LIVELIHOOD AND HEALTH CHALLENGES OF RIVERINE COMMUNITIES OF THE RIVER GANGA

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Water-To-Cloud

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Foreword

The river Ganga has for centuries been considered India's holiest river, with millions believing that its waters offer salvation to its devotees. Beyond its spiritual significance, the river offers livelihoods to many riverine communities along its banks, and its waters are widely used for bathing, drinking and fishing. In recent times, there has been mounting concern about the levels of pollution in the river and the deteriorating quality of its water.

Several flagship government programmes and projects in the past three decades have sought to clean the Ganga, including the Ganga Action Plan Phases I and II and the *Namami Gange* National Mission for Clean Ganga launched by Prime Minister Narendra Modi in 2015. These projects have sought to tackle pollution and to rejuvenate the river's waters. Government agencies and research institutions have been tracking the effectiveness of these projects by monitoring data on the river's water quality.

This NCAER study represents a collaboration with the University of Chicago's Tata Centre for Development (TCD) and explores the social and economic engagement of the riverine communities on the Ganga in Uttar Pradesh and West Bengal. The conventional monitoring of river water is done by collecting water samples from specific locations on the river and analysing the samples in a laboratory. This location and time-specific measurement provides only a partial picture of a river's health since the factors affecting water quality can vary greatly by location and time. In comparison, continuous, in-situ water quality monitoring systems provide real-time data that not only measures the river's health but also provides the basis for significant riverine research. The continuous, in-situ data collection for the Ganga was undertaken in two phases across four upstream and downstream locations in the two States, breaking away from the conventional ways of measuring water quality. Such data makes possible in-depth socio-economic studies on the implications of river water pollution on the health and livelihood of riverine communities, as well as the economic costs of river water pollution.

For this pioneering Water-to-Cloud study—meaning time-stamped and geo-tagged data from the water being shared on the cloud for further mathematical analysis of pollution spread, the sources of pollution, and for interpolating sparse data—a TCD team mapped water quality using multiple, submersible, automated sensors attached to a boat that would sail at different times of the day on a pre-defined route to gather high-resolution, spatially and temporally varying, water data. Dynamic mapping of river water quality using this high-frequency spatial and temporal data is helping understand how it changes with weather, pollution, fishing, and general use, and can help pinpoint pollution sources accurately and ensure regulatory compliance. The data makes possible powerful

visualisation through heatmaps to pinpoint pollution, control infectious diseases, and identify effective sanitation interventions.

The NCAER team complemented TCD's cyberphysical sensor network by collecting data on the health and livelihoods of the Ganga's riverine communities using household interviews, focus group discussions, and participatory rural appraisal approaches. The NCAER team also used contingent valuation techniques to understand the willingness of these communities to participate in the Ganga's rejuvenation.

This NCAER study recommends the need to formally recognise the communities settled on river banks as part of the riverine ecosystem and to synchronise their local ecological knowledge with scientific knowledge for better water monitoring and control techniques. These communities should be integrated into river development and alternative skilling programmes to enhance their livelihood opportunities. The report recommends the establishment of cooperatives in riverine villages, recruitment of *Ganga Prahari*s or Ganga guards to protect the river from exploitation by unscrupulous elements, and the promotion of decentralised regulation to prevent fishing malpractices. The NCAER study found that riverine communities were willing to join larger development efforts to improve and preserve the quality of the Ganga's water.

I am grateful to the UChicago TCD for collaborating with NCAER on this work, particularly Professor Supratik Guha, Professor at Chicago's Pritzker School for Molecular Engineering, for his insightful comments on our work. I also thank all members of the Water-to-Cloud team for their support and close collaboration throughout the project. Most important, I am grateful to the NCAER team, expertly led by Dr Soumi Roy Chowdhury and Professors Devendra B Gupta and Sanjib Pohit. Mr Rishabh Singh and Mr Mohit Pandey, Research Associates, ably supported the study.

I hope that this NCAER study will play a significant role in attracting policy attention to the crucial issue of water pollution in the Ganga and on the imperative to protect the lives and livelihoods of the communities that depend on the river for their sustenance.

July 2020

Shekhar Shah

Director General, NCAER

Preface

It gives me immense pleasure to share with you the Tata Centre for Development at UChicago and the National Council of Applied Economic Research report on a long-standing, yet not adequately researched problem: livelihood and health challenges of communities in the world's most populous river basin—The Ganga.

Lack of data has been a major deterrent to research in this field. I am glad that the Water-to-Cloud program's sensor-based dynamic monitoring system helped in collecting and collating high-resolution temporal and spatial data, aiding the study's objective of mapping the communities' perceptions with the actual water quality parameters.

Adopting a multidisciplinary approach, this study attempts at connecting data concerning the fishing community, with water quality measurements of the catchment area in trying to identify the river's water quality impact upon the livelihood and perception within the local fishing community. The study involved multiple stakeholders, including engineers, medical professionals and local administrative bodies in West Bengal and Uttar Pradesh—the two states where selected stretches of the river were studied.

I congratulate the entire team for the tremendous effort they have put in to bring out this report. I envisage that the findings of the report and ensuing recommendations will aid in designing effective future interventions and policies.

Supratik Guha

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[2] We express sincere gratitude to fishermen of the Narora and Unnao (UP) and Jangipur and Tribeni (WB) for their enthusiastic participation in the study.

Acronyms

BOD	Biological Oxygen Demand
CDOM	Coloured Dissolved Oxygen Matter
CHL	Chlorophyll
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CSE	Centre for Science and Environment
DO	Dissolved Oxygen
EC	Electrical Conductivity
FC	Faecal Coliform
FEO	Fishery Education Officer
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GPS	Global Positioning System
HH	Households
KMDA	Kolkata Metropolitan Development Authority
MLD	Million Litres per Day
NIST	National Institute of Standards and Technology
NO_2	Nitrite
NO_3	Nitrate
RRA	Rapid Rural Appraisal
SANDRP	South Asia Network on Dams, Rivers and People
SO_4	Sulphate
TC	Total Coliform
TCD	Tata Centre for Development
TOC	Total Organic Carbon
WASH	Water, Sanitation, and Hygiene Facilities
WTA	Willingness to Accept
WTP	Willingness to Pay
W2C	Water to Cloud

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Executive Summary

A large section of the population living in the Ganga river basin still depends on the river for daily use activities and livelihood. Hence, the cleaning of the Ganga river's water and making it safe for use remains a major a goal for policymakers. Towards this end, Prime Minister Narendra Modi also announced the launch of the Namami Gange Clean-up programme with a budget of Rs 20,000 crore during the period 2015–2020. However, the National Green Tribunal stated in 2017 that "not a single drop of river Ganga has been cleaned so far." In this context, this NCAER study attempts to examine the quality of the Ganga river's water at selected stretches of the river during the year 2019-20. Further, it seeks to assess the inter-linkages between pollution in the Ganga river water and the livelihood of users of the river by analysing their socio-economic profile.

This report studies a particular riverine community, that is, fisher folk, along selected polluted stretches of the Ganga river. While fishing activities are associated with many occupations, the fishing community is the most vulnerable as its members come into the direct contact with the river water and thus suffer the maximum impact of pollution in the river. The study was undertaken in two phases along identified upstream and downstream locations in the States of Uttar Pradesh and West Bengal. While Narora and Unnao in Uttar Pradesh comprised the upstream sites, Jangipur and Tribeni in West Bengal were the downstream sites. A total of 200 samples comprising 1600 respondents were surveyed in each phase from each of these locations. The survey entailed conduction of water experiments using censors, along with in-person interviews and Focus Group Discussions (FGDs).

The study found that the respondents in both the selected States belonged to the economically poorer sections of the society. About 48 and 65 per cent of the fisher folk in West Bengal and Uttar Pradesh, respectively, reported earning a monthly income of less than Rs 5,000 from fishing. This figure is comparable to the 2012-13 data from the 70th Round of the NSSO, according to which the corresponding average monthly incomes in the States of Uttar Pradesh and West Bengal were Rs 4,455 and Rs 4,636, respectively. This poor economic status of the fishing community is compounded by the prevalence of higher illiteracy levels and lack of sanitation practices among them, especially in Uttar Pradesh. About 22 per cent of the respondents, mostly from the lower income categories, were also found to be practising open defecation in Uttar Pradesh.

The study also enquired about perceptions among the fisher folk regarding the quality of the river water and its suitability for various uses such as drinking, fishing, and bathing. A majority of the respondents among fisher folk (40-65 per cent) across different sites in Uttar Pradesh considered the Ganga river's water to be suitable for all activities, including bathing, drinking, and fishing. The corresponding proportion of respondents was even higher in West Bengal, at 80-90 per cent. It was also found that the proportion of respondents in Uttar Pradesh who were actually using the river water for drinking, at about 82 per cent, was even higher than those who perceived it safe for drinking.

An important part of the study included the collation of data on water quality at a high geospatial resolution using real-time, state-of-the-art sensors. This enabled mapping of the communities' perceptions with the actual water quality parameters. The sensor data shows that the overall water quality at the study sites was suitable for fishing and the survival of aquatic life. Among all the sites, the quality of the water was most consistent in Narora while the maximum variation in quality was noted in Tribeni. The influence of anthropogenic activities was observed in both the downstream locations, that is, Unnao and Tribeni, resulting in temporal variations in water quality. Similar observations were made in the *ghat* areas where high levels of Biological Oxygen Demand (BOD) were observed.

The assessment of the water quality parameters was also done with the objective of identifying incidences of water-borne diseases. For this purpose, the survey asked questions on specific illnesses such as pneumonia, diarrhoea, cholera, cough/cold, fever, skin disease, typhoid, and jaundice. The incidences of at least one of these water-borne diseases across the various sites were found to be in the range of 76 to 96 per cent during Phase I and 88 to 96 per cent during Phase II of the survey. However, the figures for those experiencing these illnesses during the three months preceding the survey fell to 50-60 per cent among respondents in Uttar Pradesh and to 28-52 per cent among those in West Bengal if some of the common symptoms of cold, cough and fever were excluded. It was further observed that the highest incidence of diseases occurs during the monsoon season and the correspondingly lowest incidence during the pre-monsoon period. In-depth interviews with selected medical professionals provide suggestive evidence that the incidence of diseases can be linked to the quality of the Ganga river's water. The FGDs with the riverine communities also revealed that water-borne diseases were primarily caused by the poor quality of potable water in the river.

As part of the assessment of the livelihood implications, the fisher folk were also asked to report the active fishing months, the months when they earned the highest and lowest incomes, and if the amount of fish catch had changed substantially over the last five years. The respondents, particularly in Uttar Pradesh, reported a significant decline in the amount of fish catch over the years, whereas fisher folk at all the sites in the two States reported a decline in the commercially important fish species and a rise in the number of exotic or invasive species in their fish catch over the last five years. When asked to list the five main reasons for livelihood-related adversities, the respondents at all the four study sites said that low water volume was a major cause for concern, followed by irresponsible fishing manifested in the use of micro-mesh (mosquito net), which causes poisoning and also catches fingerlings and kills eggs. The participants also identified pollution as a cause for concern but only after the above-mentioned two reasons.

Community participation has always been identified as an important tool for maintaining the sanctity of the Ganga river water. A contingent valuation exercise indicated that a significantly higher proportion of the respondents in Uttar Pradesh and West Bengal, at 90–98 per cent, were willing to form a cooperative society that would ensure preservation of the river water quality but their financial constraints prevent them from making any monetary contribution to ensure the successful operation of such a cooperative. In this process, we also enquired if the respondents wanted to accept any monetary contribution from the polluting agencies as compensation for their livelihood challenges. Almost all the respondents declined, which shows their faith in the divinity of the river and willingness of the community as a whole to uphold the quality and sanctity of the river.

Overall, it was observed that the fisher folk are socially and economically fragmented. There is, thus, a need to formalise the traditional occupation of riverine fishing by providing proper licensing facilities to allow for targeted policies for the community in order to mitigate the livelihood challenges being faced by it.

Chapter 1: Introduction

India is home to 4 per cent of the world's freshwater resources, and it ranks among the top 10 water-rich countries of the world. In spite of being home to the major river systems, both perennial and non-perennial rivers, India is a designated water stressed region (NITI Aayog, 2019). Indian river basins suffer from the pressure of an ever-growing population, and rapid industrialisation and urbanisation across the country. All these factors make the basins vulnerable to the incessant release of effluents in the form of sewage and large volumes of solid and industrial wastes into the rivers.

In this report by the National Council of Applied Economic Research (NCAER) and Tata Centre for Development (TCD), we study the world's most populous river basin, the Ganga river basin. The report especially looks at the dependence on the Ganga river of particular communities settled along certain stretches of the river. The Ganga river basin spreads over an area of 860,000 square kilometres, flowing through one-fourth (26.3 per cent) of the country's total geographical area. The basin covers the entire States of Uttarakhand, Uttar Pradesh, Bihar, Delhi, and parts of Punjab, Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh, and West Bengal, and accounts for more than half of the country's population (CPCB, 2013). It also generates over 40 per cent of the country's GDP (World Bank, 2013). The river originates from the Gangotri glacier at Gaumukh (30°36′ N; 79°04′ E) in the Uttar Kashi district of Uttarakhand province in India (Vass et al., 2010). The mainstream of the river from Gangotri flows through the Shivalik Hills and enters the plains at Haridwar, which then continues southwards to Uttar Pradesh and enters Bihar in the Buxar district. After entering West Bengal through Farakka, it gets divided into two arms: the left arm called Padma river enters Bangladesh whereas the right arm called the Feeder canal joins the Bhagirathi river just upstream of Jangipur in Murshidabad district. Thereafter, it is known as Bhagirathi-Hooghly for rest of the stretch before reaching the Bay of Bengal (Rahman, 2009).

Ironically, the populous river basin is also home to a large section of the population below the poverty level, which is financially dependent on the river for survival and also uses the water for daily activities. According to a World Bank report (2013), as many as 200 million people living along the river basin are below poverty line. The river Ganga also has a special cultural and spiritual significance in India. The river is revered as a goddess, and it is believed that people bathing in its get purified and cleansed of all their sins. This spiritual significance of the river transcends its geographical boundaries, as a result of which people from across the country flock to its banks to offer prayers and bathe in the river (Rehana et al., 1996).

The very extent of dependence of large sections of the population on the Ganga necessitates its preservation. However, rapid economic activity in 29 Class I cities, 23 Class II cities, and approximately 50 towns through which the river flows, combined with inadequate infrastructure and poor environmental regulations has resulted in rapid deterioration in the quality of the river's water.[3] The Central Pollution Control Board of India (CPCB, 2013) had identified 138 drains in the Ganga river catchment,

[3] Class I cities are those with populations of 100,000 whereas Class II cities are those with populations ranging between 50,000 and 100,000.

wherein 76 per cent of the pollution load was contributed by Uttar Pradesh alone. In addition, the CPCB had identified 764 grossly polluting industries along the 50 cities that discharge wastewater into the river, thereby increasing the level of pollution. These 50 cities cumulatively together discharge 2723.3 million litres daily (MLD) wastewater, whereas the existing treatment systems available in these cities can handle only 44 per cent of the wastewater generated. Class I cities contribute 96 per cent of the total wastewater generation. The pollution is a threat to not only the livelihood of millions of individuals but also to the biodiversity of the region. It also has a detrimental effect on the health of communities that come into contact with the river. Various studies by Paul (2017), Ansari et al. (2000), Prasad et al. (1989), Singh et al. (2003), Khawaja et al. (2001), and Chaturvedi and Pandey (2006) have shown that various anthropogenic activities lead to the disposal of highly toxic non-degradable heavy metals into the river water, which, in turn, has damaging effects on human health.

Open water bodies serve as sites for laundry, washing of farm animals, open defecation, and urination. Further, the presence of raw sewage, untreated industrial wastes, pesticides, chemical fertilisers, and debris of human waste adds significantly to the pollution level, pushing it beyond permissible standards (Tayo et al., 1980). It is highly likely that when individuals bathe in the river, the polluted water enters their digestive system through either the mouth, nose, or other routes, leading rise to water-borne diseases. Further, the level of pollution and contamination in the Ganga river increases significantly during the Hindu festive season (Sharma et al., 2012; Hamner et al., 2006; Pandey et al., 2005). The association between waterborne diseases such as diarrhoea, typhoid, fever, and skin infections, on one hand, and polluted surface and drinking water, on the other, has already been discussed in various studies (Alberts et al., 2002; Hamner et al., 2006; Papastergiou et al., 2012). It has also been established that the transmission of such infections usually takes place through an oral or faecal route or even through human-to-human contact (Hamner et al., 2006).

River water pollution also has severe livelihood implications for the riverine communities. As pointed out by Manasi (2013), pollution loads through agricultural activities, urbanisation, and industrialisation have significant hazardous implications for surface water, which in turn, harms aquatic health. This situation is not unique to the Ganga river basin but is also witnessed in other major river areas. Vaseem and Banerjee (2016) monitored the effect of river water pollution on the aquatic life of the river. They found that antioxidant enzymes such as superoxide dismutase, catalase, and level of lipid peroxidation are found in higher quantities in fish collected from the Ganga river. These repercussions on losing aquatic life can be so severe as to threaten the perennial nature of the river. World Wildlife Fund has rated Ganga as one of the world's top 10 rivers at risk from pollution, and one that is on the verge of losing its biodiversity.

The loss of aquatic life also adversely affects the aquaculture industry. Changing hydrology and deteriorating environmental conditions are, to a large extent, responsible for a change in the fisheries scenario in the river. As noted by Vass et al, (2010) in their study, over the years the extent of fish caught per kilometre has significantly declined in the Ganga river while the composition of the species has also changed. The major carps of river Ganga are *Labeo Rohita* (Rohu), *Cirrhinus Mrigala* (Mrigal), *Labeo Calbasu* (Kalbasu), *Mystus Oar, Mystus Seenghala* (Singi/Singhara), *Wallago Attu*, and *Hilsa Ilisha* (Hilsa), along with several other miscellaneous species. These most prized Indian fishes have been substituted by non-major carp and miscellaneous fishes. Das et al. (2014) have reported that reduced flow, change in habitat, pollution in the form of effluents and overexploitation of the river resources have affected fish production in the riverine system. Similarly, Singh and Akhtar (2015) have studied the impact of exotic species on the river habitation and have concluded that invasive species have an adverse effect on the native fish species. These include common carp *(Cyprinus Carpio)*, African catfish (*Clarias Gariepinus)*, sucker mouth catfish *(Pterygoplichthys Spp.)*, Tilapia *(Orecohromis Mossambicus)*, grass carp *(Ctenopharyngodon Idella*), silver carp *(Hypophthalmichthys Molitrix)*, and so on. The presence of exotic species such as *Cyprinus Carpio* and *Oreochromis Niloticus* has been increasing in the river.

