly problematic as they are a part of a series of 26 projects recommended simultaneously, which could eventually be up for implementation with the passage of time *(Mazoomdaar, 2021)*.

Of the seven projects approved, Singoli Bhatwari and Phata Bhuyang were specifically linked to the Kedarnath tragedy and the Vishnugadh Project was damaged in the February 2021 floods in which more than 200 people died due to absence of a disaster warning system *(Koshy, 2021)*.These clearances do not pay heed to the rising stress and uncertainties related to global warming and glacier melt in the Cryosphere region. Recently, the government has also announced the construction of the Delhi-Dehradun Economic Corridor Greenfield Alignment, Dehradun-Paonta Sahib Road, Glass-Deck *Jhoola* in Rishikesh, Badrinath Smart Spiritual Township and Development of Infrastructure in Gangotri-Yamunotri in Uttarakhand as a means for bringing economic prosperity to the state.

These proposed developments highlight the propensity and priority of the State favouring infrastructural growth as a path towards rapid economic progress. Political leadership in these regions, especially Uttarakhand, has sought to make the State as a Power Major (*Urja Pradesh)*, admittedly stated by Uttarakhand Jal Vidyut Nigam Limited, thus rapidly increasing the number of River Valley Projects in the state. A similar trajectory can be seen in Himachal Pradesh as also in Sikkim and Arunachal Pradesh. The contradiction in the political economy of these states lies in their aspiration to be the trustees or guardians of '*devbhumi*' and Ganga Ma in order to earn revenue from pilgrims and tourism, and simultaneously also earn profits from hydroelectricity and export of energy. Himachal Pradesh and Uttarakhand are willing to accept this contradiction in policy even at the cost of complete destruction of the Upper Ganga River Regime.

8.9 OTHER ISSUES RELATED TO RIVER VALLEY PROJECTS IN THE CRYOSPHERE

The seemingly irrational pursuit of political interests and economic gains are not the only reasons why the proliferation of hydropower dams is not desirable for the Upper Ganga regime. There are other serious reasons why such dams have been opposed: a) increasing financial overruns, b) high level of sedimentation and increasing dead storage in dams, c) concerns regarding safety of the dam due to seismicity, landslides and lake outbursts, d) reduction in flowse) lack of data related to cryosphere in project plans, e) impact on biodiversity, f) social consequences relating to submergence of lands and involuntary displacement of project affected households, g) increasing fragility of the cryosphere and the riverine ecosystem, h) receding glaciers in the cryosphere due to rise in temperatures and subsequent changes in the biodiversity and E-flows, i) destruction of the vertical and horizontal integrity of the system, j) fragmentation of the upper regime i.e. cutting the integrity and continuity of flow due to damming and tunneling, k) endless abstraction, especially in the tributaries of Yamuna basin, and lastly l) increasing pollution levels due to urbanization and industrialization (See Chapter 10 for details). The recent disaster in Sikkim where Teesta III project was completely destroyed by devastating floods, despite being certified as safe by NHPC, shows the inherent risks of unrestrained dam, road and rail construction in the upper Himalayas.

Some important issues specifically related to River Valley Projects are elaborated in the section below.

8.9.1 Reduction in Flows due to Depleting Cryosphere

While increasing glacial melt, the volume of river-flow will be augmented for a few decades. Later, once the glaciers have completely receded, the volume in these rivers will reduce considerably. Even for projects today to function at their 50% capacity, the regulating function of the Cryosphere is crucial for maintaining the volume and the head. With loss of ice and snow in the Cryosphere, the hydropower potential will considerably reduce due to reduced snow and glacier melt in the dry season. Over 90% of Nepal's existing hydropower plants are the run-of-the-river type, which are generally designed based on the dry season flows. These power plants have been already facing the problem of water shortages during dry seasons and generating only about 30% of the total installed capacity in dry months. This variability in river flow especially during the dry season will make hydropower planning more complex and often non-viable. In the case of hydropower, the model in National Communication Report, Nepal, 2015, projected lower dry season flows and thus lower energy availability therefore increased energy production costs in the coming decades *(Bhatt, 2017)*.

8.9.2 High Level of Sedimentation and its Impact on River Valley Projects

The Himalayan rivers transport an enormous quantity of sediment due to the sheer force of the water gained due to heights. This factor is largely ignored while deciding human interventions which refer to large-scale tampering of the river valleys for exploiting hydropower. Divergence and abstraction has been reducing the volume of flow and dams and barrages are reducing the velocity of the flow in these Himalayan Rivers. Changing E-flows i.e., reduction in volume and velocity makes the river flow sluggishly, directly increasing sedimentation rates, rise in river bed, inundation and flooding.

High level of sedimentation not only impacts the life of the projects but also increases operation and maintenance costs arising from corrosion caused by sediments (especially quartz and other such hard elements) on the hydro machinery. Altered weathered patterns which lead to erratic floods also lead to an increase in the sediment load, which increases the costs of operation and maintenance and decreases turbine efficiency and production capacity. In Nepal, in July 1993, Kulekhani Project faced high sediment and debris inflow into the reservoir because of flooding.

The Maneri Bhali project on Bhagirathi (India), about 100 km. upstream of the Tehri town, consists of a barrage which diverts water through an underground channel to the turbines located in the power-generating unit. The dam was supposed to function as a 'settling tank' in order to reduce the velocity of the river and settle down the suspended particles. The Project was commissioned in 1984 and began functioning in 1985. However, it failed as it was found that silt was not settling sufficiently but was reaching the turbines and capable of corroding them *(Paranjpye, 1988)*.

The run-of-river projects do not have such issues of settling sediments. However, the turbines are hit with sharp sediments especially quartz which are flowing with high velocity in the rivers. Thus, corroding and piercing the blades of the turbine, thereby reducing the replacement period of the turbines and simultaneously increasing the maintenance costs.

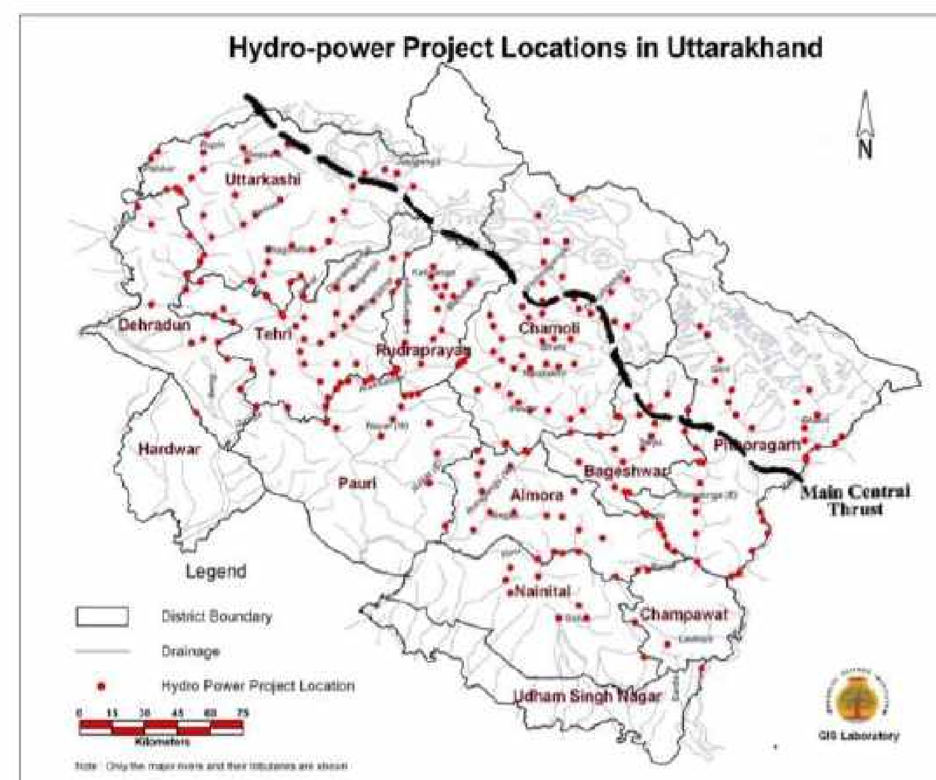
In 2017, the Ministry of Water Resources, River Development and Ganga Rejuvenation, New Delhi circulated a Draft Policy on Sediment Management. Later in February 2019, the CWC came out with 'Guidelines for Sediment Management in Water Resources and Hydropower Projects'. Both these documents have put forward several important suggestions, which if implemented, can bring a phenomenal change in the health of the rivers. However, the draft policy is heavily tilted towards promoting navigation rather than focusing on improving river health, so much so that the navigation requirements can overrule several guidelines *(WWF & SANDRP, 2019)*.

Further, the 'Compendium on Sedimentation of Reservoirs in India, 2020' published by Central Water Commission states that 'the actual rate of sedimentation is more than the design rate of sedimentation in most of the reservoirs.' This variation in actual sedimentation rate with the rate assumed at the time of design is due to the fact that enough reliable data on Indian reservoirs was not available earlier at their planning stage. The earlier assumption that the sediment would settle within the dead-storage area is no longer supported by the experience gained in India as well as other countries. The hydrographic surveys have indicated that the sedimentation takes place not only in areas reserved as dead storage but also in the higher segment meant for live storage of the reservoirs thus reducing the life of the project *(Central Water Commission, 2020)*.

8.9.3 High Risk of Tectonic shifts leading to Earthquakes, Landslides and Glacier collapses

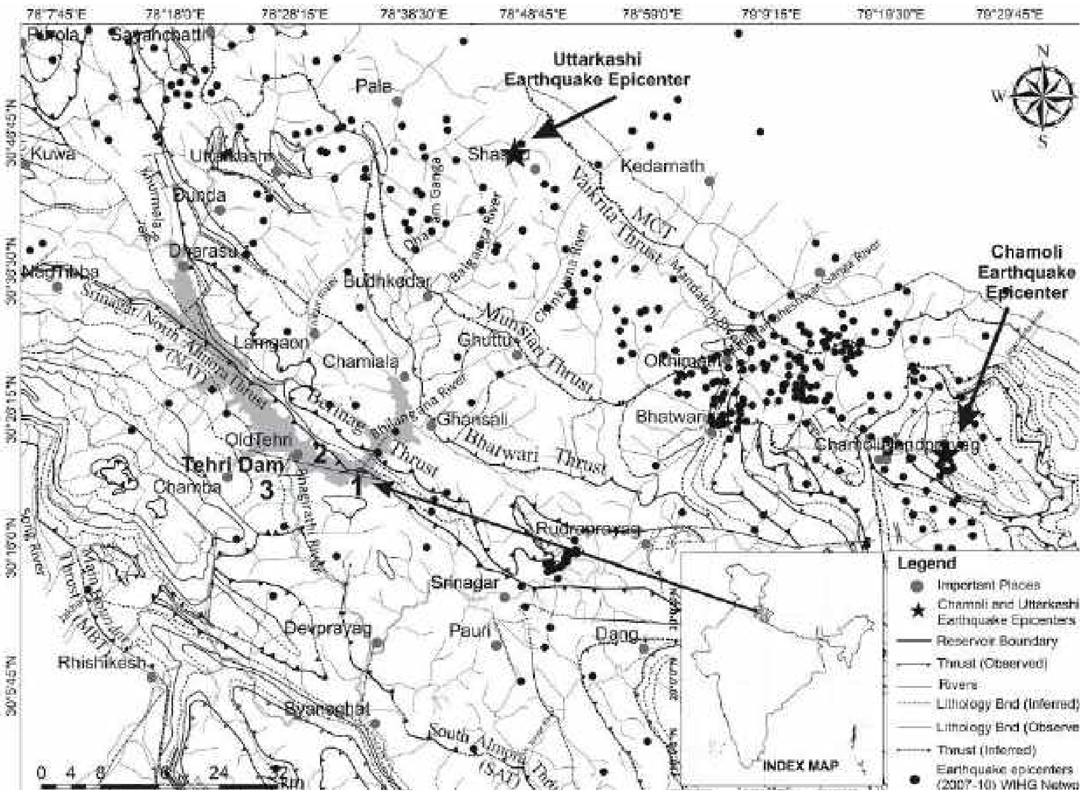
The recent incidence of glacier collapse in February 2021 in the Nanda Devi Glacier in Chamoli district and subsequent flooding of Dhauli Ganga, Rishi Ganga and Alaknanda rivers causing damage to two power projects - NTPC's Tapovan-Vishnugad Hydel Project and the Rishi Ganga Hydel Project was a grave reminder of the reality of global warming threats to the cryosphere and its impact on river valley projects. In 2014, a landslide which occurred during monsoon badly hit the United Modi Project (10 MW) in Nepal, and damaged the concrete cover slab of around 100 meters of the headrace-tunnel and canal covered by debris *(Bhatt, 2017)*. According to the Ravi Chopra Committee Report (2014), out of a 217 km stretch of the Bhagirathi River, around 70% is fragmented due to the obstruction caused by numerous hydropower projects*(Sati et al., 2020)*.

The Cryosphere lies close to Zone IV and V that fall in the highest seismic risk zones of the country. Although evidence does not suggest a rise in seismic activities, the increasing concentration of river valley projects in seismically sensitive zones has raised the degree of vulnerability to such events*(Chandel & Brar, 2010)*. As seen in the map illustrated below, the Main Central Thrust, one of the three seismic fault-lines in the Himalaya which passes through Uttarakhand in the para-glacial zone, is surrounded by many hydropower projects. These projects have rendered the cryosphere in the region susceptible to slope instability, landslides, avalanches, sudden floods and other such disasters (For details see Chapter 11).



Map 8.3 Projects in the para-glacial zones near the Main Central Thrust line. Note that 75 projects are above the MCT

(Chopra, 2015)



Map 8.4 The Regional Seismo-Tectonics Around The Tehri Dam

The WIHG Garhwal Seismic Network and local faults around the Tehri region 1) Dewar Tear, 2) Gadolia Tear and 3) Marh Tear

(Choudhury et al., 2013) (Choudhury et al., 2013)

8.9.4 Tehri Dam and Seismicity

Tehri Dam, the tallest dam in India with a height of 260.5 m., is located on Bhagirathi River in the state of Uttarakhand in the above-mentioned seismically active zone. Conceived in 1949 by the Geological Survey of India, Phase I of the dam was completed in 2006 after many delays due to technical issues and lack of funds. The Tehri dam holds a reservoir for irrigation, municipal water supply and the generation of 1000 MW of hydroelectricity. It was a part of a larger plan formulated for tapping the discharge of the Upper Ganga basin wherein some 7,400 million m^3 of water was said to be going waste.

Since its conception, the problem associated with catchment instability due to loading and unloading of the reservoir has remained unresolved. The danger of seismic activity in the region due to its proximity to the major fault lines, is one of the strongest arguments against the dam. The Project site lies between Isoseismals VII and IX of Kangra Earthquake (1905), the Srinagar Thrust is located 4 km from the dam site, Tehri Tear Fault, Tehri Bed Fault running across the river course, and Deul Tear Fault makes the dam vulnerable to seismic activity.

There have been conflicting viewpoints related to the seismic hazards of the dam. The proponents of the project claim that the earth-rock-filled dam can sustain tremors due to high inertia, flexibility and high damping/absorbing earthquake energy, enabling the dam to undergo strains without cracking *(Choudhury et al., 2013)*.

However, seismicity and reservoir-induced crustal motion studies have shown that there is a direct correlation between the changing water fluctuation levels or reservoir loading and unloading with seismicity observed in and around the dam. A study by the National Geophysical Research Institute states that there have been increasing incidences of seismic activity from December 2005 onwards, after its first filling in October 2005*(Gahalaut et al., 2018)*.[81] Sandeep Gupta of NGRI stated that 'The tectonic loading on this active fault due to local seismicity, coupled with the reservoir loading and unloading, may generate earthquake(s) and cause additional seismic risk in this critically stressed region' *(IANS, 2012)*.

Mired in controversy for over three decades, this 1000 MW dam on the Bhagirathi River, has now been supplying power and water to north Indian towns and cities, including Delhi, which was not part of the Detailed Project Report when the project was proposed. The dam has also been prone to various landslides due to catchment instability since the filling of the reservoir. Though the dam was initially designed to withstand minor tremors and ground acceleration expected from the maximum credible earthquake of magnitude 7.2, an earthquake of a greater magnitude like the 1905 Kangra tremor (magnitude 7.8) could have a disastrous impact on the dam and the downstream areas. With increasing incidences of Extreme Point Rainfall Events (EPREs), it is important that the villages downstream of the dam are not kept under a false impression of safety by denying the possibility of any untoward incident. There is an urgent need to set up disaster warning systems and immediate evacuation mechanisms for the safety of downstream populations.

Water Diversion pipes for hydro-power plant on Bhote-Koshi

(Photo: Vijay Paranjpye, Field Trip, November, 2019)

In Nepal, the Sun Koshi-Kamala Multipurpose Project or the Upper Bhote Koshi Hydroelectric Project (HEP) a run-of-river scheme constructed on the Bhote Koshi river (a tributary of the Sun Koshi), has also been a center of debate due to earthquakes and landslides. The project has an installed capacity of 45 MW, with two turbine generator units. However,

the project is generating 36 MW as per Power Purchase Agreement (PPA) according to the Nepal Electricity Authority (NEA). The project infrastructure has been greatly damaged by the recurrent floods and earthquakes.

8.9.5 Lack of Data related to Cryosphere in the Project Planning Stage

To add to these uncertainties, there is a lack of data about the cryosphere. Most of the river valley project reports reveal that the authorities have no data about the snow-bound area upstream of the proposed dam-sites. The reports contain no information on the total or average annual snowfall, the seasonal variations in the rate of snow melt, the glacier and moraine movements, which have considerable impact on the final flow or discharge of water. An important lacuna is that the database related to the annual yield, maximum probable flood, frequency of floods is incomplete and therefore, unreliable.

In the case of Tehri, Detailed Reports of 1969, (Vol I chapter VI pg 52), 1979 and 1983 all state that 'snow catchment area has not been accounted for in the computation of the Bhagirathi flood at Tehri Dam site' thus leaving out one third of the total catchment out of the hydrological analysis. There are no snow gauge stations and hence data on one third of the catchment is missing. The location and distribution of rain gauge stations are problematic and therefore values calculated on the basis of correlation formula and equations are bound to be inaccurate. There are no provisions for maximum flood design, no significant data about the quality of water which could impact the durability of the dam structures, tunnels, tail-raise channels, and power generating turbines / stations.

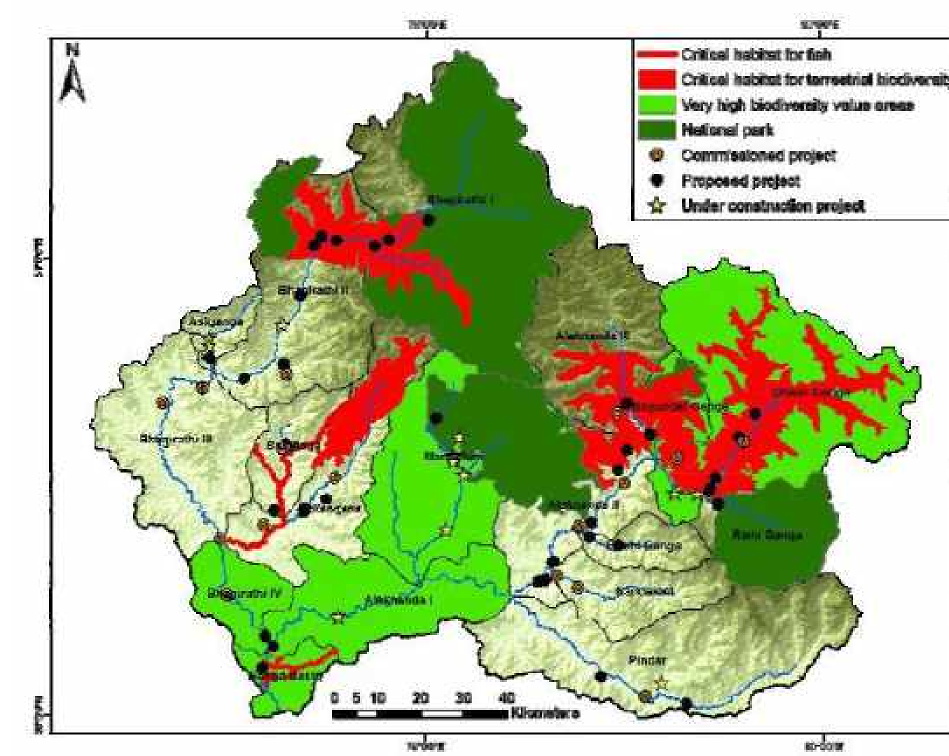
8.9.6 Emission of Greenhouse Gases

Although hydropower dams are considered to be a green source of energy or carbon-neutral projects, there are studies which claim that such dams also contribute to greenhouse gas emissions. Construction of storage dams leads to flooding and submergence of vegetation and forests (organic matter) which rot, thus continuously fueling microbial decomposition, releasing carbon dioxide, methane and nitrous oxide gas contributing to the carbon emission. Such reservoirs also have greater fluctuations in water level as compared to natural lakes. Therefore, drops in hydrostatic pressure during water drawdown enhances methane bubbling i.e. ebullition *(Harrison et al., 2017; Maeck et al., 2014)*. A study conducted by Bridget Deemer et al. published in 2016, from the Washington State University, analyzed around 250 dams and found that dams emit more methane than lakes and wetlands. The study states that rotting vegetation in the storage dams creates about 25% methane which represents about 1.3% of total annual anthropogenic global emissions *(Deemer et al., 2016; Hurtado, 2016)*.

Although such studies are yet to be conducted in the Himalayan Cryosphere, the impact of methane emission due to submergence of forests and other organic matter due to large scale river valley projects can be considered to be detrimental to the already increasing threat of rising temperatures and glacial melt in the region.

8.9.7 Impact on Biodiversity in the Cryosphere region

Based on a report submitted by Wildlife Institute of India, commissioned by the MoEFCC, which included the study of cumulative environmental impacts of 70 hydroelectric projects in the Alaknanda and Bhagirathi basins of which 17 are existing (1,851MW), 14 are under-construction (2,538 MW) and 39 are proposed (4,644 MW), showed detrimental impact on the riverine ecosystems and biodiversity. The study mentioned that if the proposed hydropower projects are implemented, of the 1,121km long stretch of the rivers that flow in the Alaknanda-Bhagirathi basins, at least 47% of the total stretch of the rivers in the basin will be affected*(Rajvanshi et al., 2012)*.



Map 8.5 Critically important habitat of valuable biodiversity components, significantly overlap with locations of hydropower projects in the Alaknanda and Bhagirathi basins. Among 18 sub-basins in the region, the most affected sub- basins with respect to fish habitat modification or loss are Bhagirathi III and IV (71%), Alaknanda I & II (48%), Mandakini (44%), Balganga (40%) and Nandakini (35%) *(Rajvanshi et al., 2012)*

Drying up of river patches, changes in the sedimentation flows and disruption in nutrient flow due to dam construction alter significant areas of the fish habitat in the basins. Out of 76 species of fish reported in the basin, a total of 66 species have been reported in the influence zones of hydropower projects. Therefore, about 87% of fish species would be affected, if proposed hydropower projects get implemented. About 17 migrant fish species found in these basins, which use different habitats for completing life cycles including their breeding cycle, will also be severely affected. Based on literature and observations made in various studies, it has been confirmed that there has been a general decline in the populations of Mahseer (*Tor putitora*) upstream of Bhagirathi due to the barrier effect caused by the Tehri dam.

8.9.8 Benefits For Whom? At What Cost? At Whose Cost?

It has often been claimed that hydropower is superior to other sources of energy generation like thermal or atomic, mainly because it is cheaper and pollution-free. However, apart from the technical and hydro-geological issues related to the dam discussed above, the social and environmental impacts of the dam due to heavy submergence and drastic alterations in environmental flows have led to many protests by local people, environmentalists and NGOs. According to an extended cost benefit appraisal conducted by Vijay Paranjpye in 'Evaluating the Tehri Dam' in 1988, the benefit-cost ratio of the Tehri dam, after including all the possible social and environmental costs and benefits, works out to be 0.56:1, where the benefits of the project are far lower than the cost of the project *(Paranjpye, 1988)*.

The argument about the push for hydropower for energy security in these regions in the Upper Ganga basin also needs to be questioned in the light of the fact that hydropower projects do not result in an increase in energy access for people living in these regions. The argument that some sacrifices need to be made for the national benefit is generally applied in situations where it is the people in such highlands who always have to pay the costs. The paradox is, that almost all hydropower projects involve the submergence of rural and agricultural lands and natural forests in upper catchments of river basins, while almost all power is supplied to the rich urban population in the cities like Dehradun, Haridwar, Rishikesh, Delhi and industrial areas in the southern districts of Uttarakhand.

Mismanagement of E-flows not only disturbs biodiversity but also forces the communities living around the water systems and downstream to adapt to the altered flow regime. This can be largely termed as 'maladaptation' as it is not just adaptation to the ecological changes in the natural systems but the cumulative impact of a series of engineering projects based on unscientific and unjust set of policies and management strategies(*Alley, 2014)*. Therefore, together with climate change impacts on the Cryosphere and policies established to cater to the demands of the few make the communities more vulnerable to changes in their water systems over time . Hence, apart from the question of 'benefits at what cost?', the most crucial question which need to be asked is 'benefits for whom, and at whose cost?' since it addresses the issue of equity.

8.9.9 Social Injustice and Public Response

Due to these unjust processes, many dams and hydro projects have been facing stiff resistance from local communities. Intense public outcry and the "fast-unto-death" by eminent scientist Prof. G. D. Agarwal in protest against the 600 MW Loharinag Pala hydropower project in Uttarakhand in September, 2010 led to complete scrapping of the project and establishing an eco-sensitive zone in the region. Later that year in November 2010, during the meeting of National Ganga River Basin Authority, other projects like Pala Maneri (480MW) and Bhairon Ghati (350MW) and Vishnusagar project (440MW) were also scrapped.
However, the cancelations of projects were short term decisions. For instance, after one year of stoppage of the Loharinag Pala project, work resumed and Prof. G.D.Agarwal continued his 'fast-unto-death' *(Bhaduri, 2012)*. Such protests involving many villagers are currently taking place in different parts of the states in this region. The tussle between the State and the anti-dam demonstrators who are opposing the projects on the basis of social injustice, environmental grounds and religious grounds, escalates from time to time.

The protests are intensified because the energy generated by the hydroelectric projects does not provide for energy supply to the remote areas under the excuse that laying extension lines for just a few households is uneconomic. For instance, in the case of Tehri project, even though the dam submerged about 100 villages in two districts of Tehri Garhwal and Uttarkashi where the per capita energy consumption is just 1/8th of the UP-state average, rural electrification was not considered in the project plan. The rehabilitation is not dealt in a just manner.In the case of Tehri rehabilitation plan, the principles of 'land for land' and 'land for the landless' were compromised by compelling many families to opt for cash-compensation which were extremely inadequate compared to the damage inflicted on these families.

8.10 ECONOMIC AND FINANCIAL VIABILITY OF LARGE RIVER VALLEY PROJECTS

Along with the issues related to environmental concerns, social issues related to inequity and rehabilitation, financial viability of such large river valley projects has been raised time and again. Though it is said that hydropower means low maintenance and operational costs as compared to thermal power, the initial investment is about the same on a per MW basis. Gestation periods are much larger in the kind of hydropower projects which are currently being undertaken.

Further, the cost-overruns of such projects also tend to be around 100% to 200% in some cases. The time taken for project completion is almost always in excess of initial estimation, which means that inflation also contributes towards cost escalation. Further, the rates of siltation in many of such projects had led to a substantial reduction in their useful life, as experienced in the case of Tehri dam. With each new plan, the number of backlog projects i.e., incomplete projects, kept on rising along with increasing spill-over costs which are generally in hundreds or thousands of crores, due to abnormal delays in completion of projects.

Due to the rapid proliferation of such large-scale projects in the region, the concept of 'continuous evaluation' which should have been followed did not get institutionalized. There are no 'ex-post-facto' studies of projects wherein the initial assumptions regarding costs and benefits made in the feasibility reports have been verified on the basis of actually realized values of costs and benefits. Rather, the increase in the number of large dams has led to dilution in technical rigor and impartial assessment based on genuine needs. Many projects are started even without an administrative/financial or environmental approval and continue to get financial allocations. The result is that Uttarakhand and other Ganga Basin States made a mockery of project appraisal procedures. There is no prioritization of projects, and no 'ex-post facto' evaluation of the completed schemes. As a consequence of such large shortfalls, society has had to bear a huge burden resulting from cost and time escalation, shortfall in the accrual of benefits, immeasurable social trauma due to inadequate and inordinately delayed resettlement and rehabilitation, and practically non-valued and non-quantified biological and environmental values.

8.11 ISSUES RELATED TO ROAD INFRASTRUCTURE

The construction of roads and big highways in the mountains has been causing instability of the slopes and stream beds leading to a severe problem of landslides (both above and below the road alignment) along the entire length of the main arterial roads and the smaller roads which connect them to villages and settlements. Construction of roads also requires deforestation of large patches of forests, thus causing damage to biodiversity.

In the view of this situation, on 11th November, 2021, the Supreme Court had reserved its judgment on an appeal made by the Ministry of Defence (MoD) for relaxing its September, 2021 order related to limiting the widening of the 889 km Char Dham highway. In September, the Supreme Court upheld the recommendation of four high-powered committee members, to limit the carriageway width to 5.5 m (along with 1.5 m raised footpath), based on March 2018 guidelines issued by the Ministry of Road Transport and Highways (MoRTH). The Centre had contended that widening of the road will facilitate rapid movement of Armed Forces and artillery such as the Brahmos missile, Vajra missile launchers, and BM-30 Smerch rocket carriers along the India-China border, which has witnessed face-offs at several points in recent times. The court had observed that – "There is no such defence versus environment argument at all… You have to balance both concerns"*(Ananthakrishnan, 2021)*.

Modifying this judgment in December, 2021, the Supreme Court upheld the government's mandate to broaden three Himalayan highways — Rishikesh to Mana, Rishikesh to Gangotri and Tanakpur to Pithoragarh, which are part of the Char Dham project, considered crucial by the Ministry of Defence (MoD) for quick troop build-up along the Indo-China border. "This court in judicial review cannot second-guess the infrastructural needs of the armed forces," a Bench led by Justice D.Y. Chandrachud said in a judgment. This verdict came after the Ministry amended its circular in December 2021, stating that "for roads in hilly and mountainous terrain which act as feeder roads to the Indo-China border are of strategic importance for national security, the carriageway width should be 7 m with 1.5 m paved shoulder on either side"*(Rajagopal, 2021)*.

The core principles of project conceptualizing, strategizing, planning, programming, prioritizing and impact evaluation have fundamentally emerged from defence and war campaigns in order to optimize resources for beneficial results. Excluding them from defence projects in fact would be detrimental to our own defence interests as it would result in poor planning and infrastructure, thus weakening our military strength in times of crisis.

There has also not been any specific process or mechanism set in place to assess the environmental impact of roads and transport infrastructure. The Char Dham Highway is currently under scrutiny after Citizens of Green Doon, a civil society organization moved NGT in 2018 stating that the highway has not undergone an environmental impact assessment (EIA) and pleaded that its cumulative impact be assessed first *(Nandi, 2020)*. However, the ministry responded to the petition stating that the EIAs are applicable only to roads which are longer than 100 km and the Char Dham highway will not need such an EIA as it is not longer than 100 km, as it is broken down into smaller segments. The Char Dham Highway Project was in reality a single project deliberately and insidiously broken up into 53 contracts, to avoid exposure to an Environmental Impact Assessment. It was inaugurated by the Prime Minister at Dehradun on 27th December 2016, at a total cost of Rs. 12,000 crores. If all this is not a travesty of truth, then what is?

Surprisingly, there is also a draft proposal being made to exempt roads for defence purposes from such an evaluation process. However, the need for ensuring that the highways in the border areas remain intact, serviceable and safe right through the year, is precisely because they are of strategic importance due to defence needs and are also used for civilian purposes. That is more the reason why they must go through the process of road safety stipulations and should be subjected to greater quality stringency so that they remain reliable in times of crises. Constructing highways which are greatly vulnerable to geomorphic changes like landslides, actually need 'slope-and-toe-stabilization-treatment' to be carried out well before the roads are laid. Similarly, rock and slope bolting with metal anchors need to be routinely carried out and the costs should be 'factored-in' while planning and implementing hill road projects. Along with physical stability the biological impact of such infrastructure also needs to be considered. There is a need to include such an evaluation process prior to construction which should include judicious selection of routes for construction through seismically safe regions and connecting the hinterlands for maximum defence and social benefits.

In addition, it should be kept in mind that such development should benefit the local population as well. Construction of roads should consequently translate in improvement of other sectors such as availability of education and employment opportunities, medical facilities and sanitation. Therefore, the planning of roads should additionally take into consideration the purpose of connecting small villages in hinterlands with the main roads, with the aim of improving economic prosperity of the local communities. However, in reality this has not happened. Most of the villages still remain distant from the main roads and lack basic infrastructure. A wider road requires additional slope cutting, blasting, tunneling, dumping and deforestation; all of which will further destabilize the Himalayan terrain, and increase vulnerability to landslides and flash floods.

8.12 ENVIRONMENT IMPACT ASSESSMENT AND CUMULATIVE IMPACT ASSESSMENT

While these roads, dams and hydropower projects have provided employment opportunities in the highlands and income through energy production, the long-term impacts of these dams are of a great magnitude. Therefore, in 1991 Government of India promulgated the Environment Impact Assessment (EIA) Notification[82].

Until the end of the 20th century, the impact of a single project was taken into account during planning, designing and execution stages. However, when the numbers of projects rose significantly and were being designed in a series of clusters it was necessary to look at the overall impact of all the dams together in a complete river basin. In 2009, the Uttarakhand High Court responded to a citizen-petition demanding a Cumulative Impact Assessment (CIA) for all the hydropower projects planned and under construction in the upper Ganga river basin. Since the EIA amendment of 2006, CIA studies are a part of the Environment Impact Assessment process, under the Environment (Protection) Act 1986. The Court ordered a scientific study to analyze land use changes and basin-wide ecological problems, and to predict the effects of a rapid and prolific development of hydropower facilities.

In Nepal, EIAs came into practice under the Environment Protection Act, 1997 after the National EIA Guideline which was endorsed in September, 1992 and gazetted in July, 1993. Since then there have been a series of EIAs and CIAs conducted for various projects across the Upper Ganga River Basin in India and also in Nepal.

One such recent extensive report is 'Cumulative Impact Assessment and Management : Hydropower Development in the Trishuli River Basin, Nepal', undertaken by International Finance Corporation (IFC) to strengthen the understanding of environmental and social impacts of hydropower development that go beyond individual project-level impact assessments by considering a multi project, basin-wide understanding of potential cumulative impacts in the Trishuli River Basin (TRB), an area of 32,000 square kilometers across the Central Development Region of Nepal, which makes up approximately 13% of the Gandaki River Basin. This final CIA report was the outcome of stakeholder consultations, qualitative and quantitative data analysis, and strategic workshops from December, 2017 to January, 2019.

There are six operational hydropower projects along the Trishuli River and its major tributaries having an installed capacity of 81 MW. In addition, seven hydropower projects (total of 286 MW) are under construction and at least 23 hydropower projects are in the planning stage with survey licenses being issued by the Department of Electricity Development, Nepal *(DoED, 2018)*. The CIA process shows that the assessed scenarios would result in significant degradation of aquatic biodiversity and several other Valued Environmental Components (VEC) which include Langtang National Park (LNP), aquatic habitats, cultural and religious sites, livelihoods and water resources (VECs in Nepal are equivalent to Protected Areas (PAs) in India) *(Tendolkar et al., 2020)*.

8.12.1 Limitations of the EIA and CIA

It is now proven that the Cumulative Impacts of these projects on the hydrology, downstream flow, sudden releases, deforestation, sedimentation, rehabilitation, and seismicity are huge concerns as compared to individual impacts. Currently, over 70 dams have been planned one after another on the rivers of the Upper Ganga Basin since 2016. The EIAs and CIAs brought forward new science and data into the public domain but to everyone's amazement, had the effect of endorsing all the planned projects without finding a single one dangerous to the ecosystems or local communities!! This has happened because all such EIAs and CIAs issue clearances in principle, with a large number of caveats and statutory conditions. Unfortunately, once the clearance is issued 'in principle', the project proponents proceed and continue with the construction work at full speed, without really bothering to comply with the conditions of approval.

When public interest petitions are filed for procuring a stay order or an injunction in such situations, the argument put forward by the contractors or government agencies is that large amount of public money has already been invested, and that any stoppage would lead to a national loss. This undesirable practice has made a mockery of 'good-governance', and become a major limitation of the EIA process.

Another limitation is that many of these reports are not based on scientific scrutiny or verifiable evidence, and there have also been changes in the stringency and transparency in the EIA procedures. The latest 2020 Draft EIA Notification in India has been criticized for its "dilution and protecting the project proponents from any kind of public scrutiny, covering up for the violations and making the Environmental Clearance (EC) process more and more non-transparent, undemocratic, unjust and unaccountable". Further, around four CIAs were reported to be missing from the MoEFCC website where they were required to be uploaded *(SANDRP, 2016, 2020)*.

Apart from these issues, the fundamental error in such assessments is the difficulty of converting social or environmental values into monetized values and defining equity and benefits. The methods of evaluation have various limitations e.g., the trauma of a displaced person, value of a tree, and costs of machinery used in construction projects are non-comparable, and assigning values to some of these factors is unfeasible. They also do not answer the question about viability and 'benefit for whom'. Such issues raise serious questions about dam evaluation studies which need detailed solutions and further research.

8.13 CONCLUSIONS AND RECOMMENDATIONS

1. River Valley Projects have not been evaluated continuously and there are no 'ex-post-facto' studies of whether or not assumptions regarding costs and benefits made in the feasibility reports were validated.

Therefore, there is a need to immediately adopt a system of continuous evaluation, wherein 'mid-term evaluation' and evaluation at the time of 'project completion', becomes mandatory for all projects irrespective of their scale. This is important because these investments are huge and come from the national budget, and their misuse or loss tantamount to squandering of public money.

2. Along with sustaining water flows through all seasons, the cryosphere is situated at a great height.The availability of ice-fed and rain-fed rivers along with the natural gradient provides great scope for hydro power generation.

There is a need to take into account comprehensive data on the Cryosphere when such projects are being conceptualized, planned, designed and implemented.

3. Large scale hydropower projects have benefited the urban population in metropolitan cities, but the dream of providing providing electricity to hilly areas still remains unfulfilled.

Therefore, it is recommended that micro hydropower projects which do not alter the river flow regimes, require no storage, tunneling and divergence of water, and use the natural energy-potential of flowing water, be prioritised.

4. Since border roads are meant for defence purposes, and reliability is of essence, they must go through the process of road safety stipulations, which includes a prior evaluation process for judicious selection of routes for construction through geologically safe regions.

5. Constructing highways in such mountainous terrain which are greatly vulnerable to geomorphic changes like landslides, etc., lead to major geo-morphological and biological alterations.

Therefore, there is a need to carry out slope-and-toe-stabilization-treatment well before the roads are laid. Similarly rock and slope bolting with metal anchors need to be routinely carried out and the costs should be "factored-in" while planning and implementing hill road projects.