Increasing pollution and the occurrence of exotic fishes are thus, challenging the livelihood of the riverine fisher communities. The communities traditionally involved in riverine fishing occupation mainly belong to the Nishad caste and are locally known as *mallah, majhi,* and *machuara* in Uttar Pradesh. In West Bengal, they are known as *majhi*, and a majority of them belong to the Halder and Malo caste groups. A significant feature of the Indian caste system is division of labour, or 'the traditional caste-based inheritance of occupations' (Jodhka 2012). Customarily, these fisher folk have the right to catch fishes from the river system.

According to the National Fisheries Development Board, fisheries-related activities are a source of livelihood for more than 14 million people. While fisher folk may be heterogeneous in their operations, ranging from small-scale fishing to fishing in open water bodies, poverty is one feature that is common across the entire fishing population in the country. Earlier studies have highlighted the fact that both the coastal and inland fisher folk are among the poorest and most marginalised groups in the country (Pandit et al., 2019; Salagrama, 2006). Some of the major reasons behind the decline in the quantum of fish caught are the change in the pace of fishing activities, increasing competition for fishing grounds, declining access to and availability of fish resources, over-capitalisation and harvesting. Further, certain macroeconomic factors also undermine the traditional fishing structures, all of which make the livelihood of fisher folk progressively unsustainable, preventing them from meeting even their basic requirements (Salagrama, 2006).

Since riverine fisher communities are heavily dependent on the river for their livelihood and survival, they are directly impacted by the imbalance in the ecological health of the river. This has forced them to look for other types of economic opportunities to sustain their future generations. However, limited access to education and lower socio-economic status make it difficult for them to achieve social mobility. Research has shown that socially and economically backward communities in India have a relatively limited intergenerational occupational mobility (Vaid and Heath 2010). Moreover, these riverine fisher communities have limited opportunities for participation in decision-making related to usage of the river waters, such as extraction of water for irrigation, hydropower projects, and discharge of effluents in the river or even in river cleaning programmes.

1.1 Objectives

Policies can be devised for the fishing community only if there is sufficient evidence of their marginalisation. Lack of credible data sources, coupled with the absence of any legal identification of this community, is a major deterrent to research in this field. There is need for holistic investigation and adoption of a multidisciplinary approach towards the collection of epidemiological data concerning the fishing community while simultaneously measuring the quality of water in the catchment areas. This study aims to achieve the following objectives through its multi-tiered approach involving State-level stakeholders, engineers, medical professionals, local administrative bodies, and fishing populations:

1. To study the impact of pollution in the Ganga river water on the socio-economic status of the riverine communities;
2. To study the impact of pollution in the Ganga river water on the health of these riverine communities;
3. To study the willingness of the riverine community to participate in the drive for mitigation of the river pollution; and
4. To assess water quality along the two stretches of Ganga river in the States of West Bengal and Uttar Pradesh.

The study surveys the fisher folk of the upstream and downstream locations of West Bengal and Uttar Pradesh in two phases through in-person interviews and the use of a range of participatory tools. The details of the survey methodology and rationale for selection of the sites for the study are detailed in Chapter 2. In Chapter 3, we discuss the socio-economic conditions of these communities. In Chapters 4 and 5, we draw attention respectively, to the health and livelihood implications for these people along with their community participation drive. Chapter 6 details the results of our laboratory and sensor-based water experiments. The report ends with policy recommendations in Chapter 7.

Chapter 2: Methodology

In this chapter, we discuss the rationale behind choosing the sites for the survey and the scoping that has been done in the process of selecting the upstream and downstream locations for the project. The discussion encompasses the mode of data collection, seasonality of the survey, and sampling of the respondents. We have also undertaken Rapid Rural Appraisal (RRA) and in-depth interview modules for our analysis, the methodology for which is discussed in detail below. Finally, the self-reported data from the respondents is complemented with data on the water quality using cyber-physical sensors, which have also been described here.

2.1 Rationale of Site Selection

We have chosen two sites each in the States of Uttar Pradesh and West Bengal, to study the impact of pollution in the Ganga water on the health and livelihoods of the fishing communities.

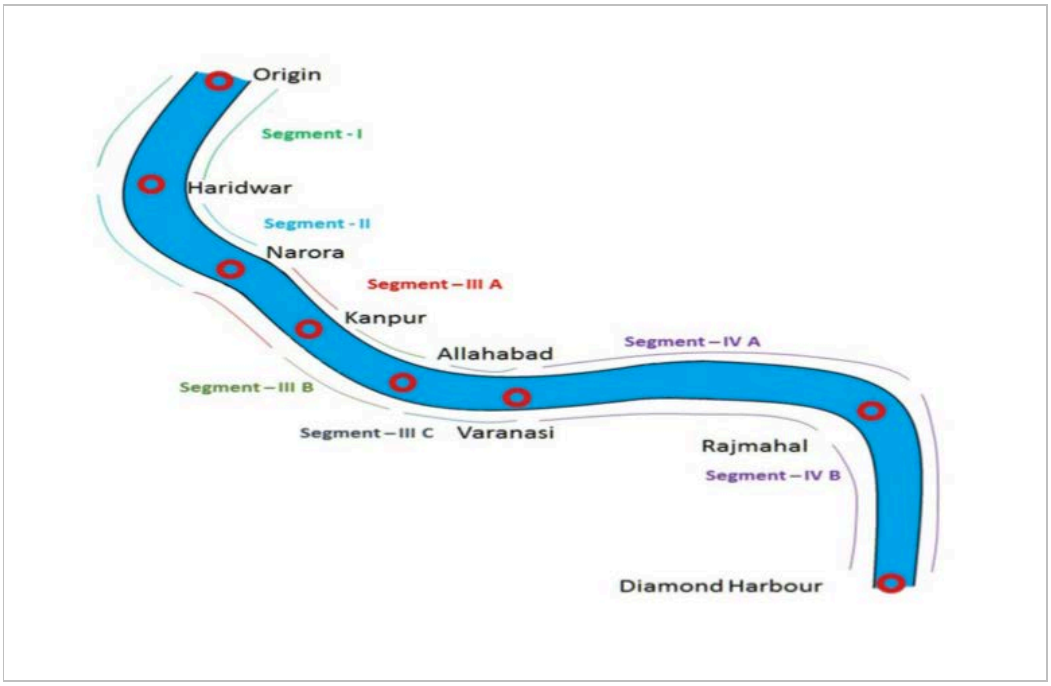
The selection of the sites followed a clustered approach. In the first step, we examined the entire stretch of the river to identify the highly polluted stretches of the river Ganga. The inadequate flow of water in the river, the growing amount of untreated sewage from cities, and the lack of enforcement against those sources of discharges led to the creation of those intensely polluted stretches. The Centre for Science and Environment (Bhushan and Das, 2017), in its report, studied different stretches of the river and provided a visual analysis of the water quality of the river. The intensely polluted areas have been marked in red whereas the blue areas are indicative of relatively cleaner sections of the river (Figure 2.1). The polluted areas are seen to be primarily located in the States of Uttar Pradesh and West Bengal. Before reaching Kanpur, The Ganga is relatively cleaner before reaching Kanpur, and after leaving Varanasi. as it traverses through the entire stretch of Bihar. Thereafter, we also see patches polluted areas of the river marked in red.

Figure 2.1: Priority polluted stretches of river Ganga

Source: Bhushan and Das (2017).

The CPCB has divided the Indian stretch of the Ganga river into four segments to address the gaps in mitigation of pollution (Figure 2.2). Segment I lies between the origin of Ganga to Haridwar downstream; Segment II spreads from Haridwar downstream to the Narora Barrage; Segment III stretches from downstream of Narora barrage to downstream of Varanasi, and Segment IV has been designated from Varanasi downstream to Diamond Harbour (Kolkata). Segments III and IV are further divided into three (III-A, III-B and III-C) and two (IV-A and IV-B) stretches, respectively.

Figure 2.2: Segment-wise Division of River Ganga



Source: CPCB (2015).

The presence of intensely polluted stretches in the States of Uttar Pradesh and West Bengal was the reason why these two States were included in the survey. Among our four study sites, Narora and Unnao in Uttar Pradesh fall under Segment IIIA, whereas Jangipur and Tribeni in West Bengal fall under Segment IVB. According to the CPCB report (2015), Segment IIIA "requires the maximum attention".

There is variability in the levels of pollution across the States of Uttar Pradesh and West Bengal. Therefore, in our second step, we chose two locations from each State, corresponding to the upstream and downstream areas. According to the CPCB (2018), these four locations have around 151 drains that need to be monitored on a priority basis. In all, these drains contribute about 348.71 to 427.83 tonnes per day (TPD) of organic load released into the river with approximate 10,612.51 to 10,720.14 million litres daily (MLD) of wastewater discharge (Table 2.1).

Table 2.1: Variation in the Flow of Priority Drains Monitored during Pre- and Post-monsoon, 2018

Site Name (as Catchment Area)	**No. of Drains (U/S and along the Sites)**	**Pre-Monsoon**		**Post-Monsoon**		**Industries**
		Flow (MLD)	*Organic Load (TPD)*	*Flow (MLD)*	*Organic Load (TPD)*	
Narora	07	66.21	1.58	315.23	1.331	Paper and distilleries, fertiliser, chemical, sugar foods and dairy, textiles, tanneries, slaughter house, dyeing
Kanpur/Unnao	23	512.60	53.5	543.98	41.399	
Raghunathganj	01	25	1.75	--	--	Small-scale industries, BTPS thermal power, pulp and paper
Tribeni	13	1,033.67	36.27	890.50	15.64	
Total number of priority drains discharging in the **Ganga (U/S and along the sites)**	151	10,612.51	427.83	10,720.14	348.71	

Source: https://www.cpcb.nic.in/ngrba/Identified_drains_postmonsoon-2018.pdf

Note: U/S: Up-stream; MLD: Million Litres Daily; TPD: Tonnes per Day.

In 2017, the CPCB published a report on bio-monitoring of the River Ganga with the aim of determining the biological health of the river from Rishikesh in Uttarakhand to Diamond Harbour in West Bengal. In this report, both our sites in Uttar Pradesh were placed under the C category (moderately polluted), whereas the upstream site in West Bengal, that is Jangipur, was under the B category (slightly polluted), and Tribeni (downstream) was under the D category (heavily polluted).[4]

In contrast, the South Asia Network on Dams, Rivers and People (SANDRP, 2016) pointed out that the entire stretch from Tribeni to Diamond Harbour, which is a 50-kilometre-long stretch passing through the towns of Berhampore, Kanchrapara, Hooghly, Naihati, Chandannagar, Bhatpara, Barrackpore, and Baranagar, is an intensely polluted stretch of the river.

The four sites of our study locations are described in greater detail below.

2.1.1 Uttar Pradesh

River Ganga enters Uttar Pradesh in the district of Bijnor, and after passing through Meerut, Hapur, Bulandshahr, Aligarh, Kanpur, Allahabad, Varanasi, and Balia, it goes onwards to Bihar. Bijnor is the most ideal site to be chosen as an upstream location but it is a sanctuary area and protected under the law. Thus, Narora

[4] For the CPCB (2017) report, the water monitoring was conducted in May 2015 and in February 2016. In the CPCB (2018) draft report on 'Biological River Quality of River Ganga' two of the sites in Uttar Pradesh were found to be moderately polluted whereas the data on West Bengal was not disaggregated to fit our sites.

has been chosen as the Uttar Pradesh upstream location. Narora (28°11′48″N 78°22′53″E) is a town in the Bulandshahr district of Uttar Pradesh, and is also one of the sampling sites for CPCB river water monitoring. Shuklaganj (26.55°N 80.49°E), located in the Unnao district, is our downstream location. It falls under the municipality of the Kanpur metropolitan area, and Unnao is the second largest city within the metropolitan area. This large industrial city is famous for its leather and chemical industries. Unnao and Kanpur are located along the two banks of the river, considered as one of the most polluted stretches of the river in Uttar Pradesh.

2.1.2 West Bengal

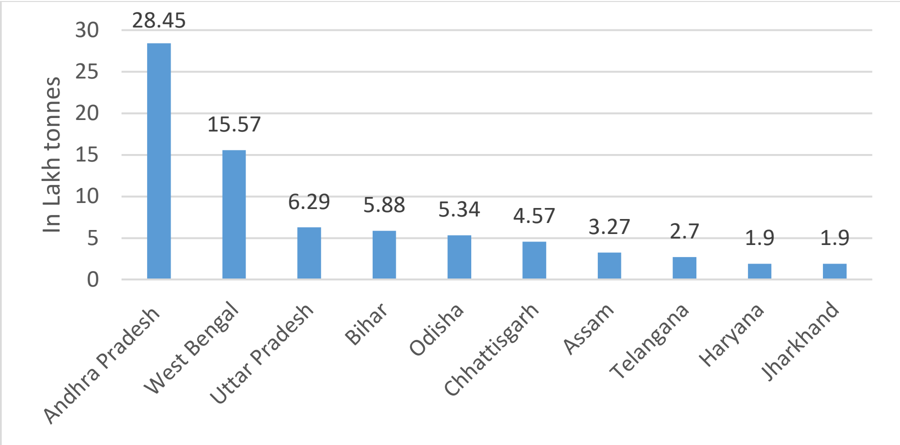
River Ganga enters West Bengal at the Farakka Barrage located on the river in the Murshidabad district of West Bengal, which is only 17 kilometres from the border of Bangladesh. The Ganga river water is conveyed to the Bhagirathi river of West Bengal through a feeder canal associated with the barrage. A 40-kilometre-long canal ensures the passage of water into the Bhagirathi river, which then meets the Hooghly river and is called the Bhagirathi-Hooghly river for the rest of the stretch of the river in West Bengal. As per the CPCB (2017), discharge from the nearby Farakka thermal power station causes slight pollution in the river. However, the absence of any major industrial belts at this place keeps the pollution within limits along this stretch. After the feeder canal meets the Hooghly river, it flows through the Jangipur Municipality, of which Jangipur (24.47°N 88.07°E) is the biggest city. We chose this as our potential upstream location. Finally, Tribeni (22.99°N 88.40°E), a city located in the Bansberia municipality of Hooghly district, is our downstream location. It falls under the command area of the Kolkata Metropolitan Development Authority (KMDA). The town located along the western bank of the Ganga river is believed to have got its name from the divergence of the Ganga, Yamuna, and Saraswati rivers, and is hence considered to be a holy town in the Hindu religion. However, presently, at the confluence of river Saraswati flowing south of the famous Hindu cremation area, commonly known as Tribeni Ghat, the Yamuna has silted up in the course of time.

2.2 Occupational Group Surveyed

We selected 1600 members of the riverine fishing for our study because of their greater economical and socio-demographical dependence on the river. While many livelihood occupations depend on fishing activities, fishermen are the most vulnerable from the perspectives of both livelihoods and health, as they come into direct contact with the (polluted) river water.

The States of West Bengal and Uttar Pradesh, respectively, rank as the second and third major inland fishing producing States after Andhra Pradesh (Figure 2.3). This explains the existence of fishing communities at large in these locations. According to the Handbook of Fisheries Statistics (2018), the total numbers of fisher folk engaged in fisheries activities on a full-time, part-time, or occasional basis are 22, 44,609 and 99,807 in West Bengal and Uttar Pradesh, respectively.

Figure 2.3: Major Inland Fish Producing States



Source: Handbook on Fisheries Statistics (2018).

We undertook both monitoring of the water quality along the river stretches and in-person surveys of fisher folk in order to accomplish the main objective of our study, which is to associate the water quality parameters with the livelihood and health challenges of the fishing communities. A total of 1600 fishermen were surveyed in two phases across the four study sites. The total respondents included 200 fishermen in each phase at each site. Along with the survey, we also used qualitative research methods—Focus Group Discussions (FGDs) and Rapid Rural/Resource Appraisal (RRA) among the fishing population. Simultaneously, in-depth interviews of the relevant people such as doctors, *mandi* owners, government officials, and experts, were also conducted to gain an insight into their daily practices, for mapping of local knowledge, and for understanding the power structures and prevalence of oppressive practices among them.

The following section describes each of these activities in detail.

2.3 Quantitative Data Collection

2.3.1 Measurement of the Water Quality

In most nations, river monitoring consists of intermittent sample collection at the point sources, followed by laboratory analysis, tabulation, and reporting of the data. For instance, in India, data points are typically collected monthly at a distance of roughly every 45 kilometres. However, this is a resource-intensive and time-consuming process, often prone to human error due to mishandling and faulty laboratory protocols. Additionally, rivers are dynamic systems that change daily, and such sparse data is unable to either accurately capture the health of the water body or adequately shape policy discussion.

Recent advances in sensor technology, the internet-of-things, improved connectivity, and the emergence of the Cloud, have enabled new approaches for measuring water over large geographical bodies in a scalable fashion. We have made use of these recent advances to collect high-resolution spatially and temporally varying water quality data to arrive at correlations between water quality and socio-economic indicators, mainly health and livelihoods. Mapping the water quality data in this form helped us to identify variations rather than just achieving point measurements.

Tools and Techniques of Data Collection

We have used a mix of an in-situ sensor-based and laboratory-based approach to do the measurements. Laboratory analysis of water samples is the traditional approach, and can be quantitatively accurate, but it suffers from shortcomings of cost, and time lag in the measurement response, and is more prone to errors related to operators and handling. In-situ sensors provide immediate data but cannot measure as many parameters as laboratory-based measurements. Mobile sensor platforms were used to pinpoint the pollution sources and hotspots. Our data collection and curation methodology has been briefly described below.

The mobile sensing platform approach was used, which is centred around a portable sensor platform equipped with GPS capability. In order to map a particular region of a river, a boat is typically rented and the sensor heads are immersed into the water at a depth of 12 inches below the water surface. The boat follows a set trajectory with the sensor platform(s) measuring 10-12 parameters simultaneously along with GPS location. At the conclusion of the boat sortie, therefore, we are able to have a dense set of points as a function of position, time, and parameter. Typically, the boat is made to follow a zigzag pattern, traversing from bank to bank, in the net, in one direction (down or upstream) for a distance, followed by reversing and returning again in a zigzag pattern. Typical boat speeds are 1-2 metres/seconds (so as not to affect the turbidity measurements), and sensor measurements occur at a distance of every 15-20 metres while the sensor measurement intervals are 10 seconds. For heat maps, the sensor-measured data is linearly interpolated between the data points. Most of our data has been collected using the mobile sensor platform approach across the four locations on the river Ganga, with repeated measurements being made at different seasons and times. However, this technique of gathering data has certain limitations. Because of the dependency on a boat, it is difficult to navigate the parts of the river that are shallow or have a high density of water hyacinths.

Laboratory measurements were carried out by taking one-litre water samples from a depth of 30 centimetres. The samples were collected in a glass bottle from the middle of the water body and close to the drain discharge points. Within 24 hours of collection, the bottles were labelled and sent to a laboratory for testing. Typically, a commercial or university laboratory was identified that was in proximity to the measurement site. Because of the lockdown due to COVID-19, we were not able to obtain results for the trace elements at the time of writing this report.

Boat routes were selected in consultation with the local authorities, and often with the specific objectives of marking industrial waste or domestic waste effects and pollution sources. Accessibility also needs to be verified, such as water depth, presence of algae, and the width of the water channel.

Our experiments used commercial off-the-shelf sensors integrated into sensor platforms. Sensor technology has made rapid progress over the past decade, with the development of compact light sources, detectors, and fluorescers. For instance, a fluorometer is used to measure the level of chlorophyll, Chromophoric Dissolved Oxygen Matter (CDOM), and tryptophan in rivers. Major improvements in optical design, electronic technology, and calibration protocol have increased the accuracy and reliability of the fluorometer. Ion-selective electrode (ISE) technology is used to measure dissolved oxygen and pH. The ion mobility method is used to determine the electrical conductivity of water and the light scattering method is used to measure turbidity.

All the sensors were certified by the US National Institute of Standards and Technology (NIST). The specific sensor platforms used were: Hanna HI9829 and Turner C3 Submersible Fluorometer as mobile sensing platforms. Given the frequently changing environment in the field, all the sensors were calibrated before measurements to check for accuracy and to minimise the drift of instruments. Laboratory sampling was randomly carried out at certain locations to validate the sensor data with the laboratory readings.

Rationale of Parameter Selection

The CPCB classifies five major parameter categories: general pollutant markers, nutrients, demand parameters, microbiological parameters, and inorganic ions. The specific parameters for this classification have been provided in Figure 2.4, along with an indication of whether our measurements of these parameters were carried out using in-situ sensors or via sampling and laboratory analysis. In addition to these five classes, we also added the measurement of one more category: bio-chemical parameters.

Figure 2.4: Various Laboratory and Sensor-Based Parameters That Were Measured

a General Pollutants

Parameter	Lab	Sensor
Temperature		x
Electrical Conductivity	x	x
pH	x	x
Turbidity	x	x
Total Hardness	x	
Total Suspended Solids	x	
Dissolved Oxygen	x	x

b Nutrients

Parameter	Lab	Sensor
Nitrate	x	x
Nitrite	x	

c Demand Parameters

Parameter	Lab	Sensor
Chemical Oxygen Demand	x	
Biological Oxygen Demand	x	

d Microbiological Parameters

Parameter	Lab	Sensor
Total Coliforms – MPN	x	
Fecal coliforms	x	

e Inorganic Ions

Parameter	Lab	Sensor
More than 20 heavy metals are analysed	x	

Major Ions

Parameter	Lab	Sensor
Ammonium	x	
Chloride	x	
Sodium	x	
Potassium	x	
Calcium	x	
Magnesium	x	

Bio-chemical parameters

Parameter	Lab	Sensor
Tryptophan		x
Chlorophyll a		x
Colored dissolved organic matter (CDOM)		x

2.3.2 Socio-economic Data Collection

The in-person surveys of the fishing population were conducted in two phases. Phase I was undertaken during the months of June-July (2019) whereas Phase II took place during the months of January-February (2020). Both phases were conducted using an almost identical questionnaire with few modifications based on the learnings from Phase I.

The questionnaire was divided into ten major sections, which have been detailed below.

Section A: General Perception: This deals with usage of the Ganga river water. It examines the major uses of the river by the respondents.

Section B: Livelihood Implications: This section is about the primary and subsidiary sources of occupation of the samples under study. Since they are the primary fishing communities, we asked them about their active months of fishing, and their perceptions regarding the best and worst water quality seasons. We also asked them about their specific perceptions regarding the adverse effects of river water on livelihoods.

Section C: Fishing Months and Catch: This section specifically focuses on the changes experienced by respondents in their fish catch and in their incomes over a course of five years. In addition, attempts have also been made to understand if the types of fishes native to the river have changed over the course of the years. The availability of fishing licences among the communities and specific investments related to their occupations have also been studied.

Section D: Perceptions on Water Pollution: This section deals with the perceptions of the respondents, who were asked to rank on a Likert scale their perceptions about various aspects of river water pollution. For example, they were asked to spell out their views on the divinity of the river Ganga, and whether it is the industrial waste or sewage that has an effect on the quality of the river water. They were also asked to indicate their perceptions about the consequences of bathing, washing, and drinking water from the Ganga river. In addition, this report examines the awareness levels and knowledge of the respondents regarding the Government's Ganga cleaning programme. The respondents were specifically asked about the Ganga Action Plan and Namami Ganga, and the effectiveness of these plans in the river bank stretches inhabited by them.

Section E: Health Status and Behaviour: This section seeks to understand the health behaviour of the fishing communities. Attempts have been made to identify any seasonal variations in the occurrence of water-borne diseases. Additionally, the health status of the household members has also been tracked. We highlighted a range of water-borne diseases such as diarrhoea, cough and cold, fever, and skin disease, and the respondents were asked if they had suffered any of these diseases during the three months preceding the survey. In order to understand the intensity of their suffering, we also asked if the diseases had caused them to miss out on their working days. The same questions were repeated for other family members. We also tried to identify if they were suffering from any other chronic diseases apart from water-borne diseases. In case of any medical issues among the respondents, their health-seeking behaviours and modes of treatment were also examined.

A special *Contingent Valuation Survey* was undertaken in Section F. Contingent surveys predominantly common in environmental studies present sets of hypothetical policy scenarios to the respondents. These scenarios are then analysed to understand the respondents' willingness to pay for a certain public good. In our survey, we presented two scenarios to the respondents: firstly, the willingness to pay towards maintaining a cooperative society that would be constituted to keep their stretch of the river clean. In the follow-up scenario, we presented them with a compensation scheme that would permit the industries to pollute in exchange for a compensation package offered to them. We sought the responses of the respondents to these two scenarios.

Finally, the last two sections of the questionnaire deal with the *demographic* information of the respondents, and with information on the household consumption of food and non-food items.

2.4 Qualitative Data Collection

2.4.1 In-depth Interviews

Interviews comprise an important method of qualitative data collection. A semi-structured interview schedule was prepared for each interviewee—doctors, government officials, *mandi* owner/agent/cooperative post holder—to understand the health and livelihood implications of the use of the river Ganga's water. At each site, we selected one doctor most sought after by the fisher folk community. Our questions were related to the general health condition of the fisher folk of that area, and the major health problems they are facing. We attempted to map the doctors' perceptions of the pollution of river water and its health implications on the fisher folk.

The interview schedule for government officials, especially the Fishery Education Officer (FEO) of the fishing department in each region, had questions related to the challenges being faced by the riverine fisher folk. We also asked about the Government's policies and programmes aimed at helping and supporting them, and the constraints and limitations faced by a government institution in the implementation of such welfare programmes. Likewise, a semi-structured questionnaire administered to a cooperative representative/*mandi* owner or agent focused on the process of buying and selling of the fishing folk, the auction criteria, and differences between the captured fish and the cultured ones, among others.

2.4.2 Focus Group Discussions (FGDs)

Focus Group Discussions (FGDs) constitute one of the profound qualitative methods, wherein researchers converse with multiple participants in a controlled environment. One FGD was organised at each of the four study sites, with the number of participants varying from 5 to 10. The aim of the FGDs was to understand the process of constructing an inter-subjective meaning of divinity and material pollution of the river Ganga, perceptions of higher and lower fish catch seasons along with the river water pollution variability. The FGDs also helped generate a common understanding of the challenges and opportunities of participation in decision-making and management of common resources. The guiding questions for the FGDs were site-specific. For example, in Narora (Uttar Pradesh), the guiding questions were related to the cooperative membership and bidding process, major pollution threats, and changes in fish catch over the years. In Unnao, (Uttar Pradesh), on the other hand, the discussion revolved around the ban on fishing due to religious reasons, illegal fishing, and police actions, and the river pollution problem. Questions on health implications, Ganga cleaning programmes, and the agency to participate, along with alternate options of livelihood were asked at all the sites. Similarly, the focus of the discussion in Jangipur (West Bengal) was on changes in the fish catch over the years, major reasons for the reduced fish catch, low volume of water in the river, and property rights along the Murshidabad stretch of River Ganga. In Tribeni, the FGD focused on challenges of the open access system, lack of social security, declining fish catch, and pollution of the river water and its impact on health and earnings. The FGD also helped us to understand the nuances of the survey data.

2.4.3 Rapid Rural Appraisal (RRA)

The Rapid Rural Appraisal technique is a bridge between formal surveys and other qualitative methods of data collection such as FGDs, observation, and in-depth interviews. We have used it in this study as a means of obtaining a Rapid Resource Appraisal by the participants in the FGDs. The objective for using this method was to map local knowledge and awareness about the major threats to the river ecology, pollution, and biodiversity hotspots in the river. With the help of the RRA, we have also attempted to map the variations in the fish catch and fish species over the years.

Chapter 3: Socio-economic Profile of the Fishing Community

The purpose of this chapter is to discuss the socio-economic and demographic profiles of the fishing communities. As noted earlier, we have a total of 1600 sample respondents from two sites each in Uttar Pradesh and West Bengal, which have been collated at two time points. For understanding the socio-economic characteristics of our sample, we primarily look at the age, education, and income distribution of the respondents. The types of sanitation facilities or the quality of potable drinking water available to the households have also been discussed in this chapter.

Different stretches of the river are different in their usability and the respondents' perceptions about usability also vary by locations. People who are in direct contact with the river water on a regular basis are often the best judges of the changing nature of the river water. Hence, the respondents were also asked about their notions of the best and worst river water quality. Before dealing with the socio-economic profile of our respondents, it would be useful to gain an understanding of the fishing popery rights and management regime throughout the length of River Ganga.

3.1. Property Rights and Management Regime

At the outset, it may be pointed out that fishing is supposed to be free for all in most parts of the river (Narayanan, 2016). Sinha and Katiha (2002) have described three type of riverine fisheries property rights and management regime: 1) Open access; 2) Co-operative management system; and 3) Private management system. In the open access system, anyone is allowed to fish anywhere in the river and at any time. Under the Indian Fisheries Act, the responsibility of managing the fish stock in an open access regime lies with the state governments. In a cooperative management system, the State governments auction the given stretches to the fisheries cooperative societies. The members of the society have exclusive rights to capture fish in that stretch and forbid the non-members from fishing. The management and decision-making power related to fisheries and fish stock in that stretch is the responsibility of the cooperative society. The contract for a particular stretch is for one year. In the private management system, a river stretch is owned by an individual or family. In this system, the right to lease out an owned river stretch lies with the individual or family. The owner may continue the lease with the same person or may transfer it to others, with a higher bid.

During our study, we found that stretches of river Ganga can be divided into five categories. River Ganga has stretches representing all the three property regimes along with the protected area management and stretches that have religious significance. Under the protected area management, a river stretch is either the part of a sanctuary area or is identified as a *Ramsar* site. In this area, fishing activity is entirely prohibited. The stretch of the river Ganga from Bijnor to Garhmukteshwar lies under the Hastinapur sanctuary area, it is a *Ramsar* site from Garhmukteshwar to the Narora barrage. Hence, fishing is not permitted in this entire stretch. We were informed that the river stretch from the Narora barrage to Kannoj falls under the cooperative management regime. In this stretch, the State government leases out the river stretches to different fisheries cooperative societies. Again, the stretch from Kanpur to Farakka falls under an open access regime. However, in recent years, fishing has been prohibited in the stretch from Kanpur to Varanasi in view of the religious importance of this stretch for Hindu devotees. In Uttar Pradesh, fishing is not permitted in and around a 500 metre area of any bathing *ghat*.

The downstream stretch to the Farakka feeder canal where the Hooghly river (locally called the Bhagirathi), converges, falls under the private ownership of the Mankundu Royal family of Odisha. We were informed that a representative of the royal family leases out river stretches to the local fisher-contractor. The local contractor levies charges on the local fishermen for fishing in that stretch. The charges vary according to the fish net usage. The river stretch in the Hooghly district falls under the open access regime. Further down to the Hooghly district, the river stretch falls under the cooperative management regime. In their study, Sinha and Katiha (2002) have found that the gross and net annual and per day returns to the fishermen are usually higher in the open access system, followed by cooperatives and the private system. With lower input costs, the net incomes per kilogram of fish catch were higher for cooperatives followed by those under the open access system.

As regards our four survey sites, we found that Narora falls under a cooperative system, Unnao and Kanpur fall under a stretch having religious significance. Jangipur falls under a private property regime, and Tribeni lies at an open access stretch. Although fishing is banned in the Unnao stretch of the river, we found that some fishermen continue to practise fishing in the river due to the absence of any alternate source of livelihood.

3.2 Socio-demographic Characteristics

The survey was primarily aimed at people who identified themselves as a members of the fisher caste group with fishing as their primary occupation. However, in some cases, we found that their investment in time and income from fishing were much lower than in the case of the secondary occupations they were practising. The respondents were asked separately about their primary and secondary occupations. As can be seen from Table 3.1, for both the phases taken together, about 98 per cent of the respondents in West Bengal and 92 per cent in Uttar Pradesh identified fishing as their primary occupation.[5]

Table 3.1: Primary Occupations of the Respondents (in %)

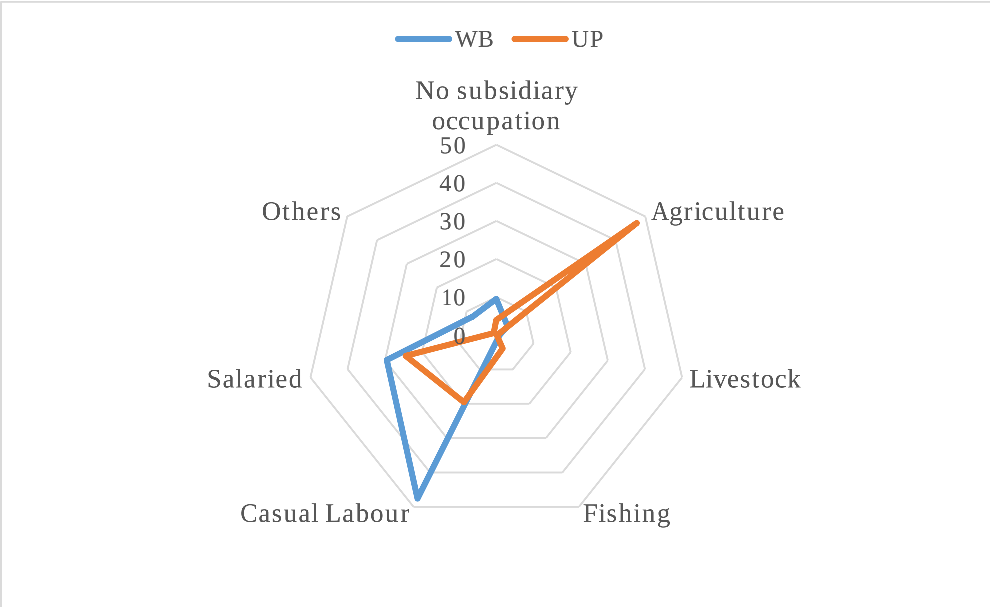
Occupation	West Bengal	Uttar Pradesh
Fishing	97.8	91.9
Others	2.3	8.1

Source: Authors' estimates from the survey.

[5] In Phase I, in addition to the majority of fishermen among our sample respondents, we also had boatmen, those engaged in agriculture, and causal labourers. Given the few data points on other types of occupation, in Phase II, we primarily focused on fisher folk as our main respondents.

Fisher folk were also asked if they were primarily dependent on fishing or if they were involved in other multiple occupations. The subsidiary occupations identified in Figure 3.1 are those of the households and not just of the respondents. While some households report no income from any subsidiary occupation at all, the practice of agriculture is the predominant occupation in Uttar Pradesh. In West Bengal, fishermen were also engaged in various forms of casual labour and salaried work (Figure 3.1).

Figure 3.1: Subsidiary Occupations of the Respondents (in %)



Source: Authors' estimates from the survey.

The reported incomes of respondents in West Bengal and Uttar Pradesh from primary occupations are shown in Table 3.2. We find that fishing communities are barely able to earn a minimum living from their primary occupation. As many as 65 per cent of them are subsisting with monthly incomes of Rs 5000 or less in Uttar Pradesh. The corresponding figure is 48 per cent for West Bengal. Only about 3-4 per cent of all the respondents reported earning monthly incomes ranging between Rs 10,000 and Rs 20,000. When compared to the NSSO 70th Round data (2012-13), we observe that the income range is representable to what is observed as the State average of Uttar Pradesh and West Bengal. For the former, the monthly average income for the base year (2015-16) for an agricultural household is estimated at Rs 4,455 at 2011-12 prices, while the corresponding figure for West Bengal is Rs 4,636.[6]

[6] In view of the lack of comparison, we took the agricultural households as a reference point of comparison.

Table 3.2: Incomes of Respondents (in %)

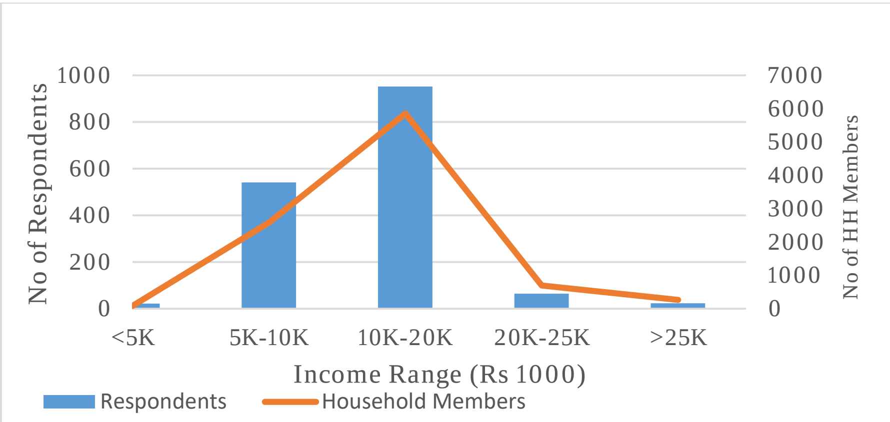
Monthly Income Range (Rs)	Primary Occupation	
	West Bengal	*Uttar Pradesh*
No income	N.A.	N.A.
<5,000	48	65
5,000-10,000	48	32
10,001-20,000	4	3

Source: Authors' estimates from the survey.