6. With changing climatic patterns, especially precipitation, the rule curves and reservoir operational schedules for all the old dams need to be immediately revised in order to effectively manage the floods in future.

It is therefore recommended that these schedules should include trade-offs between flood losses and hydropower generation. For every increase in the flood cushion there may be certain loss in hydropower generation and this would need a 'trade-off' to arrive at an optimal solution.

7. *It is recommended that the existing cadre of trained engineers and contractors be given the task of*

a) conducting dam safety analysis, technical audits of all the dams,

b) dam safety reports and retrofitting these dams by including flood management,

c) revising reservoir-operation-schedules, (ROS)

d) including fish ladders in the design.

e) improving efficiency of existing dams with mechanized ultra-modern flood warning systems, mechanization of spillways and gates, instrumentation for measuring flows and discharge rates.

8. *It is recommended that there should be a system for swift decision-making process and enforcement related to release of water or reduction of releases which can ensure reduction in flood losses.*

9. *Engineers in NDRF and SDRF should be given more powers and an appropriate mandate so that such decisions are taken by professionals (and not by untrained elected representatives).*

10. *Sediment Management Plans must be based on a strong understanding of sediment dynamics aimed at improving river health for which detailed studies have to be initiated.*

11. *Governance models which promote better efficiency in energy utilization such as 'block-tariffs' should be implemented.*

12. Environment Impact Assessment (EIA) should be carried out for every project in such regions and a 'Cumulative Impact Assessment' (CIA) should be carried out for each river basin or sub-basin where two or more projects are planned.

ENDNOTES :-

80. Kutcha road: A kutcha road is an unpaved road without a proper bed to bear vehicular load. These roads turn muddy and slippery during the monsoon and are often unfit for vehicular movement.

81. A study by Chaudhary et al. 2013 from Wadia Institute of Himalayan Geology shows that

the oscillatingreservoir has been working towards inducing stability during peak reservoir (storage) periods with earthquakes in higher seismicity observed during unloading periods. A unique observation in seismicity is in the occurrence of higher magnitude conditions of either filling or decreasing reservoir levels rather than at peak reservoir levels.

82. Further, on 27 January 1994, the Union Ministry of Environment and Forests (MoEF), Government of India, under the Environmental (Protection) Act 1986, promulgated an EIA notification making Environmental Clearance (EC) mandatory for expansion or modernization of any activity or for setting up new projects listed in Schedule 1 of the notification. Since then there have been 12 amendments made in the EIA notification of 1994. In the 1990s India also agreed to the requirement to consider transboundary effects of such projects under the Espoo Convention

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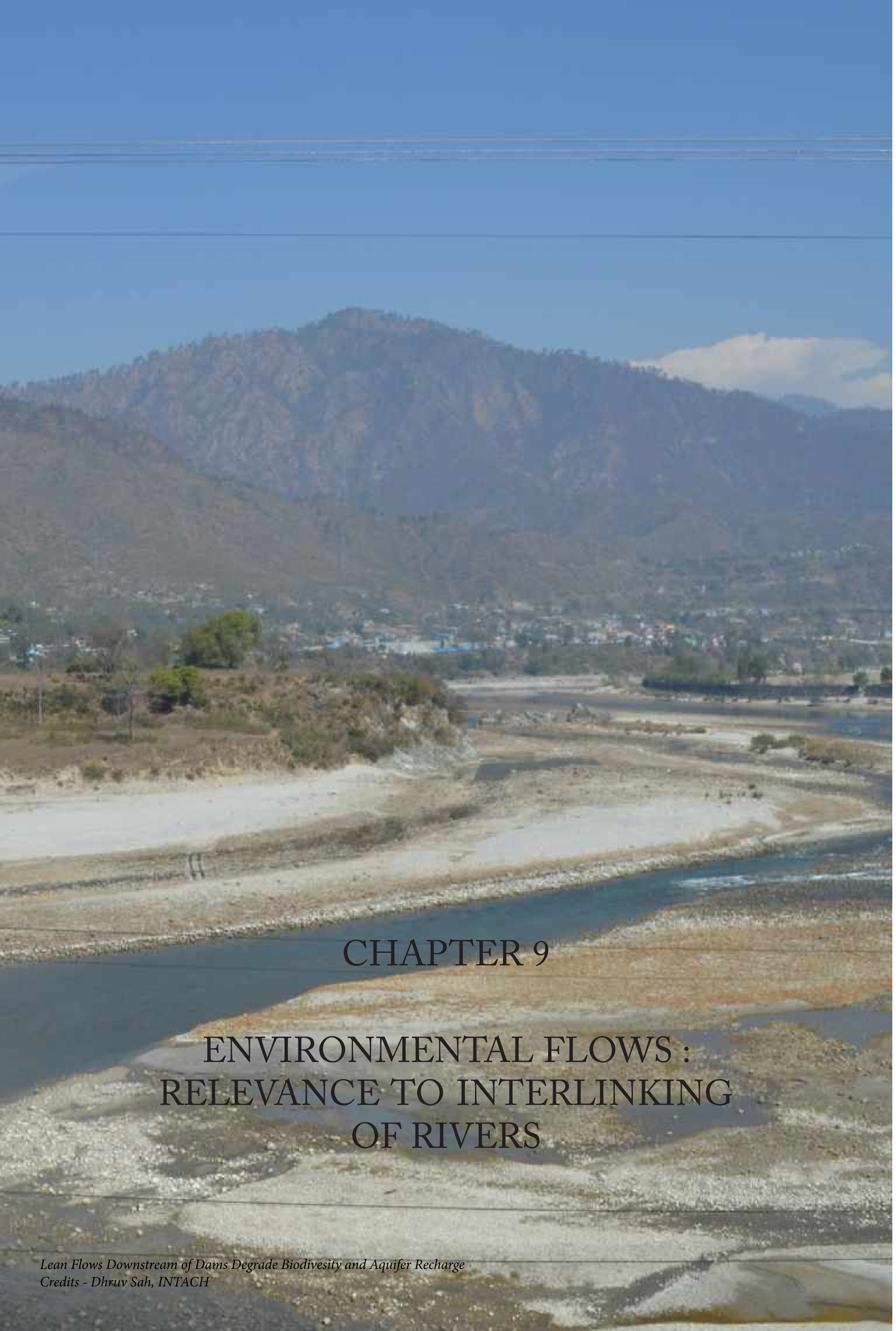


CHAPTER 9

ENVIRONMENTAL FLOWS : RELEVANCE TO INTERLINKING OF RIVERS

Lean Flows Downstream of Dams Degrade Biodivesity and Aquifer Recharge
Credits - Dhruv Sah, INTACH

9.1 NOTIFICATIONS ON E-FLOWS IN INDIA

The 2012 National Water Policy in India mentioned the importance of maintaining Environmental Flows (E-flows), but it gave no specific guidelines regarding what such minimum flow should be. It merely stated that "a portion of river flows should be kept aside to meet ecological needs". Even though a policy for maintaining 'environmental flows' had been normatively accepted, it gained crucial significance in India with the promulgation of a 'Notification on E-Flows' made by the National Mission for Clean Ganga (NMCG) in 2016. It was made mandatory for ten states and one Union Territory lying within the Ganga River Basin. The principle and practice of maintaining E-flows may be deemed as a mandatory and statutory requirement in India since the underlining principles have been included in the Cauvery (Feb, 2013), Krishna (Nov, 2013) and Godavari (July, 1980) Inter-state Water Tribunal Awards.[83]

The NMCG (GoI) defined E-flows as "the regime of flow that mimics the natural pattern of the river flows as regards quantity, quality, timing which maintain the ecological functions, as evolved over the ages and to enable the aquatic ecosystems to remain resilient to climate change impact." Simultaneously, the policy statement speaks about enabling the river to provide ecosystem services to human communities. It should be borne in mind that this statement (2016) was primarily the consequence of strong civil society demands spearheaded by Prof. G.D. Agarwal and several other voluntary organizations from 2012 onwards i.e., since the promulgation of the National Water Policy.

Subsequently, on 9th October 2018, a 'Notification on E-flows for Ganga River' was announced by the Union Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR), in pursuance of the Environment (Protection) Act, 1986. It stipulated that all current projects were required to comply with the E-flows Regulations within three years of the promulgation of the Notification, and it provided standards for minimum environmental flows to be maintained by irrigation, hydropower and industrial projects operating in the upper Ganga Basin between the glaciers at the source of the river and Haridwar, and the main stem of the Ganga up to Unnao in Uttar Pradesh.

Table 9.1 : Percentage Of Monthly Average Flow Observed During Each Of Preceding 10-Daily Period From Upper Ganga River Basin Stretch Starting From Glacier Origin And Through Respective Confluences, Finally Meeting At Devprayag Up To Haridwar
(Central Water Commission, 2019)

Sl. No.	Season	Months	(%) of Monthly Average Flow observed during each of preceding 10-daily period
1	Dry	November to March	20
2	Lean	October, April and May	25
3	High Flow Season	June to September	30

Table 9.2 : Minimum Flow Releases Immediately Downstream Of Barrages Between The Stretch Of Main Stem Of River Ganga From Haridwar, Uttarakhand To Unnao, Uttar Pradesh *(Central Water Commission, 2019)*

S. No.	Location of Barrage	Minimum flow releases immediately downstream of barrages(in cumecs) Non-Monsoon (October to May)	Minimum flow releases immediately downstream of barrages(in cumecs) Monsoon (June to September)
1	Bhimgoda (Haridwar)	36	57
2	Bijnor	24	48
3	Narora	24	48
4	Kanpur	24	48

The Notification states that, as a principle, 10-15% of monthly average flows observed during each of the preceding ten days have to be released from different projects / barrages for the period November to March. Further, 25% have to be released for October, April and May, i.e., the lean period; and 30% for the high flow season, i.e., June to September. In practical terms, the minimum flow to be discharged at Kanpur barrage will have to be 24 cumecs downstream of the barrages. These standards apply to all existing, under-construction and future projects on Ganga and its tributaries. The flow conditions will have to be monitored by the Central Water Commission at hourly intervals. As per the amended 2019 Notification, all dams and hydropower projects were to comply with these conditions with immediate effect. This meant that the original Notification had been substantially stricter, by removing the three years' grace period granted as per the 2018 Notification.

9.1.1 Issues related to Notification on E-flows

The 2018 Notification and its Amendment in 2019, were limited to a small part of the Ganga basin and had various technical issues. Experts have repeatedly raised questions regarding the scientific validity of the minimum standards provided in the notification. There are serious doubts regarding transparency in arriving at minimum standards, as the notifications do not mention the criteria for determining the norms. Keeping 10%-15% releases as the minimum flow, tantamounts to saying that about 85%–90% of the flows can be diverted at any location from the river system. A 'thumb rule' method, rather than location and river-specific criteria, was used as the basis for determining e-flow norms. The situation is similar in Nepal which mandates that 10% of water should be left to flow below the dam to maintain the ecosystem. Further, these norms seem to be based on existing releases, therefore the current minimum standards are so low that every project would automatically achieve compliance *(Pardikar, 2020)*.

Providing the E-flow standards would have been meaningful if the bar was set higher than the flows being currently released since that would have been truly beneficial to the river system as a whole.The basic idea behind maintaining E-flows should be that rivers are not mere water pipelines, but living ecosystems which carry silt as well nutrients for varied biodiversity and aquatic life. For example, in 2009-10, the World Bank set a higher standard for minimum flow for the Alaknanda River in its 'Project Appraisal for the Vishnugad Pipalkoti dam'. The World Bank appraisal report states that "A minimum flow of 15.65 cumecs of water will be left in the river at all times to sustain the aquatic health of the river. This is equivalent to approximately 45% of the average lean season flow of the river" *(Haney, 2009)*. Reaching such goals requires a radical shift in the existing understanding of e-flows and a strong political will to implement such a standard.

In spite of such low targets, many hydropower projects seem to be flouting these regulations. A review of the four quarterly status reports by South Asia Network on Dams, Rivers and People (SANDRP), of the CWC Report entitled 'Implementation of Minimum Environmental Flows in River Ganga (upto Unnao)' published from April, 2019 to January, 2020 state that "while the e-flow notification of NMCG is seriously flawed, even those token norms are not being followed by almost any of the eleven projects being monitored"*(SANDRP, 2020)*. The Maneri Bhali Phase- II hydropower project, the Vishnuprayag and Srinagar hydro-electric projects and the Pashulok barrage in Uttarakhand State have failed to meet the 15th December, 2019 deadline, and no action was taken against the violators until January, 2020 *(Central Water Commission, 2019)*." The status reports had technical errors and had failed to include all the states within the Ganga River Basin.

These norms were to be implemented by all concerned State governments for large dams and hydropower projects, by preparing demand side management plans to reduce water withdrawals from the main-stem of the river. Such plans were to be prepared in order to improve the water-use efficiency especially in agriculture and industrial use so that the water saved could augment the environmental flows. But unfortunately, such State level plans are not yet available in public domain for review or scrutiny.

An important flaw in the Notification is that it is assumes, without any scientific basis, that mini and micro projects do not significantly alter the flow characteristics of the river or stream and thus have been exempted from these E-flow norms. However, each of these mini or micro projects break the longitudinal connectivity in the upstream and downstream regimes because of divergence of river flows through tunnels, creating dry patches in the natural river bed, thus fragmenting the river. This flaw in the Notification needs to be corrected immediately. Along with water, the E-flows also need to ensure the flow of silt, nutrient and biota. Moreover, it is not just the quantum of water releases that is important, but also the manner of release which should be smooth and continuous rather than in spurts regulated by the pattern of power generation. However, the E-flows Notification does not mention these aspects at all. This leads to the unscientific and incorrect claim by Project Authorities that water flowing through the turbines of hydropower projects should be considered as E-flows.

9.2 DESTRUCTION OF NATURAL DRAINAGE SYSTEM AND IMPACTS ON E-FLOWS

The National Wetland Atlas of India, 2011 states that about 36% of Wetlands (water bodies) have disappeared in the States of Madhya Pradesh and Uttar Pradesh *(Panigrahy et al., 2011)*. Loss of wetlands due to encroachment, construction, building embankments and filling up of the natural depressions has led to reduction in storage. This reduction in storage capacity in the catchment area aggravates the water shortage problem in the lean periods and further reduces the ability to hold back flood waters during monsoon season, thus resulting in lowering the capacity of the basin to soften the extreme events of floods or droughts. Reduction in Wetlands leads to a decrease in return-flows from the groundwater aquifers, thus reducing the E-flows. This state of affairs has been mainly created due to large scale impoundment and major diversion of river water at dams and barrages. For example, the Farakka Barrage has led to increase in pondage and siltation causing a backwater effect in the river leading to increase in flooding events in Bihar.

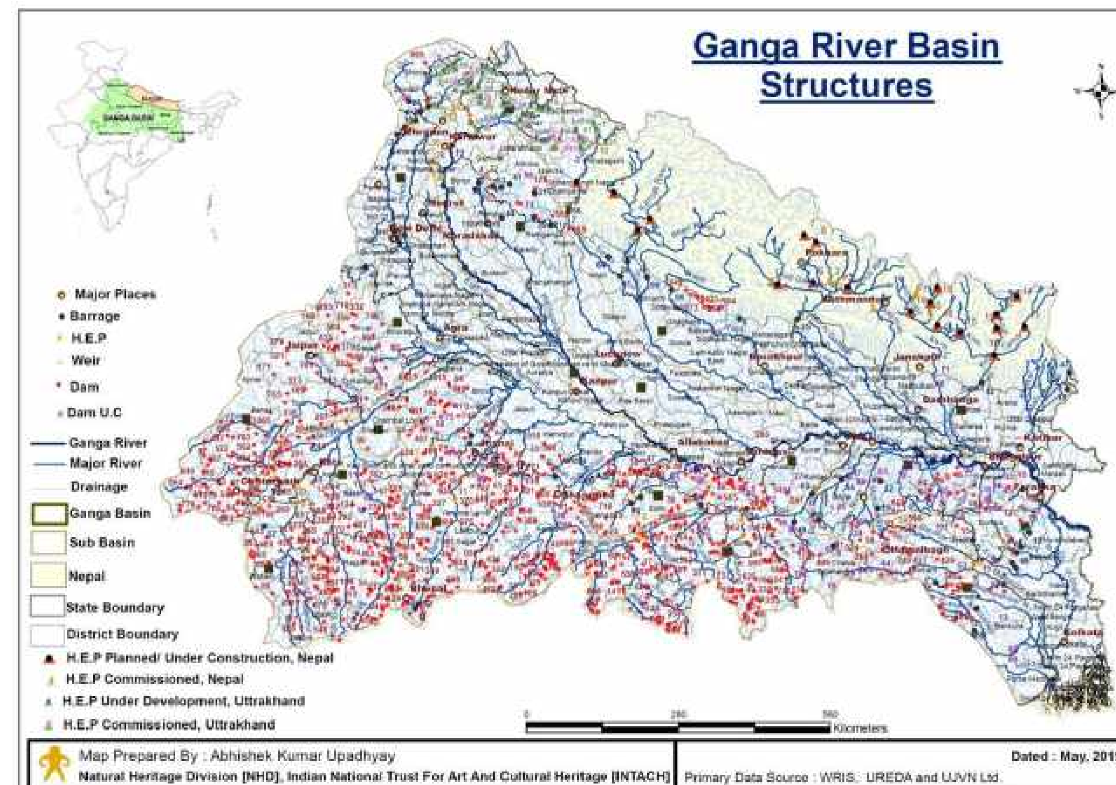
Satellite Image Showing The Divergence Of 1150 Cumecs Of Water Through The Right Bank Feeder Canal To Bhagirathi-Hooghly River, Reducing The Velocity, Pinching The Width Of The River, Causing The Emergence Of River Islands And Sluggish Flows In The Downstream Region Beyond Farakka Barrage

(Google Earth, n.d.)

Post the barrage, the velocity of water has reduced, which leads to the river becoming sluggish with periodic episodes of heavy flooding in the lower regime in Bangladesh. Apart from loss in volume of water, the quality of water has also suffered due to pollution caused by industrialization, especially due to super-thermal-plants located just downstream of Farakka Barrage.

9.2.1 Reduction in flows in the Ganga River: 1547 Obstructions - Dams, Weirs, Lift Irrigation Systems, Hydro-Power Projects!

The map below gives a clear idea of the unsustainable nature of the innumerable dams, barrages, hydropower projects and canals, which have completely destroyed the natural river system in the Ganga Basin. Various reports, when seen together, indicate that there are more than 1000 dams and barrages in the Ganga River System and more projects are in the proposal stage. This unwarranted and unchecked obstruction and abstraction has led to a dramatic reduction in the flows in many rivers in the basin. Since flow data was not available in the public domain, 'Rejuvenating Ganga, A Citizen's Report, 2019' had to rely on using the modelling technique for calculating existing flow rates in the river system. The results of such calculations show that the Ganga River and its tributaries have witnessed a drastic reduction in annual and seasonal flows over a period of 31 years (1975-2005).



Map 9.1 Large-Scale Impoundments And Diversion Of River Water At Dams And Barrages In The Basin Which Have Caused Significant Fall In Flow In Ganga Main Stem And Its Key Tributaries (*Large Scale Map in Annexure*)

The Citizens' Report states that Ganga River has seen a 45% flow reduction at the Farakka Barrage and 57% flow reduction at Ganga Sagar in just over 30 years. Without significant contributions from the left bank tributaries (Ghaghara, Gandaki and Kosi in particular), the Ganga River would have been in a dire state, since all its right bank tributaries (Yamuna, Chambal, Sindh, Betwa, Sone, and Damodar) have already been heavily compromised with dams, barrages and canals. This situation is not just seen in the plains but also in the upstream regions where the river has already started drying up in patches. At a short distance from its origin, Ganga slows to a trickle downstream off the Maneri Bhali dam.

The new data emerging from the CWC and other reports indicates that many more dams and water extraction projects have been completed during the last eight years, and the current figures stand at 1547 structures (inclusive of major, medium and minor dams, weirs, anicuts and barrages, lift irrigation schemes, hydro-electric projects, etc.). This is mainly a result of enormous pressure on State and private agencies to hasten and complete on-going projects and planning new ones *(National Register on Large Dams, 2019)*.

Apart from unchecked abstraction of water, activities such as ruthless sand mining or removal of bed-load boulders also disrupt the flows in the river system. In the light of this scenario, compounded by changing glacial melt, the implementation of Interlinking of Rivers Programme seems based on false premises and will result in irreversible damage.

9.3 A REVIEW OF INTERLINKING OF RIVERS PROGRAMME

The National River Linking Project (NRLP) formally known as National Perspective Plan or also known as Interlinking of River (ILR) Programme and other developmental projects rest on the claim that Himalayan Rivers have surplus water flows. This claim needs to be corrected in view of the changes in the current flow regimes in different Himalayan Rivers.

The existing flow in Ganga River is largely due to the left bank tributaries - Ghaghara, Gandaki and Sapta Kosi in particular, which flow through Nepal borders. Therefore, diverting Ghaghara River's water to other rivers through ILR would mean substantial reduction in Ganga river flows, especially in summer season. The main objective of the ILR is to provide water to water-deficit regions during water scarcity months, but if the main rivers themselves do not have surplus water during the summer season, the claim to provide water to other rivers and regions through canals and dams would not hold strong grounds. Such projects will further alter the E-flows drastically during monsoon and lean season flows.

Along with changes in glacial-melt and wholesale abstractions from rivers has led to reduction in flows from the upstream regime. Rampant construction of multiple dams on a single stretch of a river will completely destroy the river. The aggradation of river channels caused by water withdrawals and dam construction could reduce width of downstream channels, making river beds less elastic to extreme flows in the rainy season. The loss of river beds and the carriage of sediment outside the channel may worsen 'flood-peaks'.

In view of the nature of the river system and the present status of E-flows in the river, discussed above, it is important to review the long-proposed Plan for Integrated Management of Ganga River: (National River Linking Project or ILR). As part of the Integrated River Management approach, the National Water Development Agency (NWDA) under

the Ministry of Water Resources has proposed 30 major River Link Canals throughout the country - 14 links under Himalayan Rivers Component and 16 links under Peninsular Rivers Component for inter-basin transfer and 37 intra-state river linking projects including a network of almost 3,000 storage dams and numerous canals. The mission of this project is to ensure greater equity in the distribution of water by enhancing the availability of water in drought prone and rain-fed areas.

This official stand is greatly flawed because if the Sarda-Yamuna-Rajasthan Link Canal is constructed, enormous quantities of water will be abstracted from the Ganga River Basin and transferred to Rajasthan and Gujarat, leading to a disastrous reduction of the E-flows in the Ganga River System.

9.4 HISTORY OF INTERLINKING OF RIVERS PROGRAMME

The legacy of this programme goes back to an interlinking plan proposed by Sir Arthur Cotton, the well-known British engineer in the 19th century, to enable transport and to address water shortages in arid and semi-arid parts of the country. Post-Independence, this idea was taken up under the name of 'National Water Grid' by Dr. K.L. Rao in 1972. The plan proposed that water from surplus rivers such as Brahmaputra and Ganga be transferred to the rivers in the Peninsular Central and South Indian Rivers, which have deficit water balances. In 1978, Captain Dastoor proposed 'The Garland Canal Project' with a similar aim, but since it was considered technically unfeasible, it was rejected. In 1980, the Ministry of Irrigation (now Ministry of Water Resources) formulated a National Perspective Plan (NPP) for Water Resources Development, envisaging inter-basin water transfer in the country *(Mehta & Mehta, 2013)*. In 1987, the first National Water Policy was formulated. For the first time the Interlinking of Rivers as one of its main objectives was highlighted.

The National Perspective Plan on inter-basin transfer comprised of two components, namely i) Peninsular Rivers Development and ii) Himalayan Rivers Development. The Himalayan River Development component of the proposed plan envisages construction of storage reservoirs on Ganga and Brahmaputra and their principal tributaries in India and Nepal. Further, it proposes construction of an inter-linking canal system to transfer surplus flows from the left bank tributaries to the right bank tributaries of Ganga, or outside the Ganga basin altogether. This component has two sub-components: a) Connecting the Ganga and Brahmaputra basins to the Mahanadi basin and b) Connecting the left bank tributaries of the Ganga first to Yamuna (right bank tributary) and further on to the Sabarmati River System. These components aim at providing irrigation to an additional area of about 22 million hectares and generating about 30 million kilowatts of hydropower. This component is also expected to provide substantial flood control in the Ganga-Brahmaputra basin.

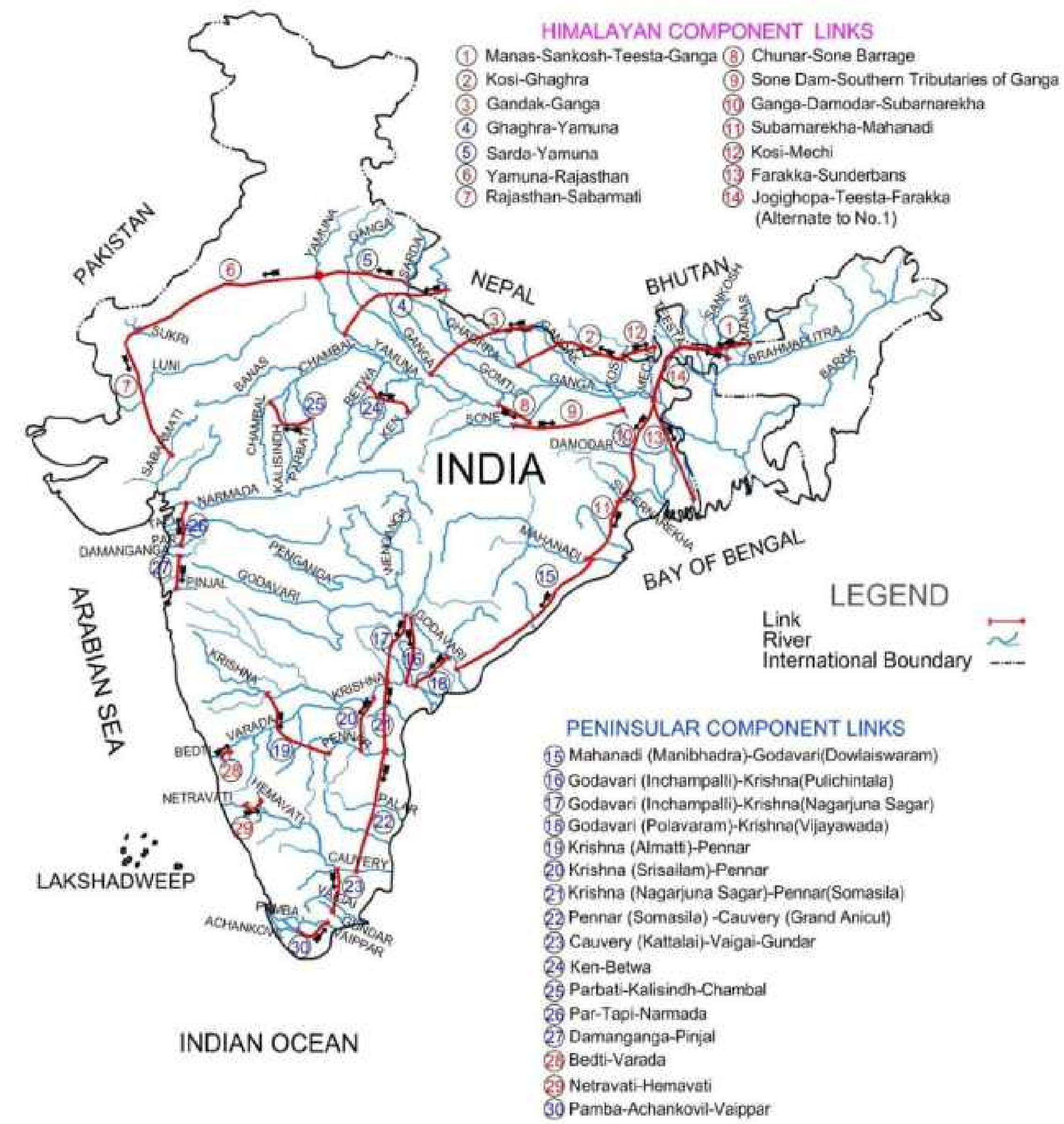
9.4.1 Update on Status of Inter-Linking of Rivers

In 2015, a Task Force for Interlinking of Rivers and a Group on Intra-State River links was formed to take the Plan forward. In 2017, a Group on Financial Aspects of the ILR was formed to consider the funding patterns for implementation of the ILR proposal. Recently in 2018, the Task Force on ILR submitted its interim project report to the Ministry of Jal Shakti.

The megalomaniac stand of all governments, past and present notwithstanding, of all proposed links, only one project, the Ken-Betwa River Linking Project has been pushed forward. In 2014, the Ken-Betwa River Linking Project got Cabinet approval, however the project was stalled due to objections from the state of Madhya Pradesh, one of the beneficiary states; the other one being Uttar Pradesh. Ken-Betwa River Linking Project (Rs 9,393 crores) "proposes" to transfer "excess" water from the River Ken to the Betwa basin through the use of a concrete canal of 221 km. The project aims to provide irrigation to the Bundelkhand region, which is one of the worst drought-affected areas in India, and provide drinking water and electricity to six districts in the region. However, the project has huge environmental costs as it would lead to submergence of nearly 6,107-8,650 hectares of forest land including parts of Panna National Park in Madhya Pradesh, and would have an adverse impact on tiger reserves and wildlife sanctuaries in the region *(Sehgal, 2021)* and yet the National Board for Wildlife (NBWL) gave a conditional clearance to this project *(Vishnoi, 2016)*. Finally, in March 2021, the governments of Uttar Pradesh and Madhya Pradesh signed an agreement that nudged forward the inordinately delayed multi-thousand-crores controversial project to link the Ken and the Betwa rivers. In the year 2022, GoI has approved implementation of KBLP at an estimated cost of Rs. 44,605 crores (at year 2020-21 price level)!

Apart from this project most of the other links are still in the process of negotiation on deciding surpluses and deficits for arriving at agreements between all the concerned State governments. The financial, social, political as well as environmental costs of the projects are tremendous, which makes the entire plan extremely unviable and disastrous. The proponents of the project claim that such a plan will solve India's water problems, thus offering an Integrated Water Resource Management solution for water security. Further, the project is also seen to offer benefits to mitigate floods and inundation, improve transport infrastructure for navigation, generate 34,000 MW of hydropower and provide livelihood sources to the rural communities through irrigation of an additional 35 million hectares of land and fish farming(Misra et al., 2007). However, some of the very basic conditions of the project are difficult to meet in the present scenario.

At the societal level, the ILR programme is based on scientifically incorrect and naive or simplistic assumptions leading to misunderstanding of the river systems. It is claimed that the ILR will take water from high water availability areas to water scarce regions. At present, water technology has evolved to the extent that transferring water from vast distances is easily possible and that it is the prejudiced environmentalists who are opposing the project. These are general societal perceptions about the project which have gained



Map 9.2 The National Perspective Plan On Inter-Basin Transfer Comprised Two Components, Namely I) Peninsular Rivers Development And Ii) Himalayan Rivers Development

(Bansal, 2014)

great support without much scientific rationale. In reality, however, the ILR will lead to the following problems:

1. **Reduction in water flows in Himalayan Rivers** : The interlinking project rests on the claim that Himalayan Rivers have surplus water flows. This claim needs to be reviewed based on the current flow regimes in different Himalayan Rivers. As discussed above the 'Rejuvenating Ganga, A Citizen's Report' of 2022 clearly states that the River Ganga and its tributaries have witnessed a drastic reduction in annual and seasonal flow over a period of 31 years (1975-2005). The existing flow in Ganga River is due to the left bank tributaries - Ghaghara, Gandaki and Kosi in particular which flow through Nepal borders. Therefore, diverting the waters of Ghagara River to other riv-

ers would mean substantial reduction in Ganga river flows, especially in summer seasons. The main objective of the ILR is to provide water to water deficit regions during water scarcity months, but if the main rivers themselves do not have surplus water during summer season, the claim to provide water to other rivers and regions through canals and dams do not hold strong grounds.

2. **Long Gestation Period** : The estimated gestation period of a project such as ILR is around 30 years. The full blown impact of climate change and its negative consequences are projected to emerge by about 2050, and the greatest likelihood is that availability of water in the 'so-called' surplus basins will further dwindle due to the rapid melting of the cryosphere in the second half of the century. Therefore, the current flow estimates will vary greatly within the gestation period of the entire programme and later after the project completion, therefore raising serious concerns about its viability in the future.

3. **Financial Overruns** : **The initial cost of the project was Rs. 5.6 lakh crores in 2002.** However, with increasing inflation rates the project cost now amounts to a very huge sum. The 1:1.5 input to output ratio as calculated in the Detailed Project Report therefore does not match due to costs of **the project as calculated in 2014 to be around Rs. 11.2 lakh crores** *(Krishna, 2016)*. The ever-increasing costs of the project with long gestation periods, no immediate returns further raise questions about the financial feasibility of such a mammoth project. In India, the time taken for project completion of large-scale water projects is almost always in excess of initial estimation, which means that inflation also contributes towards cost escalation.

4. Further, **the rates of siltation in many of such projects in the Himalayan Rivers lead to substantial reduction in their useful life**, as experienced in the case of Tehri dam. India already has a legacy of long overspending debts due to cost overlays from large scale water projects such as dams and barrages. With each new plan, the backlog of projects i.e., incomplete projects keep on rising along with increasing spill-over costs which are generally in hundreds of crores due to abnormal delays in completion of projects. The universally accepted concept of 'mid-term or periodic evaluation' is not being followed and there are no 'ex-post-facto' studies of completed dams, wherein the initial assumptions regarding costs and benefits made in the feasibility reports have been verified on the basis of actually realised values of costs and benefits.

5. **Absence Of Water Balance Studies On All The Rivers** : The ILR canals are supposed to function chiefly from October to May and have to provide water supply every year based on the agreement or treaties signed. This requires fulfilment of some basic criteria:

i. **Identifying Surplus Water Flows In The Main Rivers** : There is no study published or available in public domain, which identifies surplus water balances in any of the Indian rivers. Flow data of Ganga River has not been placed in public domain as it might raise questions from our lower riparian country Bangladesh, which is currently at the receiving end with regards to discharges from Farakka Barrage.

ii. **Identifying Deficits In Different River Basins** : Deficits have to be identified in other basins which generally override the political boundaries of different states. Therefore, deficit states and surplus states will have to come to an agreement for each river linking project. Such agreements will require declaration of water balances from every state which none of the concerned states are willing to share.

6. **Optimal Use Of Available Water** : Identifying surplus and deficits will have riders such as; have the available water resources being used optimally? Have the alternative uses of water been calculated based on natural eco-zones, cropping patterns, waste-water reuse? And even if the surpluses have been calculated, have they accounted for the stipulated requirements of the Notification on E-flows, which requires mandatory discharges to be maintained by every barrage and dam? Similarly, have the deficits/surpluses included the evaporation and seepage losses, which may account for at least 40% of the gross flows, etc.? Without satisfactorily addressing these questions the optimal utilisation of available waters in different sub-basins cannot be achieved.

7. **Links Will Have To Cross Over High Ridges Between Various Basins** : The proposed links between different rivers require the canals to cross over different river basins, mountain ranges such as the Aravallis, Vindhyas, Satpudas, etc. Transferring water through these links will involve sending water from sea level Gangetic plain to the plateau region (2000-6000 ft high). Such a transfer will require a huge amount of electricity and the technical difficulties of crossing over the mountain ranges will have to be considered. In order to avoid this difficult terrain, the proposed links go around the Central Plateau region. Thus, ultimately transferring water from the water "surplus" region in the Himalaya to the water "surplus" region in the Western and Eastern Ghats, thus, leaving the truly water scarce Central Plateau high and dry!

8. **Crossing Over Multiple State Boundaries** : Further, they entail crossing different state borders which require political cooperation between all the states involved. Presently, the natural riparian states are at competing ends for water resources. Consequently, the political circumstances under which such a huge transfer will have to be carried out makes the problem more vexatious. This is an extremely contentious political issue with extreme potential volayilati.

9. **Issues related to International Transboundary Water Cooperation :** As a signatory to the International Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 1992 and UN Watercourses Convention, 1997 the upper and lower riparian states are required to take prior-consent from the involved parties before each transfer. Therefore, a transboundary river such as Ganga requires a prior consent for water transfers, co-operation for water-use optimization and policy for no injury to other riparian states and vice versa. Existing transboundary agreements between India and Nepal over the Ganga River mainly focuses on building dams, irrigation and hydropower projects. These treaties have no component on

sharing or transferring of water (See Chapter 12). Although Bangladesh is the lower Riparian state, the ILR project does not include any treaty or agreement with Bangladesh for diverting Ganga waters to other basins within India. This situation is further aggravated with increasing political tensions between the neighbouring states thus, questioning the overall validity of the ILR project.

10. **Geological And Environmental Problems** : Such large scale projects will also have large scale impacts on the hydrogeology and environment. Some of them are as follows:

a. Most of the water scarce areas in the plateau have an underlying impermeable rock structure which can lead to cases of water logging. Presence of salt rocks such as gypsum strata in such areas, can lead to increasing salinity in water and soil due to water logging, thus degrading the entire ecosystem and biodiversity.

b. Most of these canals will require huge amounts of land thus, inevitably leading to loss of forest areas, pastoral lands or agricultural areas.

c. Changing temperatures, water quality in the water bodies will have an unprecedented impact on aquatic and terrestrial biodiversity.

d. Further, ILR will change the entire river regime downstream. Reduction in water levels in annual discharge will lead to avulsions in the plains, which during floods might get revived.

e. Constantly changing the river systems will have a significant impact on groundwater, ecosystems, aquatic biodiversity and agricultural lands.

f. The changing surface and sub-surface hydrology will impact weather patterns in an unpredictable manner as brought out by the recent IIT Mumbai study which brings out that river interlinking alters land-atmosphere feedback and changes the Indian summer monsoon.

g. Transition of arid zones into wet zones will have a severe impact on the migratory birds, fishes, mammals and therefore, will impact the entire food chain.

h. Changes in the volume of sedimentation due to obstruction leading to increase in deadweight and the sudden loading and unloading of storage-dams can lead to an increase in the natural propensity of seismic tremors due to release of latent energy in the tectonic plates.

11. Several options are available to optimize water resources within basins. Irrigation efficiency, changed cropping patterns [millets for eg.], water use efficiency, recycling of treated waste waters, rainwater harvesting should be emphasised *a priory* before extra basin imports are considered.

12. Benefit for whom and at what costs? Lastly, but importantly, construction of these canals, barrages and impounding water in dams will lead to submergence of lands of tribal populations and natural forests in different parts of the catchment of the river basin. This raises the important aspect of rehabilitation of millions of people in different parts of the country. India's experience with rehabilitation of people has not been very successful raising serious concerns about the social impacts of such a large-scale project (see Chapter 8). Mismanagement of E-flows and changing river regimes will not only disturb biodiversity but also force the communities living around the water systems and downstream to adapt to the vastly altered hydrological regime.

13. Further, the project does not include water availability for areas through which the canals will pass; therefore the canals will cater to the demands of the areas which already are water surplus as stated above. This will aggravate the pre-existing inequality in the natural water distribution wherein the central or interior peninsular region is mostly arid as compared to the coastal areas.