Note: N.A.: Not applicable.

Both primary and secondary earnings together constitute the total household income, which is depicted below. Figure 3.2 provides two sources of information. First, the number of respondents is mapped by their household income range. In doing so, we observe that 951 respondents, accounting for 59 per cent of our sample, fall are in the household monthly income range of Rs 10,000–20,000. The average monthly household incomes of our samples in Uttar Pradesh and West Bengal are Rs 11,800 and Rs 11,293, respectively. In the second set of information, we have plotted the number of household (HH) members against the household income range. The line graph denotes the number of HH members who are actually living off that income. We see that a total of 5847 household members are dependent on a monthly income of Rs 10,000–Rs 20,000. The number accounts for 62 per cent of the total population (9451) of the surveyed HHs. The next modal income class is Rs 5,000–10,000, wherein about 500 respondents supports 2500 HH members.

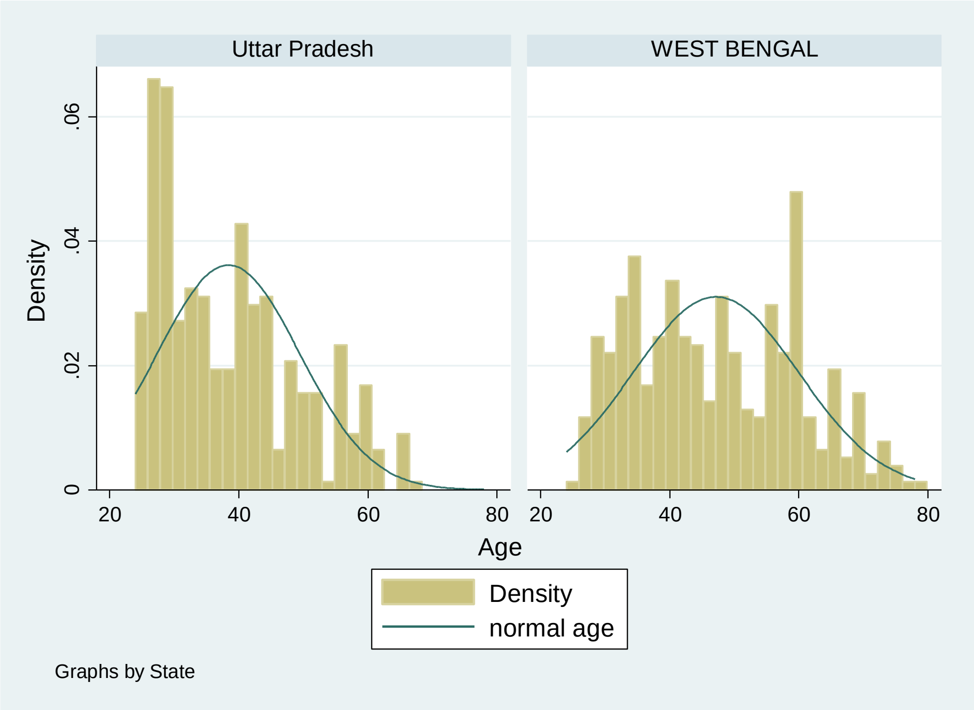
Figure 3.2: HH Income Categories and HH Income Dependency



Source: Authors' estimates from the survey.

The age profile of our respondents for Uttar Pradesh and West Bengal are shown in Figure 3.3. As can be seen from the figure, the respondents in West Bengal are more uniformly distributed in terms of their age in comparison to their counterparts in Uttar Pradesh. The respondents in Uttar Pradesh are relatively younger in age with a mean age of 36 years as compared to West Bengal, where the mean age of the respondents is 45 years.

Figure 3.3: Age Distribution of the Respondents in Uttar Pradesh and West Bengal

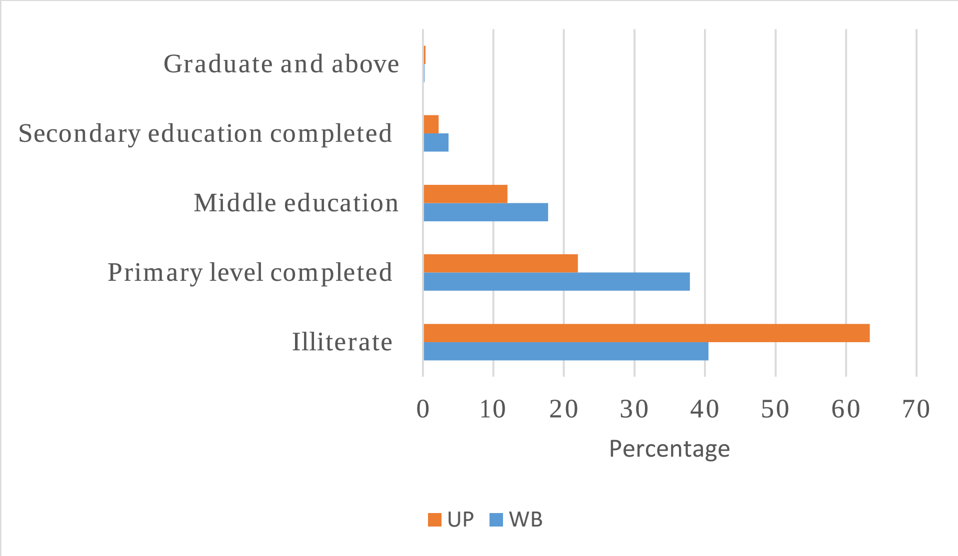


Source: Authors' estimates from the survey.

In the case of the younger age groups, we may have expected a better educational profile among the respondents in Uttar Pradesh, but this is not actually the case. Figure 3.4 suggests that our respondents were, in general, characterised by illiteracy or a low level of education. As many as 64 per cent of our respondents in Uttar Pradesh were completely illiterate with no minimum primary level of education. On the other hand, the educational profile of respondents in West Bengal was marginally better, probably reflecting the higher average literary level in the State.

Interestingly, when we asked the fisher folk about their next generation, and if their children were attending school, we observed a more positive picture. Of households with family members aged less than 18 years, about 94 per cent of the West Bengal households said that that they had school-going children who did attend school; the corresponding figure was 77 per cent for our respondent samples in Uttar Pradesh.

Figure 3.4: Educational Attainment (in %)



Source: Authors' estimates from the survey.

3.3 Water, Sanitation, and Hygiene Facilities (WASH)

Clean water is the pivot of a healthy life, which is why about 11 out of the UN's 17 Sustainable Development Goals (SDGs) revolve around it. In this context, we sought information from our respondents regarding water, sanitation, and the hygiene facilities available to them. The relevant data are shown in Table 3.3. Nearly 70 percent of the respondents in West Bengal and 62 per cent in Uttar Pradesh do not have access to potable water within the premises of their homes. The principal source of potable water is the government tap in West Bengal and the hand pump/borewell in Uttar Pradesh. It was found that most of the respondents (over 90 per cent) were using water directly without any treatment. This could be due to their poor economic conditions. Further, there was very little use of water purifiers, with only 6 per cent of the respondents in West Bengal and none in Uttar Pradesh using it.

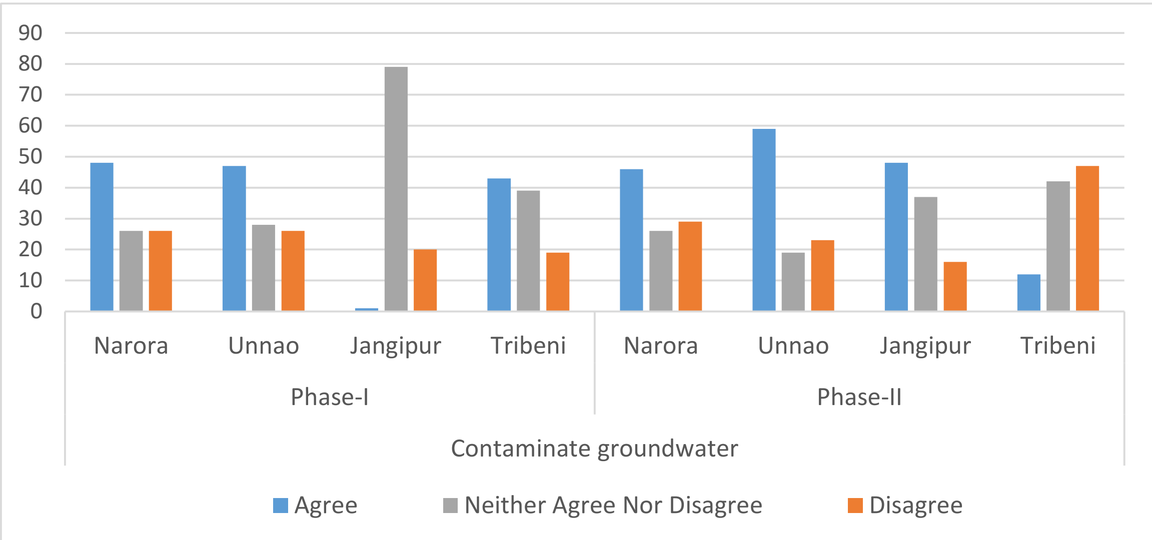
Table 3.3: Access and Type of Portable Water (in %)

Access to Potable Water	West Bengal	Uttar Pradesh
In the house	29.8	37.6
Outside the house	70.2	62.4
Types of potable water		
Government Tap	65.2	9.8
Hand Pump/Borewell	32.0	90.3
Others	2.9	0.0

Source: Authors' estimates from the survey.

The respondents' concern with regard to the quality of drinking water was very evident during our FGDs and in-depth discussions with them. At all the four study sites, they claimed that the poor quality of drinking water was responsible for their health problems. At Narora, a majority of the respondents were dependent on groundwater for meeting their daily needs. At the Tribeni site, the respondents said that the tap water supplied to them had a foul smell and was yellowish in colour. The respondents were of the opinion that the water was being supplied to them directly from the river without being filtered. The quality of the drinking water deteriorates further during the rainy seasons. Barring the handful of people who can afford to use bottled water, the rest are all dependent on tap water. They are aware of the harm that this water causes to their health, yet they are compelled to drink it in the absence of any alternative. Medical professionals, who have been practising at these sites for more than a decade also highlighted the issue of polluted drinking water being the source of many water-borne diseases. The plights of people are the same in Jangipur where the lack of access to adequate potable water places an economic burden on the families. We found that in Phase I, more than 40 per cent of the respondents at all the sites except Jangipur agreed that pollution of the Ganga water also leads to contamination of the groundwater (Figure 3.5).

Figure 3.5: Ganga Water Pollution: Contaminated Groundwater (in %)



Source: Authors' estimates from the survey.

However, in the second phase of the survey, we found that while about 48 per cent of the people interviewed at Jangipur agreed that the polluted water of River Ganga contaminates groundwater, in Tribeni, only 12 per cent of the respondents agreed to this assertion (Figure 3.5).

As regards the sanitation practices, we observed that nearly 22 per cent of our respondents in Uttar Pradesh practised open defecation (Table 3.4). However, West Bengal fares well in terms of sanitation practices. On the responses to our question as to whether low income is a possible reason for open defecation in Uttar Pradesh, we did a bivariate regression of open defecation and household income, which indicates that all the groups have a significantly lower likelihood of defecating in the open in relative to the lowest income group (with an income of less than Rs 5,000).

Table 3.4: Sanitation Practices of Respondents (in %)

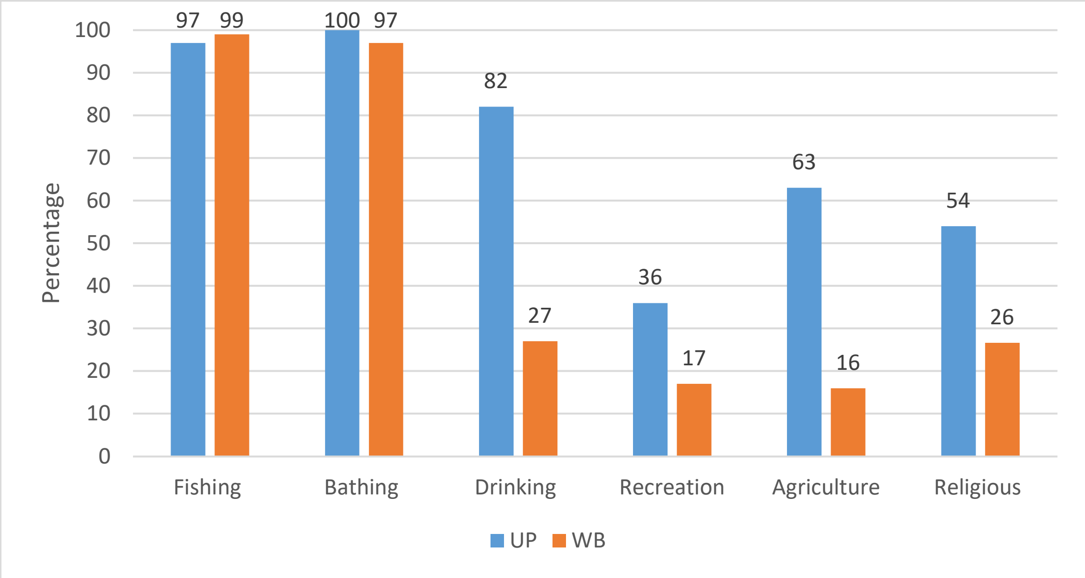
Types of Sanitation	West Bengal	Uttar Pradesh
Individual HH Latrine	98	74
Community Toilets	1	4
Open Defecation	1	22

Source: Authors' estimates from the survey.

This distinct differences between the States with respect to sanitation practices calls for a deeper understanding of the situation by the sites of the survey. Therefore, an analysis of this relationship in the city of Unnao showed that among those who defecate in the open, 52 per cent belong to the monthly income band of Rs 5,000–10,000, whereas 42 per cent and 6 per cent, respectively belong to the income categories of Rs 10,000–20,000 and Rs 20,000–25,000. The situation in Narora is not very different, with the highest percentage of respondents who defecate in the open falling in the monthly income category of Rs 10,000.

Finally, given that our primary objective is to understand the dependence of fisher folk on the Ganga river water, we asked the respondents to define their actual use of the river water apart from fishing. As Figure 3.6 shows, the Ganga river water is also used for bathing, and more importantly for drinking purposes. Thus apart from its expected use for fishing activities, we observe that almost all the respondents in Uttar Pradesh and 97 per cent of them in West Bengal use the river for bathing purposes. A majority of the respondents in Uttar Pradesh also use the water for agriculture (63 per cent) and religious purposes (54 per cent). The corresponding figures are much lower in the case of West Bengal, at 16 per cent and 26 per cent, respectively. As many as 82 per cent of the respondents in Uttar Pradesh also claimed that they used the river water for drinking. In our FGD, we were told that since fishermen tend to spend long hours in the river for fishing, they have no option but to resort to drinking the river water. The corresponding figure for West Bengal is relatively lower at 27 per cent.

Figure 3.6: Actual Use of the Ganga River Water (in %)

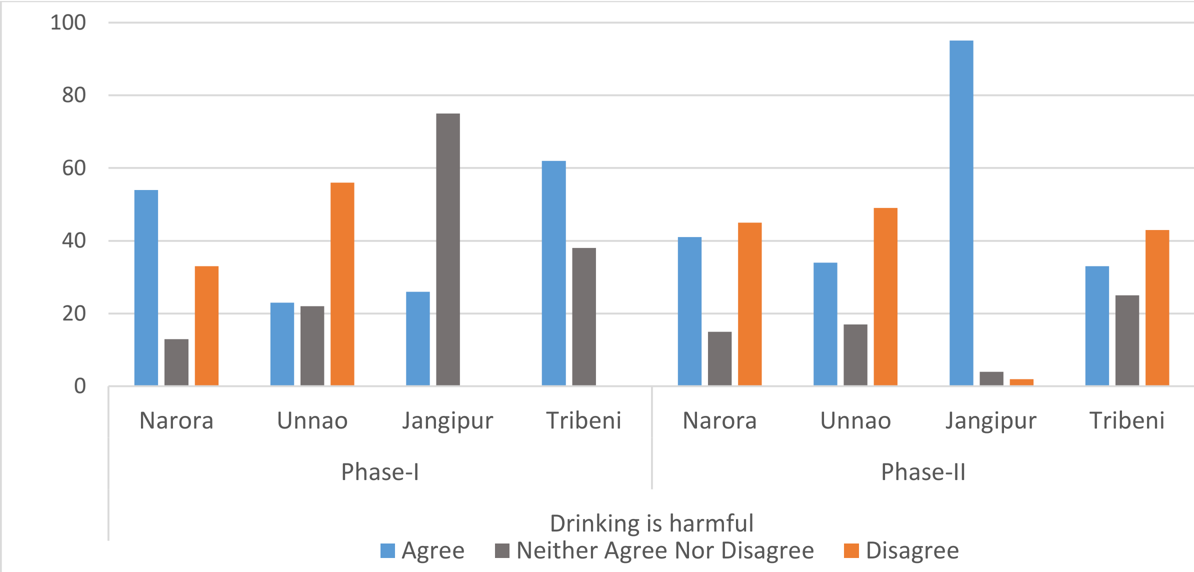


Source: Authors' estimates from the survey.

Note: Multiple options were allowed.

In order to probe further, we put forth the assertion that the use of the river water for drinking would have a negative impact on health. In the first phase of the survey, we found that about 54 per cent of the respondents in Narora and 62 per cent of those in Tribeni agreed that drinking the Ganga river water causes health problems (Figure 3.7). However, a majority of the respondents in Unnao disagreed with this. Interestingly, we found that about 75 per cent of the respondents of Jangipur neither agreed nor disagreed with this in the first phase, but in the second phase, about 95 per cent of the respondents agreed that drinking the Ganga water is harmful for health.

Figure 3.7: Ganga Water Pollution: Is Drinking the Ganga Water Harmful (in %)



Source: Authors' estimates from the survey.

The in-depth-interviews with selected medical professionals revealed that the water (both the drinking source and the Ganga water) has a negative impact on the health of the fisher folk. Consumption of and exposure to contaminated water has led to the predominance of skin diseases among the fishing community, the incidences of which have significantly increased over in the last ten years. However, the medical professionals also maintained that there is no clear distinction between the prevalence of skin diseases among the fishing versus non-fishing population.