14. Thus, the primary objective of the project to reduce natural inequities in water distribution will remain unfulfilled. Hence, apart from the question of 'benefits at what cost?' the most crucial question which needs to be answered is 'Benefits for whom, and at whose cost?' which addresses equity and social justice.

15. Considering the transboundary nature of Ganga river system as discussed in the chapter earlier and without taking into consideration the above-mentioned issues related to the ILR programme, embarking on such a programme which will change the entire morphology and hydrology of the Ganga river basin. Such a drastic change will have unprecedented impacts not just within India but across our borders especially in the lower riparian regions of Bangladesh. Considering the fact that flood disasters like the Kosi River have already increased due to destruction of the natural drainage patterns; the construction of canals and dams for ILR of such great magnitude will create further havoc. Therefore, Integrated Water Resource Management will require an integrated understanding of the river system beyond borders and beyond the historical legacy of projects such as ILR.

9.5 CONCLUSIONS AND RECOMMENDATION

1. The existing standards or norms set by the E-flows Notification are clearly based on the discharges already being achieved.

It is therefore recommended that the bar for E-flow standards should be set higher (increase in the E- flows percentages) than the flows being currently released, since that would be truly beneficial to the river system as a whole.

2. The status reports and reviews indicate that CWC is not the right body for achieving

compliance on environment flows, since it then functions as the jury and the judge.

It is recommended that an independent body that has no conflict of interest be formed for the purpose.

3. One way of looking at the question of maintaining requisite flows in Ganga River is by emphasizing on the demand side rather than supply side management of water withdrawn from the river system. This will mark a change in approach, where water is allowed to be diverted from the rivers in the Ganga basin to meet essential water needs and no more.

It is recommended that this should be achieved through greater water use efficiency, recycle and reuse of diverted water to meet irrigation, industrial and non-consumptive domestic requirements.

4. Merely promulgating an instrument like the E-flows Notification cannot and will not ensure its implementation and enforcement in letter and spirit.

Therefore, it is recommended that each of the 10 states and one Union territory also formulate specific Bye-laws and/Guidelines which make it obligatory for them to implement and enforce the provisions of the Notification.

5. *It is recommended that adequate and reliable equipment at every dam and barrage which is automated and amenable to being continuously monitored for the proper implementation of the E-flows Notification.*

6. The formidable list of arguments, obstacles and the long gestation period which will easily exceed 30 years, is indicative of the fact that even with the necessary political will to raise requisite finances, the ILR programme will not be economically viable, socially justifiable and environmentally sustainable. The full blown impact of climate change and its negative consequences are projected to emerge by about 2050, and the greatest likelihood is that availability of water in the 'so-called' surplus basins will further dwindle due to the rapid melting of the cryosphere in the second half of the century. Therefore, the basic design parameters of the ILR programme, especially those required for dams and canals, may become completely invalid for later decades.

ENDNOTES :-

83. Note: As per Article 56 in the Constitution of India, the Awards declared by the Interstate Water Tribunals are treated as equivalent to the judgments of the Supreme Court of India.

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CHAPTER 10

POLLUTION IN THE GANGA

Mass Fish Kills as a Result of Pollution - Overload of Religious Offerings Disposal
Credits - Dainik Jagran

10.1 INTRODUCTION

When one thinks of the Ganga, one thinks of the severe pollution present in it and one is reminded of the Ganga Action Plan (GAP) 1985. One wonders why it has it not got cleaned-up, in spite of being a priority on the political agenda for the last 37 years and why did the Ganga get so polluted in the first place. In this chapter we will chronologically explain why it was considered pure and divine in the past and the chronology of events in the post-independence period, especially after 1986.

10.2 PURITY OF GANGA RIVER: IN ANCIENT TIMES AND THE SITUATION TODAY

In the popular socio-cultural perception, the river Ganga can simply not be polluted because of its divine self-purifying character. The first 115 km of its path, from Gomukh to Devprayag, pass through Uttarakhand, believed to be the sacred 'Devbhoomi' of Land of the Gods and therefore considered to be pure and 'clean'. All pilgrims to the Bhagirathi-Ganga also believe that the Ganga River is clean and pure. But all this was true only in the ancient times, when saints and seers had described Ganga's water as:

"Sweet, cool and delicious; clean, transparent and nutritious; capable of banishing evil; reviving dehydrated lives; restoring lost appetite and perpetuating wisdom"

Raja Nighantu, Narahari Pandita[84]

Ancient scholars were realized that merely praising Ganga would not be sufficient since social behaviour in those times was no different from what it is today. In another Sanskrit edict, they codified 13 types of human activities which would be prohibited along the river which are listed below :

1. Gargling and other ablutions
2. Defecation in the vicinity of the river
3. Washing away sins / sinful thoughts
4. Throwing used flower offerings and other prayer-material
5. Dumping human or animal bodies / carcasses
6. Indulging in any obscene action
7. Accepting donations, pecuniary gifts or alms
8. Treating manmade shrines as superior to the river goddess

9. Flattering or praising other shrines

10. Disposing-off dirty clothing in the river

11. Bathing boisterously or disrespectfully

12. Creating ruckus or commotion

13. Discarding unclean/vile thoughts in the vicinity of Ganga

Readers will find this list familiar and applicable in modern times as well. Since industrial wastes and chemical wastes did not exist in those times and there was no need to encroach into the river bed since land was aplenty, these two aspects viz. chemical pollution and encroachment were perhaps not mentioned in the edict. Similarly, human habitations were not dense enough to create sewage which would flow into the river. Nevertheless, the taboos and strictures were clear and unequivocal, focussing on maintaining the purity of the river waters.

Modern Sources of Water Pollution :

1. Untreated sewage from villages, towns and cities

2. Industrial effluents (chemical and physical), especially wastes from tanneries, textiles, paper and pulp, and sugar distilleries

3. Farm waste (organic and inorganic, residual pesticides and fertilizers)

4. Non-Hazardous chemical waste

5. Hazardous chemical waste (heavy metals, radioactive waste, etc.)

6. Bio-medical waste

7. Animal carcasses

8. Plastics, metal, glass, wood, cloth and other solid wastes (Non sanitary waste disposal)

9. Electronic and other non-reusable or recyclable gadgets (Non sanitary garbage dumps)

10. Storm water run-off during heavy rains carrying faecal and other matter

11. Construction waste (debris)

Note: Sewage, effluents, other contaminants and solids which are gathered and collected at a point and can be treated and disposed-off systematically, is referred to as 'Point Pollution'.

All such solid or liquid wastes which enter the river outside of concentrated urban or rural centres, or is not amenable to treatment or safe disposal at one common point is referred to as 'Non-Point- Pollution'. This classification is not technical, but a matter of administrative convenience.

A separate mention must be made about the entry of 'plastics' and multi-layer packaging (MLP) into rivers and its huge impact not just on the pollution of Ganga and other rivers, but also the pollution of the ocean. Plastic carry bags and packaging of snacks has not only choked up underground sewage and storm water lines in towns and cities, but once it enters the streams and rivers, it gets buried deep in the river bed and river banks. Huge quantities of plastic and other non-biodegradable packaging has been entering the Ganges and other rivers for the past three to four decades, at the least. While a huge amount of plastic is buried in the soil and is called 'legacy plastic' an equally huge quantity of plastic is carried by the rivers to the ocean.

According to the World Economic Forum, the Indus and the Ganga carry the second and the sixth highest quantity of plastic into the oceans, respectively. According to UNESCO's Ocean Literacy Portal, plastic pollution makes up more than 80% of waste in oceans, and by 2050, plastic will perhaps outweigh all fish in the sea. It takes 500-1000 years for plastic to degrade, and even after that, it becomes micro-plastic, which is practically impossible to remove from the ecosystem. When plastic comes in contact with water, sunlight, heat, and other elements, it can bind with persistent organic pollutants such as polychlorinated

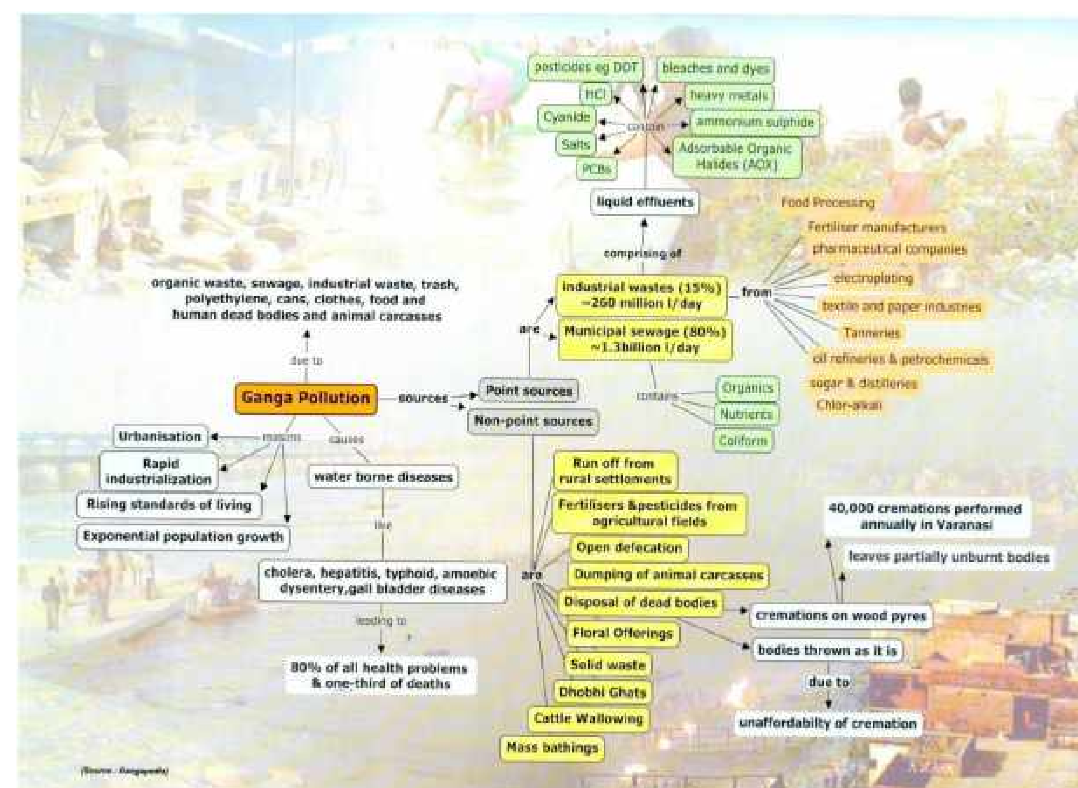

Fig 10.1 Various Sources of Pollution and Their Impacts
Source - Gangapedia, 2019

biphenyls (PCBs) and dioxins, both of which accumulate in animal fat and tissues. Bisphenol A (BPA) is used in the manufacture of polycarbonate plastic products such as plastic cutlery, bottled water and drinks, etc. BPA is classified as an endocrine disruptor, meaning that it can have adverse effects on the ability of humans and other organisms to reproduce. Recently, micro-plastics were also found to be carriers of diseases. Hydrophobic micro-organisms thrive on the surface of plastic pieces and micro- plastic. This layer of microscopic life on or around plastic pieces is called 'plastisphere'. Bacteria from the Vibrio species, some of which can cause Cholera were found in the plastisphere. In areas where there is a lot of waste plastic and poor sanitation, this can cause serious health challenges.

10.3 BACTERIOPHAGES[85]

Bacteriophages play an important role in increasing the capacity of rivers to purify water naturally. Bacteriophages are found in the Cryosphere of Ganga basin and also further down in the mainstream Ganga River. Ganga was considered to be pure and free from any pollution, because there was very little human intervention in the upper reaches of the Ganga, and hence the bacteriophages could eat-up practically all the pollutants present in the river water. 'Bacteriophages' literally means 'bacteria-eaters' because they destroy their host cells, thus, helping to destroy harmful bacteria such as e-coli, etc.[85]

Bacteriophages are found in all glaciers but their perennial presence and large numbers in the water gushing out from Gomukh make the Himalayan Rivers unique. They are also found in Mandakini, Pindar and Alaknanda rivers *(Lohumi, 2020)*, and they travel downstream right up to Varanasi. But because hardly any water from Gomukh reaches Varanasi due to over-extraction along the route, it could be stated that the source of these bacteriophages is located in the rivers originating in the Nepali/Tibetan glaciers as well,

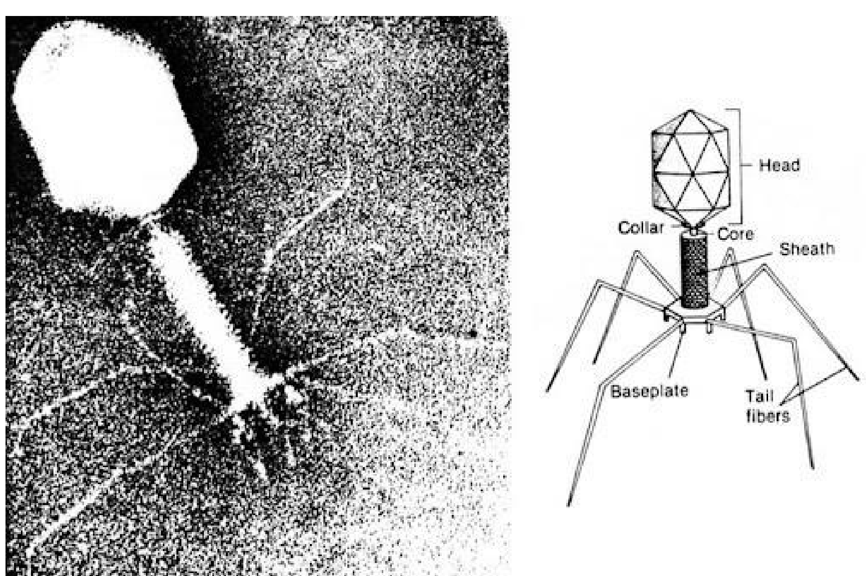

Fig 10.2 Microscopic and Graphic Image of Bacteriophage
(Todar, 2020)

i.e. in Ghaghara, Gandaki, Karnali, and Sapta Kosi, where practically no studies have been conducted. In order to establish the origin of Himalayan bacteriophages, studies will need to be conducted at the origin of all the rivers coming from the glaciers in Tibet and Nepal as well. The phenomenon of melting of permafrost and glaciers continuously provides the 'source-bacteriophages'. However, the rapid loss of glaciers and Cryosphere due to rising temperatures may dry out the unique self-cleansing seed source of these bacteriophages in the Ganga headwaters (often referred to as the '*Brahma Dravya*').

Unfortunately, in the post-independence period, the pollution levels in the river system have transgressed its self-rejuvenating capacity. With increasing population and industrialization the possibility of self-rejuvenation is remote. Therefore, the only way water quality in Ganga can be made '*nirmal*' again is through a complete course-correction i.e., complete sewage and effluent treatment, stopping the release of all chemicals, plastics, electronic waste, and other solid wastes, and restoration of E-flows.

10.4 GANGA WATERS TODAY

Today, the problem of river pollution is not just a problem peculiar to highly populated stretches, but it is also found at the origins of Ganga and the origin of all its major tributaries, mainly as a result of pilgrims who pollute the small habitations near river origins. This fact needs to be mentioned and taken seriously Any measure for pollution abatement must therefore commence at or just above the origin of these rivers and their glacial snouts. The seriousness of this matter has been revealed by studies of comprehensive microbial diversity and other pollutants, which were taken up in 2000 and 2001. Although little is known or discussed in the public domain, these studies have come up with startling results. Water samples were collected from seventeen different locations in the uppermost region of Ganga, culturally identified as Bhagirathi, starting from Gomukh and going down up to Haridwar. Contrary to religious belief and common perception, faecal coliform-count was found to be unexpectedly high in the samples taken from the farthest exit point at Gomukh itself, where it was calculated to be equal to or greater than 500 MPN/100 ml of water during summer and 300 MPN/100 ml during winter.This was a cultural shock and a revelation to scientifists. In the middle reaches, from Gangotri to Uttarkashi, the results showed an increasingly higher count of Faecal Streptococci i.e. varying between 500 MPN/100 ml in winter and 900 MPN/100 ml during monsoon *(Baghel et al., 2005; Chandra, 2017; DNA Correspondent, 2018)*.

Another unexpected and worrisome finding was that most varieties of bacteria in the upper reaches of Ganga had developed a resistance to 11 different antibiotics generally being used in the area between Haridwar and Gomukh. It is a well-known fact that at Gangotri and during the 16 km journey to Gomukh a large number of unequipped pilgrims and amateur trekkers suffer from various ailments to which they are predisposed, (pains, colds, bronchial and gastric infections). They often suffer from sudden high altitude ailments such as headache, nausea, loss of appetite, severe fatigue and oedema. They usually buy over medicines at Gangotri, often without any prescription. A combination of self-medication and random use of antibiotics often leads to severe upset of the stomach and diarrhoea. Needless to say, all this infected human excreta and the excess drugs and antibiotics flow directly into the mainstream of

Ganga. There is a complete and near criminal absence of any kind of facility for sanitizing the water or treating such waste. In this stretch from Gomukh to Gangotri, there are two camping sites at Cheedbas and Bhojbas, where all travellers without exception throw food-waste or cooking wastes, which again directly flows into the Bhagirathi. Another worrisome finding is that the waters of Ganga are highly vulnerable to human and animal faecal-matter and bacterial contamination even in the highest reaches of the Cryosphere, where indiscriminate use of antibiotics has made these bacteria resistant.

A report by the Central Pollution Control Board (CPCB), 2019 States that Ganga became more polluted along its stretch in Uttarakhand between 2014 and 2018, while in the remaining stretch in Uttar Pradesh, Bihar and West Bengal it remained as polluted in 2018 as it was in 2014 *(CPCB, 2019)*.

In order to assess the performance of the Namami Gange Mission, we have compared the data collected in December 2015 and January 2022. In 2015, the UPPCB collected the data from 53 stations, while the data was collected from 102 stations, in 2022. In order to ensure comparability, we have examined the data for the 53 common locations and arrived at some obvious results.

Table 10.10: Water Quality Values Observed at Different Locations during December 2015 and January 2022 (Uttar Pradesh Pollution Control Board, 2022)

Sr. No	Divisional Office	City	River	DO (mg/lit)		BOD (mg/lit)		Total Coliform (MPN/100 ml)	
				Dec 2015	Jan 2022	Dec 2015	Jan 202	Dec 2015	Jan 2022
1	Muzaffarnagar	Muzaffarnagar	Banganga	7.8	7.90	1.90	2.00	130	Nil
2	Gaziabad	Hapur	Ganga	7.76	10.40	3.00	1.60	1500	920
3	Bulandshahr	Bulandshahr	Ganga	8.54	8.90	2.00	1.40	610	350
4	Bulandshahr	Bulandshahr	Ganga	8.36	9.30	2.10	1.30	410	1600
5	Bareilly	Budaun	Ganga	8.00	9.80	2.30	1.12	630	320
6	Kanpur	Kannauj	Ganga	8.12	10.90	2.00	3.20	550	2400
7	Kanpur	Kannauj	Ganga	9.10	11.10	3.50	3.40	4300	3100
8	Kanpur	Kanpur	Ganga	8.40	11.20	3.80	3.10	4700	3200
9	Kanpur	Kanpur	Ganga	9.00	10.40	3.10	3.40	5800	3800
10	Kanpur	Kanpur	Ganga	9.10	9.00	3.20	4.70	6300	11000
11	Rai Bareilly	Rai Bareilly	Ganga	8.00	10.50	5.40	3.60	58000	2800
12	Rai Bareilly	Pratapgarh	Ganga	8.60	10.90	3.70	3.50	8500	2600
13	Prayagraj	Kaushambi	Ganga	9.00	9.00	3.40	2.80	8100	2100
14	Prayagraj	Prayagraj	Ganga	7.90	10.50	4.20	2.90	34000	2100
15	Prayagraj	Prayagraj	Ganga	8.00	9.20	3.90	2.70	32000	2600
16	Sonbhadra	Mirzapur	Ganga	7.70	10.80	4.60	2.20	33000	1300
17	Sonbhadra	Mirzapur	Ganga	8.00	9.70	2.30	3.70	2500	21000
18	Varanasi	Varanasi	Ganga	8.30	10.60	2.50	2.00	2100	1400
19	Varanasi	Varanasi	Ganga	8.60	9.80	3.10	3.40	3100	17000
20	Varanasi	Ghazipur	Ganga	7.50	9.60	5.30	3.80	49000	22000
21	Varanasi	Varanasi	Varuna	7.80	8.60	4.30	2.70	34000	3100
22	Varanasi	Varanasi	Varuna	8.60	5.80	3.00	12.00	8000	39000
23	Meerut	Meerut	Kali (E.)	3.00	Nil	25.60	56.00	220000	130000
24	Kanpur	Kannauj	Kali	Nil	6.40	62.00	3.20	210000	1300
25	Kanpur	Farrukhabad	Ramganga	7.10	8.40	4.50	4.20	5400	14000
26	Unnao	Unnao	Sai Nadi	8.70	7.80	5.00	3.00	6300	Nil
27	Varanasi	Jaunpur	Sai Nadi	8.10	8.50	3.00	3.10	4100	8000
28	Saharanpur	Saharanpur	Hindon	8.20	Nil	3.40	42.00	14000	Nil
29	Ghaziabad	Gautam Buddha Nagar	Hindon	Nil	Nil	38.00	43.00	21000	40000
30	Meerut	Baghpat	Hindon	Nil	Nil	67.20	52.00	330000	130000
31	Lucknow	Sitapur	Gomti	Nil	11.80	56.00	2.10	140000	1700
32	Lucknow	Lucknow	Gomti	11.00	9.60	2.60	3.10	1300	4600
33	Lucknow	Lucknow	Gomti	9.70	1.60	3.20	10.80	4600	170000
34	Varanasi	Jaunpur	Gomti	2.00	7.90	11.50	3.70	130000	21000
35	Varanasi	Varanasi	Gomti	8.20	8.20	4.20	3.50	31000	11000
36	Rai Bareilly	Faizabad	Sarayu	8.50	10.50	3.30	2.70	17000	3100
37	Mathura	Mathura	Yamuna	9.80	4.80	3.00	10.20	7000	94000
38	Mathura	Mathura	Yamuna	5.80	4.80	6.20	10.20	57000	94000
39	Mathura	Mathura	Yamuna	4.00	5.40	8.60	9.40	79000	92000
40	Mathura	Mathura	Yamuna	5.00	5.40	7.40	8.00	58000	79000
41	Prayagraj	Prayagraj	Yamuna	8.00	8.80	2.40	2.70	5800	1400
42	Sonbhadra	Sonbhadra	Rihand Bandh	7.80	11.20	1.40	1.50	2000	700
43	Sonbhadra	Sonbhadra	Rihand Bandh	7.90	10.40	1.60	2.60	2100	2200
44	Gorakhpur	Gorakhpur	Ghaghara	7.80	7.60	4.10	4.60	3000	46000
45	Gorakhpur	Deoria	Ghaghara	7.90	7.90	2.70	3.50	900	34000
46	Gorakhpur	Gorakhpur	Rabti	7.80	7.80	2.40	3.50	500	30000
47	Gorakhpur	Gorakhpur	Rabti	7.50	7.20	5.20	5.60	5000	44000
48	Gorakhpur	Gorakhpur	Ramgarh Lake	8.90	8.00	6.20	5.00	5000	60000
49	Banda	Hamirpur	Betwa	6.80	7.80	3.50	3.20	4700	Nil
50	Jhansi	Lalitpur	Govind Sagar	7.10	8.40	3.00	2.20	4600	Nil
51	Rae Bareily	Rae Bareily	Jheel (Waterfall)	5.20	7.50	4.80	4.00	8500	6300
52	Jhansi	Jhansi	Lake	3.45	1.50	96.0	14.00	28000	Nil
53	Jhansi	Jhansi	Lake	0.00	5.60		7.00	35000	Nil

Note: The deteriorated values of the measured parameters in 2022 compared to 2015 are marked in red. The values marked in red and highlighted in yellow colour have shown significantly greater deterioration.

10.5 WHERE DO WE STAND IN 2022?

1. As of 2021, about 56 stretches purely on Ganga mainstream (lying in 8 states in India which amounts to a stretch of approximately 600 km out of a total of 2525 km) are an ecologically dead zone (2019 CPCB). Therefore, about 23% of the Ganga River within India is polluted (this does not include Bangladesh and Nepal). While environmentalists and the media focus on the heavy pollution in the 23% stretches in the mainstream, the CPCB report argues that 70% of the water is potable. The real question, however, which needs to be asked, is how many stretches have changed from bad to good status since these programs were launched? Further, the status of the project should depend on actual evidence of action taken, not on how much finances have been used.

2. The 2016 Notification set out to achieve much more than just sewage treatment. It emphasized on the ecosystem approach which included all the tributaries. However, this has not been achieved even on the main stem of Ganga River.

3. Different states, cities and industries were delegated the work to reduce sewage and effluent discharge into the river. Instead of reduction, the discharge has increased. The expected installed capacity of STPs has not increased. Rather, the existing STPs are dysfunctional and often get flooded due to close proximity to the flood zone. Therefore, the relative volume of effluent and sewage keeps increasing compared to the installed capacity of functional STPs, which does not get accounted for in the original plan.

4. There is no program which focuses on floods and climate change mitigation which is an increasing threat in this river basin. Therefore, as stated in the 2017 CAG report, the Namami Gange Programme has no long-term road map for the river which will help in adapting to changing pollution levels, flooding events and other climate change related disasters.

5. While addressing the issue of pollution, there is a need to focus on limited abstraction of water which is then recycled and reused till the end of its attrition cycle. Increasing demands can be satisfied through recycled and treated water. This is not just a technological fix but a change in the paradigm about use of water.

10.6 CAN POLLUTION IN GANGA EVER BE ABATED?

In the light of the NMCG programme, a question was asked in the Parliament as to why the Ganga River was the 5th most polluted river in the world. The Parliamentary Estimates Committee Report tabled by the Ministry of Water Resources in 2016 was in response to this question. The Report states: ".... indiscriminate anthropogenic interventions like construction of HPPs in the seismically active and fragile Himalaya; divergence of 80% to 90% of water (through canals); discharge of extremely hazardous effluent by 144 drains and dumping of (unmeasured) solid wastes has converted the Ganga into one of the 10 most polluted rivers of the world. Alarmed by the drying and polluted Ganga, the Committee decided to select the subject for in depth examination with the view to accelerate the work of Ganga Rejuvenation."

The 24th Report of the Parliamentary Committee dated December 2017 entitled 'Ganga Rejuvenation' had taken cognizance of the recommendations in the CAG audit Report (2017) and asked for an Action Taken Report. The Report stated that, "on sewage treatment plants the Committee fails to understand the pitiable condition of various STPs in spite of strong directions given by the Chairman of CPCB and in the backdrop of Honourable Supreme Court's directions. The Public Accounts Committee (PAC) highly deprecated that despite huge shortages of manpower particularly, scientific and technical, urgent steps have not been taken to fill up the vacancies. What is more remarkable is that CPCB was not allowed to recruit the entire sanctioned posts at once, and (instead) phase-wise recruitment was carried out, which was also withdrawn later"(CAG, 2017).

If the existing laws, policies and various GRs are strictly implemented and enforced then there is a possibility of the River Ganga flowing nirmal and aviral. But, we (India) are known as 'a soft State', because we rarely take punitive actions against defaulters. As Ganga flows through 11 different States, including the Union Territory of Delhi, and since the 'water' is a State subject, there are State-wise variations in the interpretation, implementation and enforcement of laws and orders. State Authorities are fragmented and they are unwilling to implement the laws and policies regarding pollution abatement, maintaining environmental flows, and non-tampering with land-use. Similarly, City Municipal Corporations do not comply with the sewage treatment standards and are unable to take strict/punitive actions against the polluting industrial units, inefficient STP/ETP plants, etc. Therefore, the general public feels free to flout and ignore the laws with impunity. Very often ETP and STP plants are constructed within the flood zone of the river, therefore there is routine occurrence of flooding in ETPs and STPs, making them dysfunctional and infructuous. The reason why it is sometimes inevitable to construct STPs in such low lying areas near rivers is that the public builds houses and structures for small businesses very close to the river banks, which the administration fails to prevent or remove.We have enough laws, policies, by-laws, GR's, Action Plans, Missions, and most importantly availability of sufficient funds for cleaning the river Ganga. What is missing is the strict enforcement and implementation of these provisions, and appropriate utilization of funds.
Unless and until these measures are followed, the Ganga is not likely to be *nirmal* and *aviral* in the foreseeable future.

10.7 CONCLUSIONS AND RECOMMENDATIONS

1. It is observed that existing laws, policies and GRs are not strictly implemented and enforced.

It is therefore recommended that punitive actions be taken against the polluting industrial units and city dwellers. Punitive actions must also be taken against officers of various departments if they fail to enforce the law.

2. Very little attention has been paid to re-use and recycling of waste water and environmentally benign alternatives for power generation.

There is an urgent need to set up mandatory treatment, recycling and re-use of all the waste water generating units and advocacy and promotion of alternative power generation technologies which require very little water obstruction e.g., biomass- based energy, co-generation-based power plants, solar and wind energy, etc. Further, installation of drip irrigation, sprinklers, rain guns and diffusers should be promoted through subsidies for all categories of cultivators regardless of the size of land holding across the basin in order to significantly reduce and optimize water use in the nationwide agriculture sector, which consumes roughly 70% of the total water resources used in the country.

3. Urban areas and industries do not comply with the pollution control laws.

It is recommended that such defaulters be made to pay double the charge per litre of water used.

4. Several reports have stated that he existing ETPs and STPs are either inadequate or non- functional and do not achieve the desired results.

It is recommended that these existing ETPs and STPs should be raised above the flood-line, and new STPs and ETPs should not be located in the flood plains of the river. Their number and capacity should be increased.

5. Due to the absence of an 'Integrated River Basin Management Authority' for the Ganga Basin, there is a lack of co-ordination between different departments of the 10 states and 1 Union Territory responsible for implementing the objectives of the Namami Gange Programme.

It is therefore recommended that for the abatement of pollution, management of E- Flows and implementation of the existing laws and policies be constituted, in order to take an integrated approach that overcomes the lack of inter-departmental and inter- state co-ordination/ co-operation.

6. It has been eight years now since the commencement of the Namami Gange Project and the latest data published by the UPPCB is rather dismal:

i. Although the number of rivers to be assessed for pollution measurement has increased from 2015 to 2022, the pollution levels (especially the coliform levels) have risen drastically indicating a sharp rise in fecal contamination.

ii. There was huge reduction in the river flows, which may have led to concentration of pollution in many stretches of the river.

iii. There were many ETPs and STPs in place that are either inefficient or not of sufficient capacity to treat all the wastewater generated from municipal and industrial areas.

iv. Although we have the necessary laws in place, we do not take punitive actions against the polluters and hence are unable to stop pollution at the source. Therefore, officers in-charge of taking punitive action must be made accountable and made liable to legal action if they do not enforce the law on the industries and municipal corporations that are releasing polluted sewage / effluents into the river.

v. We have no solution for solid waste disposal which is non soluble and difficult to measure or quantify.

vi. Non-point solid waste which is common in flood plains is ultimately flowing through the river.

vii. Micro-plastic, trace elements, heavy metals (e.g. mercury, lead, chromium, etc.) are often not tested by pollution control boards for measuring the degree of pollution. Measurement of these and other pollutants must be made mandatory.

ENDNOTES :-

84. A Kashmiri polymath named Narahari Pandita who is believed to have written the thesaurus 'Raja Nighantu', sometime in the 17th century *(Prasad & Narayana, 2007).*

85. The term was derived from 'bacteria' and the Greek word 'phagein' meaning, 'to devour'.

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Jadhganga flowing through the Nelong Valley

CHAPTER 11

NATURE INDUCED AND MAN-MADE DISASTERS IN GANGA BASIN

Frenzied Road and Dam Construction Compounded by Extreme Climatic Events Resulting in Frequent Disasters
Credits - Monika Sah, INTACH

11.1 LINKING NATURAL PHENOMENA AND MAN-MADE DISASTERS

Whether it is the cryosphere or the delta region of Ganga, there have been numerous natural phenomena which have continuously impacted and altered the river basin. The most obvious examples are the earthquakes, floods, avalanches, Extreme Point Rainfall Events (EPRE), cloudbursts, Glacial Lake Outburst Floods (GLOF), landslides/rock-falls, ceaseless erosion, forest-fires, storms, cyclones, droughts, etc. The Himalaya lies in a highly volatile seismic zone due to the very formation of the mountains and continuously shifting geological plates, therefore events such as earthquakes are bound to happen[86]. Flooding is a natural event in the course of a river system due to natural variability in precipitation patterns or when there is a transition in its gradient which changes the sediment carrying capacity of the flow, especially for the Himalayan Rivers.

These events are not disasters by themselves; they are natural phenomena which occur as a response to the earth's physical functioning. They get converted into disasters when humans do not recognise the inevitability of these events and try to control or dominate them under an assumption that there is a techno-scientific fix for all such problems or colonise vulnerable areas.

Human development needs to respond to the nature of such natural phenomena in order to minimise the negative impact of such events on human life and property, and take precautionary measures. However, the present day interventions assume that technology can negate the consequences of natural events by taking measures such as flood-proofing or tremor-proofing, while experience has been otherwise. By artificially placing flood control structures, we are creating a false sense of security among the local communities; consequently the precautions, fear and concerns that existed in the past have almost disappeared and complacency has set in. Therefore, the existence of requisite laws and policies notwithstanding, illegal encroachments within the river bed or its flood plains have kept coming up with impunity.

By obstructing the river flow or building embankments for creation of flood proof zones, we are converting these natural phenomena like floods into man-made disasters. Constructing dams and barrages in seismic zones are bound to lead to destruction during earthquakes, cloudbursts or avalanches of different magnitudes. We can only take precautionary or risk-mitigation measures such as avoiding construction in such fragile eco-systems, installing early warning systems and putting in place prompt evacuation services. But even these measures evidently create a false sense of security. We cannot deny the possibility of occurrence of a flood or an earthquake altogether. The inability to respect nature's limits, take adequate precautionary measures, inadequate relief and rescue operations, converts the gravity or impact of natural phenomena into a huge disaster leading to damage depending on response patterns and human behaviour. Therefore, by not accepting natural phenomena as inevitabilities, our lack of understanding of human limits, the inadequacies in our governance structures, morphs a natural event into a disaster.

11.2 DISASTERS IN THE CRYOSPHERE

As explained in the earlier chapters, the Himalaya as a whole and the Cryosphere of the Ganga in particular, is a fragile mountainous terrain, because of its unique geology, steep profile, intense seasonal precipitation, and high seismicity. Hence, it is prone to different types of natural phenomena as mentioned above. The Himalaya accounts for 21% of the major disasters recorded across the Cryosphere between 1980 and 2015 (4,115 of 18,956 recorded globally)*(Vaidya et al., 2019)*. Characteristically, within a distance of 250 km as the crow flies north-south, the altitude varies from 100 meters amsl to 8000 meters amsl in this region, creating a series of folds or ranges which are constantly experiencing stresses and strains, faults and fissures in vertical as well as horizontal directions.

Besides these natural phenomena, anthropogenic activities like unsustainable land use practises, sand mining, reservoir induced seismicity, collapse of structures like dams, dykes, bridges, inappropriate urbanization, irresponsible tourism, garbage and human sewage further aggravate the inherent fragility of the Himalayan landscape. These events in the upstream regime result in a series of disasters in the mainstream or downstream regimes such as sudden flooding and increasing levels of pollution with changing gradients and urbanization patterns along the river streams.

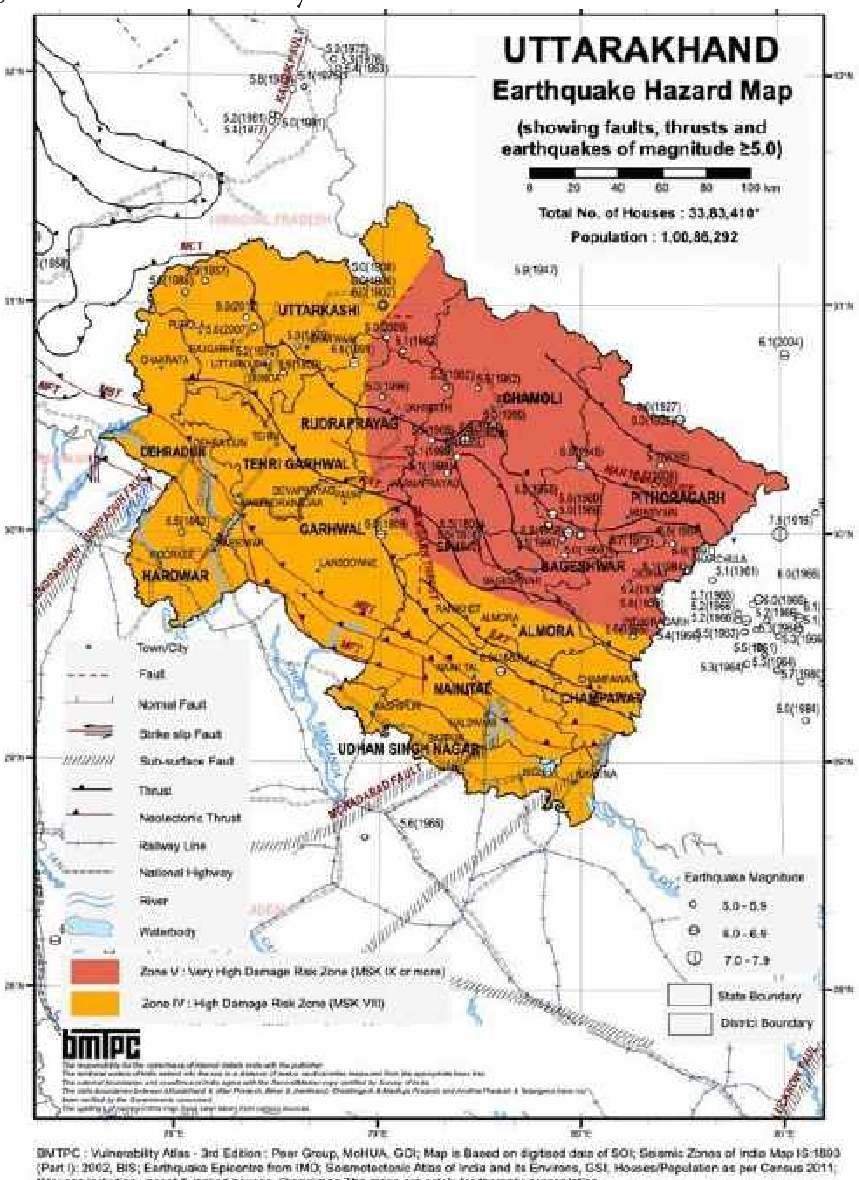
11.2.1 Earthquakes

Table 11.1: Major Earthquake Events in the Himalayan Tectonic Belt

(National Seismological Centre, 2017)

Place	Date	Magnitude	Distance (km)
Eastern Nepal	26.08.1833	7.6	364.0
India-Nepal Border region	04.10.1833	6.5	324.3
Darjeeling (West Bengal, India)	01.05.1852	7.0	370.0
Nepal-India Border Region	23.05.1866	7.0	466.5
Nepal-India Border Region	07.07.1869	6.5	466.5
Nepal-Bihar Border	15.01.1934	8.1	160.5
Nepal-India Border Region	20.08.1988	6.8	180.1
Nepal-India Border Region	18.09.2011	6.9	155.0
Western Nepal (Gorkha District)	25.04.2015	7.8	100.0

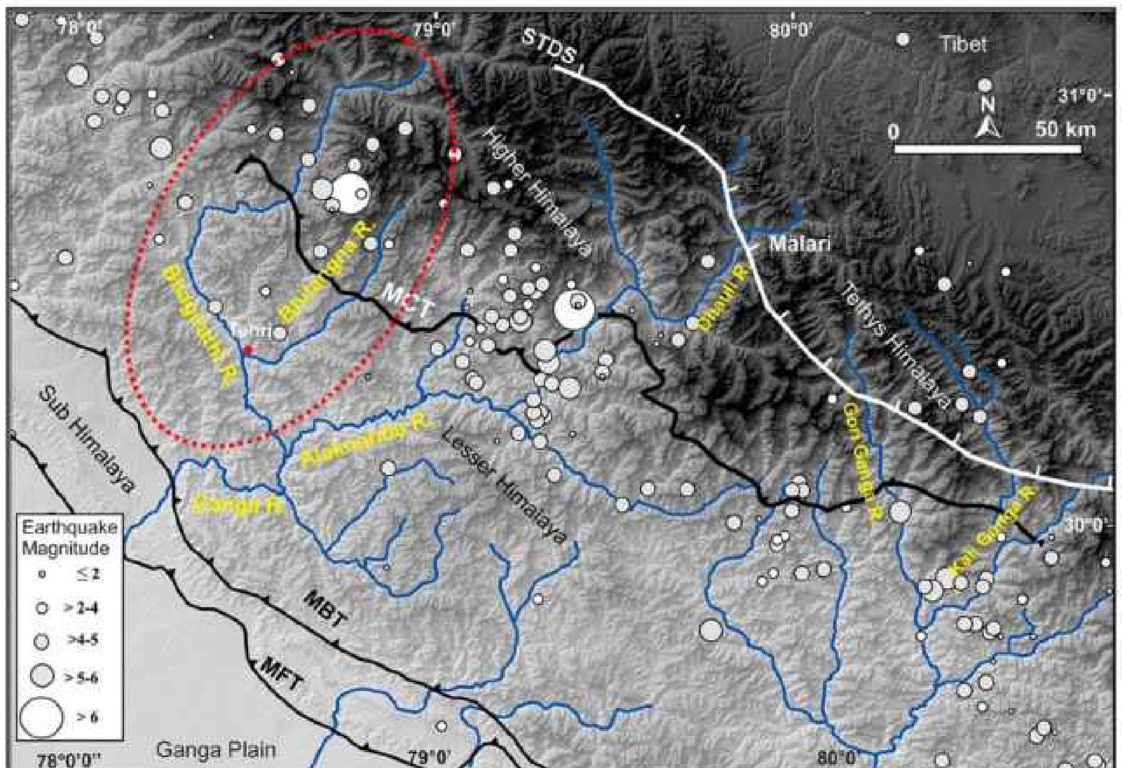
There have been at least 100 earthquakes of significant magnitude in western and central Himalaya in the past 100 years. The central Himalayan area comprising Himachal Pradesh, Uttarakhand and Nepal have experienced 68 earthquakes in the range of 5 to 5.9 on Richter scale; 28 earthquakes in the range of 6 to 6.9 on Richter scale; 4 in the range of 7 to 7.9 on Richter scale and 1 in the range greater than 8 on the Richter scale. The Central Himalaya has an 'observed return period' for such earthquakes of one year, while the north western Himalaya has an observed return period of two and a half years *(Arya, 1992)*. The earthquakes of magnitude greater than 7 Richter scale have occurred in Shillong (1897, Mag. 8), Kangra (1905, Mag. 7.8), Bihar-Nepal (1934, Mag. 8), Assam-Tibet (1950, Mag. 8.6), Chamoli (1999, Mag. 6.8,) and Kashmir (2005, Mag. 7.6), and Nepal (2015, Mag. 7.8); mainly around the 'Main Boundary Thrust' (MBT) separating outer Himalaya from lesser Himalaya and the 'Main Central Thrust' (MCT), which separates the lesser Himalaya from Himadri, i.e. the central Himalaya.



Map 11.1: Landslide and Earthquake Hazard Map of Uttarakhand State from Vulnerability Atlas of India

(Building Materials and Technology Promotion Council (BMTPC), 2019)

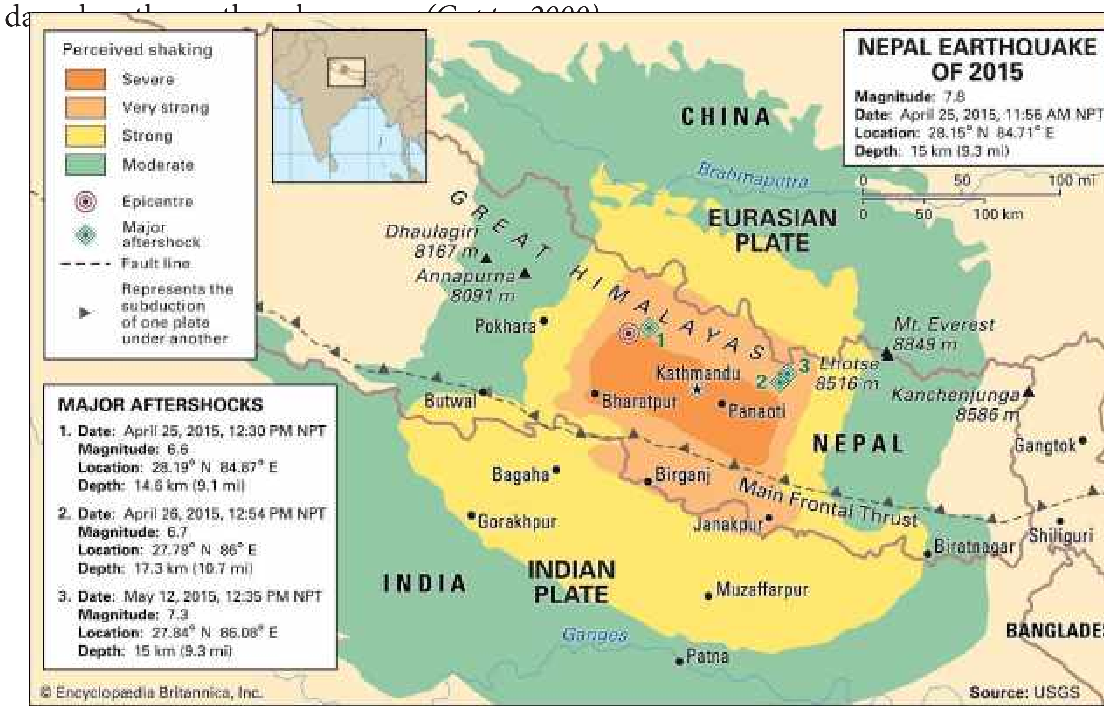
Uttarakhand is located in the seismic gap of the 1934 Bihar-Nepal earthquake and 1905 Kangra earthquake, and is categorized as falling in Zone IV and V i.e., in the highest seismic risk zones of the country and has been captured in the 'Vulnerability Atlas' as shown in the map above *(Building Materials and Technology Promotion Council (BMTPC), 2019).* On 20th October 1991, an earthquake of magnitude 6.6 on the Richter scale occurred near the Uttarkashi- Tehri region of Garhwal which was close to the MCT. Fortunately, no damage was noticed at the main foundation of the Tehri dam which is located close to MCT during this earthquake. Besides these, many earthquakes of magnitude greater than 5 on the Richter scale have occurred recently, which have had a disastrous impact, but may not have got recognition.



Map 11.2 Different Litho-Tectonic Units And The Distribution Of Earthquake Epicenters Are Overlain On Digital Elevation Model (DEM) Of Uttarakhand Himalaya. The Bhagirathi Valley Is Shown By Dotted Red Ellipsoid. Note The Concentration Of Recent Earthquakes Located Between The STDS And MCT *(Sati et al., 2020).*

The recent catastrophic earthquake in April 2015, also known as Gorkha earthquake was devastating for life and property in Nepal. The earthquake and its aftershocks were the result of thrust faulting (i.e., compression-driven fracturing) in the Indus-Yarlung suture zone and released compressional pressure between the Eurasian plate and the Indian section of the Indo-Australian plate *(Rafferty, 2015).* According to a UN report, almost one-fourth of the population of Nepal was affected, since this was the largest earthquake since 1988. The initial shock of 7.8 magnitude followed by two aftershocks of 6.6 and 6.7 magnitude each and multiple minor tremors damaged 14 existing hydropower dams, including the 45 MW Upper Bhotekoshi Hydropower Project, according to the Nepal Electric Authority *(Schneider, 2015).*

A study on 'Major and Great Earthquakes in the Himalayan region: An overview' shows that if the 1905 Kangra earthquake which had claimed 30,000 lives was to repeat today, between 88,000 and 3,44,000 human lives would be lost, depending upon the time of the d



Map 11.3 Nepal Earthquake of 2015
(Rafferty, 2015)

A team of scientists from UC Riverside, funded by the National Science Foundation in partnership with Government of Nepal's Department of Mining and Geology and other universities conducted a study of a network of 45 seismometers in the ground immediately after the 2015 Nepal earthquake and developed the most high-resolution model of the Main Himalayan Thrust *(Mendoza et al., 2019)*. The study concludes that there is growing stress in this and surrounding faults. Thus, there are chances of severe earthquakes in the near future. With the high-resolution model it would be possible to predict these events but not completely obliterate their possibility. This requires adequate preparation and emergency planning to reduce the seismic risk. Therefore, reducing anthropogenic activities in the region and employing prompt evacuation systems would be advisable to reduce the impact of the disaster on life and property.

11.2.2 Cloudbursts and Extreme Point Rainfall Events

A cloudburst or extreme point rainfall event is a localized phenomenon which occurs for a short period of time, within a short distance and the resulting storm generally does not exceed beyond 15 to 30 km across. Consequently, they escape meteorological observation. It is believed that such an outburst occurred in 2013, presumably within the Asi Ganga Basin, but escaped from being detected early enough for taking precautionary action. Such events have been recorded in large numbers in recent years.

At times such intense rainfall may continue for eight to ten days which can trigger landslides in large numbers and floods. Researchers from G.B. Pant Institute conducted a detailed study of the 2013 Uttarakhand disaster and such events in the recent past. Detailed records of Bhagirathi flash floods which occurred in 1978 have been elaborated in this study. A similar flood disaster in 2010 led to the death of 76 people and another 172 missing and affecting a total population of about 9.3 lakh persons *(Nandargi & Dhar, 2011; Sundriyal et al., 2016)*. As the Arctic grows warmer, outbursts of cold and dry air currents are likely to increase. This will produce intense rainfall triggering additional EPRE events and subsequent floods as experienced recently in Indian and Nepal regions.

11.2.3 Landslides

Landslide events in Himalaya account for 52% of the global landslide events and 61% of deaths due to landslides recorded in Asia. Hydro-climatic and seismic sensitivity in the area has further increased the chances of landslides in recent decades. Also, anthropogenic influences like excessive resource exploitation, deforestation and slope cutting for road building have also adversely affected slope stability and aggravated the occurrence of landslides. Melting of permafrost leads to creation of loose material or debris which can lead to land subsidence. In the case of hard rock, it will lead to loss in weight of material. In both cases it can lead to a landslide, not triggered by seismic tremors, but due to melting of permafrost. Very little is known about such events as they are yet to be studied and correct assessment is yet to be made so that the causes of landslides and floods are clearly identified for implementing precautionary measures.

The Bhatwari landslide zone, also in the MCT vicinity, has been experiencing major changes in the region due to tremors, causing deep fissures and creating an unstable geology. Therefore, the Loharinag-Pala hydropower project (600 MW) upstream on Tehri dam near the vicinity of MCT has been under criticism for its unsafe location. The Gyansu Nala landslide in 1980 killed 24 people and destroyed several houses. Further, the Malpa landslide is considered to be one of the worst landslides which wiped away the entire Malpa village in Pithoragarh district of Uttarakhand on 18th August, 1998. According to the report of the Wadia Institute of Himalayan Geology, the 1979 and 1980 earthquakes were deemed to be the underlying cause of the Malpa landslide.Landslides triggered by heavy rainfall and floods in September 2003 in Varunawat hills in Uttarkashi have together caused an estimated loss of Rs. 3,559 crores. Another landslide on Berinag-Munsiari road, Pithoragarh, Uttarakhand took 43 lives on 8th August, 2009. According to a 2011 report by the United Nations' Food and Agriculture Organization (FAO), Nepal has one of the

highest fatalities from landslides in the world *(Bhushal, 2020)*.

11.2.4 Avalanches

Avalanches are another hazard that mountain residents have to face, as they frequently occur during winters. Heavy precipitation and accumulation of snow and ice hurtle down into the inhabited valleys. During the catastrophic Gorkha earthquake of 2015, hundreds of smaller tremors kept shaking up the mountainside in Central and Eastern Nepal, which triggered off a large number of landslides and avalanches in areas which had been left standing precariously earlier. This hugely increased the fear among the communities living in the mountains, who did not know when this would end, or which landslide would sweep away their village. The mortality and economic losses were staggering, and due to the remoteness of the area, its quantification and estimation was practically impossible. The year 2015 was a particularly bad year when the Hudhud cyclone which emerged several hundred kilometres in the Bay of Bengal, ended up traveling right up to Nepal, resulting in heavy precipitation and triggering another round of avalanches and landslides.

11.2.5 Glacier Collapse or Rift

Glacier collapses or rifts have become a common phenomenon in the cryosphere due to increasing incidences of landslides due to slope instability, glacier thinning due to rising temperatures and tremors.The term glacier burst is a misnomer as in many cases when a part of the glacier protrudes beyond a tipping point, it collapses causing a landslide or an avalanche. Technically speaking these should not be called 'glacier bursts' but 'glacier collapses or rifts'.The recent February 2021 Raini disaster, a result of collapse of a hanging glacial cliff in the Nanda Devi region, led to an avalanche and deluge in Dhauliganga, Rishiganga and Alaknanda rivers destroying two power projects, NTPC's Tapovan-Vishnugad hydropower project and the Rishiganga hydropower project, and loss of human life trapped in the hydropower tunnel. Studies of the aftermath link this disaster to an ice avalanche which occurred in 2016, resulting in the formation of this hanging glacial cliff which was on the verge of breaking with even a slight movement or downpour.

Heavy rainfall witnessed in the first week of February finally led to the breaking of the hanging glacial cliff including the part of the rock cliff itself on 7th February, 2021. On 24th April, 2021 another incident occurred in the same district-Chamoli in Neeti Valley due to a glacier collapse which led to an avalanche affecting operations on the Sumna-Rimkhim road and the Border Roads Organisation camp in Sumana village. It is very crucial to understand the interconnections between different seismic and rainfall events or series of events in the cryosphere which could cumulatively trigger a greater disaster. A study titled 'Acceleration of ice loss across the Himalayas over the past 40 years' conducted a 40 years' review of satellite observations across India, China, Nepal and Bhutan, indicating that glaciers have lost over a vertical foot and half of ice each year since 2000, double the amount of melting since 1975 to 2000*(Kurian, 2021)*. Such rapid recession of glaciers are not just impacting the river flows but also disrupting the geology of the glaciers creating fragile cracks and faults, which then lead to such glacial collapses when affected by heavy rainfall, snowfall or earthquake tremors and landslides.

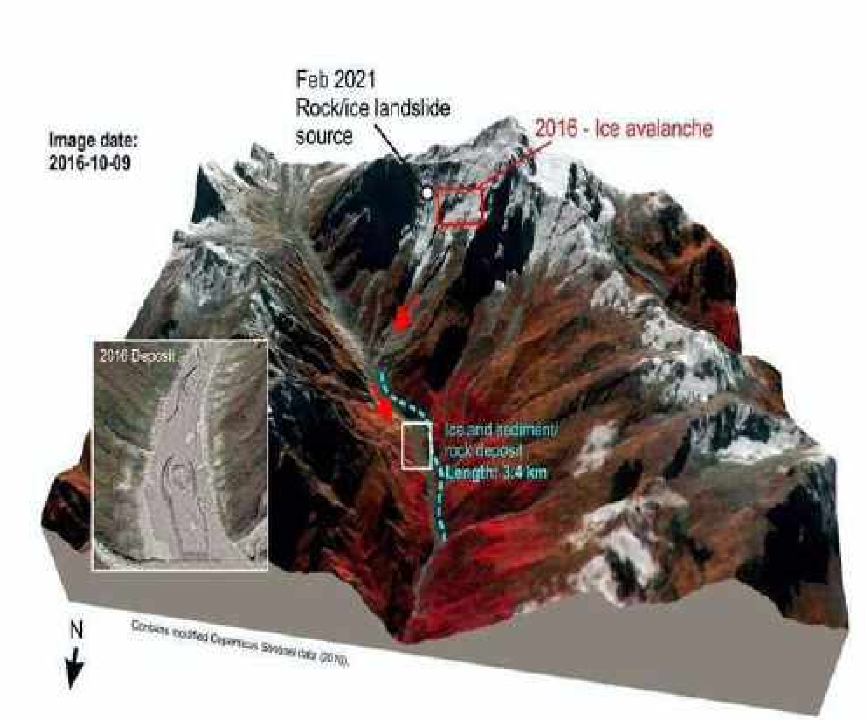


Diagram 11.1 : Showing Location Of 2016 Ice Avalanche Which Led To Creation Of The Hanging Glacial Cliff Which Eventually Collapsed On 7th February, 2021 Due To Heavy Downpour. Image Originally Contains Modified Copernicus Sentinel Data From 2016
(Panthri, 2021)

Before And After Images Of The Hanging Glacial Cliff
Source: Planet dataset (Som & Ghosh, 2021)

11.2.6 Glacial Lake Outburst Floods (GLOFs)

As per records available till the year 2000, Himalaya has witnessed 33 identifiable Glacial Lake Outburst Floods (GLOFs) caused by expanding and bursting of glacial lakes (found at the margins or on top of the glaciers or beneath the cirques) that led to flooding and devastation in the downstream regions. Increasing temperatures, heavy rainfall and snowfall, increasing occurrences of earthquakes, landslides and melting of glaciers and ice are all cumulatively responsible for these events. A case in point is the recent Sikkim GLOF disaster which swept away the Teesta III HEP.

Earthquakes can also create landslides and dislodge large sections of glaciers or ice-walls, which can cause a GLOF if they fall into a glacial lake. GLOFs can erode the toes of hill slopes downstream, adding sediment to the river and raising the riverbed, which in turn can lead to blockages in the river and the formation of small lakes. Such lakes continue to expand till the natural blockage can withstand the pressures. However, since such walls are not firm and integrated, they can unexpectedly give way, leading to a lake burst and further toe-slope erosion downstream. Such cascading processes were witnessed during the 1970 floods on the Alaknanda River in Uttarakhand *(Higaki & Sato, 2012)*[88]

On June 17, 2013 a GLOF upstream of Kedarnath in Uttarkashi district, the Chorabari glacial lake near Mt. Kedar, led to the destruction of small hydropower dams and impacted the lives of more than 100,000 people. The 2013 catastrophe was primarily caused due to heavy rainfall leading to the lake outburst on the Chorabari glacier upstream of Kedarnath.

In July 1981, a sudden ice avalanche caused a Glacial Lake Outburst Flood (GLOF) in the Zhanzhabu-Cho Lake in Tibet. The ensuing debris flow caused a flood on the Bhote-Koshi River, destroyed bridges and sections of the Araniko highway and the Nepal-China highway, causing a huge economic and material loss, as well as losses due to property and human deaths. The repair and maintenance work has been going on for several years and still continues. Unfortunately, even after this disaster, no Risk Assessment has been undertaken while planning the upcoming projects on the Koshi river system.

In Nepal, thirteen GLOFs have been observed from 1960 to 1990 indicating a very high frequency i.e., greater than once in every three years *(ICIMOD, 2011)*. In another investigation in Nepal, the maximum GLOF discharge at the upper Arun dam site was observed to be three times the spillway design flood capacity selected for the concrete dam on Arun! Potentially a very dangerous situation indeed.

11.2.7 Landslide Dam Outburst Floods

Dams created by landslides are nothing but heaps of rock and mud ending up on the riverbed and completely blocking the flow of the river. Such a dam is not integrated or homogenous and greatly susceptible to breaching. Landslide dam outburst floods (LDOFs) are caused due to dams created by landslides in the river stream. They have been causing heavy destruction as was witnessed in the monsoon months in Nepal in 2016 *(Bhatt, 2017)*.

The massive Kanodia-gad landslide in 1978 in the MCT zone obstructed the Bhagirathi River in India. The dam created by the landslide finally breached causing large-scale downstream destruction and change in the channel morphology of the river *(Sati et al., 2020)*.

In 2020, a massive landslide in Sankhuwasabha district on Arun River in Nepal led to damming of the river, creating an impoundment of an almost 40 m wide lake which led to breaking of embankments in the river channel, leaving downstream settlements at risk of flooding *(Shakya, 2020)*. Similarly, the powerful earthquake in Nepal (April 2015) led to a series of landslides and resulting outburst floods which damaged 14 existing hydropower dams, including the 45-megawatt Upper Bhotekoshi Hydropower Project, according to the Nepal Electric Authority *(Schneider, 2015)*.

Wasson et al. (2008; 2013) reconstructed a 1000-year history of floods in the Alaknanda valley using sedimentological evidence and suggested that the majority of the floods were generated by LDOFs due to rapid and heavy destruction of the terrain due to commercial forest felling and hydropower projects. The Alaknanda flood of 1970 is an example of such a natural dam burst which is also known to be the highest flood in the last 100 years *(Wasson et al., 2013)*. Since the 1980s, commercial forest felling has stopped in the Uttarakhand Himalaya and thus, the coupling between deforestation and flash floods has been discontinued. However, in recent years, the terrain has been tampered by rampant proliferation of road construction and hydropower projects, increasing the occurrences of LDOFs *(Sati et al., 2020)*.

11.2.8 Landslide Blockage on Sunkoshi River in 2014

In August, 2014, a huge landslide blocked the Sunkoshi river near the town of Barabise on the Araniko Highway (Kathmandu-China). This blockage created a large lake that submerged a hydropower station located upstream. The hill slopes on both river banks had collapsed into the river and buried many houses and killed more than 150 people. The local villages had to be evacuated, as the natural lake created by the landslide could have given away at any time causing a sudden devastating flood. This artificial lake was a reminder of the power of natural phenomena to wipe out human efforts to tame and harness natural forces.

A disaster like this could not have been completely averted. However, had there been a systematic Risk Assessment as mentioned above, the administration and the community would have been better prepared and a disaster response mechanism would have been put in place.

The Araniko Highway connecting China and Nepal, which was the main artery of trade and commerce between the two countries came to a standstill. The landslide had ripped out a stretch of 6 kms of the Araniko highway leading to a massive traffic jam. The landslide created an artificial hill on the Sunkoshi riverbed, with a volume of 5.5 million m3 of rock and debris. Eventually, the Nepali army was brought in and personnel from other countries also contributed to the unprecedented disaster management operation on a Himalayan river. With the use of controlled explosives and dynamite, the Nepali army was

finally able to cut a canal, gradually draining out the lake. The lake on Sunkoshi was 400 meters long and 47 meters deep. Besides the threat to villages, the lake burst could have easily destroyed the Lamusanghu hydel power project located downstream. Fortunately, the disaster was successfully averted. The landslide had caused devastating effects far beyond the Sindhupalchok district of Nepal. The artificial dam was threatening to unfurl a huge flood which could have wiped out hundreds of downstream villages in Nepal and further up to Bihar!

11.2.9 Droughts in Arid Himalaya

The arid and semi-arid regions like the Tibetan Plateau and the northwest highlands of Nepal are located in highly drought-prone areas. These regions rarely have rainfall of more than 500 mm., and in some years falling below 250 mm *(Dahal et al., 2016; Wang et al., 2013)*. Further, humid and semi-humid regions face severe water shortages during dry months of the year. The IPCC 2012 Report has predicted that climatological hazards, including extreme temperatures like heat waves, cold waves and extreme winter conditions can also lead to disasters. The Himalaya is presumed to be a high rainfall area therefore it is sometimes not appreciated that in certain years there can be disasters due to droughts. These events are specifically related to the Cryosphere and are rarely perceived as disasters and hence are not duly considered in Disaster Management Plans and similar strategies.

11.3 LINKING PRIMARY AND SECONDARY HAZARDS

Primary hazards may be geophysical i.e., caused due to tectonic or seismic activity below the earth's surface, or hydro-meteorological i.e., due to landslides, which triggers secondary hazards such as landslide-dams *(Gill & Malamud, 2017)*. In 2015, the Gorkha earthquake resulted in 4000 large and small landslides. The following table shows primary and secondary hazards:

Table 11.2 Linking Primary and Secondary Hazards
(P. Wester et al., 2019)

Primary	Secondary	Occurrence
Earthquake	Landslides	• 2005 Kashmir Earthquake in India and Pakistan • 2008 Wenchuan Earthquake in China • 2015 Gorkha Earthquake in Nepal

Landslide	Landslide dam and subsequent out-burst flood	• 2014 Nepal: Jure landslide that dammed the Sunkoshi River • 2010 Pakistan: HunnzaAttabad Landslide • 2008 China: Landslide-dammed lake at Tang-jiashan, Sichuan Province
Flood	Erosion and Deposition (aggradation and degradation), Sand Casting (deposition)	• 2008 Koshi floods in India and Nepal • 2013 Kedarnath Flood, Uttarakhand, India • 2021 Vishnugadh Disaster

One such phenomenon which represents the linkage between primary and secondary hazard is the drying up of springs in the Himalayan region due to increasing incidences of landslides and avalanches, etc. During the devastating earthquake in Nepal in 2015 and later years, a large number of springs had either dried up or changed their locations, increasing vulnerability of local communities to water scarcity in these mountainous regions.

11.4 NATURAL EVENTS LINKED WITH MAN MADE DISASTERS

The anthropogenic activities enumerated below further aggravate the inherent fragility of the Himalayan landscape : like construction and encroachment within the river bed, sand mining, reservoir induced seismicity, collapse of structures like dams, dykes, bridges, inappropriate urbanization, illegal construction along the roads by disturbing the upper and lower slopes of the road shoulders, digging up additional farmlands and fields without the traditional contour bunds for plantations, converting community forestlands into horticultural lands, constructing concrete structures on steep slopes along the roadside without sufficient sub-soil support and storm water evacuation, careless tourism, garbage and human sewage, etc.

Embankment breaches or dam failures in the upstream regions ultimately lead to flooding events in the mainstream region of the Ganga. The following section discusses disasters caused by such activities, flooding events and increasing pollution in the mainstream region of Ganga.

11.4.1 Disasters Caused by Dams and Non-Sustainable changes in Land-Use

There are increasing incidences of dam and embankment failures in the Ganga river basin due to increasing dead weight in the reservoirs, changing precipitation patterns and increasing age of infrastructure thus further demonstrating the fact discussed previously of converting natural phenomena into man-made disasters.

The 'Assessment of Environmental Degradation and Impact of Hydroelectric Projects during the June 2013 Disaster in Uttarakhand' submitted to MOEF by the Expert Body led by Ravi Chopra (published in December 2013) stated that "... the damages during the 2013 disaster were more concentrated / aggravated in the immediate upstream or around or mainly on the downstream of existing and under construction barrages of hydropower projects...thus, the existing and under construction hydropower projects had indeed increased the proportion of the disaster". The Rishiganga Hydropower Project (13.2 MW) upstream of Alaknanda was the first to face the brunt of the avalanche. The debris from this plant damaged other units downstream and endangered the lives of the people working there. This includes the state-run Tapovan (520 MW) and PipalKoti (4×111 MW) projects and the private Vishnuprayag (400 MW) project *(Rajendra, 2021)*.

The Expert Body Report further stated that the 2012 floods were mainly caused due to the Tehri dam. In order to retain flood inflows in the face of water levels rising beyond the permitted Full Reservoir Level (FRL) the dam authorities had to seek permission from the Supreme Court to release water from the spillway. In the meantime, it led to inundation of the upstream town of Chinyali-saur and later, draw-down fresh landslide zones were created around the project area and downstream regions.

Blasting mountains for construction of the run-of-river project tunnels, impounding and road construction have been increasing the fragility of the mountain slopes increasing landslide and flooding events. A recent study 'Modified hydrologic regime of upper Ganga basin induced by Natural and Anthropogenic Stressors', states that upstream hydrological modifications have altered the basin hydrology increasing extreme flooding events in the Upper Ganga Basin post 1995 *(Swarnkar et al., 2021)*.

As a response for controlling flash-floods, India and Nepal have planned the Sapta Kosi high dam (269 m) with an installed hydropower capacity of 3000 MW in Barahakshetra region. However, major apprehensions are being raised about the appropriateness of the location of the dam, as the dam site is located near a new rupture line which begins from 80 km. north-west of Kathmandu and continues eastwards for another 130 km., aligned to the geological fault line which was created during the 2015 Gorkha earthquake. Construction of this dam in such a sensitive location can lead to further disasters of different magnitudes thus threatening the downstream regime.

11.4.2 Forest Fires

Although thunder and lightning lead to natural fires, a majority of such forest fires are due to acts of human negligence. Climate change has further accelerated these incidents. Forest fires, whether they are natural or manmade are the greatest destroyers of natural vegetation. They usually start from non-decomposed forest litter. In the higher altitudes in the Ganga basin, forests are dominated by deodars, firs, spruces and pines. Fires here are usually restricted to the ground. On the other hand, crown-fires, i.e., usually near tree tops, are prevalent in low level coniferous forests in Shivaliks. The natural ones are usually due to lightning, but the man-made ones are due to the careless throwing and burning of matches and cigarette butts in forest areas.

Some are known to occur due to deliberate and intentional burning of patches by villagers to trap wild animals, or for harvesting forest honey. In the agrarian areas, farmers sometimes deliberately burn out weeds growing in the peripheral areas, or deliberately burn brush-wood in order to enrich their fields with ash. Although controlled fires may have a beneficial effect, however, when they go out of hand, the destruction caused by such forest fires is far in excess of the benefits from controlled fires on farmlands. Unfortunately, this practice has been increasing rapidly. About 15% of the forests in the Himalaya are prone to frequent fires while 33% to 83 % are vulnerable to occasional fires. Unprecedented and probably man-made fires in 1995 and 1999 in Uttaranchal and Himachal Pradesh were obviously the reflection of the rural communities' resentment towards government policies. Shepherds and grazers also deliberately start fires for controlling thorny bushes and growth of fresh luscious grass. Awareness programs, education, and schemes which benefit local communities and are implemented in a committed manner are the only solution to this problem.

Nepal's Department of Hydrology and Meteorology Flood Forecasting Section issued a Special Flood Bulletin on 26th July 2016 due to the fact that weather stations at rivers - Kankai, Koshi, Bagmati, Narayani, and Karnali basin recorded dangerously high levels of rainfall. A United Nations report stated that, between 12th and 27th July, 7983 families were affected, of which 5376 families were displaced during this disaster in Nepal *(Davies, 2016)*.

11.5 THE KOSI RIVER: 'RIVER OF LIFE' OR 'RIVER OF SORROW'?

Technically, floods in Bihar can be caused either by surplus flood waters coming from the west on the mainstream Ganga (Ganga and Yamuna), or by flood waters coming from the north (i.e., the Sapta Kosi coming from Nepal). They can also be due to a combination of both. However, in reality, the level of abstraction for irrigation on Yamuna and Ganga is so large that a relatively small fraction of the water actually reaches Bihar. Consequently, especially during the non - monsoon period, any major flood in Bihar is attributed mainly to the floods from Sapta Kosi. During a heavy downpour, when all the 56 gates of Kosi barrage are opened, North Bihar receives around 23,000-29,000 cumecs of water for several days causing enormous flooding as was witnessed in July 2019 *(ANI, 2019)*. Thus, understanding or responding to annual floods in Bihar becomes meaningful only if we have a full understanding of everything that is happening in Nepal on the Sapta Kosi. In addition, Ghagara and Sapta Kosi rivers have been causing floods in Uttar Pradesh and Bihar almost on an annual basis due to the sheer volume of waters being brought down from the Himalaya, the gradient change and sediment load which these rivers carry. The extra water due to surplus precipitation in Nepal is discharged through the Ghagara and Sapta Kosi system.

11.5.1 Traditional Flood Resilience Techniques

In the past, farmers living in this region were aware of the nature of the river and had

therefore organised their settlements and cropping patterns in a manner which would enable them to live with the floods or avoid the peak damages which the flood might bring. Their simple technique was to physically travel to higher altitudes when floods came in and travel back to their hometowns or villages after the floods receded. This was done in order to benefit from large-scale sedimentation which would make their soil more fertile. Therefore, there was a system of coexistence or cohabitation with the river and its various phases.

However, the hydrological engineering which was imposed on the Indo-Gangetic River System since around the Independence period was intrusive, invasive and absolutely in contradiction to the natural drainage pattern of the Indo-Gangetic plain. The natural fluvial pattern of the river system earlier included the phenomenon of Kosi River avulsion within the plains. But in their arrogance, hydro engineers felt that they could tame or shackle the Kosi with an artificial channel, embanked on both sides by huge concrete walls.

Map 11.3 The Breach At Kusaha Led To The 2008 Kosi Disaster
This Avulsion Diverted The 80-85% Of The Flow Of River To A New Course; And Has Been Called As One Of The Greatest Avulsions In Any Large River System In World In Recent Times
(Siddiqui, 2008)

11.5.2 Connection between Sapta Kosi Embankment, Farakka Barrage and Floods in Bihar: The 2008 Kosi Breach

For centuries, flooding has been a natural, annual phenomenon in the course of the Kosi River due to its continuous avulsion (discussed in detail in Chapter 2); however, studies have shown that the Kosi embankment had increased the flooding area from 2.5 million ha. to 6.8 million ha. since 1950 due to the inability of the embankment to withhold huge amounts of water and sediment. The Kosi embankment which was built to hold about 0.95 million cusecs of water breached at Kusaha in the hilly region in 2008 at just 0.14 million cusecs causing devastating floods in the downstream region. Since 1963, Kosi river has breached seven times and the 2008 breach at Kusaha was the most disastrous, leading to a 120 km. eastward avulsion.

Instead of being regulated and channelised by the embankment, the Kosi River continued to perform the second most important function of the river, which is, unloading sediment from the Himalaya into the channel. The increasing silt deposition led to an increasing river bed by about 4 m., blocking the main river channel as well as other tributaries. The rise in the river bed within a short period of time created an artificial riverbed within the embanked river course which was higher than the lands on both sides, further leading to permanent water logging. The construction of the artificial channel did not take into account the innumerable smaller streams and channels which were expected to evacuate the surplus waters from the plains. Therefore, these artificial embankments started acting like permanent barriers. Neither did the river water flow through central channels, nor could the water which spread outside the channels flow through the natural drainage lines as they were completely disturbed. Eventually, the rivers flowing in from the north breached their embankments, partly due to the hydraulic energy of the river itself and partly due to human vandalism *(Mishra, 2008)*.

Further, studies and analyses are showing that the recent August 2021 floods in Patna, Bihar are not just related to heavy rainfall patterns but are connected with the increasing sedimentation levels in the river channel and consequent rise in the river bed due to Farakka barrage which leads to an upward cascading and flooding effect. "Farakka construction has caused siltation in Bihar and eastern UP, leading to a rise in the Ganga riverbed's height, which caused floods in August", say experts *(Roy, 2021)*.

In addition, to satisfy their irrigation needs, farmers deliberately breached the embankments at several locations, which then got enlarged as a consequence of hydraulic pressures which broadened the breach. So, evacuation of flood waters and even deposition of sediments which are the key and fundamental functions of a river could not be performed as a consequence of these hindrances. Construction of dams, barrages and deliberate or artificial channelization ultimately led to water logging, long periods of farmlands under submergence, inundation of canals and natural courses, and a sequence of unanticipated series of geo- morphological events. The unanticipated result of this artificial channelization of a river as large as Sapta Kosi, is the unpredictable flow of the river waters due to complete destruction of the natural flow regime of the river. Today, due to this destruction and obstruction in the natural flow of the river courses and streams, even a small flood converts itself into a large-scale human disaster *(Mishra, 2008)*.

11.6 THE BIHAR PARADOX: FALL IN GROUND WATER TABLE AFTER HEAVY FLOODING

By February end, 2020, the water level in Bihar, especially in Seemanchal and Southern Bihar had plunged in the range of 13 ft to 25 ft, and Patna had experienced a 17 ft fall in the groundwater table. A recent report states that the groundwater table had gone down from 10 to 200 ft during the last 10 years. While the earlier recorded range was 40 ft to 200 ft, the recent lowering of the water table had taken it down to a range of 60 to 250 ft. It may be noted that this sudden fall in groundwater had taken place even though the immediately preceding year (2019) had been a 'good' monsoon year, and the entire state of Bihar, including Patna city, had experienced a long period of water-logging after the floods. The cause of such contradictory changes in groundwater levels have not been clearly identified, but this could be the result of destruction of vertical and horizontal integration of the river system due to rapid proliferation of canals, dams, barrages, and unchecked groundwater extraction in the region.

These examples demonstrate the fact that natural events such as heavy rainfall and earthquakes are rather aggravated by man-made activities such as natural drainage distortion, thus converting natural phenomena into man-made disasters. When hydropower projects, road construction and other such activities defy the terrain boundary conditions and are not blended with rigorous scientific scrutiny, they lead to significant collateral damage, thus affecting the terrain stability and sustainability of the local inhabitants.

11.7 PROPOSED SOLUTIONS TO AVERT THE CRISIS

It is very crucial to understand that once there is an anthropogenic intervention which changes the natural river regime irreversibly, trying to correct it only increases problems. Hence, it is advisable to avoid any intervention which may become geomorphologically irreversible.

Shri. Kumar Arun Prakash, Special Secretary, Minor Water Resources Department, Government of Bihar stated, that under the Jal, Jungle, Hariali Mission an exercise to remove encroachments from water-bodies was undertaken and tanks were de-silted. About 3000 ponds were cleaned and 2000 check dams were to be completed. But we need to look beyond reclamation of encroached water bodies. Administration in these states needs to strictly implement all the existing laws about water abstraction, place a temporary moratorium on new planting of water guzzling crops, not allow new encroachments on water bodies (currently, according to the Census Survey of Water Bodies in Ganga Basin, 34,555 water bodies have been encroached upon(Quality Council of India (QCI), 2021), and to simply follow the rule of law and 'natural resource ethics'.