3.4 Perception on River Water Quality

3.4.1 Divinity and Pollution

The Ganga river has both a religious and an emotional significance for people. For the purpose of this study, the divine qualities of the Ganga river were discussed with the respondents in the second phase. We wanted to understand their belief in the river and their perception of it as a goddess with supernatural power. It was not surprising to find that almost the entire sample (90-100 per cent) across the sites asserted that the Ganga river for them was a supernatural entity that had the power of salvation. They expressed the belief that its waters would help them get rid of their sins. This emotional connect with the Ganga leads us to map the respondents' perceptions on the divine quality of the Ganga river and the impact of water pollution on its divinity. During the first phase of our survey, we realised that most of the respondents laid more emphasis on stopping the industrial effluents as they perceived the Ganga river as a mother goddess and most of them even addressed the river as 'Gangaji' or 'Ganga Maa' (Figure 3.8).

As one of the respondents at Tribeni put it:

"Ganga ekti pobitra nodi aar amar kache ma er shoman. Amra taka r binimoye onake apobitra korte pari na. Ganga amar jibikar o pradhan karon"

(*To me Ganga is like my mother and it is a very sacred river. I must not allow her to get polluted by taking money. It is the main source of our income.*)

Similarly, one respondent at Unnao opined:

'kyonki, ye mere liye pavitra jagah hain, aur mujhe paise lete hue achcha nahi lagega'

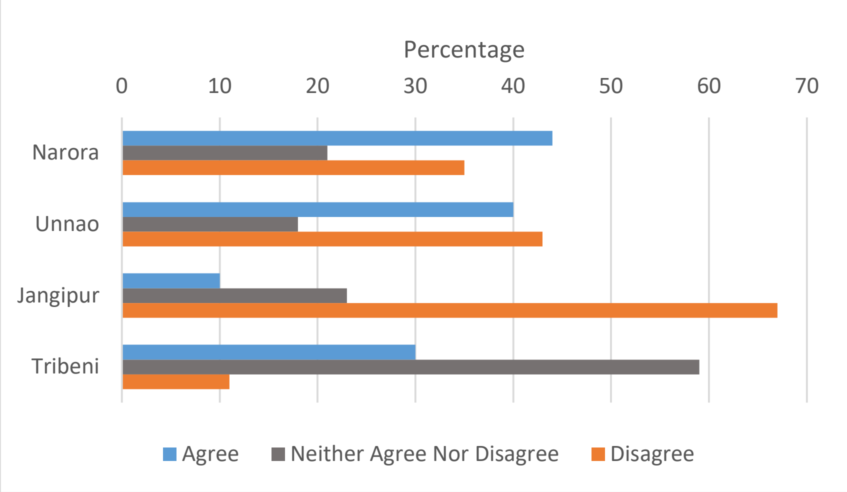
(Because, it is holy place for me, and I won't feel good to accept money)

Figure 3.8: Sentiments about Ganga River

Source: Created by the authors.

It is interesting to note that believers actually differentiate between the physical and metaphysical quality of the river; something that Alley (2002) also indicated in her paper and something that we also explored further. As can be seen in Figure 3.9, the respondents, particularly in Uttar Pradesh (comprising about 40-44 per cent of the total) said that they believed in the innate sanctity of the river despite its material pollution. This trend is lower in West Bengal, particularly for the population in Jangipur, where about 67 per cent of the respondents disagreed with the perception of the river's sanctity.

Figure 3.9: Impact of Pollution on the Divine Quality of the Ganga (in %)

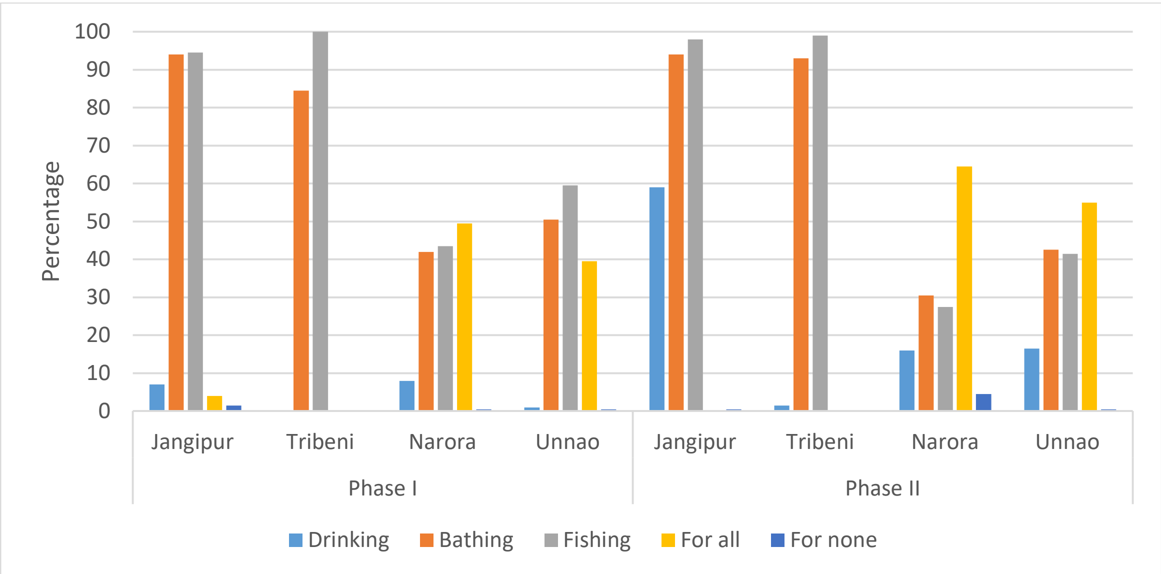


Source: Authors' estimates from the survey.

3.4.2 Acceptability of the Ganga Water

The respondents were also asked to give their opinion on whether the river water was suitable for drinking, fishing, bathing, and many such other activities. Figure 3.10 presents the data for the various sites in West Bengal/Uttar Pradesh by the timing of the survey. The figure shows that most of the respondents in West Bengal felt that the water of the river was suitable for fishing and bathing throughout the year.

Figure 3.10: Acceptability of the Ganga River Water (in %) (By Sites and Phases)



Source: Authors' estimates from the survey.

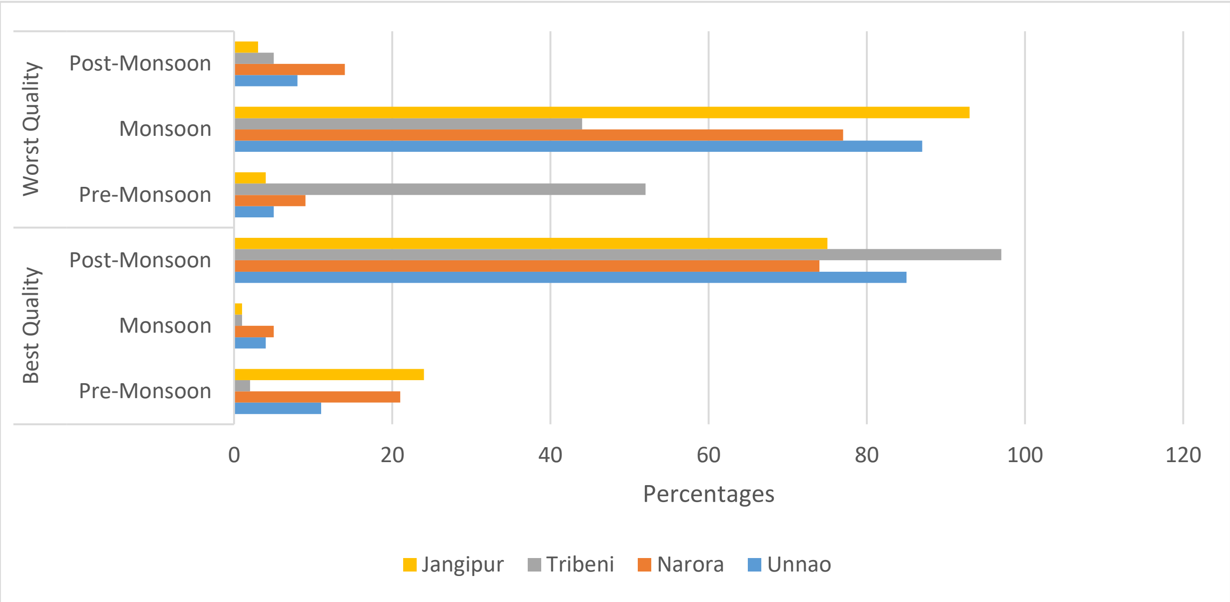
Note: 'For all' and 'For none' are exclusive categories. For the rest of the categories, multiple options were allowed.

While the responses did not vary much over the phases for bathing and fishing, it is interesting to observe that in Phase I, water was not considered to be suitable for drinking, whereas in Phase II, except in Tribeni, there was a jump in the perceived acceptability of water for drinking. These differences by phases provide insights into the manner in which the people's perceptions change in the short run. Phase II was conducted during the post-monsoon period, which is characterised by increased flow of the river. Also, as will be seen later in the subsequent tables, the respondents identify the post-monsoon period as one with the best water quality of the river. These perceptions about the water quality also seem to be reflected in the perceived acceptability of the Ganga river for multiple uses. For instance, in Uttar Pradesh, the acceptability of the water for all uses increased from 50 to 65 per cent in Narora and from 39 to 55 per cent in Unnao. This reiterated the fact that the respondents pointed to higher acceptability of the water in Phase II. We explore this finding further more by asking the respondents directly about the specific seasons when they think the quality of the water is at its best.

3.4.3 Perception on the Quality of the River Water

The respondents' perceptions regarding the quality of the river water were collated during our interaction with them. They were asked to indicate the season when the quality of the river water was good or bad. The seasons were classified as pre-monsoon (February, March, April, and May), monsoon (June, July, and August, September), and post-monsoon (October, November, December, and January).

Figure 3.11: Perceptions about the Quality of the River Water (in %)



Source: Authors' estimates from the survey.

According to most of the respondents, the quality of the water is the best during post-monsoon period at all the four sites (Figure 3.11). The quality is the worst during the monsoons in three of the four sites, according to our respondents. At Tribeni, the responses indicated that the worst water quality was witnessed during the summer season or the onset of the monsoon. The presence of manufacturing units in and around Tribeni that drain their water into the river along with the low level of water during the summer pollutes the river water further. These perceptions of the respondents indicate the implications and impact of the Ganga river water on their daily lives, which are discussed further in the following chapters.

Chapter 4: Implications on Health and Livelihood

Most of the respondents spend a considerable time in/near the river water due to their livelihood requirements. Almost all the fisher folk also take bath in the river water during the course of their fishing exercises. In this chapter, we focus on two specific issues: one the implications of river water use on the health of our sampled communities, and two, the livelihood challenges faced by these communities in relation to their fishing in the river water.

4.1 Health Implications

Information was sought from the respondents regarding the incidence of diseases affecting them and their family members. The fisher folk were first asked to self-rate their general health status. Overall, 80 per cent of the respondents rated their health to be at least 'good' or 'better'. This was followed with specific health questions. In our in-person survey questionnaire, we provided the fisher folk with a list of the most prevalent water-borne diseases, such as pneumonia, diarrhoea, cholera, cough/cold, fever, skin disease, typhoid, and jaundice. The respondents were asked if they or their family members were affected by any of the above illnesses.

The relevant data are summarised in Table 4.1. This table presents information on the incidences of disease among the respondents, as well as children and adult members of the household. Fever, cold and cough are common symptoms that can be associated with many illnesses; hence, the statistics in the table are shown separately for all diseases and also for diseases without common symptoms like cold, cough, and fever. If the incidences of all diseases are covered, we find that the reporting percentage increases to 88-96 for all areas barring the Tribeni site in West Bengal in Phase I. However, if we exclude common diseases, we find that 50-60 per cent of our respondents, who are in direct contact with water in Uttar Pradesh, mentioned the incidence of diseases. In West Bengal, the incidence of diseases is lower: only in Tribeni in Phase II, 52 per cent our respondents mentioned the incidence of diseases other than the common ones.

The phase-wise comparison of the results also provides interesting insights into any seasonal fluctuations in the incidence of diseases. While we see almost a uniform reportage of diseases in both the phases, this does not hold true for West Bengal; in Jangipur, a higher percentage of fisher folk were reportedly ill in Phase I (43 per cent) as compared to the corresponding figure in Phase II (28 per cent).[7] In contrast, in Tribeni, more respondents in Phase II reported the occurrence of the disease as compared to Phase I.

The household members of our respondents among the fisher folk are also dependent on the river in multiple ways and hence directly or indirectly come into contact with the river water at times. The figures for adults and children indicate the percentage of the sampled households that had at least one adult and/or child member in the family with reported incidences of water-borne diseases. We make two

[7] These statistics exclude the incidences of cold, cough, and fever.

observations here: the incidence of diseases among the adult members is very similar to our observations for the respondents whereas the corresponding figures for children indicate that the incidence of diseases among them were far lower in West Bengal as compared to Uttar Pradesh. This is true for both the phases. The figures indicate that children are more susceptible to common cold and fever than the rest of the water-borne diseases.

Table 4.1: Incidences of Diseases (in %)

Sites	Reported Incidences of All Diseases among			Reported Incidences of Diseases excluding Cold, Cough, Fever among		
	Respondents	*Dependent Child*	*Dependent Adults*	*Respondents*	*Dependent Child*	*Dependent Adults*
Across West Bengal						
Jangipur: Phase I	96	33	93	43	13	41
Jangipur: Phase II	90	21	37	28	4	7
Tribeni: Phase I	76	27	59	43	6	17
Tribeni- Phase II	96	13	28	52	3	4
Across Uttar Pradesh						
Narora: Phase I	88	55	96	51	25	37
Narora: Phase II	96	63	78	53	16	18
Unnao: Phase I	90	67	97	56	30	30
Unnao: Phase II	88	38	85	58	10	23

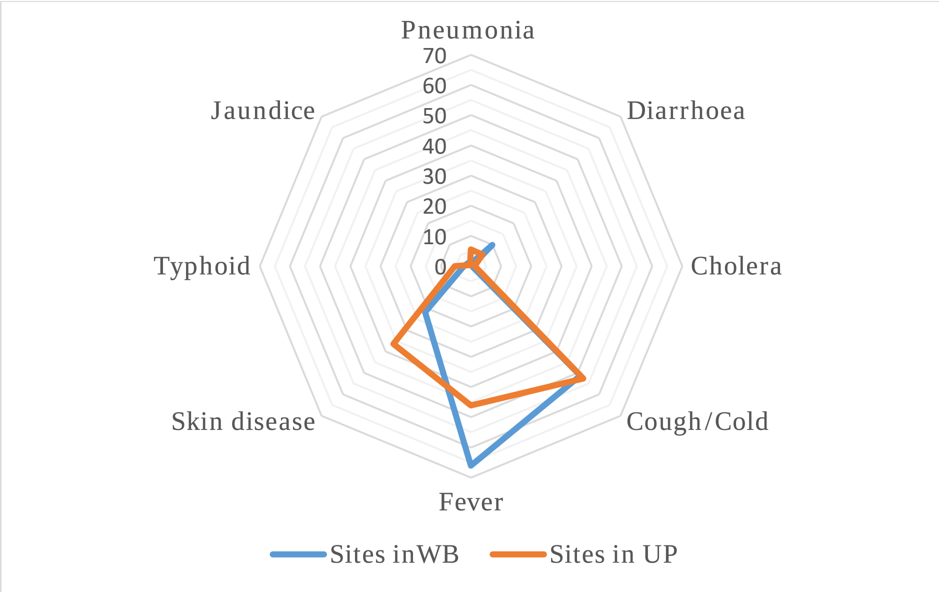
Source: Authors' estimates from the survey.

As regards the types of diseases reported in our samples, Figure 4.1 indicates that fever, cough/cold, and skin disease are the dominant diseases. The prevalence of water-borne disease like typhoid and jaundice is low. About 2.4 per cent of the respondents in West Bengal reported the occurrence of typhoid against a corresponding figure of 5.4 per cent in Uttar Pradesh. We could not find any common pattern between two phases and also between the two States in the case of jaundice. Pneumonia was almost non-existent in Phase I but almost 10 percentage of the Uttar Pradesh respondents have reported this illness in Phase II.[8] This can be attributed to the period when Phase II was conducted, when temperatures fall up to zero degrees Celsius.[9]

[8] About 9 per cent of the respondents belonged to Unnao whereas 11.50 per cent were from Narora.

[9] As per the Indian Meteorological Department's press release, in January 2020, temperatures fell to zero degrees Celsius in many parts of eastern and western Uttar Pradesh, https://mausam.imd.gov.in/backend/assets/press_release_pdf/extended2.pdf

Figure 4.1: Types of Diseases in Both Seasons (in %)



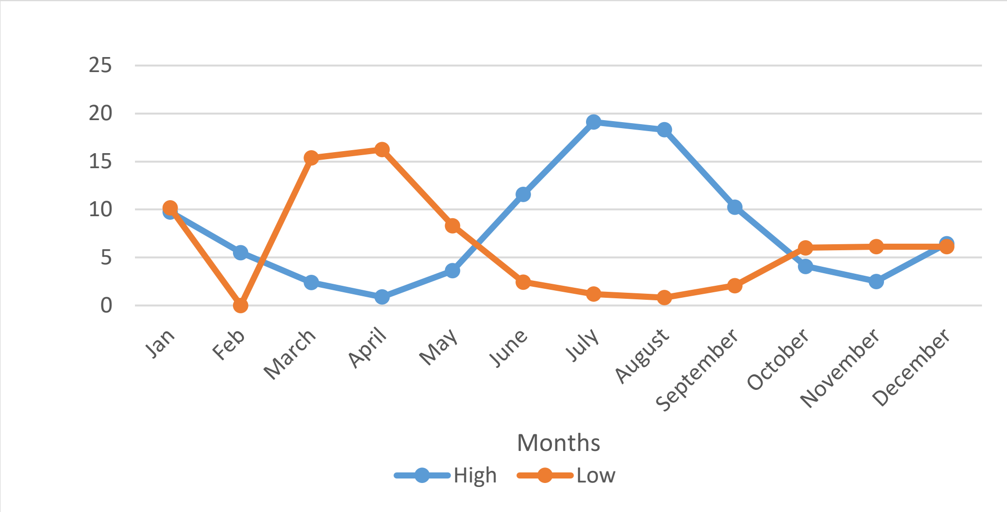
Source: Authors' estimates from the survey.