Further, these examples indicate that there is no option to 'the traditional paradigm of living with the rivers, and living with the floods', where human settlements are temporary and the permanent settlements are higher than the natural flood line. As was seen in the February, 2021 Raini disaster, the traditional settlements were higher than the historical flood line and there was not much river encroachment by villagers. Therefore, there was minimal damage to life and property during the recent disaster. The hydropower projects which were destroyed were those which were built in the natural channel of the river, thus signalling the fact that we need to abide by the rules of the river, understand our limits and respect nature's power. During the lean periods, more than 70% of the flows in the Bihar-Jharkhand segment and down till the Farakka Barrage is contributed by rivers flowing in from Nepal. If used judiciously, the situation can be substantially salvaged. The rivers Bagmati, BudhiGandaki, Gandaki, Kamla, Balan, and Kosi will be legitimately acknowledged as *Jeevan-dainees*, 'rivers of life', and not as 'rivers of sorrow'.

11.8 UNDERSTANDING VULNERABILITY AND RISKS FROM DISASTERS

All these examples and discussions clearly point to the fact that most of these disasters are man-made, resulting from inadequate implementation strategies and conflict of interests which increase our vulnerability and risks which manifest in different ways. According to the Asian Water Development Outlook (AWDO) 2013, India and Nepal are countries most prone to hydro- meteorological hazards. AWDO considers vulnerability as a function of the following elements: degree of exposure, soft-coping capacity and hard-coping capacity which depends on the social, economic, physical or environmental factors. India and Nepal have lower Human Development Index (HDI)[89] values than the world average and therefore their social vulnerability is much greater. India and Nepal also rank high in Multidimensional Poverty Index (MPI)[90] which suggests that their economic vulnerability is also high *(Alkire & Robles, 2017)*.

Some of the determinants of environmental vulnerability are environmental mismanagement, overconsumption of natural resources, degraded ecosystems, decline in risk - regulating ecosystem services, and climate change. Depletion of natural resources (for example, Wetlands) exposes people and infrastructure to natural hazards like floods and storm surges. Nepal is both a Climate Change hotspot and a densely populated region. This factor contributes to thedepletion and degradation of natural resources, which is a major cause of increased vulnerability.

As we can see in the table below, this region faces high natural-hazard-risks. Climate Change is further aggravating the loss of flora and fauna habitats, forest biodiversity, degradation of wetland and riverine island-ecosystems. Further, there has been a decline in forage and fodder availability, a depletion of agro-biodiversity, an increase in forest fires, deterioration in soil fertility. In addition, undesirable changes in land-use patterns, and an increased variability in agricultural output are factors which have increased the degree of risk. Therefore, there is a need to take steps to reduce vulnerability and consequently risk.

Table 11.3: Human Deaths from Disasters in Nepal Since 2000 to 2015

(Ministry of Home Affairs, 2015)

Year	Flood / Landslides	Thunderbolt	Fire	Hailstorm	Wind storm	Avalanche	Epidemic	Earthquake	Total
2000	173	28	37	1	2	0	141	0	382
2001	196	36	26	1	1	0	154	1	415
2002	441	6	11	0	3	0	0	0	461
2003	232	62	16	0	20	0	0	0	330
2004	131	10	10	0	0	0	0	0	151
2005	141	18	28	0	0	21	41	0	249
2006	141	15	3	1	0	0	34	0	194
2007	216	40	9	18	1	6	0	0	290
2008	134	16	11	0	2	0	3	0	166
2009	135	7	35	0	0	2	10	0	189
2010	240	70	69	0	2	2	462	0	845
2011	263	95	46	2	6	0	36	0	448
2012	123	119	77	0	18	9	9	6	361
2013	219	146	59	NA	3	7	4	0	438
2014	241	96	62	NA	3	38	12	0	452
2015	129	128	69	0	3	14	14	8980	9337
Total	**3155**	**892**	**568**	**23**	**64**	**99**	**920**	**8987**	**14708**

Based on this, a risk reduction approach and various other strategies have been suggested by HKH Assessment by ICIMOD, 2019 for the Himalayan region as elaborated in the table below:

Table 11.4: Disaster Risk Reduction Elements and Behavioural Change Strategies

(P. Wester et al., 2019)

	Information	Infrastructure	Institutions	Insurance
Command and Control Mechanisms	Zoning and Building code Enforcement	Infrastructure Development Projects; Technical Design Standards; Building Codes; Land Use Plan / Zoning	Institutionalization of formal and informal institutions	

	Information	Infrastructure	Institutions	Insurance
Incentives		Rural Housing Reconstruction program (RHRP) financial support for seismic resistant housing; Budget for Infrastructure Development		Subsidizing infrastructure premium a farmer has to pay for index-based weather insurance for crops
Persuasion	Providing hazard maps	Technical guidelines and dissemination training by engineers regarding infrastructure development	Support from formal and informal institutions	Engaging NGO's as social mobilizers to raise awareness of market insurance for crops
Nudging	Community based flood early warning systems (CB-FEWS)	Promoting retrofitting with nudges to consider traditional and cultural preferences	Institutional arrangement for community-based flood early warning systems (CB-FEWS) Reviving Drying Springs	Encouraging self-insurance through personal savings motivated by a clearly visible purpose such as loss of crops due to floods

11.9 DISASTER MANAGEMENT ACTION PLANS AND GOVERNANCE SYSTEM IN INDIA AND NEPAL

In Nepal, the Disaster Risk Reduction and Management Act of 2017 has been a significant development over the Natural Calamity Relief Act, 1982 (Nepal). The act focuses on disaster risk management as a process focusing on different stages of disaster management cycles, preparedness, response, rehabilitation and mitigation as well as institutional set-up from central to local level. Disaster Risk Reduction and Management Act, 2017 has made provisions for setting up the National Council for Disaster Risk Reduction and Management (NCDRRM) as the nodal body.

In the Indian states of Uttarakhand and Himachal Pradesh, the most important organisations which are providing rapid relief measures are the National Disaster Response Force (NDRF) and State Disaster Response Force (SDRF), set up by the Central Government. Along with these, the Himalayan states are also supported by the Indo-Tibetan Border Police and army units for relief measures in times of crisis.

In Uttarakhand specifically, the State Disaster Response Force and the District Disaster Response Force function under the National Disaster Management Authority (NDMA) as
mandated by the Disaster Management Act, 2005. Government of Uttarakhand has a special Disaster Mitigation & Management Centre working as an autonomous apex institute under the aegis of Department of Disaster Management, Government of Uttarakhand. The aim of this centre is the protection of the community by providing early warning and prediction, relief distribution, training and capacity building of the community to provide support during the disasters.

The Himachal Pradesh State Disaster Management Authority is responsible for disaster relief management implementation in the state of Himachal Pradesh. The Himachal Pradesh State Disaster Management Plan, 2017 provides a detailed framework for hazard and risk analysis, risk mitigation strategies, disaster preparedness, response, relief and recovery for the state and district authorities. National and international disaster relief organizations, NGOs, funding agencies and other civil society organisations have also been instrumental in providing disaster relief to the region.

11.9.1 Inadequate and Fragmented Disaster Management Laws and Polices

Although policies, institutions and mechanisms are set in place, these organisations work in a fragmented manner, thus hampering proper risk mitigation and recovery. The current performance of the disaster management system in both countries is inadequate for dealing with issues emerging from the global warming phenomenon. In addition, the political establishment and society at large have a rather inappropriate mindset which exhibits the following elements.

1. A denial of the reality that we have practically no control over the forces of nature accompanied by a belief that modern technology can control or circumvent the occurrence of disasters.

2. Denying responsibility for the event by calling it an 'Act of God' and resorting to fire-fighting measures related to disaster relief which are inadequate and temporary.

3. Construction of dams and barrages, technological interventions create a false sense of security leading to arrogant and impudent behaviour on part of the government as well as local communities. Instead of becoming cautious, people throw precautions to the wind.

4. Each technology, however unsustainable or sustainable, is inalienably linked to a set of unstated assumptions. They also have a set of precautionary 'dos and don'ts'.

However, as interventions proliferate, the standard operational procedures (SOPs) and are forgotten. This mindset completely defies the rational precautionary approach towards development of human interventions and has resulted in encroachment of flood zones, construction in high seismic areas, unchecked construction of roads and other infrastructure. Consequently, human fatalities and property losses are substantially larger than otherwise. It is astounding that even after witnessing multiple disasters, the governments of India and Nepal tend to overlook the ecological reality of the region and continue to take irresponsible investment decisions which serve short term political interests.

In addition, poor coordination at the local level, lack of early-warning systems, slow and inadequate responses, paucity of medical personnel, lack of search and rescue facilities, poor community empowerment and absence of nodal agency, multiplicity of organisations lead to chaos, confusion and loss. Time and again this has resulted in a 'trust deficit' .

11.9.2 Urgent Need to Align Laws and Policies on Disaster Management

To reduce the disaster-risk, it is recommended that the policy makers recognise the interconnectedness between different hazards and accept that the cascading chain of events can unfold rapidly, or occur after certain lapses of time. To address these issues, it is essential to have an early warning system and establish a protocol for 'practice-drills'

Education and gender inequality are high in India and Nepal, but the indigenous knowledge systems form the basis of community coping practices, which in turn build up resilience to disaster and play an important role in disaster risk reduction. This specific knowledge system and community coping practice needs to be integrated into the governmental disaster management programs.

There are disaster management plans set in place for certain projects. For example, the elaborate Disaster Management Plan (DMP) of the Upper Trishuli (UT-1) Hydropower Project (216-MW) as part of the Project Development Agreement (PDA) signed between the Government of Nepal and Nepal Water and Energy Development Company (NWEDC) *(HECT Consultancy, 2018)*. The plan clearly aims to prevent disasters and their impact on families, infrastructure and environment and build resilience by providing effective response in times of emergencies. However, actual implementation of such plans needs coordination beyond the mandate of a single project management team and require state-wise coordination and execution measures in times of serious calamities which affect various projects and numerous communities. Such examples need to be replicated for all such projects and linked with different project teams, agencies and government disaster management mechanisms.

11.10 Orissa Disaster Management Model

One of the most robust and time-tested disaster management strategies is known to be the Orissa Disaster Management Model set in place by Chief Minister Naveen Patnaik. In 1999, the Orissa government learned about the change of path of the super cyclone pretty late. Soon after, the state's communication networks collapsed and the situation could no longer be monitored , which led to the death of around 10,000 people. This led to the creation of a disaster management system which includes: setting up of a community-level warning system, multi-purpose cyclone shelters under National Cyclone Risk Mitigation Project and an Early Warning Dissemination System with last-mile connectivity.

Subsequent cyclones in Orissa demonstrated that with such measures in place, the capacity to deal with natural disasters at the community level has increased tremendously, as was seen during Cyclone Phailin, 2013, Cyclone Fani, 2019. Orissa has successfully conducted a very rapid, mass human evacuation and rehabilitation exercise for almost 1.2 million people (World Bank India, 2019). This was possible because it relied on scientific meteorological predictions and a highly focused Disaster Management Plan, where the State Disaster Response Force (SDRF) and other agencies were given a complete mandate and authority to take decisions, with no interference from legislators and bureaucracy. "...Now, cyclone warning by the IMD comes pretty early and is accurate, with least number of deviations, and observed path and predicted path almost going along the same lines. This has not just inspired confidence among the people on the ground, but also among the officials. It has prevented a large number of unnecessary evacuations. However, this improvement has not happened in one day. Odisha took a conscious decision and gradually built upon its capaciiesy, particularly at the community level." stated Professor Santosh Kumar of the National Institute of Disaster Management *(Mohanty, 2021)*. The state's disaster management is now focusing on the next step, i.e., to build capacity for minimising the loss of assets and livelihood.

With such a disaster management strategy the trust deficit in Orissa has been bridged because the government has managed to deliver immediate safety and relief measures in coordination with local community requirements. "Odisha has a great community outreach system through which people are being reached on time. It now has a network of over 870 cyclone and flood shelters that can house 1000 people each. Over 450 cyclone shelters have maintenance committees where youth have been involved and trained for search and rescue, first aid medical attention, and for providing cyclone warnings," said Deepak Singh, lead disaster risk management specialist at the World Bank.

The Odisha model demonstrates the principle of 'living with the natural phenomena'. The state's efforts in the context of Cyclone Phailin already finds a place under the umbrella of best practices in India's 2019 draft National Disaster Management Guidelines for Community Based Disaster Risk Reduction*(Bose, 2020)*. Nepal and the states of Himachal Pradesh, Uttarakhand, Uttar Pradesh, Bihar, West Bengal as well as Bangladesh need to appreciate and appropriately replicate these strategies and implement and enforce the rules and procedures to improve the disaster risk reduction and mitigation efforts in the Ganga river basin. We don't have to wait for a quantifiable volumetric increase in incidents related to climate change. Only when we start preparing and planning now can we be ready to face the disasters of greater intensity in the future.

11.11 CONCLUSIONS AND RECOMMENDATIONS

1. The mountainous region of India and Nepal are highly vulnerable to meteorological and geo-morphological hazards, such as increasing incidence of landslides and avalanches, extreme point rainfall events (EPREs), flash floods, cyclones and seismic

tremors. The Himalaya accounts for 21% of the major disasters recorded across the cryosphere globally between 1980 and 2015, i.e., 4,115 of 18,956.

2. When hydropower projects, road construction and other such activities defy the terrain boundary conditions and are not blended with rigorous scientific scrutiny, they lead to significant collateral damage, thus affecting the terrain stability and resilience of the local inhabitants. Therefore, natural phenomena are converted into man-made disasters.

3. Although such natural phenomena cannot be completely arrested, a systematic Risk Assessment, Risk Aversion and Disaster Preparedness as witnessed in the Orissa Disaster Management model, can certainly reduce or minimize losses.

4. In view of the large number of hydel projects already in existence, floods induced by glacier collapse are under imminent danger of being destroyed.

It is recommended that in order to minimise the losses or avoid catastrophes like the Rishiganga-Dhauliganga tragedy of February 2021, a strict implementation of Building and Construction Guidelines and Development Control Rules(The Uttarakhand Building Construction and Development Bye Laws / Regulations, 2011 (Amendment 2017)) be immediately enforced.

5. Disasters are inter-linked and transboundary in nature.

It is recommended that i) a Risk Aversion Assessment, ii) a Disaster Management Plan and iii) a Relief and Rehabilitation Plan be envisioned and prepared at the river sub-basin and basin levels. Such basin level plans should be based on real-time data collected from weather stations and seismological stations which should be disseminated in areas showing disaster hotspots. Only such a co-operative international exercise will yield optimum benefits and results.

6. *It is recommended that a hierarchic but decentralized system of primary data collection, periodic reporting, aggregation, collation and interpretation of data be established for enabling the formulation of evidence-based policies for Risk Aversion and Damage Reduction.*

7. Key to good disaster management is handing over complete command and control mechanisms in times of crisis to the best trained agency in this case the NDRF or SDRF.

It is therefore recommended that agencies such as the NDRF, SDRF, Indo-Tibetan Border Police, Geological Survey of India, Central Water Commission, National Institute of Hydrology and non-government organisations should function on a common platform where they can exchange experiences and lessons. Detailed SOPs in regional languages must also be prepared and placed in the open domain. This must also include a Complaints and Redressal Procedure so th that responsibilities can be fixed and relief can be immediately provided.

8. *It is recommended that Nepal and India should sign an agreement wherein risk insurance and life insurance policies could be fully aligned between the two countries.*

9. In case of earthquakes and landslides, it has been observed that many natural springs have disappeared or their discharges have greatly reduced.

It is therefore recommended that a program for spring rejuvenation be taken up on a regional basis and be implemented in a targeted manner in order to optimize the returns to investment.

Further, it is recommended that in order to revive drying springs the following strategies are implemented:

i. Accurately identify groundwater recharge areas;

ii. Prepare hydro-geological layout maps of the spring-aquifers and recharge area;

iii. Build simple artificial recharge structures (e.g. contour trenches, plantation of indigenous trees, channels for diverting water, etc.);

iv. Incentivize rainwater harvesting in farmers' fields;

v. Build local institutions i.e. Water Users Groups for regulating water demand and setting up a command and control mechanism.

There is no option to 'the traditional paradigm of living with the rivers and living with the floods' where the human settlements can be temporarily shifted to safer elevations.

ENDNOTES :-

86. Earthquakes are a very long term phenomenon and the degree of unpredictability and uncertainty is great.

87. The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes on the scale 1 to 10, with 10 indicating an earthquake of strong magnitude. Magnitude and intensity measure different characteristics of earthquakes. Magnitude measures the energy released at the source of the earthquake. Intensity measures the strength of shaking produced by the earthquake at a certain location.

88. Some of the world's largest documented GLOFs have occurred in the Karakoram Himalaya. Similarly in the upper Shayok River (Indus Basin) a GLOF was caused by the 'Chong Kum Dan' glacier, which formed a huge lake and a sudden outburst of this lake occurred in 1929. This led to a rise in the river water level by eight meters up to 740 kms downstream of the dam.

89. The Human Development Index (HDI-UNDP) is the most widely used indicators for measuring quality of life.

90. The Multi-dimensional Poverty Index (MPI) assesses poverty at individual level and complements traditional income- based poverty measures by capturing the severe deprivation that each member faces with respect to education, health, and living standards.

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CHAPTER 12

MULTILATERAL COOPERATION ON GANGA

12.1 GANGA BASIN NEEDS MULTILATERAL COOPERATION

India badly needs the co-operation of Nepal, China, Bangladesh, and Bhutan, if we wish to achieve the objectives of *nirmalta, aviralta and jeev-vividhata* for equitably satisfying the human needs of all riparian countries. We also need a commonly agreed Master Plan, preferably a legally binding one, especially if the two Big Brothers, India and China, can be made to share the waters of Ganga and Brahmaputra with smaller countries, in order to ensure the long-run environmental sustainability of the GBM. This approach requires an Integrated River Basin Management (IRBM) approach which is nothing but a basin-specific and pragmatic form of Integrated Water Resources Management (IWRM).

IRBM is not limited to the ecological or hydrological aspects alone, but includes equitable sharing of costs required for the development of sustainable projects, and the distribution to all riparian communities of the benefits arising from it. It assumes 'optimal-utilization' of resources, but not 'exploitative-maximization' of natural resources. The aim of Multilateral Cooperation will have to be to substantially reduce the fragmentation of the decision-making processes which are currently an inherent part of the strategies for dealing with irrigation, hydro-power, water-ways (navigation), flood-control, disaster management and the mitigation of negative climate change impacts. The plethora of committees in each country will need to be combined into a broad framework similar to the Water Framework Directive of the European Union (EU) since it has been successfully applied to river basins like the Danube, with complex problems, involving several countries such as Germany, Austria, Hungary, Slovakia, Romania, Bulgaria, Serbia, Maldova, Croatia and Ukraine. In case of the Rhine, which concerns Austria, Belgium, France, Germany, Italy, Liechtenstein, Luxembourg, Netherlands, and Switzerland, the state of Baden-Württemberg has pledged to contribute 13 flood-retention areas with an overall capacity of 167.3 million m^3 towards accomplishing the ambitious international goal of controlling floods. The Integrated Rhine Programme (IRP) was established in 1996 in order to achieve this objective. If these 19 European nations with different political and economic ideologies, disparate navigation and trade policies, can function together for solving common issues like flood control, pollution abatement and ecological restoration, then so can India, China, Nepal, Bhutan and Bangladesh! But this will require Integrated Planning and budgeting of projects, synchronization of all river operation schedules for all dams and barrages between states and countries, alignment of relevant laws, and policies in relation to the current problems faced by the GBM today.

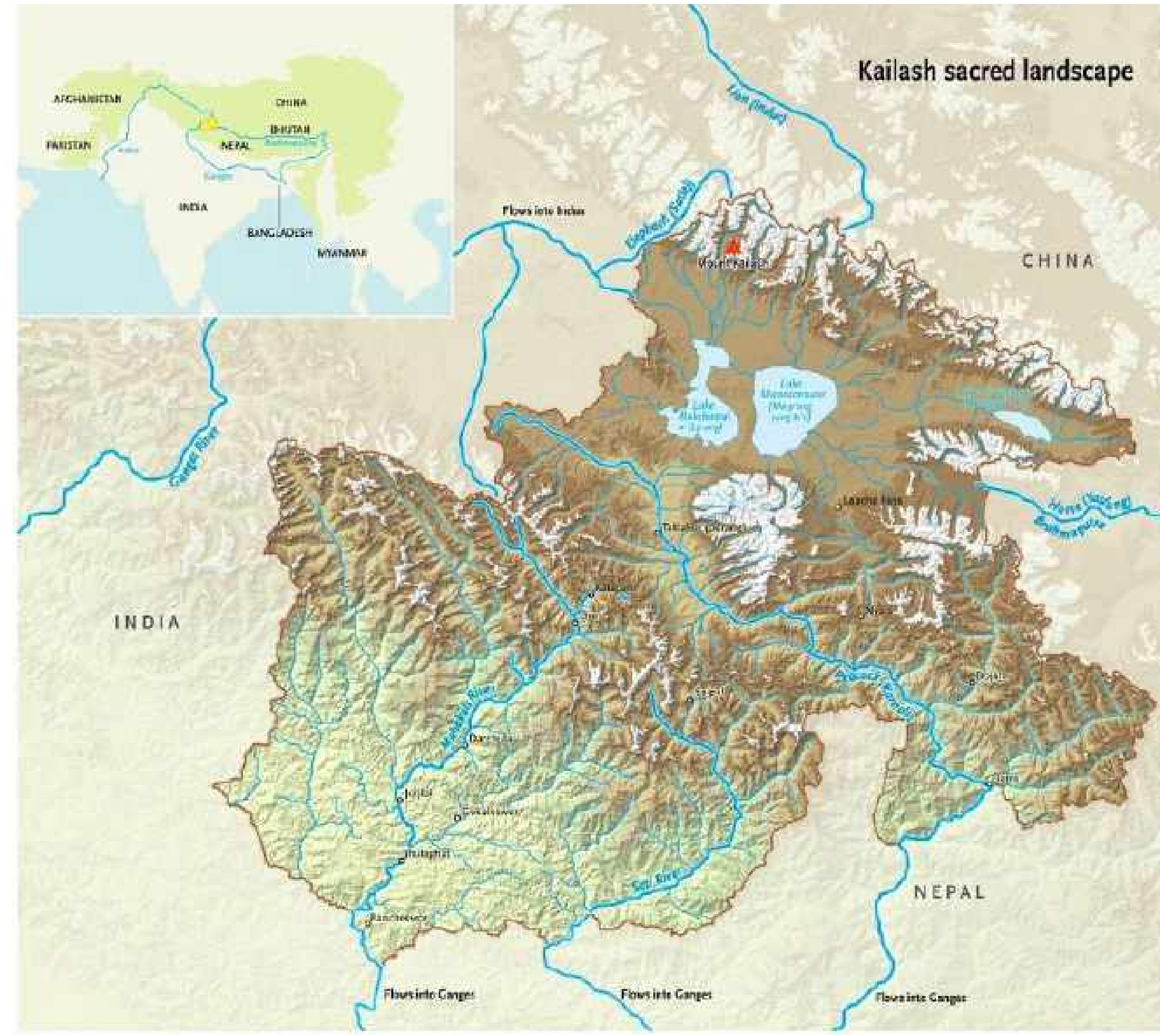
Various aspects related to the vertical and horizontal integration of the river have been discussed in the earlier chapters about the river system, cryosphere, and biodiversity. The current management system still has a fragmented approach as regards the ownership of the river, its development, access to it, and rights and responsibilities. This fragmented approach has arisen out of administrative bureaucratic procedures based on State and National boundaries and excessive compartmentalization e.g., a multiplicity of departments and authorities. All these administrative or governance-related aspects need to be synergized in order to ensure that we maintain the integrity of the river basin. We should never forget that, just about 250 years ago such administrative boundaries did not exist. But it is certainly possible (like Rhine and Danube) to have a common program for managing pollution, e-Flows and floods in the GBM without jeopardizing sovereign boundaries. A well-negotiated Integrated Master Planfor River Basin Management, say for the period 2025-2050 could be prepared for all aspects on which there is a consensus. Contentious matters could be kept in abeyance and resolved as things evolve.

12.2 KAILASH SACRED LANDSCAPE CONSERVATION AND DEVELOPMENT INITIATIVE

One such example of integration beyond borders, is the multilateral and multi-institutional initiative for demarcation and governance of the Kailash Sacred Landscape (KSL) Conservation and Development Initiative spread over an area of 31,000 sq.km. This region includes the origin of vital rivers such as Indus, Sutlej, Brahmaputra, and Karnali. At the behest of the Indian Government the origin of Ganga and some of the surrounding areas were also included. The region supports a population of almost a million people in the geographical areas of the three Riparian countries - Nepal, India, and China. KSL is an ecologically diverse, multicultural and geo- morphologically fragile landscape. In terms of ecosystem diversity, it encompasses rangelands or grasslands, wetlands, forests, high altitude lakes, rivers and the cryosphere. The region is home to people from different religions and has a network of pilgrimage sites revered by Buddhists, Hindus, Jains, Sikhs, and Bons, which include not just temples and monasteries, but also mountains and lakes. Initiated by ICIMOD and funded by BMZ (German Federal Ministry of Economic Cooperation and Development), from 2012 to 2017, this collaborative program was governed and administered by a multi-institutional body which included representatives from China, India, and Nepal, and was supported by UNEP and GRID.

The main objective of the KSL Conservation and Development Initiative was to prepare an Integrated Management Plan for water catchments; to access and develop genetic resources with the purpose of enabling equitable distribution of benefits. It is an outstanding example of an Integrated Management Approach of a common River Basin area managed by multiple sovereign states, which has evolved through a participatory and iterative process into a trans-boundary initiative. In 2019, the Archaeological Survey of India (GoI) and UNESCO included the Indian part of KSL in a list of natural and cultural heritage sites. Consequently, both China and Nepal have proposed the landscape as a world heritage site to UNESCO. This success story illustrates the power of the Negotiated Approach which could be kept in mind and emulated in our dealings with China and Nepal on contentious matters as well.

Since its inception in 2012, this KSL Initiative has managed to survive and make headway through political and ideological changes, diplomatic standoffs, and even military skirmishes. This highlights the long term and far-sighted vision needed for developing a



Map 12.1 Map of Kailash Sacred Landscape from The Himalayan Climate and Water Atlas
(Pravettoni, 2015)

The introductory chapter of this book elaborates the concept of the River Ganga not merely as a source of water for satisfying the growing needs of each of the Riparian states, but as an entity which represents the continuum of ideas, processes, human relations, religions, cultures, ecological flows as well as the hydrological cycle. All these concepts are encapsulated in the KSL Initiative. It provides an effective strategy for multi-sectoral planning and development, a platform for negotiation and mediation, and an opportunity for recognizing cultural, linguistic, and religious traditions through Integrated River Basin Management.

Some of the important components for Integrated River Basin Management such as putting in place a centralized data system, synchronized sharing of knowledge in public domain and many other aspects, can be implemented through such collaborative programs. Although it is true that this region is least contested in terms of water sharing, the moot point is that diverse civilizations are voluntarily participating in the effort. The fact that these three countries could work together for six years, keeping aside dissimilarities in languages, ideologies, political and governance systems, development approaches, cultural and religious traditions,diplomatic differences, provides a truly optimistic paradigm of multilateral co-operation. Such examples, which require an in-depth understanding of the history of geo-political relationships between the respective riparian countries, can be further replicated across the Ganga River Basin. This would help to develop a long-term vision for equitable and sustainable water sharing and management.

The following section describes the history and present status of Indo-Nepal bilateral relations, with a specific focus on Water Treaties and Agreements. The current status of Indo-Bhutanese and Indo-Chinese diplomatic / legal agreements will also be touched upon. The next chapter (Chapter 13) will include a similar discussion about Indo-Bangladesh relations.

12.3 COMPLEXITIES IN INDO-NEPAL BILATERAL RELATIONS

12.3.1 Nature of Interdependence

India and Nepal have a complex history of bilateral relations in many sectors, in the economic, social and political arena. Sharing of water resources forms a major part of the geo- political interactions between the two nations. The two countries have been involved in trans - boundary water cooperation since the British Colonial period in India. India, as the lower riparian state, is heavily dependent on Nepal for flood management, irrigation, drinking water, hydropower and navigation. Rapidly industrializing countries such as India have an infinitely growing demand for hydropower and Nepal has the potential of generating about 40,000 MW of hydropower, badly needed by India.

Hence, cooperating on development projects on these rivers during the high-demand season can benefit both countries. Annual occurrences of floods have had devastating impacts in Nepal and India. Similarly, the implementation of cross-border flood-control mechanisms is another major sector for research and dialogue between the two countries. Nepal's growing population invariably requires increasing agricultural output. Hence, the Indo-Gangetic plains in India as well as Nepal (Terai) are heavily dependent on the Ganga for irrigation. In addition, navigation, tourism, fisheries, trade are other areas of interdependence between the two riparian countries. Bilateral co-operation is therefore of critical importance.

12.3.2Bilateral Treaties and Agreements

The international discourse on trans-boundary water management has evolved through several stages: a) the doctrine of 'absolute sovereignty' which gives upper riparian states absolute right and an advantage over the river waters for unilateral diversion and use, b) the 'doctrine of territorial integrity', which tries to ensure a fair share of water for lower riparian states as well, and then followed c) 'the principles of equitable utilization' for addressing the trans-boundary conflicts that arose from the application of the two earlier doctrines. This led to a discourse on the formulation of laws and treaties related to

trans-boundary water management in the present context. The formulation of the Helsinki Rules in 1966, drafted by the International Law Association, was an important landmark in this discourse. It is in this context that Nepal and India, two of the mid-riparian states on Ganga's international water course, have tried to frame bilateral treaties on Ganga waters.

Other international laws and conventions which have guided the trans-boundary water management discourse include the 'Brisbane Declaration on Ecological Flows' (2007) (applicable to trans-boundary rivers protected under Article XXIV of the UN Convention No.197); the 'Non- Navigational River Uses of International Watercourses' (1997); 'Law of the Sea' (1956); the 'Monroe Doctrine' (1823), etc. The long history of trans-boundary water relations between India and Nepal is punctuated by a series of bilateral treaties, agreements and understandings that are guided by these international laws and discourses.

Chronologically, the following treaties that guide water storage and sharing practices, flood management, hydropower generation, and other river management related issues have defined bilateral cooperation between the two nations:

Table 12.1 Bilateral treaties between Nepal and India on different rivers.
For details see (Dhungel & Butler, 2016)

Year	Name of the river for which the treaty/agreement has been signed	Nature of the Treaty / Agreement
1920	Sarada/Mahakali River	First treaty signed by Nepal and India during the British India Government for construction of Sarada barrage (constructed in 1928) on Mahakali/Sarada River
1954	Kosi Treaty	Envisaged the construction of a barrage at Bhimnagar (completed in 1962) also known as Hanumannagar barrage, to control the Kosi river which causes massive floods and devastation in India as well as Nepal.
1959	Gandak Treaty	Permitted India to build a barrage on the Gandak River at Bhainsa-lotan for irrigation purposes in India and Nepal, and for construction of a hydro-electric powerhouse for supply to Nepal.
1991	Memorandum of Understanding for Tanakpur Barrage	Memorandum of Understanding for construction of Tanakpur Barrage on Mahakali river, also known as the controversial Tanakpur Treaty.
1996	Mahakali Treaty	Planned to supply water and energy to Nepal from the Tanakpur barrage, water from the already existing Sarada barrage, and build a link road between Tankapurbarrage toMahendranagr in western Nepal for transport purposes. The treaty also set forth the plan for Pancheshwar Multi-Purpose Development Project.

Apart from these treaties which address large-scale water management projects, the two countries have entered into 'agreements and understandings' for small scale, localized studies and dialogues:

1. Agreements related to feasibility studies on the multipurpose river projects such as Karnali-Chisapani Project, Sapta-Kosi High Dam Multipurpose Project (3300MW), Sun- Kosi-Kamala Diversion Project,

2. Studies on the navigational possibilities on major rivers such as Kosi, Gandaki and Karnali,

3. Exchange of data on flood forecasting, Master Plan for flood management, dealing with inundation issues, etc.

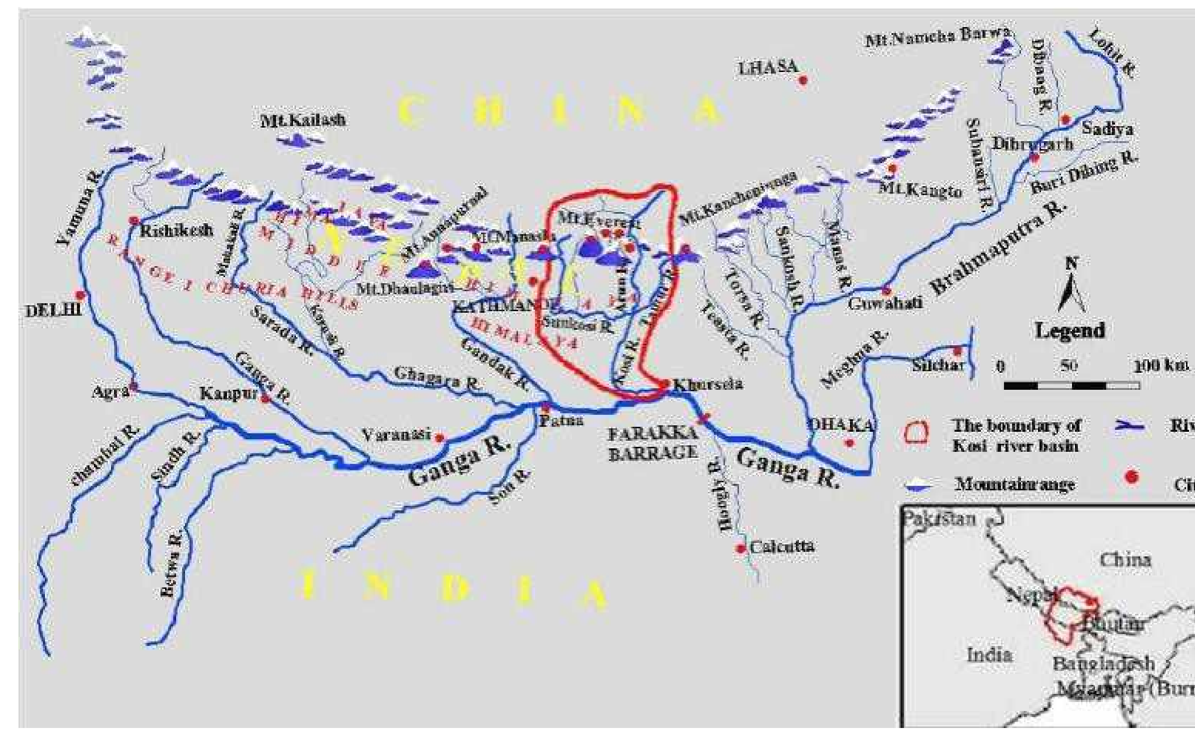
Eleven different Joint Committees such as 'Joint Standing Committee on Inundation Problems'; 'Nepal-India Joint Commission on Water Resources'; 'Joint Standing Technical Committee' and more have been formed since the 1920s to discuss, plan, manage and implement various schemes, projects, and studies.

From the point of view of Integrated Water and River Basin Management, maintaining eleven different committees, several commissions, treaties, multiple MoUs and legally binding agreements is totally redundant. What we urgently require is disbanding many of these and freshly appointing two High-Powered-Committees, (A) one for all River Valley Projects and Hydro-Power and one for (B) Trade and Tariff, Road Transport, Health Infrastructure, Cultural Heritage and Religious Matters, Tourism, Applied Research, etc.

12.4 TREATIES BELEAGUERED BY A HISTORY OF MISTRUST

In spite of the presence of such formally binding treaties and agreements, India and Nepal's water dialogues have been a source of controversy and tension. The Nepalese perception about these treaties has been that they have been loaded greatly in favor of India. Though India is heavily dependent on Nepal for water, being a powerful nation, it does not hesitate to use its 'hard power' on its smaller neighbor, while negotiating on water. Consequently, the treaties mentioned above have been framed from the point of view of India's 'national interest' with very little or no benefit to the Nepali population. All these treaties and agreements have, surprisingly, never specified the quantity of water to be allocated to Nepal as an entitlement. The people of Nepal and current political leadership feel that these treaties have provided considerable benefits to India, but denied comparative advantages to Nepal. These feelings are strengthened by the fact that the social, economic as well as environmental costs (externalities) of these projects have all been borne by the people of Nepal (Dahal, 2018). The remedial measures such as rehabilitation and compensation have remained substantially unaddressed since the 1920s.

The Kosi Treaty for instance, did not have any provision for supplying water to Nepal for irrigation. The project was built on agricultural land (around 9,034 ha.) in Nepal, but the project was entirely under India's control and no consent from Nepal was required for its execution, or for making modifications in the project *(Dahal, 2018)*. This perception has resulted in the establishment of 'The Kosi Victims Society' (K.V.S.) for safeguarding the interests of Kosi project- affected people. It has been following up on getting compensation for loss of land due to displacement. However, compensation has not been fully paid by the Government of India. In spite of repeated appeals from the Nepali Government through various Joint Committees on Water Resources between the two countries, the issue of compensation and rehabilitation is still a festering sore. And the issue remains unresolved till date.



Map 12.2 Geographic location map of the Kosi River Basin

(Chen et al., 2013)

In the summer season, the Indian authorities close some of the water discharge gates in the Kosi barrage fearing that Kosi floods will swamp North Bihar. However, this leads to flooding of large tracts of land in Nepal, displacing people, and creating hostility between the two countries (*Upreti & Acharya, 2016)*. The Nepali water expert, Surya Nath Upadhyay (2013) states that the project was designed to serve the interests of India with the objective of controlling floods in Bihar and irrigating the lands in India. Any benefit to Nepal was only a by-product. The time-frame of the treaty was 199 years which is problematic in itsef, as it outlives the technical life of the project *(Dahal, 2018)*. Due to a specific request made by Nepal in 1966, an amendment was made in the Treaty, whereby Nepal's consent was required in case of a deviation from the main design of the project. This amendment notwithstanding, the control of the project still remains in the hands of the Indian Government. The amendment made way for Nepal to have a say on future projects on the river.

However, Nepal's authority was subject to conditions and special arrangements specified in this provision. Though fishing rights were given to Nepal, permission to fish up to a certain distance from the barrage was to be granted by the Indian barrage authorities.

In spite of the absence of a water-sharing-clause between India and Nepal, Nepal has rarely experienced shortage of water for irrigation or other uses, primarily because of the natural abundance of water. However, as regards 'sovereign-rights', Nepal did get the wrong end of the stick.

At present, other projects on the Kosi River, which are to be guided by the Treaty of 1954, are the Sapta-Kosi High Dam Multipurpose Project and the Sun-Kosi-Kamala Diversion Project, which are proposed to be built on the higher reaches of the river for flood control. For Nepal, this project will submerge around 19,600 ha. of land and displace 75,000 people. Based on previous experience, satisfactory compensation and rehabilitation are not likely to happen. The 'Kosi High Dam Struggle Committee' has been opposing the project on environmental grounds and also because it is perceived as not being in Nepal's interest. They also perceive India's argument of flood control in Bihar as a façade for actually pursuing its hidden agenda of constructing its ambitious River Interlinking Project. Without going into the veracity of such arguments and the intentions of the negotiating authorities, what clearly emerges is the fact that such issues of friction need to be cleared and resolved through an open and mutually honorable mechanism for negotiation. Such a platform can only be 'regional' and multilateral in order for it to be transparent and equitable.

The Gandak Treaty also faces similar criticism since it has curtailed Nepal's right to use the river's water except during three months of the rainy season. Nepal has suffered from loss of land, repeated inundation due to faulty drainage structures and siltation. Further, water released in the eastern canal of the project is not sufficient for generating electricity for Nepal (about 15 MW) which was agreed upon in the original treaty. Such genuine concerns will need to be openly addressed by the high-level diplomats or water resources engineers of both sides. In the 'old- school-diplomacy' concluding an agreement favorable to the stronger/larger country was not uncommon. However, in the new Climate Change paradigm where the position of strength can quickly alter or change due to meteorological or physical phenomena, a more magnanimous position will need to be taken by India if it wants to hasten the process of completing the projects, and, one may add, securing the northern borders of India.

In 1988, the Indian Government completed the construction of Tanakpur Barrage and a hydroelectric power station with an installed capacity of 120 MW, located on the Mahakali River, near the common border between India and Nepal. According to the concerned department of Government of Nepal, these projects were completed without a formal agreement or a negotiated treaty. However, the fact is that Mahakali, being a shared river, requires a bilateral agreement for any kind of development project or construction work, since it affects both the Riparian countries. Nepal's perception on this matter is that India had completely ignored and neglected the international laws governing trans-boundary waters. However, this situation changed in 1991 when the Tanakpur Agreement was signed.

12.4.1 The Tanakpur Barrage Impasse

The Tanakpur Barrage was constructed by India in the 1980s on her territory on the Mahakali River, as an "alternative" to the aging 1920 Sarada barrage, to irrigate 1.61 million hectares of land in India. The sill level[91] of the Tanakpur regulator for the Nepal canal is EL 245 meters, which is 3.5 meters (11.5 feet) higher than the sill level for the corresponding regulator for India. India stresses that specified quantity of water flow for Nepal will be assured as the pond level of the barrage for power generation will be maintained at EL 246.7 meters. Such promises were made on the Gandak barrage, which also has a powerhouse on the canal, but as the pond level was not maintained, Nepal never got the specified quantity of water from the Gandak barrage. Since then, India has been totally deaf to Nepal's request to lower the sill level. Instead, India, argues that the Tanakpur regulator for Nepal was already "constructed in 1992, before the treaty." India's modus operandi, whether it was for the Farakka, Tanakpur, or Laxmanpur barrages or the Mahakali Sagar, Rasiawal-Khurd-Lotan, or Kalkalwa-Holiya bunds, has always been to 'first construct' and then, over the years, 'formalize' it through a post-facto agreement. Like many of the structures along the Indo-Nepal border, if Nepal does not take a firm stand, then the Nepal canal sill level at Tanakpur is heading to be another *fait accompli*, for Nepal.

Tanakpur Barrage on Mahakali River
(Skyscanner, 2013)

The Tanakpur Agreement had become a controversial issue in the Parliament of Nepal, because the opposition claimed that it required ratification from the Parliament of Nepal by a two- thirds majority vote. Finally, after a lot of opposition and criticism, in 1996, both countries signed a new treaty on 'Integrated Development of Water Resources on Mahakali'. This, in effect, subsumed the Sarada Treaty of 1920, and at the same time validated the Tanakpur Project, albeit after completion of the project. However, some of the provisions for canal and road construction, and other promises made in the new treaty remain unfulfilled till now. In an interview, Dr. Dipak Gyawali, a senior bureaucrat and an ex-minister in the Government of Nepal, stated that since the stipulations of the new treaty had not been fulfilled, such ratification could not be treated as a final closure of the agreement *(Upreti & Acharya, 2016)*. It now appears that there is a considerable amount of ambiguity that still exists on the status of these agreements and that the current political disposition in both the countries does not appear to consider the issues important enough to be urgently resolved.

This issue is further aggravated because the Mahakali River forms the border between India (Uttarakhand) and Nepal, and has been the cause of a niggling dispute. Unfortunately, neither India nor Nepal has officially published a full map of the Mahakali River Basin, correctly showing all the tributaries and drainage lines. Consequently, there is ambiguity about the tiny area which lies above the origin of Mahakali River. This area is called 'Kalapani', and it is claimed by both the countries. The area in question, a 370-square-kilometre strip has been under Indian administration for a long time. But Nepal argues that, under the terms of the 1816 Sagauli Treaty[92], the region belongs to Nepal and should be returned to it.

12.4.2 The Unresolved Conflict between India and Nepal

The conflict between the two countries still remains unresolved. These two areas cover a distance of about 40 kms of the Indo-Nepal border. Currently, it is controlled by India's Seema Sashastra Bal (SSB) forces, and lies under the administrative control of the Pithoragad district in Uttarakhand. It is indeed desirable from the point of view of both countries, that this matter is resolved, because it will pave the way for the implementation of the Indo-Nepal (water) Treaty. It will also enable the two countries to open the India-Kailash Mansarovar route for pilgrimage. In addition, this will also open the traditional trade route between Uttarakhand and Tibet through the Kalapani valley, at the head of which stands the Lipulekh Pass – traditionally used by the Bhutia community as a trade route. On maps of Nepal, an area of 35 sq. kms is shown as a part of Dharchula District, but is claimed by both countries. A Joint Technical Committee of Indian and Nepali officials is studying and discussing the matter since 1998! The importance of the Sagauli Treaty lies in the fact that it demarcated the eastern and western borders of Nepal through a formal treaty, and barring a few modifications, it is still relevant for ascertaining the Indo-Nepal jurisdiction.

12.4.3 Sagauli Treaty of 1815

In 1815, the British General Ochterlony had evicted the Nepalese from Gadhwal and Kumaon for brutality and repression during the 25 years of occupation by the Gorkha army in this region. The position of the British in India being that the border begins with the 'Kalapani Springs' and that the area above the springs is traditionally a part of Kumaon district, therefore, the Sagauli Agreement did not apply to this area. The moot point is that

the effective and optimal planning, development and management of Mahakali-Ganga will be possible only when such disputes are resolved. Its non-resolution continues to be a festering sore which needs immediate resolution.

Map 12.3 Limpiyadhura-Kalapani-Lipulekh dispute area between India and Nepal. *Note that this map is not based on India's position related to the Indo-Nepal border. Also note that this map was published by the Nepal government*

(Koirala, 2020)

On the extreme eastern edge lies the Mechi River, on which India has proposed a River Interlinking Project (part of the larger River Interlinking Project). This has not yet taken off the ground because India and Nepal have not yet signed a water-sharing agreement on it. Accepting and admitting that the relevant treaties need to be quickly opened for negotiation is mutually beneficial, since suitable amendments can be made. This will enable the situation to ease and allow the two countries to move forward. Such a negotiated resolution is the only solution to the impasse.

The failure of these poorly envisioned treaties has led to a growing but unnecessary mistrust against the Indian government amongst the Nepali people. The Nepalese have realized that the agreements are biased towards India's national interest, and that the Nepalese were taken for granted during earlier decades. In recent years, Nepal has been engulfed with multiple problems related to water resources, such as floods, displacement, inadequate compensation packages, population growth, climate change, threatened ecosystems, water pollution, and livelihood issues. Fragmented and non-functioning committees, non-availability of data, lack of transparency, poor designs, inefficient implementation, and bad maintenance of existing projects have further created a feeling of dissatisfaction on both sides.

12.5 REASONS FOR DISSATISFACTION

Equitable water-sharing-agreements are a pre-condition for stability in managing hydro-political conflict among the Riparian countries. Nepali researchers like Upreti and Acharya (2016) have pointed out that, this basic pre-condition has been repeatedly overlooked in every negotiation between India and Nepal, a strategy which appears to be a result of political intent, rather than technical exigence. Lack of political consensus and cooperation gets unnecessarily transformed into a conflict in such situations. The legitimate concerns of the Nepalese people need to be taken cognizance of by the Indian side.

Though Nepal is rich in natural resources and has the potential to harness a lot of hydropower, it lacks the financial as well as technical capacity to build and maintain large projects. Hence, it depends on foreign aid, mostly from India, for developmental projects. Out of the total foreign aid, India alone accounts for 40% of the total aid to Nepal and most of this aid is for Water Sector Development. Due to geographical proximity and India's growing needs, India proves to be the best buyer as well. Nepal is a small, landlocked country with slow economic growth and heavy dependence on subsistence agriculture. Nepal's contact with the outside world is mostly via Indian routes. Similarly, trade and foreign policies are often influenced by India. Currently, with the growing importance and role of India as a large and progressive economy, which has an avowed pro-neighbor international policy, India can easily afford to be more flexible and magnanimous, reaching out to bring about amicable settlement of these festering water-related issues.

India has been known to exploit Nepal's dependency on India for its own strategic interest. India's 'Big Brother Attitude' towards Nepal's water resources is often resented by the people of Nepal. For instance, India's insistence on constructing a high dam on Sapta-Kosi River in Baraha area of Nepal was opposed by people from 11 villages. However, India did not take this matter seriously. Similarly, other projects such as Laxmanpur, Lotan-Rasiawal-Khurda, Mahakali-Sagar close to the Indo-Nepali border have led to flooding of agricultural land and displacement in Nepali villages. India needs to proactively open a dialogue to address their grievances.

12.6 INDO-NEPAL TRANS-BOUNDARY WATER GOVERNANCE

Apart from these issues, Nepal's water governance also lacks institutional capability, technical know-how, and inclusion of traditional water structures in agency-driven large projects. The situation is further worsened by practices such as incorrect information in project contracts, contracts which are open-ended, inflexible electricity pricing, lack of transparency, inequity over water rights as seen in various project plans, etc. The Arun-III Project, Kali Gandaki Project (144 MW), Mid-Marsyangdi Project, (750 MW)and West Seti are all examples of the complications faced by River Valley Projects in Nepal.

Currently, water management in both countries is fragmented since the decision-making power for different aspects of river management rests with different departments. In the case of India, decisions related to trans-boundary water are not made by the Water Resources Ministry but by the Ministry of External Affairs. To add to the confusion, water and electricity are State subjects, not within the purview of the Central Government. Hence, every state can have a different approach to addressing issues related to the same river, thus making comprehensive planning an extremely difficult task. Nepal's national interests are not strongly represented by the 'Liaison Officers' who are often political appointees. Hence, the Water Resources Ministry is dominated by state and non-state actors in policy and the decision-making processes. A lack of clarity in national consensus is further reflected in its water policy related to River Basin Management.

12.7 THE FOREIGN AID CONUNDRUM

Since water does not abide by man-made boundaries, the interests of other actors and stakeholders further complicate the matter. Apart from Government policies and ministries, other factors have also been critical in shaping the present-day scenario of Indo-Nepal water dialogue. Nepal is a highly 'aid-dependent' and hence, 'aid-driven' country, and it is common for Aid Agencies to dictate the terms of agreements in many water-related projects. Trans-national water market initiatives led by multinational companies and supported by multilateral aid agencies, global markets, industrial lobbies, financers, and investors such as international banks have been influencing the nature and scope of various projects and treaties in both the nations.

Due to the unstable political situation in Nepal, investors are sometimes unwilling to invest in development projects. This could be an opportunity for the Government of India to offer a helping hand and ensure that the interests of the people of Nepal are guarded, without sacrificing India's interest. This 'water diplomacy' could pay greater dividends than mere bureaucratic lip- service.

Social activists, environmentalists and water professionals have been lobbying for a more egalitarian approach to water resource management. These groups exert moral pressure on international investors for withdrawing their financial support from inequitable or environmentally disastrous projects. As in almost all countries around the world, the conflicting interests of developmental needs and ecological needs plague the river management strategies of both India and Nepal as well. It is only through a Negotiated Approach that a consensus can be reached to reconcile these apparently conflicting needs.

12.8 THE 'HYDRO DOLLAR': AN AVENUE FOR COOPERATION!

In the context of all these complexities, Nepal and India entered into a Power Trading Agreement (PTA) in 2014, termed 'historic' by both the countries. The treaty authorizes the two neighbors to develop transmission interconnections, grid connectivity, power exchange and trading through government, public and private enterprises, on mutually acceptable terms. It also allows licensed electricity producers, buyers and traders from both countries to engage in cross-border electricity trading and to seek cross-border transmission-access as per the laws of the respective countries. However, the fact that the Indian market will be the single largest end-buyer and consumer of electricity produced on export-oriented foreign investment, has been considered as a problematic factor which could lead to further dependence of Nepal on India. Several existing Joint Committees on Water Resources have failed to function regularly, thus giving rise to misgivings regarding the creation of yet another committee headed by the Energy Secretaries of the two countries. Therefore, due to the risks involved in the implementation, the PTA, 2014 was under scrutiny.

Fortunately, these complexities notwithstanding, India and Nepal agreed to begin a power trade for the first time in history in November 2021. Nepal recently became an energy surplus country ever since the 456 MW Upper Tamba Kosi Hydropower Project started full operations in August 2021. According to the Nepal Electricity Authority, Nepal now has surplus power even during peak hours, usually between 7 pm and 8 pm. The peak hour demand stands at 1,500 MW. The country is currently producing 2,000 MW of electricity, of which 1,900 MW is generated from hydropower projects. On 1st November 2021, the Indian Central Electricity Authority allowed Nepal to sell 39 MW of electricity produced by the 24 MW Trishuli Hydropower Project and the 15 MW Devighat Hydropower Project to the India Energy Exchange (IEX). Such trade is likely to continue in future as Nepal Electricity Authority would now be able to participate in an auction in the Indian Energy Exchange everyday in order to sell power *(PTI, 2021)*. Although this is a market-driven option, it is likely to create a 'level-playing-field' for trade in hydro power.

12.8.1 The Need to Move beyond Hydropower

In the light of this scenario, where mutual trust and cooperation have been previously strained, such a power trade relationship can be quite beneficial for strengthening Indo-Nepal relationship. This relationship should reflect and magnify in transparent and equitable management of Ganga River. However, the problem with just focusing on hydropower is that it ignores other avenues for cooperation and development. As stated earlier, the ever-increasing need for hydropower will reach its peak at some stage and Nepal will also have increasing energy demand in years to come. However, the regulation of flows from storage dams will always be required for irrigation and flood control in both countries. Such schemes could not only aid in increasing avenues for promoting economic livelihoods such as tourism, navigation, and fisheries but also help in supporting aquatic biodiversity.

12.8.2 Climate Change and Floods

Climate Change studies have predicted an increase in water flows from the Himalayan Rivers, leading to more frequent and devastating floods. Hence, the nature of agreements needs to shift from being hydropower-centric to irrigation and flood-control centered. India could consider provisions which allow the water to be used for irrigation and navigation in winter and for flood control in summer. If this option is pursued, Nepal would not have to suffer population displacement and flooding of lands, thereby supporting economic prosperity for many, rather than benefiting just a few rich investors, as in the case of hydropower projects. The downstream beneficiaries could be made to pay for their share of investments and not allowed to be just 'free loaders', thereby adding to the national benefits of Nepal *(Gyawali, 2010)*. These strategies need an Integrated Approach to River Basin Management.

Water-related negotiations are of a long-term nature, leading to surprises and unexpected outcomes in times of change of regime or international power dynamics. Thus, water as a resource needs long-term mutual cooperation and goodwill. Water diplomacy based on equal rights is needed for generating proper long-term solutions for water related issues, and cannot be resolved by any other means. The trans-boundary water issues between India and Nepal are based on three basic principles: a) equitable water rights, b) duties towards maintaining the integrity of the Ganga River ecosystem and c) peer level cooperation for planning, implementation and management of the Ganga River Basin.

12.8.3 Conflicts carry the Seeds for Solutions

Conflict and disputes can be the starting point for better coordination and negotiation as it can pave the way towards positive outcomes. This can be observed in the long and checkered history of relations between India and Nepal which has evolved over several decades. While during the first two decades, India dominated the negotiations with Nepal, since 2001, Nepal has become progressively more assertive. This sense of equality in power to negotiate needs to be supported and strengthened in order to maintain healthy bilateral relations, specifically for trans-boundary water decisions.

12.9 INDO-CHINA RELATIONS RELATED TO WATER

The Indo-China border dispute has blown to such proportions that negotiating an agreement on water allocation in trans-boundary river basins, treaties on power trading, pro-active and mutually beneficial exchange of hydrological and meteorological data, etc. have almost gone off the radar. However, this need not necessarily be so, as most people are aware that the Indo-Pakistani Treaty on the allocation of water from the Indus River (the Indus Treaty, 1960) has withstood not only the test of time, but also the chronic belligerence between the two countries.

This issue has been studied by Nilanjan Ghosh, Jayanta Bandyopadhyay, and Sayanangshu Modak, whose work dispels the notion that an MoU on exchange of hydrological data would be beneficial for flood forecasting and management in lower Brahmaputra. Their assessment reveals that China has consciously hidden the water data relevant to high rainfall areas, while sharing data in the middle and western parts of the Yarlung Tsangpo. This makes the existing MoU (updated in 2018), quite meaningless for flood management.

An existing Memorandum of Understanding (MoU), first signed in 2002, on the sharing of flow data on the Yarlung Tsangpo by China to India is one such example of the need to have comprehensive agreements/treaties with China on all trans-boundary rivers. This MoU was renewed in 2008, 2013 and 2018 and is presently operational. The MoU is aimed at facilitating advance warning for flooding in India during monsoon. The MoU requires China to share data on rainfall, water level and discharge, primarily during the monsoon period, i.e. May 15 to October 15, when the chances of flooding are the highest. The agreement also ensures sharing of data in the non-flood season when the water levels at the designated stations are close to breaching the danger level. For its part, India is required to pay a mutually agreed sum of money for the data. It is also required to share information regarding data utilization. The exchange works in conjunction with the establishment of an institutional mechanism, known as the India-China Expert Level Mechanism (ELM) on Trans-border Rivers.

However, the agreement in question is considered redundant, as the choice of three hydrological gauging stations by China, i.e., Nugesha, Yangcun and Nuxia from which the flow data is shared does not take into consideration the areas endowed with greater rainfall, located in the south-eastern Himalaya (China). These three stations are located in the rain-shadow, in the north-eastern part of China. While much of the flow in the Yarlung Tsangpo River, that enters Arunachal Pradesh in India as Siang River, is generated in the south-eastern region of the Himalaya. There is thus an absence of flow data in the stretch of the river from the mountain crest- line to the China-India border. In view of this gap, for all practical purposes, the MoU is considered to be inadequate in establishing a comprehensive early warning system downstream *(Ghosh et al., 2020)*.

There is a need to establish gauging stations between Nuxia and Tuting for a comprehensive and effective early-warning system. Experts have suggested two locations in Tibet from where high season flow data needs to be accessed by India for early warning of untoward incidents.The first location is at Gompo Ne, at the confluence of the ParlungT sangpo and Yarlung Tsangpo, located about 150 km upstream of Tuting (Arunachal Pradesh, India); the second gauging station for data access can be at Mêdog, at the confluence of the Chimodro Chu and the Yarlung Tsangpo, located about 50 kilometres upstream of Tuting. Researchers, Nilanjan Ghosh (Director, Observer Research Foundation Kolkata), Jayanta Bandyopadhyay (former Professor of Environment and Development, IIM Calcutta) and Sayanangshu Modak (Research Assistant, Observer Research Foundation, Kolkata) state that 'if the MoU can be amended with the modifications in the choice of gauging stations, it will also improve Indo-Chinese bilateral hydro-political relations with respect to the Brahmaputra'.

An attempt at separately opening a negotiation on a treaty on water sharing, flood control and management, cooperation on rescue and relief during water related disasters can and should be made in the long-term interest of the South Asian region, especially in the GBM river basin. Based on the historical proverb that "in politics there are no permanent friends or enemies", cooperation on water resources and negotiations for resolving land disputes need not be mutually exclusive.

12.10 INDO-BHUTANESE BILATERAL RELATIONS

Like Nepal, Bhutan is also a landlocked country but with far less socio-political fractions or economic aspirations. Since the political economy is strongly centralized, albeit within a limited democratic framework, entering into agreements is much easier. Further, Bhutan professes a unique paradigm of 'human happiness', very much akin to the Human Development Index . The Bhutanese government has therefore been able to make its foreign exchange earnings through tourism, which goes a much longer way than countries which pursue a conventional industrial growth model. The country has wisely used its 'comparative-cost-advantage' through international trade and tourism, by generally following the principle of bilateral cooperation with India, and political neutrality with the rest of the world. It is therefore ideally placed for entering and supporting any regional agreement or convention on the sustainable and integrated use of trans- boundary water resources, especially on the Brahmaputra River.

Currently, India and Bhutan have a scheme for establishment of 'Hydro Meteorological and Flood-forecasting Network' (32 Stations), Royal Govt. of Bhutan & Govt.of India, on eight common rivers; i.e.,Puthimari, Pagladia, SunKosi, Manas, Raidak, Torsa, Aie, and Jaldhaka. The last meeting was held at Paro in Bhutan in March 2019. There is also a Joint Group of Experts on Flood Management, which last met in Jan. 2020. Indo-Bhutan Joint Hydro-Power Project (Tandi Dorji & Jaishankar at Thimpu), a 600 MW Kholongchhu, is a 50:50 Joint-Venture between the two countries.

In the light of increasing incidences of climate change-related disasters, it is very important to recognize that sharing data is of utmost importance. Adapting and responding to climate change related events will require a multilateral exchange of data, cooperation for responding to disaster management and the signing of multilateral agreements which go beyond the competition between nations for control over natural resources for only their economic value.

12.11 CONCLUSIONS AND RECOMMENDATIONS

1. Optimizing the resources of Ganga River needs a collaborative effort based on a basin-wide approach which goes beyond political and administrative borders.

Therefore, there is a need to focus on multilateral cooperation based on Sustainable Development Goals which focus on delivering basic facilities rather than getting caught in ideological or geopolitical gains.

2. Existing disputes and conflicts related to trans-boundary rivers will need to be systematically resolved.

It is recommended that this be done through a participatory process of negotiation and dialogue between all the Riparian countries of the GBM basin i.e., Nepal, China, India, Bhutan, and Bangladesh.

3. Floods often occur because of blockages and embankments in the natural and man-made drainage system in urban and rural areas in Riparian countries.

It is recommended that a single integrated Joint Committee, which functions regularly, be established for information sharing and regular updates. Diplomacy on water-related issues needs to find cohesion, consistency and a strong political will in order to arrive at agreements for fair benefit sharing. Therefore, there is a need for confidence-building measures and a mutual agreement on voluntary disclosure of information since relations between different countries are influenced by various geo-political and economic dynamics.

4. Avoiding mistakes from the past and strengthening ties with a long-term vision for equitable and sustainable water management and sharing require top priority.

It is recommended that initiatives such as the 'Kailash Sacred Landscape Conservation and Development Initiative' be replicated across the river basin which would lead to an in-depth understanding of the geo-political relationships between the respective Riparian countries which could help avoid conflicts in future.

5. Many of the existing treaties are out-dated or partisan, leading to mistrust and dissatisfaction among the less powerful Riparian countries.

It is recommended that these treaties be re-negotiated through an iterative process and then redrafted to reflect the current socio-political and economic situations. Separately opening a negotiation on a treaty on water sharing, flood control and management, cooperation on rescue and relief during water related disasters should be made in the long-term interest of the South Asian region, especially in the GBM River Basin.

6. There is an urgent need for collecting data and sharing this data between Riparian countries.

It is recommended that, in order to improve the benefits of data sharing, the existing MOU between India and China over data exchange on Brahmaputra River needs be re-negotiated and amended. There is an immediate need to establish gauging stations at Gompo Ne and Mêdog, in the southern part of the YarlungTsangpo (Brahmaputra)River in Tibet near the Indian border from where the data on high season flow can be accessed by India for early warning of untoward incidents, especially flash-floods.

7. Climate change studies have predicted an increase in water flows from the Himalayan Rivers leading to more frequent and devastating floods.

It is recommended that the Impact of Climate Change and changing economic demands be taken into consideration while formulating new agreements and prioritizing objectives. Hence, the nature of agreements needs to shift from being hydropower-centric to irrigation and flood-control-centric. Adapting and responding to climate change related events will require a multilateral exchange of data, cooperative response to disaster management and multilateral agreements which transcend political boundaries and the tussle for control over natural resources for commercial gain.

ENDNOTES :-

91. Dams have a Sill Level which refers to the bottom of canal sluice(s) and represents the level up to which a dam can be emptied by flow through gravity.

92. The Treaty of Sagauli was signed between the East India Company and the King of Nepal and ratified on 4th March 1816. The treaty established the national boundary line of Nepal following the Anglo-Nepalese War from 1814 to 1816. Prior to this treaty Darjeeling, Sikkim, Nainital, Kumaon, and Gadhwal belonged to Nepal but were ceded to British India and now continue to be part of Indian Territory today.

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CHAPTER 13

THE TAILS OF GANGA

Satellite Imagery of Sundarbans Delta
Source - NASA

13.1 INTRODUCTION

The river Ganga, along with the complex network of its contributaries, distributaries and the groundwater flow, forms the terrestrial part of the larger hydrological cycle. As was discussed in the earlier chapters, this terrestrial form finds its origin in the various ridges and valleys of the great Himalayan ranges. Until they meet in the delta region, all these rivers are independent entities having diverse origins but commonalities in their final regimes, as they merge and intermingle. Therefore, the tails of Ganga form a cluster of con-tributaries and distributaries at the very end of the GBM River System. They are the final repositories of all that comes down in the form of excess water which cannot be held back by the basin and all the sediments or particulates which are dissolved.

Over millions of years, the tails have been swishing and oscillating between the far eastern border of the delta and the furthermost point on the coast of West Bengal. The mouth of the GBM River System spreads almost 350 kms. from west to east, the western end being known as Sagar Island in West Bengal where the Bhagirathi-Hooghly exits into the Bay of Bengal; on the easter edge lies the Bhola Island in Bangladesh, from where exits the combined flow of the Ganga, Brahmaputra and Meghna Rivers.. The Bengal delta, or the GBM delta as it is also called, is a reflection of all that goes on, good or bad, right or wrong in the enormous GBM River Basin which covers a total area of about 1.72 million sq.km. It is the culmination and result, not only of the dynamic natural phenomena taking place over millennia but also mirrors all the anthropogenic interventions and actions which impact the river regime and its functions. Unfortunately, this important tail-region has been a 'blind-spot' in the Indian perception of Ganga. The current understanding of the tail-end gives importance to only the aspects related to reduction of the flows, yield, volume and annual flows of the river. Further, the continuous deterioration in the quality of water and increasing sedimentation at the Diamond Harbour near the Sagar Island in West Bengal has also been largely ignored.

Therefore, the understanding of the Ganga Basin can be complete only when impacts of the mainstream basin on the delta and reciprocally, the impact of changes in the delta on the mid- stream of Ganga, are considered together. In this chapter we hope to draw the attention of policy makers and general readers to this important interrelationship between the Ganga Basin and its Delta, which are interdependent, and socio-politically significant for both countries. Further, the fact that it forms an integral part of the larger GBM Basin, reiterates the need to admit this reality and reformulate our development and trade policies, especially in the areas of inland waterways, disaster mitigation and management, and conservation of the coastal mangroves of the Sundarban.

13.2 THE TALE OF THE TWIST IN THE TAIL

13.2.1 The Socio-cultural and Historical Perception

In the Indian perception, the Ganga River is believed to terminate at the Gangasagar Island (where Ganga is known as Adi Ganga) in West Bengal when it flows through the channel of Bhagirathi-Hooghly. The Adi Ganga, also known as the Gobindpur Creek[93], or Surman's Canal, and presently known as Tolly's Canal (named after William Tolly[94]), was the main flow of the Hooghly River between the 15th and 17th century. The earlier course of the lower Ganga as it flowed through the Bhagirathi-Hooghly channel was somewhat different from what it is today. At Tribeni, near Bandel, the Ganga branched into three streams. The Saraswati (not to be confused the ancient Saraswati River or the tributary of Alaknanda of the same name, located in Uttarakhand) flowed in a south-westerly direction, past Saptagram. The Jamuna (not to be confused with the Yamuna River in North India or many other streams of that name in eastern Bengal) flowed in a south-easterly direction and the Bhagirathi-Hooghly flowed in the middle. It glided down to Kolkata and then flowed as Adi Ganga, past Kalighat, Baruipur and Magra to the sea. As far as the old route of the Adi Ganga is concerned, the original channel was the same as the present day Tolly's Canal from Khidderpore to Garia and further on to the sea. According to old records, the Adi Ganga emerged out of the Sundarban at Kakadweep, from where it passed along the Baratala River (Mauriganga) and then "found a passage along a creek between Dhoblat and Monosardeep, and proceeded first in a westerly and then in a southerly direction until it fell into the Bay of Bengal at Ganga Sagar" *(Mukherjee, 2016)*.

The ancient mainstream of the tail reaches of Ganga, the Bhagirathi-Hooghly is about 260 km. in length, originating in the district of Murshidabad in West Bengal, India. Since this was the flow of the stream for the entire prehistoric and historical period for several thousand years, the Bhagirathi-Hooghly was engraved in the socio-cultural and historical perception as the end point of Ganga. The Hindu legend of the Ganga in Bengal, as mentioned below, provides an insight into the importance of the river for the communities.

"The king of Oudh, Sagar, who was the 13th ancestor of Lord Rama and the 7th incarnation of Vishnu, performed the Aswamedha Yajna (horse sacrifice) 99 times. He was desperate to perform the yajna one more time, but Lord Indra, the king of heaven, who had already performed it 100 times and earned the title "Satamanna," was jealous of being displaced by Sagar. He subsequently stole Sagar's horse and concealed it in a subterraneous cell, where the sage Kapilmuni was meditating. The 60,000 sons of Sagar started searching for the horse and ultimately, they were able to trace it (to Kapilmuni's kuti). They assaulted Kapilmuni as they suspected that he was the thief. Besides himself with anger, the sage cursed them and they were burnt to ashes. A grandson of Sagar came to Kapilmuni and begged him to redeem the souls of the dead. That was only possible if the waters of Ganga (the aqueous form of Vishnu and Lakshmi) could be sprinkled on the ashes. Bhagirath prayed before Brahma, the creator, to send Ganga to earth. Bhagirath led the way as far as Hathiagarh in the 24 Parganas, but was unable to show her the way beyond that. Ganga, in order to make sure of reaching the desired place, divided herself into numerous channels, and thus formed the delta. One of the channels reached the cell, washed the ashes, purified the souls which then could reach heaven."

Adi Ganga thus became the sacred stream, the sea took its name 'Sagar' *(Hunter 1998)*, and this point of junction of the river and the sea (known as Ganga Sagar where an annual festival is held) is considered to be a holy place by Hindu pilgrims *(Mukherjee, 2016)*.

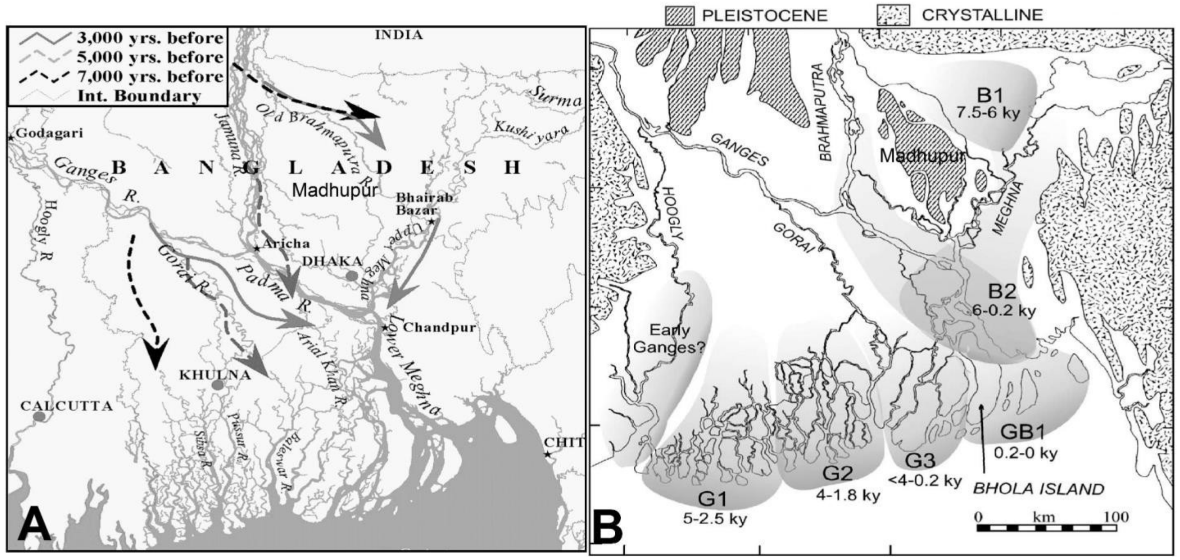
However, this socio-cultural perception and the geo-physical reality of the river were synchronous only until the 1770s, after which the Bhagirathi-Hooghly River started desiccating. The virtual drying up of the river is often connected to it being artificially linked to the lower channel of the Saraswati, whereby that became the main channel for ocean-going ships as the Adi Ganga almost stopped flowing. Tolly's Canal could therefore be identified as the first major human intervention in the tails of Ganga River.

The old route of Adi Ganga was revived by the excavation of Tolly's Canal which was the first revolutionary step taken by the colonisers to avoid the existing route which was not only circuitous, but also impractical for the movement of the country boats, especially during monsoons. In 1776, the old bed of the Ganga was excavated from its confluence at Hastings, south-eastwards to Garia, a distance of 13 km. Then the canal was excavated till the point it met the Bidyadhari River at Samukpota, a distance of 15 km. The 27 km long Tolly's canal was opened for navigation in 1777 to accommodate boats of 400 maunds[95](about 14,800 kg). Apart from playing a huge role in trade and transportation, the canal acted as an outlet for wastewater of the city.96 During the second half of the 19th century, W.W. Hunter reflects, "The old channel of Adi Ganga is still traceable as far as Hathiagarh Fiscal Division, where it loses itself. This channel long ago dried up, and the bed now consists of a series of tanks. The Hindus still consider the route of the channel sacred as it was the 'Adi' or original Ganga, and burn their dead on the sides of the tanks dug in its bed"*(Hunter, 1875, reprinted in 1998)*.

13.2.2 The Eastward Shift of Ganga's Tails

While the colonists were trying to control and tame the river for power and economic benefits, the Ganga River was also going through changes in its hydrology due to complex geo- morphological factors. During the last 7000 to 5000 Years BP, the southward shifting sands were pushing the shoreline continuously towards the east, leading to 'progradation' or expansion of the tail end reaches of Ganga as well as Brahmaputra, independently. This progradation was not linear and evenly distributed but happened in periodic stages. The earliest progradation (coinciding with the late Vedic period more than 5000 years ago) was in the vicinity of the current Gangasagar Island. The mouth of the river then moved eastwards in the periodic stages (G1, G2, G3) as can be seen in the map given below. This shift led to the increasing flow in Padma, an erstwhile smaller distributary of Ganga, which travelled in the south-eastern direction. It is this Padma River channel which gained importance due to the increasing water discharge, when the Bhagirathi-Hooghly started desiccating.

The drastic shift in its course happened after an earthquake in 1782, followed by mega-floods in 1787, which led to the westward migration of Teesta River[97], thus ultimately joining the Brahmaputra system. This migration of Teesta River, which earlier flowed into Padma, led to consequent changes in the river system. udden increase in the flow of Brahmaputra River led to its westward migration and creation of a new channel or ana-channel named Jamuna[98]. This new channel ultimately merged with Ganga (Padma) River near



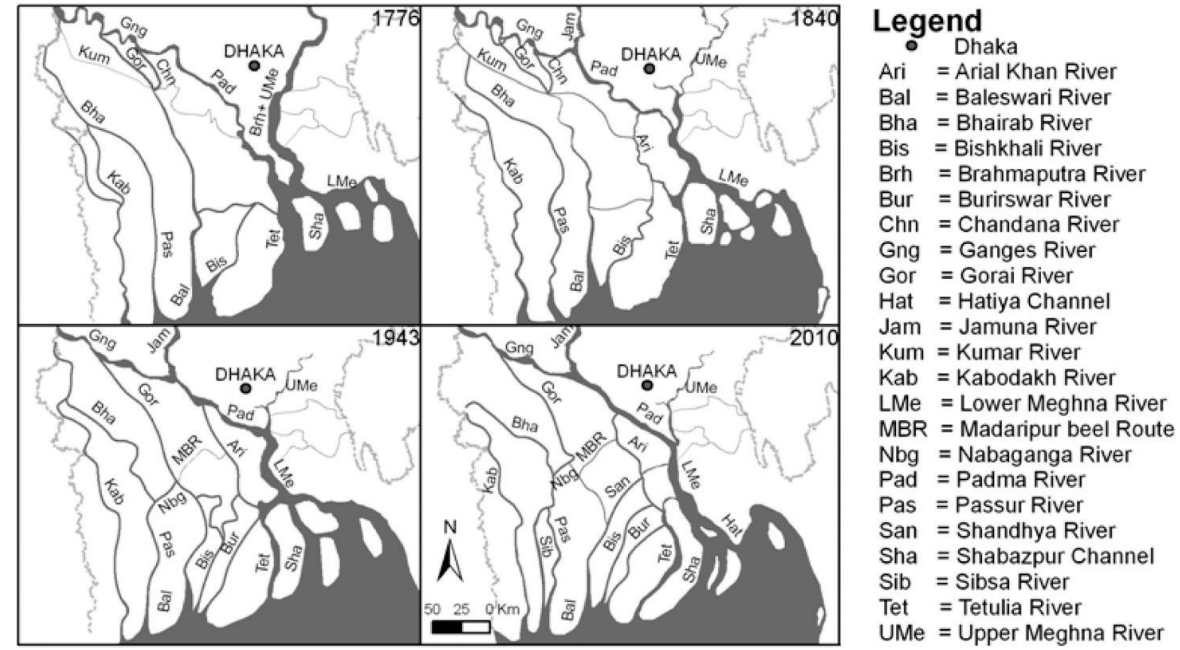
Map 13.1 Map of (A) Paleo-geographic map and (B) the pathways and timing of the phases of late Holocene growth of the lower delta-plain associated with the Ganges (G1, G2, G3), Brahmaputra (B1, B2), and combined Ganges–Brahmaputra (GB1)

The time span for Brahmaputra avulsion to and from eastern and western sides of the Madhupur Tract is about 2000 to 3000 years. The last avulsion of the Brahmaputra from the east to the west along the Jamuna course started following an earthquake in 1782 and major flood in 1787. The Brahmaputra which created its own fan of deltaic deposition expanded in the region as delta B1 and B2, ultimately forming GB1 after joining Meghna

(Allison et al., 2003; Goodbred & Kuehl, 2000; Sarker et al., 2013).

Rajbari district. Until then, Ganga (Padma) and Brahmaputra rivers flowed independently into the Bay of Bengal. (See map by cartographer James Rennell (1786) in Chapter 2). While the Brahmaputra migrated towards the west, its old channel continues to flow sluggishly even today, known as Old Brahmaputra.[99] This new confluence of Ganga and Brahmaputra (Padma and Jamuna) further merged with Meghna (Barak) ultimately forming the GBM delta where the tributaries and distributaries of all the three-river systems braid and spread water.