Statistically, we find that the occurrence of diarrhoea is significantly higher in West Bengal as compared to Uttar Pradesh while that of skin disease is higher in Uttar Pradesh than in West Bengal.[10] The respondents were also asked to report any chronic diseases that they may have been suffering from; the objective of this query was to understand if long-term exposure to the river water had any long-term health implications. About 2 per cent of the respondents reported facing liver problems, issues with gall bladder stones, and kidney issues, among others. All these health complications could have associations with the presence of heavy metals or chemical exposure in the river water or in drinking water.

As has been mentioned in the previous chapter, and also in discussions throughout the report, our FGDs held at these sites point to evidence that the health issues cited by the respondents could be attributed to the quality of the drinking water. The respondents alleged that their source of drinking water was of sub-standard quality. The respondents in West Bengal were of the opinion that the water dispensed from government taps is untreated, emits a foul smell, and is not suitable for drinking. Medical professionals also expressed the view that most of the water-borne diseases are predominantly caused by their drinking water sources. In Jangipur and Unnao, the presence of arsenic was highlighted as the biggest problem associated with the ground water.[11] In Narora, the respondents spoke of the contamination of the ground water caused by the Narora Atomic Power plant. However, we also found that more than half of the respondents (55 per cent) in our sample were drinking the Ganga river's water. Of these, almost 90 per cent reported facing at least one incidence of disease. This is also reflected in our bivariate regressions which indicate that the respondents who drink the Ganga river's water are more likely to report higher incidences of diseases.

[10] The occurrence of diarrhoea was higher in Jangipur (reported by 25 per cent of the respondents than in Tribeni (reported by 13 per cent of the respondents).
[11] At the time of publication of this report, the trace element analysis report for the submitted samples had not been received, as the laboratories were are closed due to the COVID-19 related lockdown.

Figure 4.2: Months with the Highest and Lowest Incidences of Diseases (in %)



Source: Authors' estimates from the survey.

Note: Based on only Phase II data.

The occurrence of diseases among the respondents peaked during certain seasons, as is reflected in Figure 4.2. We have plotted the months against the percentage of respondents reporting the months with the highest and lowest incidences of diseases. As expected, the two line graphs are found to be mirror images of each other, wherein the highest incidence of diseases was reported in the months of July and August (that is, the monsoon season) whereas the lowest incidence was reported in the month of April.

4.2 Livelihood Implications

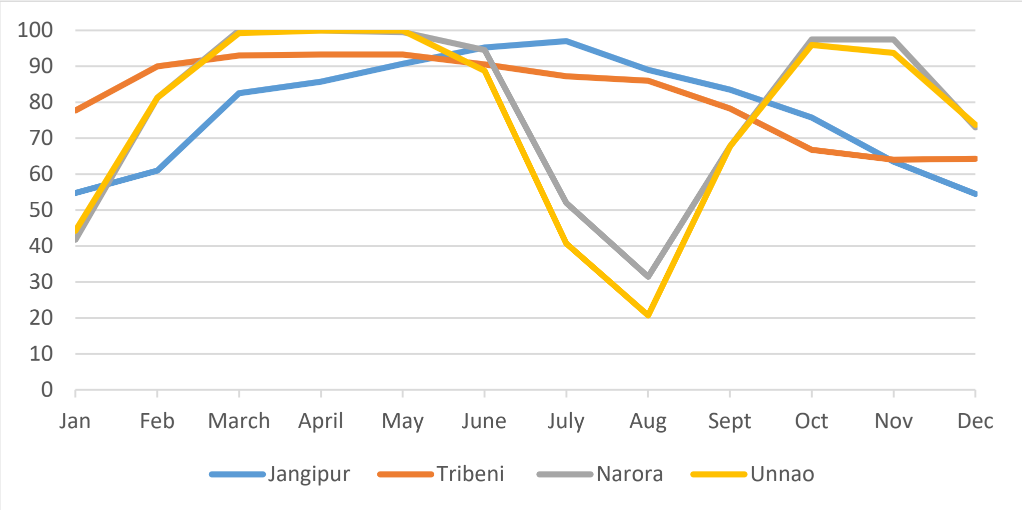
In the previous chapter, we discussed the stretch-wise variation in property rights and regime over the river in the context of fishing. During our exploration of the survey sites, we were informed that fishing was banned along the Kanpur–Unnao stretch of the river, as this was categorised as a religiously important stretch. We visited the office of the fisheries department to gather further information and a copy of the circular/order related to this. The official at the Block Development Office (BDO) verified the information, but we could not obtain any official documents related to this.

Despite the ban, fishing is still taking place in this stretch of the river. We realised that fishermen do not have any other option but to fish clandestinely or at night. They told us that they were caught by the water police (*jal police*) many times and sentenced to jail and also fined by the court. However, they agreed to participate in our survey on the assurance of anonymity.

The respondents in our sample were also asked about the months when they undertook fishing activities. Figure 4.3 summarises the perceptions of the respondents at the four sites of the survey for each month of the year. As the figure suggests, the months of February to June, and September to December were reported as the favourable months for fishing by a majority of the respondents at all the sites. The months of July-August seem to be unfavourable for fishing at both the sites in Uttar Pradesh since the monsoon season serves as a breeding period for most of the fishes.

There is also a State-wise ban on fishing during this period to help conserve the fishes and to protect the lives of fishermen from the stormy monsoonal river flow. The issue of the fishing ban was highlighted only during our FGDs and in-depth discussions. Less than 40 per cent of the respondents reported these months to be *active fishing months*. Most respondents in West Bengal, however, considered all the months as active fishing months.

Figure 4.3: Active Fishing Months (in %)



Source: Authors' estimates from the survey.

Ideally, there should be a positive association between the active fishing months and income from these months. In other words, do the fishermen earn more income during the months indicated as fishing months? During the survey, we sought information from the respondents regarding their highest and lowest income months. The top three modal values for the highest and lowest income months, as indicated by the respondents, are shown in Table 4.2. As indicated by data in Table 4.2 and Figure 4.4, the active fishing months need not be the months generating the highest income.

Table 4.2 suggests that the highest/lowest income varies across sites. For instance, the highest income months are February-April in Tribeni (West Bengal) and July in Jangipur (West Bengal). On the other hand, May is perceived to be the highest income month at both sites in Uttar Pradesh. We also observe that January is the lowest income month at both sites in Uttar Pradesh whereas March and May are the lowest income months in Jangipur (West Bengal) and Tribeni (West Bengal), respectively.

Table 4.2: Top 3 Modal Values for the Highest and Lowest Income Months

Months	Highest Income Months				Lowest Income Months			
	Sites in West Bengal		Sites in Uttar Pradesh		Sites in West Bengal		Sites in Uttar Pradesh	
	Jangipur	*Tribeni*	*Narora*	*Unnao*	*Jangipur*	*Tribeni*	*Narora*	*Unnao*
January					2	2	1	1
February		1					2	3
March		3			1			
April		1	3		3			
May			1	1		1		
June	3			2				
July	1	2						
August	2							
September		3		3				
October			2	3				
November								
December						3	3	2

Source: Authors' estimates from the survey.

The highest and lowest monthly incomes earned by States are delineated in Table 4.3. The average highest income for all samples taken together is Rs 10,119, and the mean lowest income of the sample is Rs 2,838. While Uttar Pradesh and West Bengal are very comparable with regard to the highest income, the gap between the highest and lowest income is higher in Uttar Pradesh than in West Bengal.

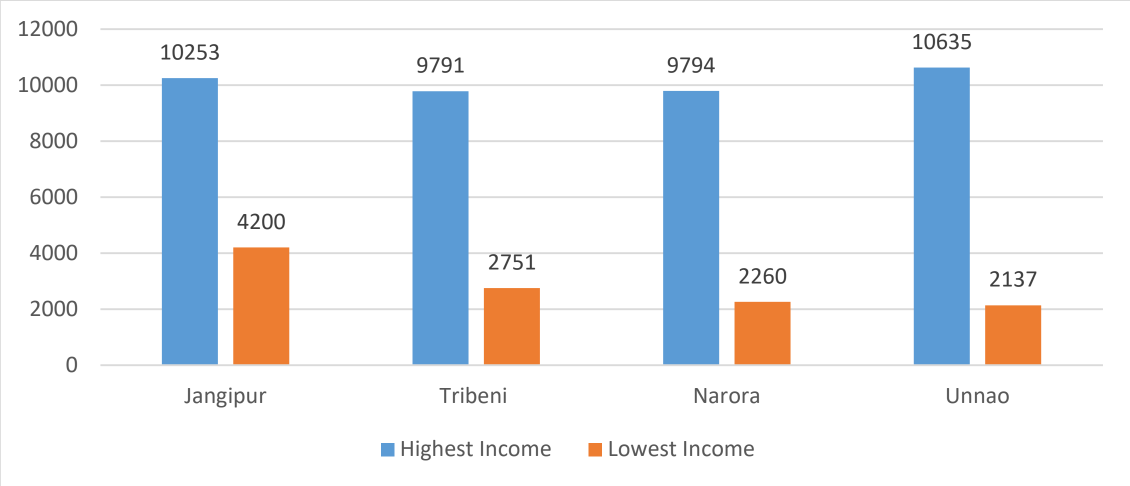
Table 4.3: Highest and Lowest Monthly Incomes (Rs.)

Variable (All samples)	Obs.	Mean	Std. Dev.	Min.	Max.
Highest Income	1,592	10,119	3,992	1,000	70,000
West Bengal	793	10,024	4,092	1,000	70,000
Uttar Pradesh	799	10,214	3,889	2,000	25,000
Lowest Income	1592	2,838	149	300	10,000
West Bengal	793	3,482	1,607	300	10,000
Uttar Pradesh	799	2,199	1,034	400	8,000

Source: Authors' estimates from the survey.

Figure 4.4 shows that the respondents in Unnao and Jangipur earned the most. Note that the variation between the highest and lowest incomes earned was the least in Jangipur. At other places, the income may have declined to 20-25 per cent of the highest income.

Figure 4.4: Highest and Lowest Monthly Incomes (Rs.)



Source: Authors' estimates from the survey.

By its very nature, fishing is an uncertain occupation because of fluctuations in the regularity of the catch. A majority of the fishermen in both the States (92 per cent) revealed that there are many active fishing days where they tend to catch no fish at all. This happens as frequently as at least two days every week when they go for fishing but without any success.

The responses to our question on the catch of fishes and changes in the quantum of the catch over the years are presented in Table 4.4. The table shows that the catch has not varied much over the years in West Bengal but at both the sites in Uttar Pradesh, higher percentages of respondents are reporting lower fish catches.

Table 4.4: Quantum of Fishes Caught during the Current Year and Five Years before It (in Kg)

Catch 5 Years before the Current Year	Jangipur	Tribeni	Narora	Unnao
<10 kg	79	65	43	37
10-15 kg	20	20	26	37
15-20 kg	1	7	15	21
>20 kg	0	9	17	7
Catch during the Current Year				
<10 kg	50	53	92	96
10-15 kg	16	19	3	2
15-20 kg	12	5	0	1
>20 kg	21	23	5	1

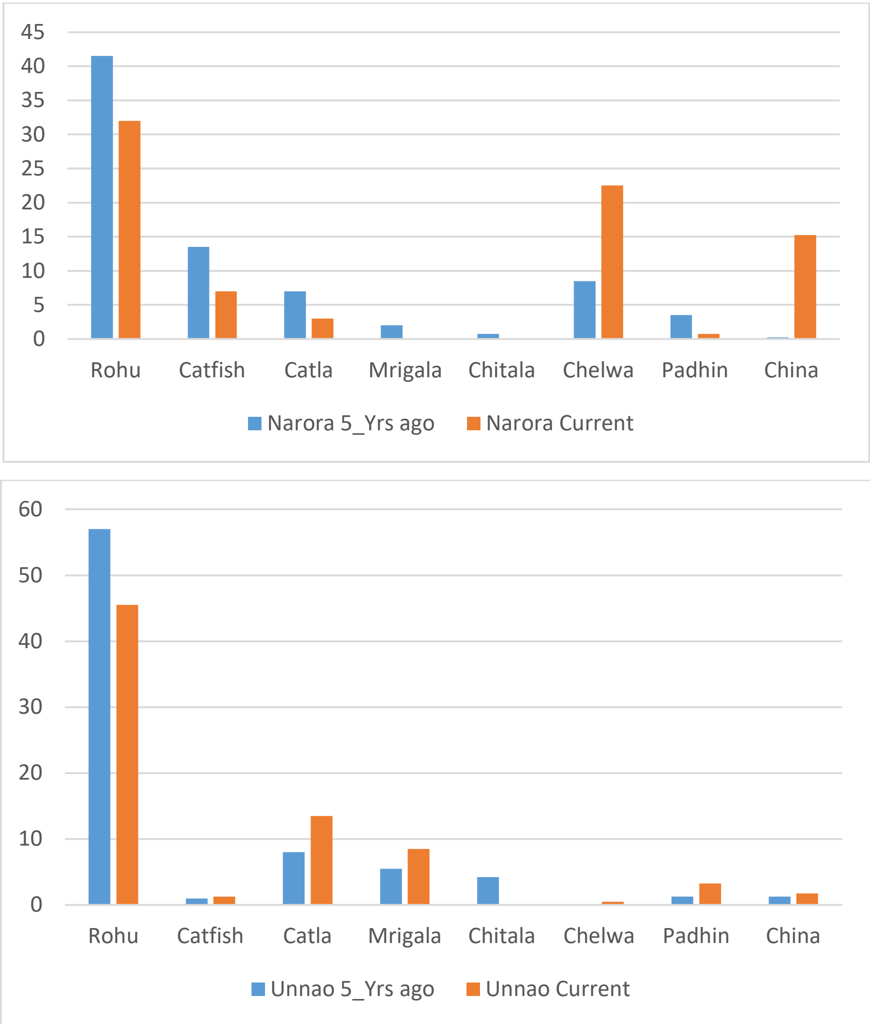
Source: Authors' estimates from the survey.

4.2.1 Fish Species

The respondents at all the sites mentioned that the quantum of commercially important fish species in their catch has reduced over the last five years, but the quantum of some exotic or invasive species has increased in their catch (Figures 4.5 and 4.6).

At both the sites of Uttar Pradesh, that is, Narora and Unnao, a majority of the respondents reported that Rohu (Labeo Rohita), followed by Catla (Gibelion Catla and Catla Catla), were the most frequently caught fishes in a fish catch. However, the presence of these fishes has decreased over the years. At the upstream site of Uttar Pradesh in Narora, about 42 per cent of the respondents reported that Rohu was the most found fish in their fish catch five years ago, but this figure had declined to 32 per cent for those reporting it as the most frequently caught fish in the current catch. Similarly, in the case of catfish (Mystus Sps.) varieties such as Singhara and Tengara, about 14 per cent of the respondents claimed it to be the most found fish in a fish catch five years ago, but this figure had fallen to 7 per cent for those reporting it in the current fish catch. In the current fish catch, after Rohu, the presence of Chelwa, also known as Flying Barb *(Esomus Danrica)* and China *(Cyprinus Carpio)* was reported to be high, followed by that of Catfish and Catla.

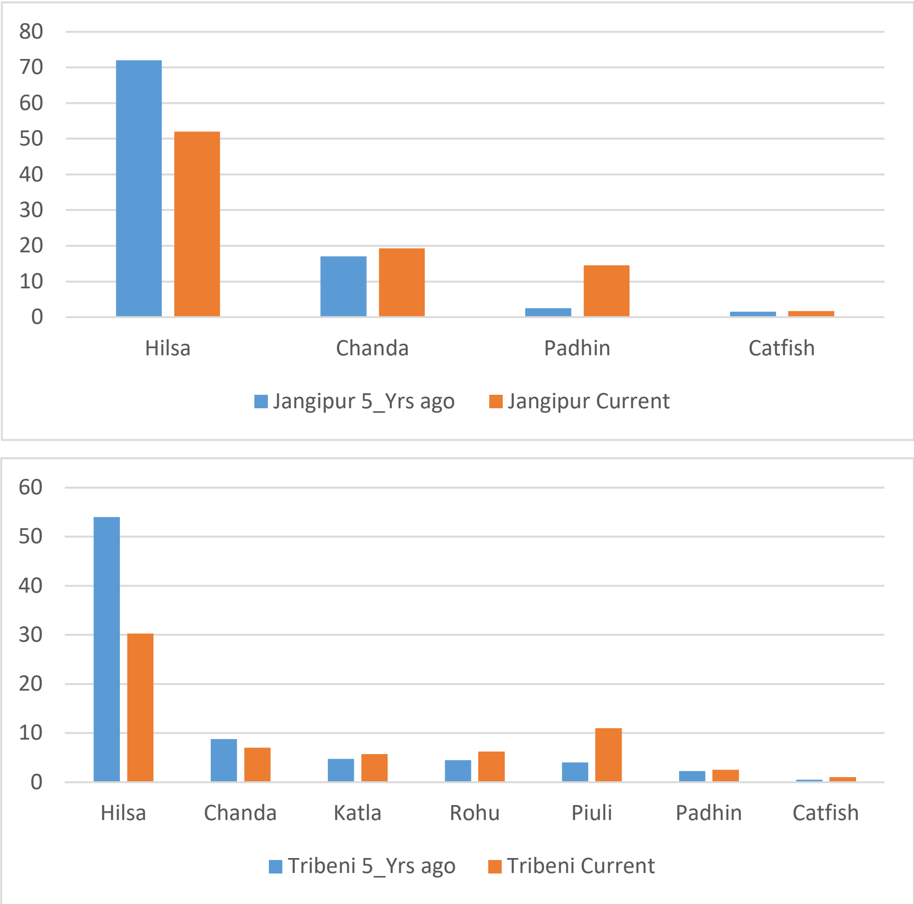
Figure 4.5: Most Found Fish Species in a Catch (Uttar Pradesh) (in %)



Source: Authors' estimates from the survey.

In Unnao, though Rohu was the most found fish in comparison to Narora, the presence of Rohu in a fish catch has decreased over the years. Nearly 57 per cent of the respondents mentioned Rohu as one of the top fish in their fish catch five years ago whereas, in the current fish catch, only 46 per cent of the respondents reported it to be the most found fish in a catch.

Figure 4.6: Most Found Fish Species in a Catch (West Bengal) (in %)



Source: Authors' estimates from the survey.