Consequently, since the 1780s, there have been a series of changes in the tail reaches of this river system as the delta is still evolving, leading to one of the most dynamic configurations of deltas in the world. Subsidence due to tectonic movement, accretion due to sedimentation accompanied by tidal movement and sea level rise are constantly altering the entire delta region. Besides the eight different mouths of GBM (described in Chapter 2), there are literally hundreds of smaller rivers which directly enter the sea through various creeks and estuaries. A special characteristic of the delta is that due to these processes new lands are continuously emerging and old lands are submerging all along the coastline. After the construction of Tolly Canal, the Farakka Barrage in 1975 was probably the second most significant human interventions which altered the present day GBM delta.



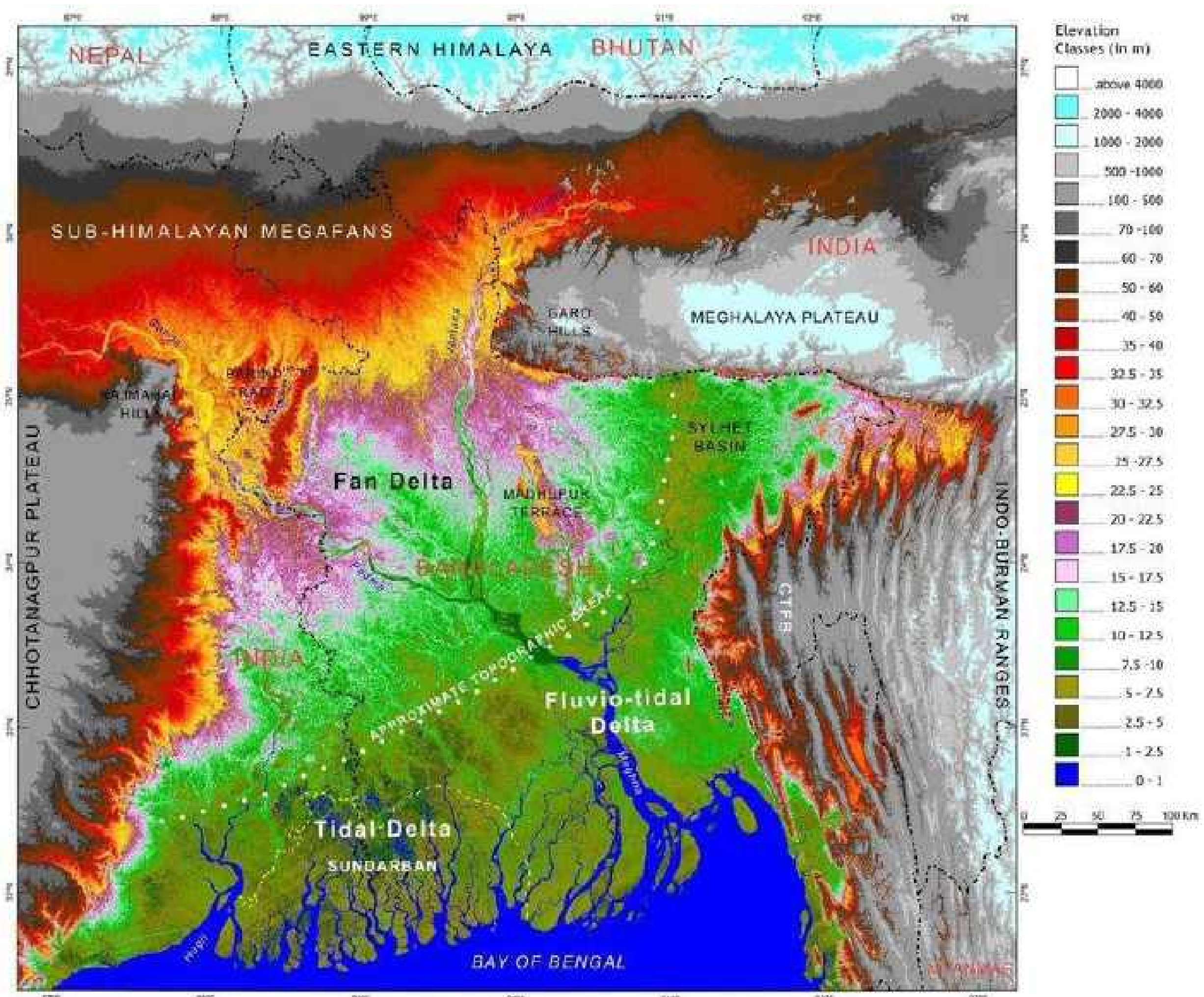
Map 13.2 Development of important rivers in Bangladesh over time

(Sarker et al., 2013)

13.3 WHAT WE UNDERSTAND AS TAILS: THE MEGA DELTA

In the case of the Ganga River, a large number of tributaries contribute to the main stem till the river reaches the northern limits of the Murshidabad district in West Bengal, India, where the main stem starts its dispersion or attrition from Farakka barrage. Therefore, according to our study, the tails of Ganga River begin from this first attrition point where the flow is dissected into the Bhagirathi-Hooghly through the artificial Feeder Canal and into the Padma River which flows into Bangladesh where it forms the GBM Mega-Delta.

The GBM delta is now correctly named as the Mega-Delta as it is the largest in the world and covers an area of approximately 1,05,641 sq.km., of which two-thirds is in Bangladesh and one-third is in India. The cumulative average water discharge through the GBM delta is the fourth largest in the world i.e., about 28,692 cubic meters per second (cumecs), with maximum discharge being about 80,984 cumecs and minimum, approximately 6041 cumecs *(Delta Alliance, n.d.)*. There are almost 700 rivers within the delta with a running length of around 24,000 km. However, it is the largest, not only because it drains down the water from two of the largest Asian river sub-basins, but also because they transport the largest amount of suspended sediments and bed-load from the youngest and tallest mountain ranges which are unstable, fragile and brecciated. About 75% to 80% of this delta has been created by sediment deposition over a period of the last 100,000 years consisting of (a) the Upper-Fan Delta, (b) Fluvio-tidal Delta and (c) Tidal Delta *(M. M. Rahman et al., 2020)*, as shown in Map 13.3 below. It is estimated that about 2.4 billion tons of sediments are carried every year and deposited partly in the delta and substantially in the Bay of Bengal (Banglapedia, 2021a). It spreads about a billion tons of sediment per year across the southern delta front, which is 380 km in width. This makes it the largest sediment dispersal system in the world (Allison, 1998). Such deposition has created a shallow submarine shelf which extends several kilometres in the Bay of Bengal.



Map 13.3 Physiographic Setting Of The Ganga Brahmaputra Delta. Elevation Model Prepared From 90m Shuttle Radar Topography Mission Data Of 2000

(S. Bandyopadhyay, 2019)

The plateaus and other highlands generally occupy the zones above 60 m. Elevation of the alluvial fans, palaeo-deltas and Pleistocene terraces approximately range between 25 and 60 m. The delta proper is made up of areas which are at a lower altitude. The elevations of the delta roughly decrease from NW to SE. Limit of the Sundarban region are shown in yellow dashed line. CTFB stands for Chittagong-Tripura Fold Belt.

13.4 HOW POLITICS DIVIDES A NATURAL DELTA

Although the delta has been politically split by a boundary which divides it between two sovereign states, it is in fact a single geological entity with almost identical physical and

morphological characteristics. The northern part, which roughly forms a triangle within the delta, has a slightly higher elevation ranging from about 10. m to 30 m. The uplands consist of the forests in the Barind, Madhupur and Chittagong hill tracts to the eastern and western sides of the Brahmaputra River, which flows north-south in the uplands. The Chittagong hill tract holds the Kaptai Lake created by a dam on Karnaphuli River. During monsoons, the lake spreads over an area of 1036 sq.km. Practically all the rest of the delta region which forms the deltaic lowlands below the Ganga and Brahmaputra confluence has an elevation of less than 5 m. above mean sea level. The delta is thus divided into the uplands formed during the Pleistocene period and the Deltaic lowlands.

The delta is surrounded by the Chhota Nagpur plateau and the Rajmahal hills on the west, the sub-Himalayan mega-fan, Garo hills and Meghalaya plateau in the north. The Ganga travels into the delta between the Rajmahal hills and the sub-Himalayan mega-fan, while the Brahmaputra enters the delta from the north through a narrow gap of 125 km between sub- Himalayan mega-fan and the Garo hills. The Brahmaputra then flows north-south in the delta till it meets the Ganga (Padma). The Barak River System which originates and emerges from the Manipur hill state in northwest India is a relatively lesser known river system, albeit very vital for the mega-delta and Ganga River System, as will be elaborated later in the chapter. It must be noted that the names of rivers, confluences, lakes, and newly evolved channels in the 'tail' region of GBM basin are based on the same mythology as the names prevalent in the 'heads' of GBM. This clearly indicates that the ancient perception of the Ganga encompassed not just the upper and middle regime, but also the lowermost deltaic regime of GBM.

13.5 WHY ARE THE TAILS IMPORTANT?

13.5.1 Rejuvenation of Ganga

In the general discourse about the Ganga-Brahmaputra-Meghna basin, Ganga and Brahmaputra overshadow the Meghna (Barak) River. In fact, the Meghna is a fairly large river with a length of about 947 kms. with 14 tributaries, and covers a geographical area of 52,000 sq.km. When it flows down from the Manipur hills bordering Myanmarto, Assam, it is called Barak, and then it splits into two rivers - Surma and Kushiyara, creating an island between the two rivers *(Banglapedia, 2021b)*. The two rivers meet once again in Bangladesh, and then continue onwards as one river, known as Meghna. To offer a comparison, the Barak-Surma/Kushiyara-Meghna System has a total yield of 51 BCM, far greater than the Narmada River, which has a total yield of 45.6 BCM *(India-WRIS, 2012)*. The need to focus on the tails is because of this lack of understanding of the importance of these rivers, both in terms of utilisable water, hydropower potential, strategic importance, and in terms of the socio-cultural canvas of water resources in India.

Further, it is the Teesta, Brahmaputra, and Meghna rivers which maintain the aviralta and nirmalata (purity) of Ganga towards its tail-end, that is, in the last stretch of 300 km. It is in this last stretch that the waters of the Ganga River are replenished with large quantities of clean water, thus aiding the natural rejuvenation process of the river system while keeping the regime alive and supporting biodiversity, quite similar to the rejuvenation of the Ganga River in the middle regime, thanks to large quantities of clean water brought by the Nepali rivers - Gandaki, Ghagara and Sapta Kosi and their tributaries! In the animal world, anatomically, the tail helps to maintain balance. Metaphorically speaking, the tail of the Ganga River in Bangladesh performs a similar function. When the upstream regime changes in terms of volume, speed or quality of water, it is the tail which helps in restoring the balance. Therefore, it is necessary to understand and acknowledge the importance of the tails of the GBM basin.

13.5.2 The Sundarban, Badabon (Big Forest)

The Sundari Mangroves Of The Sundarban
(Hippopx, 2017)

In the Deltaic lowlands, which are currently being used mainly for rice cultivation, lies the largest mangrove forest in the world, which is popularly known as the Sundarban, named after the most dominant mangrove species called the 'Sundari' (Heritierafomes) within an area of about 10,000 sq. km[100] of which 60% is in Bangladesh and 40% in India. The Sundarban have been declared as a UNESCO Natural World Heritage Site. It is a unique example of ongoing ecological processes characterised by the delta formation and colonisation of species with an exceptionally high level of biodiversity. There are three Protected Areas within this World Heritage Site and the area spread between the Baleshwar River in the east and Hari-Abhanga River in the west within Bangladesh is known as the Sundarban Reserve Forest, a Ramsar Wetland site.

The formation of the delta has been simultaneously accompanied by the growth of different species of mangroves such as Sundari (*Heritiera fomes*), Goran (*Cariops decandra*), Geva (*Excoecaria agallocha*), and many others, for over 7000 years. Abdul Aziz and Ashit Ranjan Paul of Bangladesh Department of Forests have identified around 65 species of

Map 13.4: Approximately 60% of the Sundarban Mangrove Forest is located in Bangladesh and the remaining 40% in India
(Baltazar, 2015)

In the Indian part, Jouleskona Barik and Chaudhary have made a distinction between 24 species of mangroves. These mangrove species have a special morphological character and are found as pure stands with aerial roots which sink to the floor and germinate without detaching from the parent plant. The intertidal space is their preferred location and left to themselves, they can spread by seed or spore-disposal. The best known among these and perhaps the most valuable is the endangered fragrant Keora (Sonneratia apetala) mangrove species.

Mangroves With Pure Stands Of Aerial Roots Which Can Sink To The Floor And Germinate Without Detaching From The Parent Plant
(Hippopx, 2017)

The Sundarban have been acting as a buffer zone between land and sea and ill effects from either side are substantially tempered by the existence of these mangroves. During and after the 2004 tsunami and Amphan cyclone of 2020 it has been recorded that the impact of cyclones, storm surges, tidal surges, seawater intrusion, and extreme events like tsunami in the mangrove areas was far less than areas without them. In the past couple of centuries, the mangroves have proved to be very effective storm surge and cyclone barriers for populations living upstream as well.

The mangroves of the delta are arguably the largest in the world, consisting of the most diverse mangrove species in the world, hosting 334 plant species, including the tenacious *Babul* tree (*Acacia arabica*) as well as natural and cultivated bamboo which feed the paper industry. About 165 varieties of algae and 13 species of orchids have also been identified in this region. Fauna such as water buffalo and the Bengal Tiger have specially adapted to the saline and semi-saline mangrove ecosystem found in the upper and lower Bengal delta. In addition, the delta is home to about 49 mammals, over 50 reptiles, more than 210 species of fish, 24 species of shrimps and prawns, 12 species of crabs, 45 species of molluscs and at least 250 species of birds and insects including a variety of honeybees. The report of the Zoological Survey of India (ZSI) 'Fauna of Sundarban Biosphere Reserve' has described 25 phyla under different categories and has compiled an inventory of 2,626 species of fauna which includes mammals, birds, fishes, spiders, reptiles, oysters, crabs, etc.*(Chandra et al., 2017)*.

Although the entire delta is green with luxuriant growth (paddy fields, swampy grasses, bullrushes, scattered babul trees), very little area is actually under tree cover, found mainly in the northern and north-eastern tracks or hill slopes covering an area of about 2-3% which lies 30 m. above the mean sea level. The presence of sloth bear, barking deer, leopard, swamp deer (barasingha), and hog deer are common in the Chittagong hill tracts. Certain Burma-Malay (currently known as Myanmar and Malaysia) sub-species are also found in these hilly tracts. The districts of 24 Paraganas(South and North) include the most important areas of Sundarban in India. The Susu Dolphin, also known as the Gangetic Dolphin or the Irrawaddy Dolphin, is found in the river systems in these areas.[101]

The Susu Dolphin or Gangetic Dolphin
(Malaviya, 2017)

It is also encouraging to note that the entire Sundarban area has been a subject of biological and zoological research by various national and international organisations. The Zoological Survey of India, the Forest Department of Bangladesh and India, National Zoological Park of the Smithsonian Institute, WWF India and Bangladesh, Wetlands International, Wildlife Institute of India and various other NGOs are working on biodiversity documentation, environment conservation and sustainable livelihoods in these areas. The IUCN has also been running a project in the Sundarban since 2016.

Royal Bengal Tiger Of The Sundarban. Skulls And Body Weights Of Sundarban Tigers Are Found To Be Distinct From Other Subspecies, Indicating That They May Have Adapted To The Unique Conditions Of The Mangrove Habitat *(Verma, 2013).*
Photo: www.Sundarbannationalpark.in

13.6 LAND-USE CHANGES DURING THE COLONIAL PERIOD

The first region in the delta to be inhabited by the human settlers, in this case the British colonisers, was the swampy region of Calcutta[102], presently known as Kolkata. In 1690, Job Charnock, along with his council and a contingent of 30 troops, landed on a narrow strip of land on the bank of the Bhagirathi-Hooghly River, surrounded by swampy forests and brackish lagoons. In spite of the uninhabitable nature of the region, Calcutta was chosen as the colonial capital due to its 'ecologically subsidised' nature, i.e., its waterscapes provided unique opportunities for mercantile trade, defensibility, riverine transport as well as provided solutions to drainage, sewerage and sanitation for the upcoming city area *(Ghosh & Sen, 1987)*.

With the arrival of colonial rulers, the region began expanding in trade and urban settlements. The Battle of Plassey in 1757, which the East India Company won due to their superior armament, was the turning point for the future of the Bengal Delta. Soon after, proprietary rights were obtained by the British East India Company from the Mughal Emperor Alamgir II. Since the agents of the East India Company were primarily interested in collecting revenues from land, the area was mapped by the Surveyor General as early as

1769. Systematic management of this forest tract started in the 1860s after the establishment of a Forest Department in the Province of Bengal, in British India.
The officers of the East India Company started clearing large areas of mangrove forests and converting them into rice fields. Such land was then leased out to local farmers surrounding the reclaimed lands. Until then, most of the deltaic region was largely uninhabited due to the thick mangroves and marshy lands. Thus, from 1839 to 1865, a considerable area of mangroves was leased out to farmers on a 99-years lease period, changing the ecosystem. Just as the landlords in Bengal were known as the *zamindars*, the leaseholders in the Bengal delta were known as the *jatdars* and *jahagirdars*. The leasehold land was then converted into privately owned lands after 1865. In the uplands, the open pasture lands on the slightly higher grounds were similarly converted into cultivated paddy fields. This has happened all over the delta region, in India as well as in Bangladesh. Over a 200-year period there were two major land-use changes which played a major role in spurring the growth in human population and simultaneously depleting the wilderness areas and pasturelands.

13.6.1 Ecosystem People of the Sundarban

This new community of farmers and fisher-folk began settling and adjusting in the deltaic region just over the last 200 years. Today, approximately five million people live around the Sundarban in small villages and frequently enter the Protected Areas for collecting timber, firewood, honey, bee wax, fish, etc. There are about 25,000 people regularly fishing in the area. An additional 35,000 people collect Non-Timber Forest Produce (NTFPs) from the mangroves. Adapting to the saline and semi-saline riverine or aquatic ecosystems, communities started cultivating rice in brackish water (where the salinity is not very high), along with saline -water fishery. In the upper (northern) portions of Sundarban, the local farmers have opened up lands for agriculture especially where new mud-flats emerge in the swampy areas. These are close to the tidal streams and channels. Over the years, different aquatic flora and fauna have also adapted to such cultivated areas. Artificial prawn-cultivation came into practice, because mere subsistence-based rice cultivation and fishery was not profitable.

Commercial fishing developed further with the emergence of continental shelf or marine fishing. In coastal lowlands there was a major shift from agriculture to aquaculture and brick making because of the increased water salinity and soil salinity. In addition, due to inadequate leaching of salts, there was a shift from agricultural crops to aquaculture not only because such fisheries were amenable to healthy growth, even with high salinity, but also because aquaculture yields a much higher return on investment.

All these varied forms of cultivation and fishing practices exist in this region even today. The diversity is greater when there is a close interface or overlap between two or three different ecosystems - ranging from freshwater to saline water ecosystems. The mangroves near the rice field are also very rich in bird diversity. The bird droppings under the canopy add to the nutrient value in the paddy cultivation fields, and therefore support a complex food web with several trophic levels. The Sundarban serve as the nursery or breeding ground for 90% of aquatic species in the coastal areas of Bangladesh as well as West Bengal

in India *(Danda et al., 2017; C. S. Das & Bandyopadhyay, 2012)*.

Thus, the Sundarban is bustling with life and different species having intricate inter- relationships. Consequently, there is also a very high density of human population in these regions. Due to their direct dependence on the natural ecosystems, the land and habitations of people living in these areas are periodically flooded or changed when the tributaries shift their location. They move and live with the river and therefore are closest to the human communities adapted to amphibian lifestyle. Having naturalised and adapted to this kind of livelihood, they are true ecosystem people, and can be termed as the 'sea-coast-transhumance people', i.e. a community which has not settled on any piece of land, but keeps migrating almost continuously between islands and creeks.

In other words, this region demonstrates that large tracts of land are not needed for establishing vibrant human settlements. This very character of being 'non-settled' is quite similar to the transhumance in the upper Ganga regime (elaborated in Chapter 6). However, the 'ecosystem people' of the Sundarban represent an interesting sociological phenomenon which has not been studied in particular, probably because sociologists and anthropologists have not looked at communities entirely dependent on aquatic ecosystems as a significant category of social structure. A similar interesting corollary lies in the fact that the Forest Departments of India and Bangladesh, like most other countries, did not recognise mangroves as a forest category till very recently.

The pre-Independence Wildlife Act(1927) in India and the Bangladesh Wildlife Amendment Act of 1974 did not recognise any local rights within the reserved forest areas, as regards to entry and collection of forest produce or any other kind of permits issued by the forest department. This legal stipulation notwithstanding, the Sundarban provides sustainable livelihoods for millions of people. Further, although densely populated, there is no concept of land ownership in this region, since the physical situation is dynamic and keeps changing almost every year or two, if not more. The population residing in these areas are mostly 'boat people' and therefore do not have to worry about the issue of land rights and territorial human-animal conflict which is commonly seen in other National Parks. Reports state that about 300 people are killed each year either by tigers or by saltwater crocodiles. However, the livelihood opportunities appear to override the physical threat. It appears that in the Bangladesh segment, there is very little discussion on human-animal conflict, probably because a large segment of it is a wildlife sanctuary declared under the 1974 Bangladesh Wildlife Amendment Act.

Recognising the importance of mangroves, the Government of India set up the National Mangrove Committee, under the aegis of the Ministry of Environment and Forests in 1976, to advise the government about mangrove conservation and development. But this activity was still not under the Forest Department since there was no opportunity for revenue generation of any kind - neither timber revenue, nor silviculture, nor community forestry. This is one of the main reasons for loss of coastal mangroves after independence, especially in the eastern region, since they were not systematically surveyed as they could not be physically categorised as forest land. Further, more often than not, they are a part of

The 'Boat People' (Sardar) Of The Delta. The Locals Call These Fishers 'Babaija'
(Salam, 2021)

Saltwater Crocodile (Crocodylus porosus) of the Sundarban
(Sarangi, 2019)

13.6.2 Human Interventions after 1947

The erstwhile united Bengal delta was partitioned into West Bengal, with Calcutta as its capital, and East Pakistan (presently Bangladesh), with Dhaka as its capital. This partition was purely based on religious considerations without any regard to the geo-morphological continuity. Along with the partition of land, the Ganga Basin and River System was also fragmented. In the post-independence period, the change in land-use pattern was considerably reduced if not completely stopped. The western boundary of Bangladesh was drawn in such a manner that the 45 km. segment of the main-stem Ganga, which travelled north-south, was aligned with the border. Having partitioned the lands arbitrarily, the issues related to water-sharing between the two countries, and fragmentation of several thousand hectares of private land had been kept unresolved for several decades. The long overdue process of rationalization of land settlement and citizenship was recently resolved under the 2015 India-Bangladesh Land Boundary Agreement.

On the other hand, the Tolly's Canal and other important canals and drainage lines in Calcutta and other areas in the delta region which were well-maintained during the colonial period are currently being neglected, and therefore becoming derelict. This has had severe socio- ecological impacts on the river system and the surrounding areas. Siltation, flooding, inundation and water-logging have become a common occurrence every monsoon. The once navigable canals have been transformed into mere nullahs (drains) due to lack of repair and maintenance.

13.7 HOW THE BHAGIRATHI-HOOGHLY WAS KEPT ALIVE

The construction of Tolly's canal, the eastward shifting of Ganga and the 1787 mega- floods together led to the gradual desiccation of the Bhagirathi-Hooghly River. In the meantime, the Diamond Harbour was being constructed and it was not anticipated that the flows of Bhagirathi-Hooghly would reduce so rapidly. But within a period of around 150 years, the silting up of the Diamond Harbour had noticeably increased due to reduction in the river flows. After Independence, the need to continuously dredge the Bhagirathi-Hooghly became unavoidable, making it increasingly difficult for the ships to dock at the port. Simultaneously, the need to flush out the silt meant that the flow of Bhagirathi-Hooghly would have to be substantially augmented. Such augmentation was possible only if a barrage with a height of 13 m (classified as 'large dam' as per CWC norms) was constructed to raise the water level of Ganga by at least 10 m in order to artificially divert water into the Bhagirathi-Hooghly.

A barrage was therefore designed in such a fashion that the water level of the Ganga could be maintained at an elevation which was 10 m. higher than its natural elevation. The reservoir created behind the barrage enabled the engineers to artificially cut the embankment and dig a canal which could sufficiently augment the flow of Bhagirathi-Hooghly with a continuous flow of 1135 cumecs. The Diamond Harbour has thus been kept alive by this 42 km long Feeder Canal. The Farakka barrage, which began its operations in 1975, was not meant for irrigation, but for artificially flushing out silt from the Bhagirathi-Hooghly. A spin-off was the installation of the Farakka Super Thermal Power Station with an installed capacity of 2100 MW which was made possible due to the availability of continuous water supply for its cooling towers.

The Feeder Canal from the Farakka reservoir was built in such a fashion that local ephemeral rivers namely Gumani, Trimohini and Kanloi could directly flow into the canal, further augmenting the volume and velocity of Bhagirathi-Hooghly. This could be considered as the third intervention in the river system just for augmentation of the river, i.e., to keep the Adi Ganga or Bhagirathi-Hooghly River alive. Considering the present state of affairs, it appears that many more such interventions will be needed to artificially augment the river. This is so because this smart design has created another problem. When these three local rivers were in flood they would still flow into the canal and cause inundation and heavy flooding in the surrounding areas as the canal could not carry more than its channel capacity of 1135 cumecs.

The tail-waters of the Farakka reservoir reach up to 50km, causing a 'backwater lift', leading to siltation and water logging in the surrounding floodplains for weeks together. It has been reported that the recent Bihar floods (August 2021) are a result of this 'backwater lift' effect caused by the Farakka barrage. "Floods in Bihar this year have not one, but two anthropogenic causes. The state saw early floods in June, which have been attributed to climate change. It then saw floods in August, which are being ascribed to the Farakka Barrage on the Ganga in West Bengal, Bihar's eastern neighbour"*(Pulaha Roy, 2021)*.

13.8 CONSTRUCTION OF OTHER DAMS AND PROJECTS IN THE DELTA

During this time, large structures were being constructed in the Indian segment of the river system. Construction of the Farakka Barrage (1975) was followed by the construction of Gazaldoba barrage on the Teesta (1987) and the Duani barrage in the Lal Monirhat (1990). The fourth major project proposed on the Barak (Meghna) River System, the Tipaimukh dam, is yet to be constructed as it is facing major opposition not only from water experts from Bangladesh but also from people being displaced or negatively impacted within Assam and Bangladesh.

13.8.1 The Anti-Tipaimukh Dam Movement

The Indian government recently resumed the construction of the Tipaimukh Dam on the Barak River just one km. north of Bangladesh's north-eastern border. The construction work was stalled in March 2007 in the wake of massive protests from within and outside India. The proposal to build the Tipaimukh dam in Assam on Barak River for controlling floods and generation of electricity has been a cause of conflict because it would impact the Haor region in Bangladesh. Experts have argued that the dam, when completed, would cause colossal disasters such as rendering vast stretches of farmland arid, negatively impacting agriculture and threatening food security in Bangladesh and India, with the former being vastly affected. Reports claim that the dam would virtually dry up the Surma and Kushiyara rivers (important tributaries of Barak - Meghna). Therefore, this controversial dam project has generated immense public discontent leading to wider mass-movements in Bangladesh, India and around the world. The movement has taken various forms, ranging from simple protests to a submission of a petition to the United Nations *(Islam & Islam, 2016)*.

Society for Activists for Forests and Environment claim that if the dam is built, the migratory route of the Ganga Dolphin (the National Aquatic Animal of India), which currently migrates from Meghna to Brahmaputra and then to the Ganga River System, will be obstructed. The Susu Dolphin may become extinct in Barak because it's upwards migration will be cut off due to the barrage. In spite of such severe opposition, it appears that the construction of Tipaimukh was taken up without there being an agreement between India and Bangladesh on the Surma and Kushiyara rivers. The National Hydropower Company, the Sutluj Jal Vidyut Nigam Ltd. and the Manipur Government were to execute the construction of the 1500 MW dam in 2013 (Tipaimukh Hydro Electric Project, PIB, GoI, 2013).

13.8.2 Pre-emptive Controls over Ganga's Waters

It needs to be understood that the construction of the Farakka barrage, the Gazaldoba barrage as well as the Duani barrage were post-independence pre-emptive actions to control the water use of Ganga. The construction of the Farakka barrage began in 1961, which indicates that planning and designing of the barrage must have begun immediately after Indian independence, when Bangladesh was still under Pakistani suzerainty. Therefore, as an upstream nation, the construction of the barrage and other projects could be considered as a pre-emptive strategic decision, and as a way to ensure control over Ganga, Brahmaputra and Meghna's waters before its entry into erstwhile East Pakistan (now Bangladesh). This is similar to the Chinese attempts at constructing dams and barrages in the Tibetan regime of the, Brahmaputra (Yarlung Tsangpo). All of these interventions thus call for a better understanding of the hydrology, socio-political as well as economic dynamics in the tail-end regions of the Ganga river basin. The strategic interests and the trans-boundary nature of these river systems have time and again, raised issues related to sharing of international waters attracting various international trans-boundary laws, creating a need for bilateral treaties and agreements on water sharing between India and Bangladesh in the GBM basin.

13.9 IMPACT OF HUMAN INTERVENTIONS ON THE DELTA

13.9.1 Reduction in Flow and Increase in Sedimentation

Since there was no border prior to independence, the East India Company dealt with the delta region as a single dominion. Therefore, the impacts of natural phenomena and consequences of land-use changes arising from human interventions mentioned above are very similar in West Bengal and Bangladesh and continue to remain the same with varying degrees of intensity. Environmental issues were not important for the imperial government because its objectives were completely colonial in intent (i.e. indiscriminate exploitation of resources and transfer of wealth to Britain). This mind-set of indiscriminate exploitation of resources appears to have continued during the post-independence period as well. The result of this approach has been evident during the last 75 years in the form of drastic changes in the river flow patterns as a result of sedimentation, pollution, and climate change which are severely impacting biodiversity and livelihoods. Tourism numbers remain relatively low as compared to the upper Ganga regime due to difficulties in access and limited transport arrangements or accommodation.

During the last 75 years, abstraction and divergence of water, construction of dams and barrages, sand mining, and encroachments in riverbeds and their floodplains have reduced water discharges in the Ganga River by almost 57% *(WWF & SANDRP, 2019)*. The water received by Bangladesh beyond the Farakka barrage varies from a maximum of 170 cumecs during the monsoon season to less than 5 cumecs during the lean period. This danger looms large, because the releases from Farakka barrage are continuously showing a decreasing trend, while the minimum environmental flows required for the Sundarban have been calculated to be at least 194 cumecs. Certain months experience nearly negligible amounts of fresh water discharge which has led to saline ingression and salinity imbalance. Reduction in volume has a severe impact on water quality, especially during the dry season when the flow of freshwater is minimal.

Satellite Image Of Gazaldoba Barrage. An Official Release From Bangladesh States That No Water Has Been Released From The Gazaldoba Barrage During Winter, Since 2011, Only The Regenerated Flow From The 70 Km Downstream Riverbed Is Arriving Towards The Teesta Barrage. Reduction Of Winter Flow Has Reduced Crop Production, Caused Fish Loss In The Rivers, Increased Irrigation Cost, And Affected Hilsa And Brackish Water Prawn Breeding

(Image: Google Earth, January 2022)

The rate of delta progression has decreased and the availability of lean period water flows has already fallen by more than 50%. But an even more worrying impact is the increasing rate of sea level rise. The mean rate of terrestrial subsidence of the delta front has been recently calculated as 3.9mm per year over the last few decades(M. Rahman et al., 2018). If we add the current rate of sea level rise induced by climate change i.e., 3.1 mm. then the total sea level rise adds up to be approximately 7 mm. per year (3.9+3.1), and the rate is likely to increase over the next few decades.

13.9.2 Flooding and Drought Events

The drastic changes in water levels in the river have led to episodes of floods and droughts in the deltaic region. During monsoon, similar to the upper Ganga regime, the lower Ganga regime also witnesses heavy precipitation, which leads to flooding events. In the deltaic region, this situation is further aggravated due to coincidence of the following factors a) during monsoon season, the delta is fully saturated and therefore loses its water absorption capacity, b) inflow from the upstream region is also the greatest during these months as the gates of upstream barrages and dams have to be kept open, c) there is minimum water abstraction in the mid- stream regime during this season, and d) due to a low gradient, water evacuation is also the lowest in the deltaic region. In addition, all the rivers in Bangladesh are in a continuous state of flux which make them meander in different directions, or get braided due to various reasons such as construction of embankments, highways and bridges, which fragment the smaller sub-basins. Therefore, it is not just the flooding event at its peak but the period of submergence of land, which is of greatest danger during the monsoon season.

It is generally presumed that there can never be any scarcity of water in the delta, rather, it is an impossibility since all the used and unused water ultimately flows into the delta. This 'misSundarstanding' needs to be corrected forthwith, because during the lean period, the water flows reduce drastically and it is only during the months from July to September that there is high water flow. The other eight months experience lean flows, thus leading to a scarcity period. It is also in these months that there is no natural precipitation and the amount of water abstraction and divergence also increases considerably in the middle or central Ganga regime. This water scarcity has a very significant impact as the population density of the delta (1200 per sq.km) is more than two times the density of the central Ganga regime (490 per sq.km). Along with reduction in flows, mixture of saline water with freshwater further reduces water availability. Therefore, relative inequality of water distribution is the highest in West Bengal and in Bangladesh, resulting in a direct impact on biodiversity and human communities. This has been a major blind spot in the understanding of the GBM delta which needs immediate attention.

13.9.3 Impact on Biodiversity

Rainfall variations, reduction in environmental flows, pollution, floods, and, droughts have been negatively impacting the biodiversity in the region. Currently, some of the major threa ts to the mangrove ecosystem have been forest exploitation, reduction in nutrient levels, and alkalinity, consequent to rapid urbanisation over the last three decades. As per IUCN, among the forest animals, the swamp deer, barking deer, hog deer, the Javan-Rhino, Asian small clawed otter, estuarine crocodile, Asiatic wild water-buffalo have been known to exist here for a long time, but have not been recorded during the last few decades.

The IUCN has declared 40% of the species in the Indian segment of Sundarban as endangered under their Red Data List Framework which covers an area of about 4,260 sq.km in India, out of the total area of about 10000 sq.km. In the last 200 years, different kinds of toxins, plastics, suspended material and other pollutants been invading the delta region, thus reducing the overall trophic levels.

Normally, the different species would have adapteded to sea level rise, however it has been the anthropogenic activities such as coastal tourism, oil spills, mechanised boats, etc. which are harming the species-diversity. Practices such as animal poaching, which makes use of gelatine-sticks to create blasts in the river to stun the fish to increase the catch, monoculture of prawns and other species have been disturbing the ecosystem balance in the region. The Susu Dolphins are being caught for their flesh and oil which are sold in the commercial market.

In the midst of all this destruction, an interesting phenomenon noted by many private researchers is that many of the endangered species of mangroves and other flora and fauna are more often located outside the Protected Area network. Therefore, it is recommended that the areas where the threatened species are more commonly found outside PAs be identified and demarcated in order to create a strictly regulated and managed buffer zone around such areas under a single management system (ideally in the Indian and Bangladesh segments together).

13.10 EXISTING AGREEMENTS AND TREATIES BETWEEN INDIA AND BANGLADESH

In order to address these issues related to human interventions, there is a need for meaningful bilateral dialogue between the two riparian countries. In the following section, we have tried to provide a brief overview of the existing status of agreements and treaties between India and Bangladesh. In1947, after the Partition of India, a total of 54 sub-basins in the Ganga- Brahmaputra-Meghna River Basin now became trans-boundary rivers. Of these, 54 trans- boundary rivers, only one treaty has been signed between India and Bangladesh in 1996.

There is a need to have a multilateral agreement between Bangladesh, India and China on Brahmaputra and other rivers in order to manage the flood waters draining into the delta from the upper riparian regions. Initiating a dialogue with China on Brahmaputra River is important because the lean period water contribution from the Tibetan cryosphere is significantly large. Without an agreement on Brahmaputra, the lean period scarcity will be aggravated while the monsoon period flooding will get more severe. There is also a need to have a bilateral agreement between Bangladesh and India on the Meghna River System, as the waters from its tributaries are essential for agriculture, other livelihoods and ecosystems in the delta region.

The construction of the Gazaldoba barrage and the Farakka barrage has already reduced water flows in Teesta and Ganga (Padma) Rivers respectively. Further, they have not provided water for irrigation of lands in these areas, which was one of the main objectives of these projects. Construction of the Tipaimukh dam, if it is built, will have similar consequences on the Meghna River as well. All these projects provide an argument in support of the need for agreements prior to the commencement of any upstream or downstream structures on trans-boundary-rivers, as they inevitably change the river regimes and the deltaic systems. An umbrella agreement in the form of principles and guidelines culminating in broad-based agreement on water sharing and access to the remaining 53 rivers is also urgently needed. All the planned and proposed projects need to abide by such agreements in order to ensure an equitable share of rights and responsibilities between all the riparian countries. The *aviralta* and *nirmalta* of Ganga can be ensured in the long run only if these common minimum terms of reference are accepted and followed.

However, the current geo-political situation is not conducive for arriving at such agreements. The one and only Indo-Bangladesh treaty i.e. the Farakka Treaty took nearly 50 years after Independence, to come into existence. It was only in 2015 i.e., after 64 years, that the India-Bangladesh Land Boundary Agreement was signed, which purportedly reconciled and solved the land ownership issues. Hence, the problems related to land and water fragmentation, which arose during Partition, remained unresolved for many years. Consequently, issues such as inundation, flood disasters, saline water intrusion in freshwater river systems, soil erosion, and destruction of embankments have been left with no mechanism for relief, rehabilitation or resolution of conflicts.

13.11 THE CHINA-BANGLADESH AGREEMENT ON TEESTA

13.11.1 Teesta River Comprehensive Management and Restoration Project

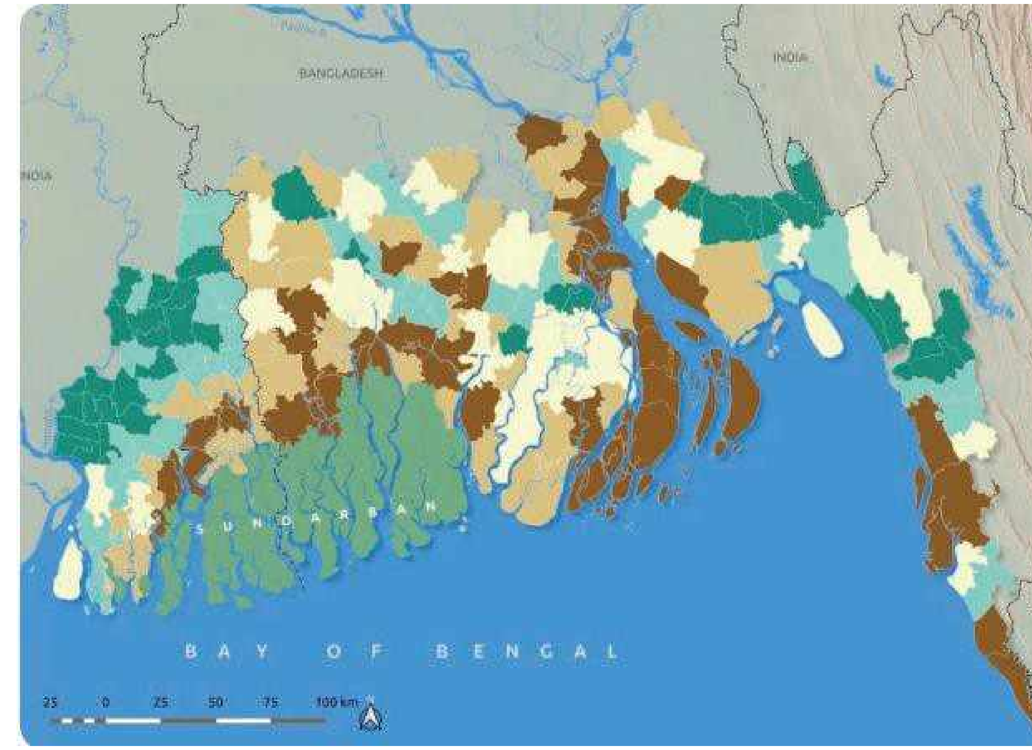
Bangladesh and China are currently in the planning stage of implementation of the"Teesta River Comprehensive Management and Restoration Project'. The Bangladesh Water Development Board, and Power Construction Corporation of China (Power China), a state-owned enterprise, signed a non-binding memorandum of understanding for this project on 28th September 2016. The Bangladesh Water Development Board will work as its implementing partner and the project is due to be completed in 2025. In recent years, Bangladesh has seen water levels drop dramatically in the Teesta during the dry season, due to dam construction and irrigation canals upstream, and the impacts of climate change. The project offers hope for the people living in the northern region of Bangladesh, who face floods and erosion during the monsoon and severe water shortages during the dry season.

The plan is to build over 100 kms. of embankments along both sides of the river, from upstream of the Teesta barrage near the border with India to the confluence with the Brahmaputra. The Project includes engineering measures to protect the riverbanks and prevent erosion by building groynes[103], cross bars and levees. It will also involve dredging and deepening the Teesta to improve navigability and promises to improve agricultural output in the Teesta river basin. This China-backed project is seen with much scepticism from within Bangladesh, as Chinese financial assistance may have strong economic and geo-political implications. Further, the environmental and social impacts of this project are a cause of discontent amongst scientists, hydrologists and environmentalists. A geo-political outcome of the project was, that after the announcement, India reached out to Bangladesh and promised to resume the much-delayed meeting of the Bangladesh-India Joint River Commission to discuss six treaties on trans-boundary Rivers between the two countries, including the Teesta. *(Azaz, 2020; Pinaki Roy, 2020)*

In the light of such a scenario, India has announced a huge 'inland waterways development project' on Ganga, Brahmaputra and Meghna. However, this project has not been developed jointly with Bangladesh. It is recommended that the 'Inland Waterways Development Plan' be redesigned to include the interests of Bangladesh and its local communities so that it becomes an important trade exit not only for India and Bangladesh but also for Bhutan and Nepal, which are landlocked. If it is connected through the Kosi and the Teesta River Systems, then a trade route can be envisaged for Sikkim, West Bengal, Assam, Bhutan, and Nepal through Bangladesh.

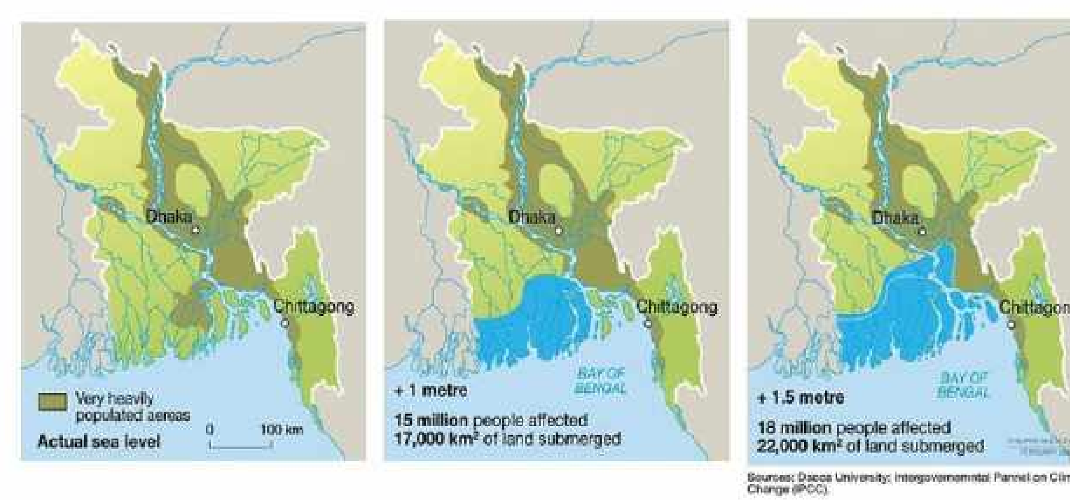
13.12 CLIMATE CHANGE IMPACTS AND RESILIENCE IN THE DELTA

Along with the impact of human interventions, there is also a rising threat from the impact of climate change. It has been stated time and again that the 'ecosystem people' of the delta will be able to adapt to these changes and continue to thrive in the region. Unlike the city folks, these 'ecosystem people' are prepared for uncertainties as their concept of life and death is adapted to the ecosystem cycles i.e., living with the uncertainty of nature. Since they are perennially used to shifting lands, the anticipated sea level rise consequent to climate change is not likely to scare them or force them to migrate. The habitations which will be affected the most are the sedentary populations which are settled in the inlands as their land rights will be threatened, almost lost, or obliterated due to sea level rise and inundation, making them 'climate refugees'. Until the trophic levels in the coastal areas are able to sustain life, the 'ecosystem people' or the 'boat people' will keep migrating and adapting to the changing river regimes and tidal forces.



Map 13.5 Assessment Of Levels Of Sub-District Level Social Vulnerability In The Trans-boundary Ganges- Brahmaputra-Meghna Delta In Bangladesh And India. Brown Colors Indicate Sub-Districts With High And Very High Social Vulnerability. This Indicates That The Population Living In The Inland Districts Will Be The Most Affected

(Vincent, 2018)



Map 13.6 Sea Level Rise Is Expected To Cause Widespread Flooding As Climate Continues To Change. This Low-Lying Area In Bangladesh, Vulnerable To Flooding, Is Likely To Displace About 18 Million People. Three Maps Show 18 Million People Would Be Affected

(Rekacewicz, 2020)

This is a unique character of the tails of the GBM delta. However, sea level rise combined with increased events of disasters such as cyclones, thunderstorms, floods, tidal surges, squalls and extreme events like tsunamis are increasing the vulnerability of biodiversity as well as human populations in this region. Climate change impacts are said to be more pronounced in the coastal regions all across the world and therefore, disaster prominence is not linear across the basin. It increases considerably towards the tails and therefore, within the South Asian region, the delta region will be the most severely impacted.

A Joint Study to understand climate change impact on the delta region conducted by institutions in Japan and Singapore headed by the International Centre for Water Hazards and Risk Management, Tsukuba, Japan *(Masood et al., 2015)* concluded that:

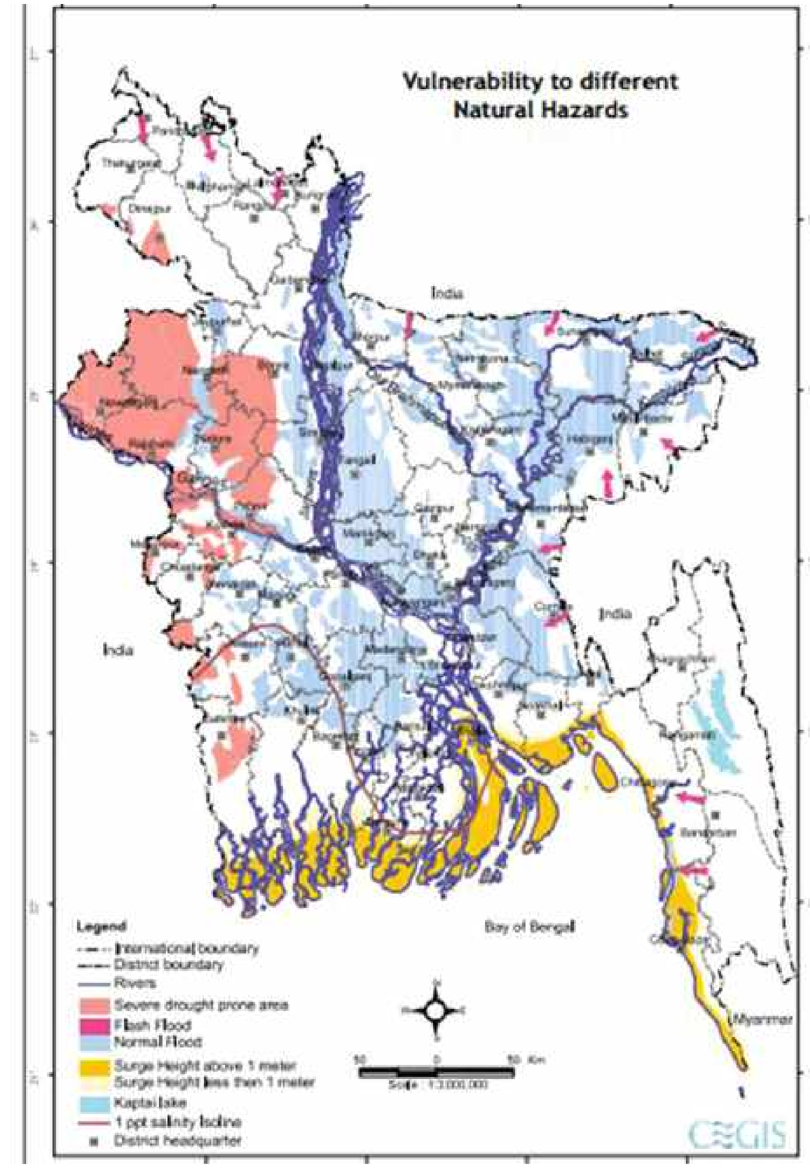
a. In the best-case scenario i.e., if all climate-change-compliant emission targets are achieved, there will be an increase of 10C as compared to current temperature and in the business-as-usual scenario, i.e., if the trend-line of the current rate of emission continues to increase, the average GBM temperature will be raised by 4.3^{o}C.

b. Within the GBM, by 2039, the currently cooler Brahmaputra basin will be relatively warmer than the Ganga and Meghna sub-basin.

c. Considering a high-emissions seenario, by the end of 21st century, the Iong-term mean precipitation is projected to increase by 16.3%, 19.8% and 29.6%, and the long-term mean run-off is projected to increase by 16.2%, 33.1% and 39.7% in the Brahmaputra, Ganga and Meghna basins, respectively

Since 1960, the lower delta has been subjected to the construction of polders and embankments. 'Polders' are circular or semi-circular dams which enclose a clump of villages or settlements and protect them against tidal waves and surges. However, such technology, originally developed in the Netherlands, and its replication in Bangladesh presumes micro- management and precise monitoring. It also assumes that all activities related to land and water levels need to be cleared by the concerned technical departments which raise the embankments and polders in the first place. Unfortunately, Bangladesh does not have a cultural mind-set where such procedures and operative guidelines can be observed, monitored and followed very strictly. This was a clear case of a technology not yielding expected results because the community using it is not used to abiding by the guidelines laid out for maintaining and operating such 'polders'. Therefore, in order to ensure the effectiveness of a new technology, there is a need to understand the specific requirements of the region, as well as the social and cultural mindset.

Fortunately, there are various plans being proposed and in operation in the delta region, the two major ones being the Bangladesh Climate Change Strategic Action Plan (BCCSAP) 2009, a knowledge strategy built upon the National Adaptation Programme of Action (2005) and the National Adaptation Program of Action (NAPA) 2009 which have tried to address the issues related to food security, disaster management, mitigation and low carbon development, capacity building and institutional strengthening.



Map 13.7 Showing The Vulnerability Of Bangladesh To Different Natural Hazards And Rapid-Onset Groups Of Hydro-Meteorological (E.g. Flash Floods, River Floods, Tidal Surges, And River Erosion) Hazard Risks

(MoEF Bangladesh, 2008)

The Bangladesh Delta Plan, 2100 and the National Plan for Disaster Management, 2010-2015 have also tried to build in these aspects and further learn from the previous experiences in order to build climate change resilience in the region for successful adaptation and mitigation. The European Space Agency has helped Bangladesh to put into place gauging stations spread across the delta and reconstructing the regional water level maps starting from the 1970s.

In terms of effectiveness of the implementation of these plans and policies, those that are working satisfactorily include early warning systems, risk management, education and awareness-raising. However, these adaptation policies are mostly disaster-focused, lacking clear sectoral coherence and with little attention to climate change adaptation in terms of resilient land use, livelihood diversification and research and development. Gender norms, cultural practices, and customary laws are viewed as deterrents in policy implementation by local stakeholders. The rights of Internally Displaced Persons (IDPs) are not recognised. There is neither any legal basis to protect their properties and possessions left behind after a disaster, nor is there an access to entitlements, or social and psychological services *(DECCMA, 2017)*.

13.13 AVENUES FOR COOPERATION BETWEEN INDIA AND BANGLADESH

Due to different political borders, the GBM delta in the Indian part and that in the Bangladesh part, have very different resource and disaster management strategies. In spite of this geo-political difference, it is crucial to remember that similar to the cryosphere, the GBM delta forms a continuous or homogenous geo-morphological area. There are comparative advantages in both the political regions and they have to be utilised in a coherent way in order to optimise benefits and reduce risks. Not doing so would mean an increase in displacement and therefore need for resettlement. This would mean recognising the entire region from the Gangasagar Island in the west to the Bhola Island in the east as a contiguous hydrological and societal entity which on the one hand recognises the sovereignty of both nations but also recognises the commonality of causes and aims.

This can be done by undertaking cooperative investments aimed towards core, long term changes that are required across sectors in development planning and future natural resource management. This can be carried out under the same banner by reducing overhead costs , i.e. reducing overall infrastructure and operational costs, and simultaneously increasing efficiency and avoiding duplication. Further, by exchanging hydrological data and experiential data such as sharing lessons learnt through various strategies. It also includes continuously evolving and adjusting the strategies in order to reduce costs and investments, maximise gains and minimise vulnerabilities. All of this will require inclusion of multiple stakeholders such as pre-existing local and national associations working as fishermen, woodcutters or honey gatherers' associations at local and regional scales. The following section elaborates on such programs and strategies related to livelihood, well-being and adaptation common in both the regions which are mostly interdependent need to be prioritised.

1. **Planned In-Situ Rehabilitation And Adaptation** : Includes repairing, reconstructing or converting the non-permanent residences into permanent residences which are flood and storm proof. This also includes raising of coastal polders for preventing seawater intrusion.

2. **Planned Relocation And Assisted Migration :** In cases where in-situ rehabilitation is not possible, people should be assisted in their migration and relocation process to ensure their basic fundamental rights are supported and taken care of.

3. **Temporary Evacuation :** Evacuation should be temporary and people should be relocated to their original settlements after the calamity. There should be an organised security system for ensuring safety of abandoned properties, assets, etc. This will require an advanced early warning system for pre-empting incoming cyclones, storm surges and tidal flooding. The time-tested systems set in place in the Orissa Disaster Management Model, elaborated in great detail in Chapter 11, should be implemented all across the delta region in West Bengal and Bangladesh.

4. **Mobile Healthcare Boats :** Mobile Healthcare Boats working as ambulances in these mangroves can ensure in providing immediate health treatment facilities to otherwise inaccessible islands and hinterlands. Such mobile healthcare boats are already in existence in Bangladesh . Similar mechanisms should be set up in India as well.

5. **Building Cyclone And Stormwater Shelters :** Cyclone and surge-wave shelters have to be located in a dispersed manner and practically every settlement should have access to a shelter. These have to be designated shelters, so some of them might be built newly where no public buildings are available for conversion or in some cases, they can be school, dormitories or any storm-proof buildings. They should be within a distance short enough for the residents to travel within the time range of the early warning system.

6. **Strengthening Disaster Relief Recovery Agencies :** Ensuring independence of disaster relief agencies so that local political interference does not hamper relief operations, standard operating procedures (SOPs) for evacuation and preparation of District Management Plans.

7. **Implementing Drinking Water And Sanitation Programs :** These could be relatively medium-term programs, which include construction of borewells with appropriate depth, protected Reverse Osmosis (RO) water dispensing stations especially when there is saline surge and reduction in potable water quantities. Provision of toilets and sanitary disposal of all waste should be made in a decentralised manner, and construction of septic tanks should be made mandatory.

8. **Capacity Building Of Government Organisations/Civil Society Organisations :** Includes capacity building and training of all the local level organisations including PanchayatiRaj institutions, self-help groups as well as local associations and NGOs to deal with disasters and their after-effects.

9. **Promotion Of Salt-Resistant Varieties :** Salt resistant paddy, prawns cultivation and other such crops should be promoted for building livelihood resilience and ensuring food security in the region.

10. **Expanding Coastal Afforestation Programs :** Programs such as Green Belt Project

and replicating mangroves plantation should be taken up as a long-term-resilience program.

11.

12. Mainstreaming Climate Change In Sectoral Developmental Planning : Such long-term programs will need governance change including departmental reforms, statutory provisions, budgeting, implementation mechanism and integration of all sectors.

In the case of the delta region, relief and rehabilitation organisations need to be functioning all throughout the year due to high risks and dense population. Equally appropriate systems can be put in place in the upper regimes (Himalayan regions) as well. Similar to the mobile healthcare boats, mobile healthcare dispensaries and ambulances on trained mules could be implemented in the mountainous region. In both heads and tails of Ganga, there is an urgent need for both short term as well as long term hazard management.

All these efforts will not stop disasters but will definitely increase the resilience and therefore aid in increasing the 'trust factor' or 'confidence levels' within local communities, consequently reducing the propensity to migrate both within and outside the national boundaries. Inspite of ensuring these measures, there is a need to accept human fragility and incompetence when facing natural forces. Therefore, there is a need to recognise human rights, the right to migrate during calamity and the right to be treated with dignity when dealing with climate refugees as more fundamental rights which both the countries have to respect and abide by.

13.14 CONCLUSIONS AND RECOMMENDATIONS

1. *It is recommended that a comprehensive agreement for all 54 trans-boundary rivers in the GBM basin, especially in the tail-end reaches, be formulated which guards the integrity and wholesomeness of the GBM delta. Such an agreement needs to abide by the principles enunciated in the UN Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992).*

2. The old Farakka Agreement between India and Bangladesh lapsed in 2016.

It is therefore recommended that a new agreement be re-negotiated keeping in mind the fact that, India as an upper Riparian state must re-work the monthly schedule of release of water from Farakka barrage since the circumstances which prevailed in 1996 (25-year ago) have changed considerably.

3. There is a need to enter into a fresh agreement on Brahmaputra, Meghna and Teesta by openly sharing all the available data and plans mutually between the two countries in order to build trust and confidence between the two riparian countries.

4. The consortium of species living in the delta (especially Sundarban), perform an important function of converting all the biodegradable human waste into sediments which increase the trophic level for marine life. This is a free ecological service provided by the mangrove ecosystem which has not been evaluated in economic or financial terms. Simultaneously, the toxins and plastics etc. which have a negative impact on marine life have also not been studied.

It is recommended that a combined study which evaluates both benefits and losses be conducted to assess the net impact of anthropogenic disposal of wastes.

5. It has been found that many of the endangered species of mangroves and other flora and fauna are more often located outside the demarcated Protected Area network. Therefore, it is recommended that the areas where the threatened species are more commonly found outside PAs are identified, demarcated and strictly monitored as buffer zones under joint India-Bangladesh management.

6. India has announced a huge Inland Waterways Plan on Ganga, Brahmaputra and Meghna. But unfortunately, this project has not been developed jointly with Bangladesh.

It is recommended that the entire 'Inland Waterways Development Plan' (IWDP) be re-designed in order to include the needs and aspiration of Bangladesh. The IWDP can then become a great trade exit not only for India and Bangladesh but also for Bhutan and Nepal, which are landlocked Riparian countries.

7. It is well know that India and Bangladesh share several commonalities in terms of socio-cultural history, trade, economic cooperation, biodiversity ,etc.

It is recommended that a 'Free Trade Zone' be created between India and Bangladesh.

ENDNOTES :-

93. The Adi Ganga was also known as the Gobindapur Creek as it marked the southern boundary of the Gobindapur village.

94. On 6th July 1775, Major William Tolly applied for permission to excavate a canal between the Hooghly and the salt lakes (to the east of Calcutta) at his own expense. He initially suggested two alignments—one to the north and the other to the south of Calcutta. The latter received the government's approval. Tolly received a temporary land grant from the government for a term of 12 years, and the right to levy tolls at 1 % on the price of all goods carried by country boats that would take this route using the canal. His enterprise was a financial success.

95. Maund : a varying unit of weight in some Asian countries, especially an Indian unit of weight equivalent to about 37 kg.

96. From various official reports and letters, we find that the colonisers invested in timely maintenance of the canal. This was imperative, as the functioning of the water route accomplished colonial capitalist intentions promising huge returns over investment. There are records that reveal boat traffic and goods carried through Tolly's Canal during the 19th century. It is interesting to note that the water-borne traffic (including Tolly's Canal and other canals) to Calcutta was seven times more than what was carried by the Eastern Bengal State Railway during the 19th and early 20th century *(Mukherjee, 2016)*.

97. Three rivers, Karatoya, Purnaprabha and Atrayi combine together and form the Tristrota in Sikkim. The name was later morphed into Teesta, which moves along Darjeeling and Siliguri and enters Bangladesh in Rangapur division where it finally meets Brahmaputra.

98. In the Indian tradition, rivers which pirate water from the other rivers by creating a new channel are all named Yamuna, in this case colloquially addressed as Jamuna (*Dandekar, 2015)*.

99. When the old channel disappears there is avulsion, in the case of Brahmaputra and Bhagirathi-Hooghly the old channel still exists, which is termed as an 'anachannel' in hydrological terms.

100. Not to be confused with revenue land area (10,000 sq. km.) since it excludes aquatic/marine areas which are normally not included in terrestrial catchment. According to IUCN and ZSI, 26,000 sq. km is the area under Sundarban which includes 104 islands. This divergence of almost 16000 sq. km in area covered, is because IUCN and ZSI include the 104 islands and the adjacent areas which support marine species.

101. In a certain geological period, the Ganga, Brahmaputra and Indus may have been connected through water corridors. One evidence for this fact is that the susu dolphin is found all the way from Irawaddy river in Myanmar (east) to the Indus river basin in Pakistan (west).

102. Interestingly, the nomenclature "Calcutta" is a reflection of its hydraulic topography. Calcutta lay in the centre with Sutanuti to the north and Gobindapur to the south. The middle portion of the landmass was marked by indentation in the coastline because of creeks and inlets. To denote this, a Bengali word was used, "kol- kata," "kol" meaning shore or coast and "kata" meaning cut open. The two words together imply a coast or shore cut open by creeks and inlets *(Mukherjee, 2016)*.

103. A groyne is a shore protection structure built perpendicular to the shoreline of the coast (or river), over the beach and into the shore-face (the area between the nearshore region and the inner continental shelf), to reduce longshore drift and trap sediments.

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EPILOGUE

क्षमस्व मां गंगे

O Ganga, Forgive Us Our Trespasses

Over the last four decades, the Ganga River Basin has taught us many lessons, but we have repeatedly failed to learn from them. The disastrous earthquake of 1988 (6.8 magnitude), again in 2011 (6.9 magnitude), and once again in 2015 (7.8 magnitude), leading to terrible destruction. We did not heed these warnings and continued building untenable structures in the river bed and on the de-stabilised slopes. In 2013, the Chorabari Glacial Lake burst open and flooded entire towns and villages downstream, and washing away the entire township of Kedarnath. Haridwar and Rishikesh also experienced the wrath of the Ganga, sweeping away people and property. The Rishiganga flood in February 2021, destroyed major hydel power dams i.e., Tapovan-Vishnugad, and caused hundreds of casualties. These phenomena were natural events to begin with, but the painful consequences were a result of human transgression of the laws of nature, transforming them into man-made disasters. Thus, history repeats itself and we do not learn from it.

The frequency of such events has been on the rise because the incidents of repeated transgression of the limits of nature have also been increasing at an alarming rate. In addition, recommendations made by experts and government-appointed Committees, and even Government directives have been repeatedly ignored by citizens, administrators, and people's representatives alike. The Nainital Municipal administration, for instance, has been made aware of the probability of a triple coincidence of disastrous events in the vicinity of the Naini Taal Lake, i.e., the possibility of land subsidence under the famous Mall Road, the impending landslide due to a huge rock slab balanced precariously on a rock face, and the drying up of Sukha Taal. And yet, no steps have been taken to either prevent or mitigate these impending disasters. The same situation is observed in several other locations. These are all graphic and tragic illustrations of wanton disregard to warnings by Expert Committees.

The latest in the line of transgressions is presently being witnessed at Joshimath, located on the upper hill slopes of the Bhagirathi River. The town, with a population of barely 5000 people in 1976, has expanded into a township with 25,000 inhabitants. Today, it attracts over 5,00,000 tourists and pilgrims during the peak yatra period, going to Hemkund, Valley of flowers, Kedarnath and other pilgrimage destinations. The Wadia Institute of Himalayan Geology, the Geological Survey of India, and the National Disaster Response Force (NDRF), have all been recommending the evacuation of the inhabitants and permanently re-locating them on stable land, since the entire township is located on a much older landslide which had left behind a layer of moraine, debris, and loose rocks. According to their reports, the process of subsidence of land has been speeded up because a groundwater aquifer right under Joshimath has started breaking up, as a result of construction of pucca buildings on top, thus leading to subsidence. As far back as 1976, the Mahesh Chandra Committee had recommended imposing severe restrictions on heavy/pucca construction, avoiding, and phasing out even agricultural activities in the town's vicinity, banning tree-cutting, and placing huge concrete blocks at the bottom of the hill for controlling toe-erosion next to the Alaknanda River bed.

The revelation – the Report released by the Indian Space Research Organization (ISRO) and National Remote Sensing Centre (NRSC) which stated that a dip of 5 cms had taken place at Joshimath in just twelve days. As if this were not enough, the NTPC has been digging a 12 km. long tunnel skirting Joshimath. In addition, work began in earnest on the Chardhaam road widening project, and finally, a railway station has been planned to so that passengers can go almost up to Joshimath. All these disastrous projects notwithstanding, the State Government, with full support from the concerned ministries of the Central Government, are continuing with construction projects at full speed. They have disregarded the orders of the National Green Tribunal (NGT) and the recommendations of the Expert Committee appointed by the NGT. To top it all, the annual number of pilgrims and tourists was 17 lakhs in 2022, a record of sorts! The State of Uttarakhand appears to be in a self-destruction mode.

We are paying a heavy price for ignoring such warnings. Besides, we continue to pollute the river waters and destroy its eco-systems in the naive belief that Ganga will wash away our sins. However, we are not willing to discard our arrogant attitude towards the river. It is not enough to salute the Ganga (Namami Gange), the time has come to admit our mistakes, and beg her forgiveness for all our transgressions, "*Kshamaswa maam Gange*, (क्षमस्व मां गंगे)" and to make a paradigm shift in the way we approach the river or harness its resources.

One needs to move beyond the so-called 'traditional beliefs' based on epics and mythological stories composed at a time when the geological and sociological conditions were different from those prevailing today. The reality of rapid geo-morphological changes in the still-evolving Himalayan region and the Ganga Basin, the negative effects of Climate Change, unforeseen or unanticipated impact of human interventions, unsurpassed pollution from solid waste and chemicals, cannot be ignored. We have explained in our Report, how the legendary centuries-old purity of the Ganga River is being grossly violated due to such misconceptions. Thus, a scientific approach, based on real-time data and continuous in-depth research, would help in finding optimal solutions for restoring the purity of Ganga waters.

Similarly, the so-called 'patriotic fervor' which lays claim to the Ganga as 'our own national river', whose waters can be utilized (or over-utilized) for our immediate needs, contaminated or polluted, impounded, or released without taking into consideration its impact on eco-systems and downstream communities, needs to be discarded. This must be converted into a desire for restoring the quality and reviving the dying flows of this mighty river, and which we share with millions within our country and those living in the Riparian nations of Nepal, China, and Bangladesh. We are convinced that such changes in the conception and implementation of Bilateral, Multilateral and International Agreements and Treaties at the diplomatic level, will enable a meaningful resolution of the complex problems of the Ganga River Basin.

In our Report, we have dealt at length on various aspects of the Ganga River System, from its 'Heads' (Cryosphere), through the middle regime, right down to its 'Tails' (Delta), discussed in detail the related problems, and made several specific recommendations in each chapter. The Report addresses the common questions and concerns expressed by various stake-holders, from the communities living within the Ganga River Basin and communities living on its periphery, and also takes into consideration the economic needs and political aspirations of the eleven states within the Ganga basin as well as those of the four sovereign countries which lie on or within its boundaries. In addition, the discussion addresses the ecological concerns voiced by researchers from various disciplines at the national and international level. Undoubtedly, economic interests and political exigencies must be taken into consideration, but mere gratification of short-term goals is not only undesirable, but must be avoided for our own survival. And finally, the factors largely beyond man's control, such as climate change, glacial recession, sea-level rise, meteorological calamities, etc., all need be looked at in an integrated manner in order to find comprehensive, holistic, and sustainable solutions.

It is for this reason, that this Report strongly advocates a paradigm shift in our perception about the Ganga River and its Basin, and by extension, to all other river basins. First and foremost, it highlights the urgent need for statutorily adopting a River Basin Perspective. This alone will ensure the effectiveness of all our efforts for the improvement in Ganga Waters. For instance, the high-profile Namami Gange Program, which is considered a very important national initiative, focuses on reducing pollution in the mainstream Ganga, without paying heed to the pollution brought to the Ganga by the Yamuna and other rivers. Consequently, it has not yet succeeded in achieving its avowed objectives. A River Basin Approach would be able to identify such roadblocks and factor them into a Master Plan.

The lack of co-operation and co-ordination between the eleven states within India and the four Riparian countries is another major hurdle which prevents our management policies, interventions, and legal instruments from being effectively enforced. Since this requires not just technical interventions or top-down administrative policies, but also efforts to build confidence and trust among different stakeholders at different levels, only an Integrated River Basin Planning, Development and Management Plan would be able to achieve the desired results.

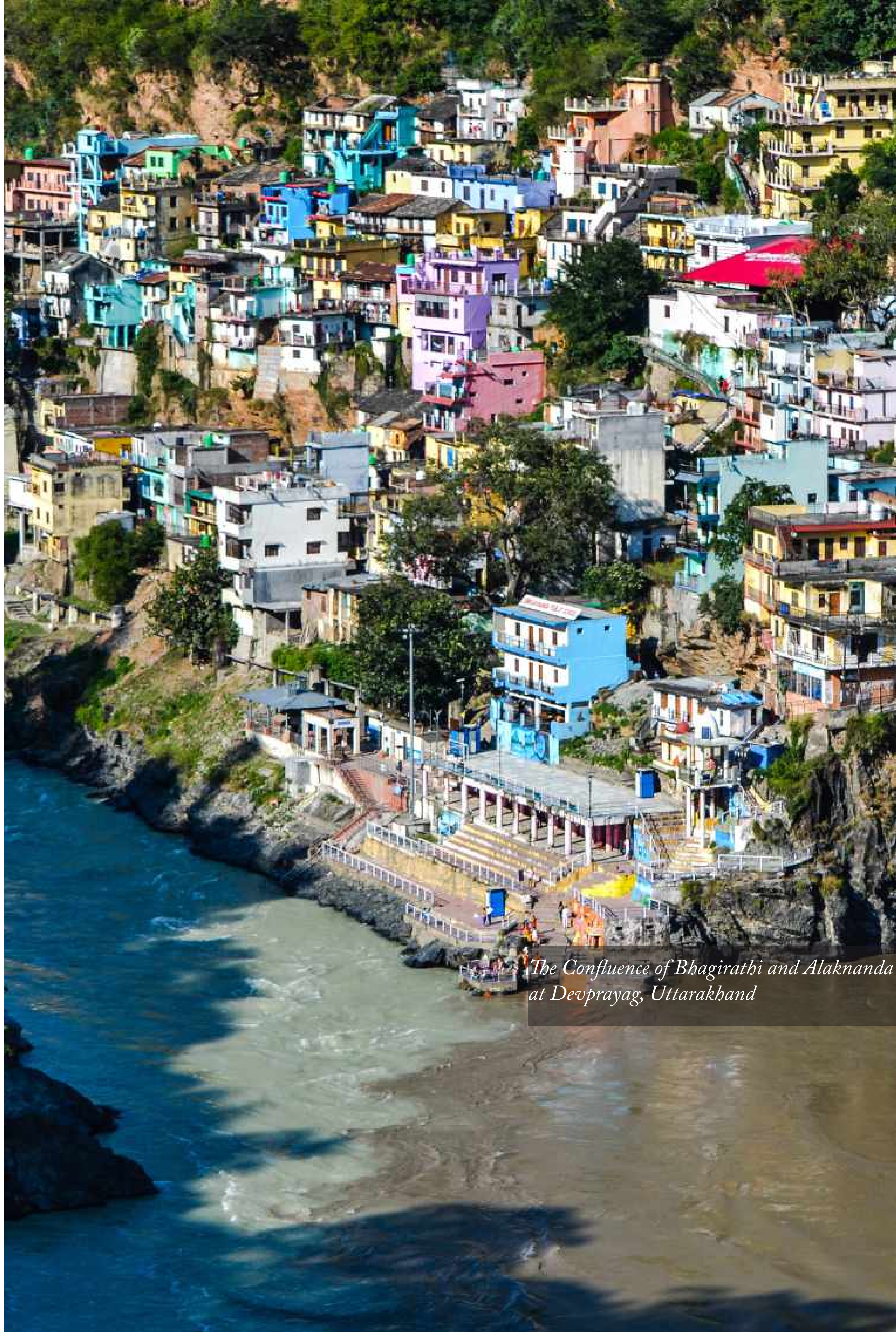
Our Report strongly advocates a participatory approach, which not only takes into consideration the needs of various local communities, their livelihood concerns, etc., but also takes into account their traditional wisdom, based on their exposure to natural elements, which has enabled them to cope with natural calamities over the centuries

Our current perception about the Ganga River and the paradigm of economic progress looks at the Himalaya as something to be harnessed and conquered - for providing us with electricity or water for irrigation and other purposes. While it is true that these are good reasons for impounding or diverting its waters, the emphasis should be on meeting our needs in a way that the impact on the river flows, eco-systems etc. will be minimized. This would be possible if we change our attitude from the predatory, 'conquest of nature' mode, to humbly acknowledging and respecting the eco-system services which the river offers. In this Report, we have described how the 'eco-system people' have survived for centuries in this hostile natural environment.

In ancient literature, this relationship between people and nature has been codified into the following prescriptive principles, viz., i) The importance of protecting the origins of rivers by creating 'Sacred Groves' (Deobans) with self-imposed restrictions on cutting trees or harming the natural environment. We see this principle applied at the origin of the Ganga at Gangotri, where we find the sacred groves of Chidbasa and Bhojbasa. ii) As prescribed in the Mahavansha (written between 459 and 480 C.E.), Jala rakshakas (water guards) for protecting rivers were appointed by the Kings; iii) The principle of least interference, which recognized the primacy of the natural order, and the need to impose restrictions for safeguarding the delicate balance within the hydrological cycles. The sacred Ghats which run parallel to the river flow, enabled the utilization of water right through the length of the river, running through towns and cities, since the primary stream or flow was never obstructed. Such ghats are seen at Prayagraj, Haridwar, Varanasi, etc.; iv) The principle of optimality (Suvarna Madhya): when lakes were created and dams were built, their scale was determined not only by economic or political compulsions, but also by the level of socio-economic competence and ecological limitations. The best-known example of such restraint is the Bhopal Taal built by Raja Bhoj in the 11th century CE, without blocking or damming any major river. The water, collected from 365 small streams, was channelized towards the lake with sluice gates for fulfilling the needs of downstream eco-systems and communities; v) The Principle of Equitable Access and Distribution of Water was enunciated and elaborated by Kautilya in his treatise, Arthashastra (written sometime between 3rd century BCE and 3rd century CE). Kautilya lays emphasis on codifying the procedures of water distribution and utilization by describing in minute detail the institutional frameworks necessary for ensuring benefits to all users. The concept of sustainability was embedded in these principles, as is evident from the fact that such structures and systems have survived the test of time. Those which deviated from them have perished.

Just as the Himalaya is the measuring rod for human accomplishments, the Tails of the Ganga are the standard bearers or markers of the impact of our actions, interventions, and policies on the 2525 km. long journey of the Ganga River from its Heads to its Tails. The quality and quantity of the water which reaches the Tails (Delta), the impact of human and animal life, aquatic systems, mangroves, etc. at the tail-end reaches are impacted by the changes resulting from upstream activities. Therefore, the upstream population and the Riparian states must take the responsibility for the consequences of their actions on the downstream region. The Heads remind us of the need for humility and the Tails emphasize the need for maintaining a balance, the 'suvarna madhya' or the 'golden mean,' which characterized the ancient Indian ethos!

We hope that the inter-disciplinary and integrated approach, which this Report advocates, will open new vistas for a sustainable and more equitable development and management of the Ganga River Basin. We would like to add that this is, by no means, an exhaustive study. More in-depth studies will reveal new information. Like the waters of the Ganga, we hope that the findings of this Report will percolate to all levels and bring about a shift in policies and institutional framework towards an Integrated River Basin Management Perspective.


The Confluence of Bhagirathi and Alaknanda at Devprayag, Uttarakhand

About The Author

Prof. Vijay Paranjpye, born 8th September 1948, taught Economics at the Ness Wadia College from 1972 till 1994. In 1982-84, he was appointed in the first Committee for drafting the syllabus on Environmental Economics by the University Grants Commission. He founded and directed the Pune Office of the World Wide Fund for Nature (1980-90), an NGO (1992-2000), and now works as the Chairperson of the Gomukh Environmental Trust for Sustainable Development (1995 to 2011). He has also represented India in various International Conferences including the UNCED Conference at Rio-de Janeiro in 1992, World Water Conference at Hague in 2000, World Summit on Sustainable Development at Johannesburg in 2002, etc. However, his main contribution has been in the field of socio-economic and environmental assessment and analysis of river valley projects and impacts of large dams. Some of his research work has been published as books, and the better known publications include the work on Bedthi Hydro-power Dam (1981) in Karnataka, Tehri Dam (1988) Uttarakhand, Narmada Dam (1990), and the Three Gorges Dam in China (1990). He was invited by the US Congressional Committee on Science and Technology (First Session of the One Hundred and First Congress) in October 1989, where he made a detailed submission on the impact of Sardar Sarovar Dam.
Mr. Paranjpye has also been an avid mountaineer and has climbed several peaks in the Himalayas ranging between 18000 ft. to 23000 ft. Besides the Himalayas, he led the 1st Trans-Sahyadri Expedition in 1985 covering a distance of 1200 kms. over a period of 40 days and has collected a vast amount of information on the Northern Western Ghats.

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