In the case of West Bengal, it was found that Hilsa *(Tenualosa Ilisha)* is reported as the widely present fish species in a fish catch. However, during the current reporting period, the presence of Hilsa in a fish catch was reportedly low. Five years ago, about 54 per cent of the respondents at Tribeni and 72 per cent at Jangipur identified Hilsa, followed by Chingari /Chanda *(Parambassis Ranga)* as the most caught fish species. However, as regards the current fish catch, only 30 per cent of the respondents at Tribeni and 52 per cent at Jangipur identified Hilsa as the most found fish, followed by Puili *(Notopterus)* in Tribeni and Chingari/Chanda in Jangipur. Padhin *(Wallago Attu)* has also become one of the most found species in a fish catch in recent times at Jangipur. It may also be noted that the respondents at Narora and Tribeni mentioned the presence of more varieties of fishes in their fish catch in comparison to Unnao and Jangipur.

Exotic fishes were also reported as part of the fish caught at all the four sites. The respondents in Uttar Pradesh identified China *(Cyprinus Carpio)* and Tilapia *(Oreochromis Niloticus)* as the species of exotic fishes in their respective fish catches. Singh et al. (2010), in their study, have inferred that the presence of exotic fishes has a negative impact on the indigenous fishes as it poses a threat to the latter, even causing them to shift from their natural habitats.

4.3 Causes and Effects of Water Pollution

In our FGDs at all the four sites, we asked the participants to identify the five main reasons for the decline in the quantum of their fish catch over the years. Interestingly, at all the four study sites, low water volume was identified as a major reason, followed by irresponsible fishing in the form of the use of a micro-mesh (mosquito net), which also catches fingerlings and kills eggs, and leads to poisoning. The participants in the FGDs at Narora and Unnao also identified pollution as a major reason for decline in the catch, but only after the above-mentioned two reasons.

In our survey questionnaire, we also posed questions to gauge the level of awareness about the various sources of pollution and peoples' perceptions about the impact of river water pollution on their health and livelihoods (Table 4.5).

Table 4.5: Perceptions about the Causes of Ganga River Water Pollution (in %)

Industrial Effluents	Phase I				Phase II			
	Naror	Unna	Jangipu	Triben	Naror	Unna	Jangipu	Tribeni
Agree	100	100	*	100	99	100	99	97
Disagree	0	0	*	0	1	0	1	3
Domestic Wastewater								
Agree	99	99	99	98	91	91	97	86
Neither Agree Nor	1	1	1	2	6	5	2	11
Disagree	0	0	0	0	4	4	1	4
Agriculture Runoffs								
Agree	36	23	46	93	36	41	94	80
Neither Agree Nor	13	18	52	6	20	10	5	15
Disagree	51	59	2	2	45	50	1	6

Source: Authors' estimates from the survey.

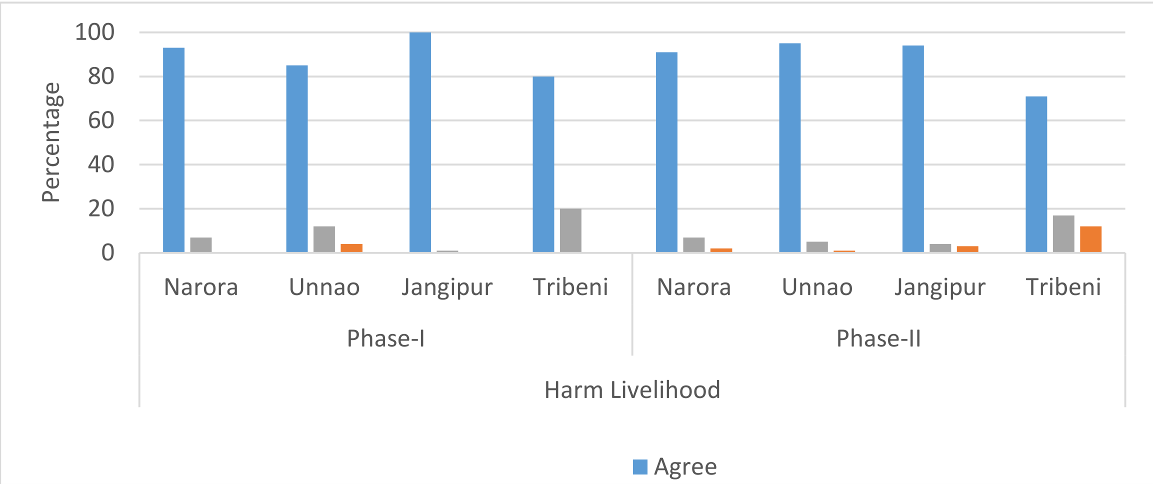
**Note:* There was an error in the first phase of data collection for this variable.

The survey data shows that in the first phase, all the respondents at the three sites agreed that industrial effluents cause river pollution. Interestingly, on the question of pollution due to agricultural run-offs, at Unnao, in Phase I, 23 per cent the respondents gave a positive answer, but the corresponding figure went up to 41 per cent in Phase II. Similarly, a significant change was noticed among the respondents at Jangipur too. At Jangipur, during the first phase, only 46 per cent of the respondents agreed to this assertion but during the second phase, the number of such respondents rose to 94 per cent. However, at Narora and Tribeni, no significant change was noticed in the opinions of the respondents.

Further, on the issue of pollution due to the domestic wastewater discharged in the river, a majority of the respondents at all the four sites answered in the affirmative. Thus, our data shows that most of the respondents are of the opinion that domestic and industrial wastewater are major sources of river water pollution. However, there is a difference of opinion on the pollution impact of the agriculture run-offs.

In order to assess the people's perceptions about the implications of river water pollution on the livelihoods and health of the respondents, we also inquired whether pollution of the river water had an adverse impact on the livelihoods of the respondents. We found that in both the phases, a majority of the respondents agreed that pollution had a harmful impact on their livelihoods, as seen in Figure 4.7.

Figure 4.7: Ganga River Water Pollution: Negative Impact on Livelihood (in %)



Source: Authors' estimates from the survey.

As regards the question of the impact of river water pollution on agriculture, the survey data shows that during the first phase, 50 per cent of the respondents in Tribeni and 53 per cent in Unnao agreed that pollution of the Ganga river's water had a harmful impact on agriculture whereas the corresponding figures in Jangipur and Narora were only 6 per cent and 25 per cent, respectively. We further analysed whether the involvement of the fisher folk in agriculture as a secondary occupation can also be attributed to this variation in people's perceptions at the different survey sites.

Table 4.6: Negative Impact on Agriculture Based on the Subsidiary Occupations of the Respondents (in Numbers)

Subsidiary Occupation: Agriculture				
	Phase I		**Phase II**	
	Narora	**Unnao**	**Narora**	**Unnao**
Agree	37	29	37	38
Neutral	17	14	20	12
Disagree	23	64	43	43
Total	**77**	**107**	**100**	**93**
Subsidiary Occupation: Casual Work/Salaried				
Agree	47	17	33	26
Neutral	17	15	12	17
Disagree	25	35	53	48
Total	**89**	**67**	**98**	**91**
Occupation: Casual Work/Salaried				
	Raghunathganj	**Tribeni**	**Raghunathganj**	**Tribeni**
Agree	94	9	11	97
Neutral	79	127	57	20
Disagree	15	57	46	5
Total	**188**	**193**	**114**	**122**

Source: Authors' estimates from the survey.

Agriculture, as a subsidiary occupation, is widely practised at both the sites of Uttar Pradesh (Table 4.6).[12] Fishermen use sand belts in and along the river for farming, calling *reti pe kheti* or farming on sand. Further, these sand belts are not owned by anyone. However, in Narora, fishermen reported that they need to pay a sum of money to the local bully to cultivate on sand belts. Similarly, in Unnao, fishermen reported that their crops were destroyed by a gang of local leaders under the pretext of following the 'Clean Ganga programme' organised by the State government.

Normally, the agriculture cycle in this sand belts starts from the months of February-March and the harvest period is from May to August. Mostly seasonal vegetables and fruits such as bottle gourd, pumpkin, cucumber, watermelon, and musk melon are cultivated on this land. However, on some sand belts, farming is done throughout the year to grow seasonal vegetables. Farmers dig ditches in the sand belts and use their water for irrigation. Our respondent said that this water was cleaner than the water flowing in the river as it was filtered by the sand, which helped remove all the impurities. We also found that the subsidiary occupations of the respondents do not have any significant impact on their perceptions about the negative impact of pollution on agriculture.

We asked the same question with regard to the impact on fishing. A significantly high percentage (90-95 per cent) of the fisher folk agreed that water pollution has a harmful impact on the production of the fishes. However, in our FGDs, the participants primarily cited the decrease in the flow of the river as a reason for the decline in the fish catch. Breeding also becomes difficult when fishing nets that are smaller than the acceptable ranges are used, as they lead to the catch of smaller and smaller fishes. In their FGDs, the fishermen were very vocal about the irresponsibility of the *jal police,* as they are called, who should have been the custodian of these rights. Instead, these police personnel allegedly resort to corrupt practices and ignore the

[12] In West Bengal, in the first phase only 10 people said that their subsidiary occupation is agriculture and only 20 in Phase II.

malpractices of some powerful fishermen groups and local goons in lieu of receipt of bribes. Since fishermen largely belong to marginalised communities, they are not able to stand up against these corrupt practices of the powerful. They claim that even though they are aware of the offenders and their malpractices, they are not in a position to do anything. This poses a threat to their occupations and livelihoods.

Chapter 5: Challenges and Opportunities for Community Participation

In the previous chapter, we described the various health and livelihood implications faced by fishermen, and their perceptions on how the Ganga river water pollution has impacted their lives. Through this chapter, we want to focus on the initiatives and the roles played by the government to alleviate some of these concerns. It will be of interest to see how these government initiatives are perceived by the fishing community and if that differs across different survey sites. The community participation drive is also an alternate mechanism for ensuring that the livelihoods of the fishing community as a whole are protected. Towards this end, we undertook a contingent valuation exercise with our fisher folk respondents to examine if they were willing and able to participate in such an initiative to create a public good.

5.1 Government Programmes

We started by asking the respondents if they were aware of any measures or steps taken by the government to resolve the problems of Ganga river water pollution. Although a majority of the respondents replied in the affirmative to this question, it may be noticed in Table 5.1 that the responses are extremely skewed by States. Almost all the respondents in Uttar Pradesh said that they were aware of some Government measures whereas in West Bengal, almost 85 per cent said that either no such measure had been introduced or they did not know about any such policies.

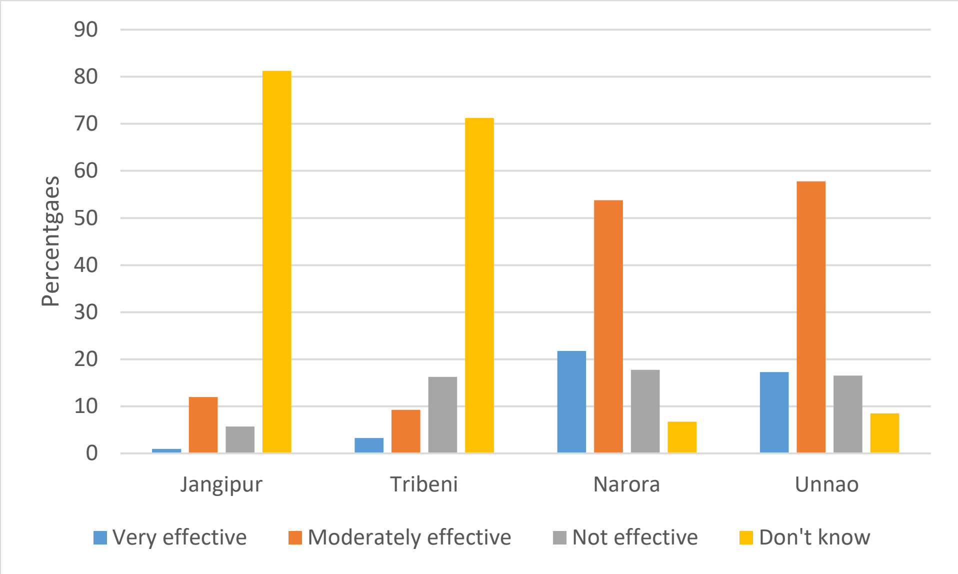
Table 5.1: Government Steps on Water Pollution (in %)

	West Bengal	Uttar Pradesh
Yes	15	98
No	42	1
Do not know	43	1

Source: Authors' estimates from the survey.

We then specifically asked questions about the most popular Ganga cleaning drive missions such as the Namami Ganga. The respondents were asked to evaluate the effectiveness of Namami Ganga in their particular stretch of the river. Even here, we see the stark differences in responses between the two States. As can be seen from Figure 5.1, awareness about the programme was significantly lower among respondents in West Bengal as compared to their counterparts in Uttar Pradesh. The figure shows that in Uttar Pradesh, 98 per cent of the respondents had heard about the program, whereas the corresponding figure in West Bengal was only 10 per cent. These figures can be explained by the geo-political situation prevailing in the two States.

Figure 5.1: Perceptions about the Effectiveness of the Namami Ganga Programme



Source: Authors' estimates from the survey.

The respondents were also asked to recommend policies to the Government. In other words, we asked them about the kinds of programmes they would like to see getting implemented at their particular locations of the river. The measures suggested by them are also indicative of the constraints being faced by them. In response to these questions, a majority of the respondents in Uttar Pradesh (77 per cent) said that they wanted to see action against factory-level discharge. In West Bengal, on the other hand, a majority of the respondents (37 per cent) wanted to see policies being implemented to compensate for livelihood-related adversities. In contrast, this figure was barely 10 per cent in Uttar Pradesh. About 22 per cent wanted health facilities in their respective areas to address the issue of water-related illnesses while about 35 per cent wanted a solution to the problem of factory-level discharge.

5.2 Community Participation

In addition to what the Government is currently doing, community participation in preserving the river was also considered important. The Central Government's National Mission for Clean Ganga is considered as a remarkable community project. The underlying theme of the programme is to make people aware of the pollution problem and empower them to participate in the programme. The National Mission for Clean Ganga elicited the participation of the local communities in their initiatives by providing platforms through Panchayati Raj System, capacity development, and payment for ecosystem services. Another objective of the scheme is to implement conservation education programmes for the riverine communities of the Ganga river. We undertook a contingent valuation exercise for assessing this programme.

Contingent valuations exercises are primarily undertaken with the objective of undertaking cost-benefit analyses. This is done to help the Government measure the social costs of any policy that are not reflected in the existing markets and prices but are still crucial for ensuring people's well-being (World Bank, 2016). The Clean Ganga programme is akin to being one such public good that is crucial for sustaining the livelihood of the riverine communities but does not promote a market for itself. Since there is no price associated with this good, the valuation of clean river water is made by creating hypothetical markets through a contingent valuation exercise.

In a market economy, the valuation of a commodity or service is done through demand and supply dynamics, but in the case of a missing market, where there is no supply of any commodity or services, such a valuation becomes a challenging exercise. In these situations, we can use concepts of contingent valuation like the 'willingness to pay' (WTP) and 'willingness to accept' (WTA) to meaningfully understand the market dynamics. This will help institutions like governments, NGOs, and corporations to play a role in mitigating the problem of missing markets.

As Martín-Fernández et al., 2010 writes,

The value attributed by contingent valuation methodology to a good or service can be studied from the perspective of willingness to pay (WTP), the maximum amount a person would be willing to offer for a good, or by the willingness to accept compensation (WTA), the minimum monetary amount required for an individual to forgo some good, or to bear some harm.

The missing market problems can be solved through well-defined property rights and regulations. Regulations can be implemented in order to promote the use of resources in a sustainable way or by defining property rights. In the context of our study, we can define property rights in multiple ways, which can solve the problem of missing markets by creating the market itself.

To understand if there is demand for clean river water, we use the WTP concept and ask consumers if they are willing to pay for that service. Another way in which we could look at this problem is by offering the right to clean the river to the people affected by the pollution who, in turn, can demand compensation from industries that pollute the river. On the basis of this concept, we can ask the affected community about their willingness to accept a compensation by giving up their right to clean water. A few studies attempt to estimate the economic value of public resources using the concepts of WTP and WTA. Below, we provide an overview of such studies.

A study by Janko and Zemedu (2015) attempted to calculate the demand among fishermen for a fishery management authority in Lake Zeway, Ethiopia, using the WTP method. A fishery management authority would manage fisheries in the region by re-stocking different fish species, buying and distributing boats, recommending fishing gears, and hiring the control over the lake to manage fish on behalf of the fishing community. A Tobit model result revealed that income from fishing, educational levels, experience, and perceptions about lake fishery management have a positive and significant effect on WTP. Alternatively, the income earned by the respondents has a significant negative effect on the respondent's WTP. Halkos (2013) attempted to understand the attitude of people towards water resource valuation in Greece. He measured the total economic value of water resources using a measuring scale by differentiating between the direct and indirect use of water resources. Halkos explored the relationship between the WTP, general attitude towards the river, income, education, and origin of the respondent using techniques like principal component and cluster analyses together with logistic regression. Halkos found a high degree of associations between the WTP of individuals towards river protection and their characteristics, like education, income, and origin).

5.3. Survey Methodology

In the context of our study, we have used the concepts of WTP and WTA to evaluate the cost of pollution in the Ganga river for the riverine community. Pollution in the Ganga river affects the health and livelihood of the nearby riverine community, which predominantly comprises poor farmers and fishermen. They consume the river water for both household and commercial purposes. Polluted water is hazardous to marine life, which, in turn, reduces the fish catch and consequently the incomes of the fisherman.

There are two stages in which the contingent valuation exercise is undertaken. Before introducing the questions to the respondents, a script detailing the present state of affairs regarding the pollution levels in the Ganga river is explained. In addition, a hypothetical policy scenario is presented to them, following which they are asked if they want to participate in a cooperative system which would take steps to clean the river. The script is presented in Box 5.1. This participation decision is a binary 'Yes' or 'No'. Those who were willing to participate in this cooperative system were then given a follow-up question, in which we assigned them random bid amounts, wherein the bids represented the monetary value they would need to pay to make this cooperative work every month. The bids allotted to the respondents are derived from the scoping activities conducted before the survey, and they have been randomised in a way that each bids reaches an equal percentage of respondents. The amounts used in this survey are as follows:

Rs 100, Rs 200, Rs 400, Rs 600, Rs 800, Rs 1,000.

Box 5.1: Survey Script

Despite a plethora of government schemes, initiatives and campaigns, and various court orders, untreated sewage and toxic industrial effluents continue to make their way into the Ganga river.

Water table decreased—slow-moving mud has replaced the gurgling of clear flowing river.

Not all sewage treatment plants are functioning; also, not all the proposed plants have been set up.

The Government and industrialists came together and proposed a water cleaning mechanism, but both the parties are now shrugging off their responsibility and blaming each other for the pollution mess.

Polluted water affects our livelihood, forces us to move to other occupations, creates health hazards, and has other adverse implications.

Failure of the Namami Ganga and ignorance among industrialists about the need to clean the river can lead to two options:

(i) Consider a cooperative system wherein individuals or predominantly the users of the river should come together and take the responsibility to keep it clean and free of pollution.

(ii) The direct users of the river water should be compensated by the polluters for polluting the river in order to counter the adverse livelihood implications of the pollution for the latter.

In this context, I will ask you related questions from the following two scenarios to know your preference.

Part 1: Willingness to Pay

Let us assume that a cooperative system is developed in your village. Mostly all the users who are directly or indirectly dependent on the river are the members of the cooperative system. The members supervise the source and level of pollution and try to revise them. Since the management of the cooperative needs funds, all the users or the villagers will have to pay a certain amount of money to generate the funds. The initiative will clean the water, and make the river water suitable for boating, fishing, or even drinking. The aesthetic value of the river will be preserved, and health hazards, and foul odour of the river water will be done away with, and livelihoods (that is, fishing and washing) will improve. But on the other hand, paying for the river will mean that you may have budget constraints and will have to shift some of the resources from your necessary needs.

Whether you want to participate in such type of a cooperative?

Yes / No

Each respondent was presented with two scenarios; as described above, the first was the respondent's willingness to contribute in monetary terms towards a clean Ganga. The second was a compensation scenario. Fisher folk were asked if they were willing to accept compensation from the polluting industry in exchange for the right to have a clean river Ganga. In other words, the fisher folk were asked whether they were ready to accept some compensation from industries if the latter were ready to buy pollution permits to continue with their industrial discharge.

Box 5.1 …

Part 2: Willingness to Accept Compensation

The other option can be the compensation route. The untreated water from industrial discharges drains into the river, which makes the river polluted. At the outset when industries cannot stop their production or when the sewage treatment plants are not always operational, polluted water keeps on flowing into the river, leading to all the adversities mentioned earlier. Users who are directly or indirectly dependent on the river water would thus require a compensation amount to deal with the level of pollution. Precisely, the deal would be that industries will pay the users of the river to pollute the water. The downside of this deal is that pollution in the river will increase heavily in the long run as industries will no longer treat their water before discharging, and ultimately it will adversely impact the fishes and livelihood.

Whether you would like to receive compensation from industries to participate in the compensation scheme?

Yes/ No

The two concepts of the 'willingness to pay' and 'willingness to accept compensation', as explained in Box 5.1, are plotted in Figure 5.2. The figure addresses two sets of questions delineated below.

The first set of questions pertains to whether the respondents are willing to participate in a cooperative society that will be responsible for preserving the aesthetic value of the river. Conditional on their saying *yes* to the first question, they will be asked a follow-up question as to whether they are willing to contribute in monetary terms to ensure the functioning of such a cooperative. We observed a general acceptance of such a cooperative system among the respondents. Almost 90 and 98 per cent of the respondents in Uttar Pradesh and West Bengal, respectively, were willing to participate in such a venture. However, when they are asked if they were willing to contribute monetarily towards such an initiative, only about 31 and 25 per cent of the respondents in Uttar Pradesh and West Bengal, respectively, were ready to do so. The rest of the respondents expressed their inability to pay the amount, which to them was unaffordable, explained as follows by one respondent:

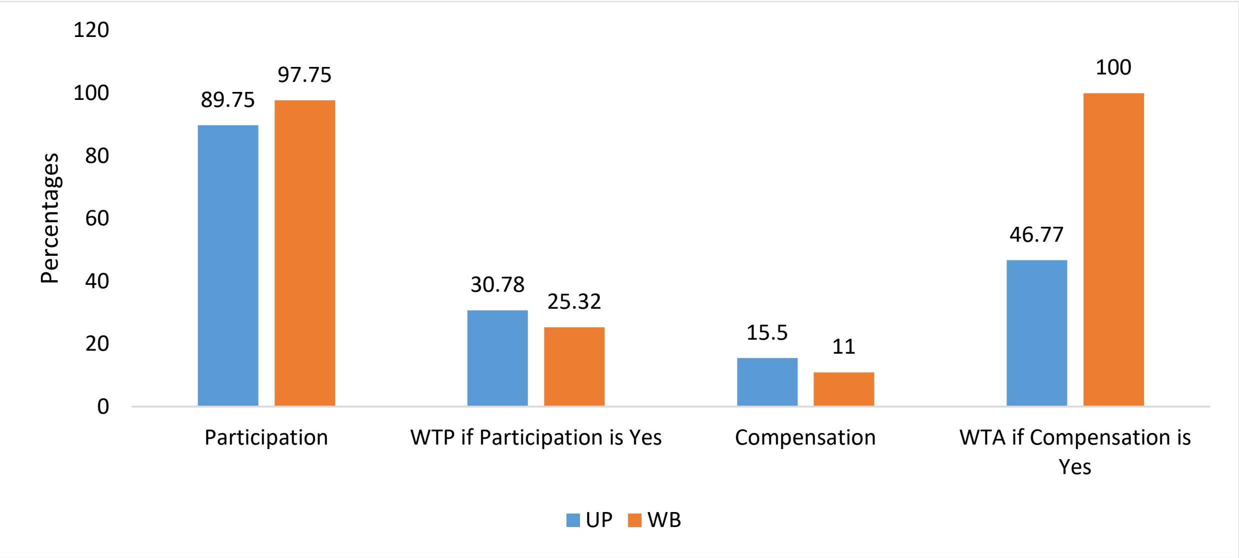
"*Since I am a poor person and am already facing financial difficulties in terms of fulfilling the needs of my family, I am unable to contribute financially towards this initiative*".

Similarly, the second set of two questions asked if the fisher folk were willing to accept a compensation from certain polluting agents. The compensation amount would be the money a fisherman would receive in exchange for the income lost by them due to the pollution of the river. Conditional on whether they would be willing to accept compensation, they were asked if they were willing to accept the monetary compensation for the pollution. We observed that only a handful of people in both the States agreed to receive any compensation, a finding that has a bearing on the divinity of the Ganga as people do not want to pollute *Ganga Maa*, the holy river, which is also a source of livelihood to all. As a respondent in Narora puts it,

> *"Ganga maiya main gandagi karna sweekar nahi ho sakta"*
>
> *(I cannot accept polluting mother Ganga).*

Of those few people who indeed are ready to accept the compensation, almost all in West Bengal and about a half in Uttar Pradesh agree on the compensation amount to be provided to them.

Figure 5.2: Participation and Compensation Decisions (in %)

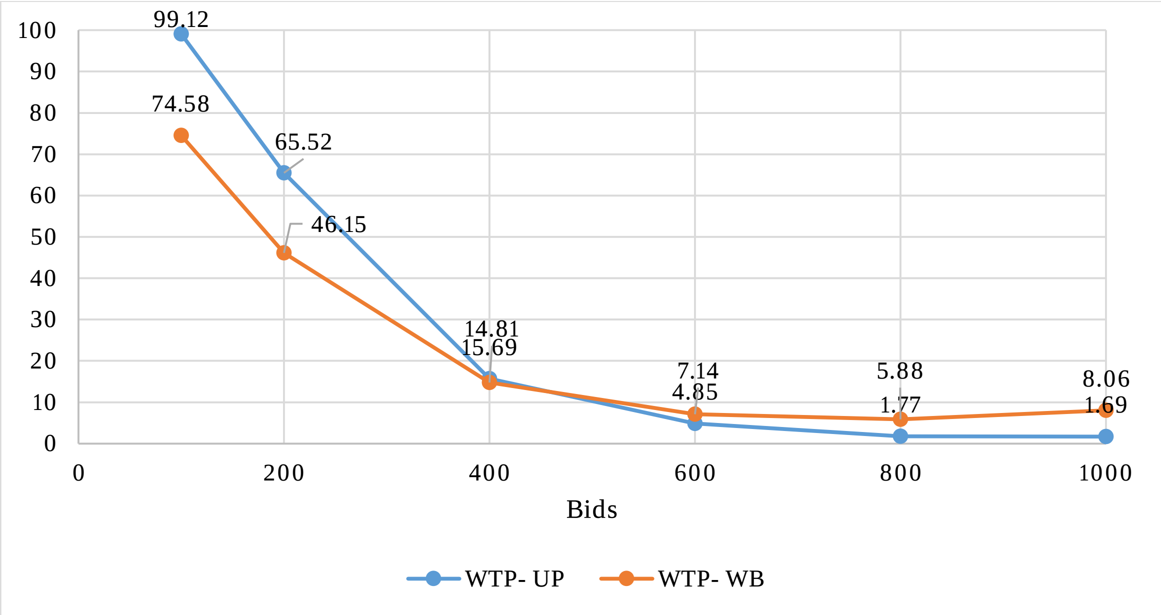


Source: Authors' estimates from the survey.

Note: WTP: Willingness to Pay; WTA: Willingness to Accept.

The plotting of the bid amounts in Figure 5.3 indicates the proportion of respondents who said *Yes* to the random bid values presented to them. Adhering to the economic theory, the line plots a downward sloping curve which implies that the proportion of respondents saying *yes* to the bid amounts decreases as the amount itself increases. For example, of all the respondents who were asked if they would pay Rs 100 per month towards the cooperative society, about 99 per cent said *yes*. The corresponding figure was 75 per cent for West Bengal. When the respondents were asked if they would agree to pay higher amounts, such as Rs 1000 on a monthly basis, only about 9 per cent of the respondents in West Bengal and 2 per cent in Uttar Pradesh said that they were willing to pay.

Figure 5.3: WTP for Formation of a Cooperative (in%)

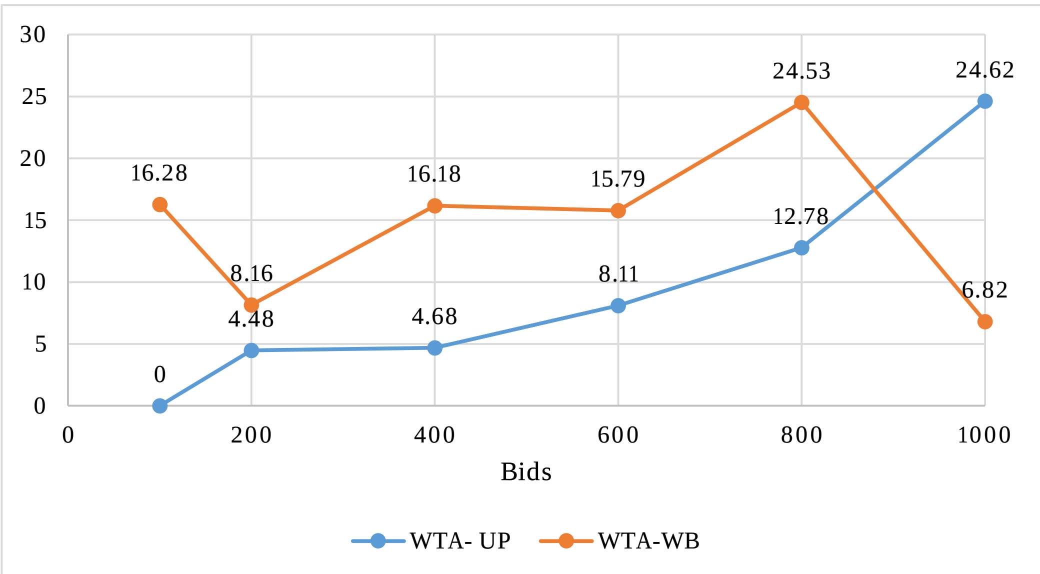


Source: Authors' estimates from the survey.

Note: WTP: Willingness to Pay; WTA: Willingness to Accept.

Similarly, in Figure 5.4, we plot the percentage of respondents willing to accept a random amount as a compensation from industry for giving up the right to a clean river. The line plot shows an upward sloping curve, which depicts the increase in the percentage of respondents willing to accept the bid amount as the amount increases. It may be observed that the WTA for respondents in West Bengal is higher than that for the respondents in Uttar Pradesh, possibly because there is a higher sense of spiritual value for the Ganga river among the respondents in Uttar Pradesh.

Figure 5.4: WTA Compensation from Industries (in %)



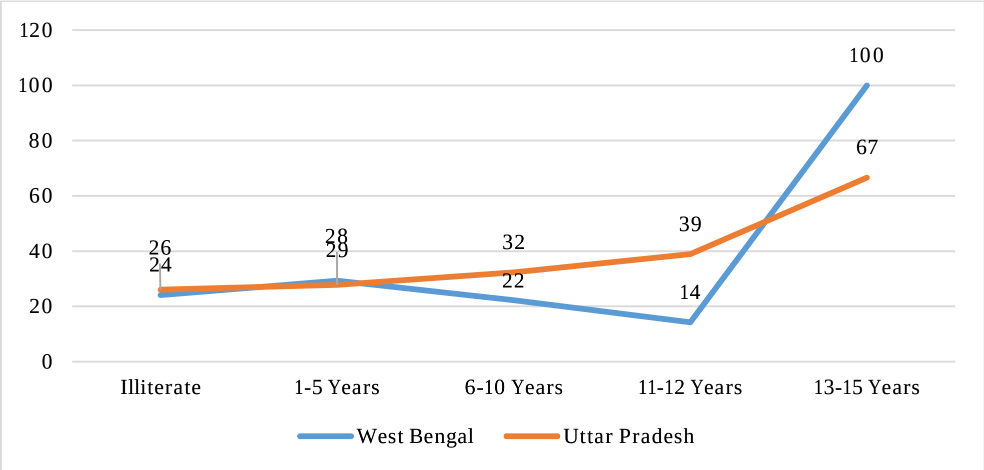
Source: Authors' estimates from the survey.

Note: WTP: Willingness to Pay; WTA: Willingness to Accept.

5.4.2 Association between WTP and Socio-demographic characteristics

Understanding the 'willingness to pay' responses in the context of socio-demographic characteristics is important. Perceptions differ among different groups of people separated by race, culture, education, and social dominance (Levin, 2004) and hence, it would be interesting to see if the WTP responses are more skewed among certain groups than the rest.

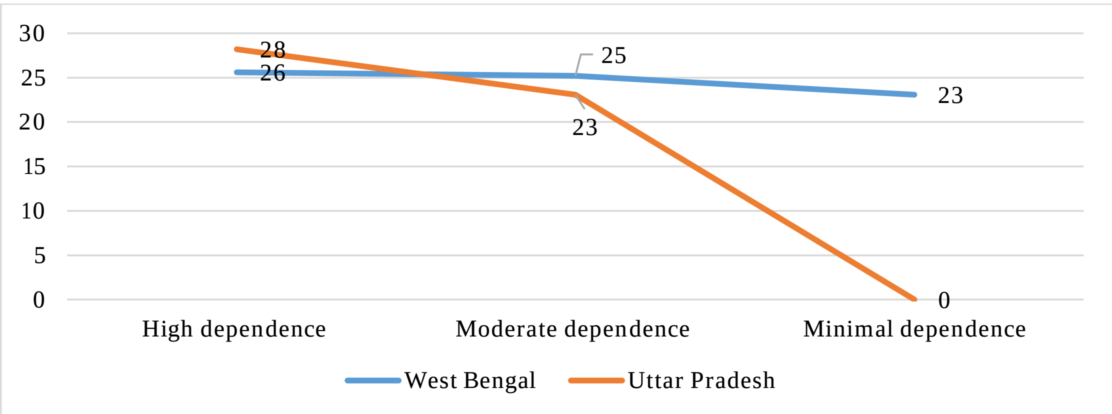
Figure 5.5: WTP by Education Levels (in %)



Source: Authors' estimates from the survey.

Figure 5.5 plots the respondents' willingness to pay with their level of education. For Uttar Pradesh, the association between the WTP and the highest number of years of schooling is more pronounced and positive in comparison to those observed for West Bengal.

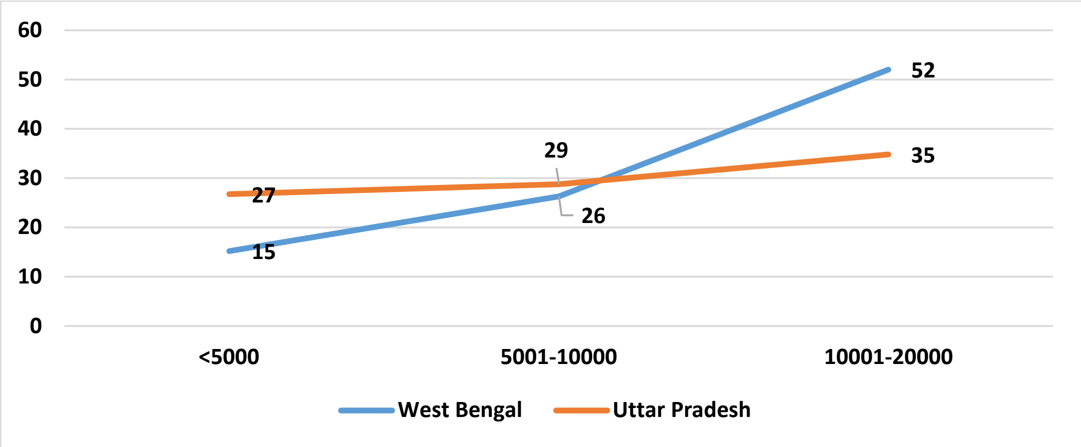
Figure 5.6: WTP by Dependence on the Ganga River (in %)



Source: Authors' estimates from the survey.

Individuals are more likely to contribute towards a public good if they have a higher use of the good. This is reflected in Figure 5.6, where we have plotted the extent of dependence of the people on the Ganga with the preferences revealed by them. There is suggestive evidence, especially for Uttar Pradesh, that with higher dependence, there is a higher tendency to pay for the public good.

Figure 5.7: WTP by Monthly Income Levels (in %)



Source: Authors' estimates from the survey.

Finally, as we plot the WTP by the income levels in Figure 5.7, we find an upward sloping relationship between the given variables, which implies that as the income level increases, the WTP of the respondent also increases. We observe a steeper line plot for West Bengal as compared to that for Uttar Pradesh.

Chapter 6: Water Quality at the Selected Sites

For the socio-economic study two survey sites were selected each from Uttar Pradesh and West Bengal. The survey sites in Uttar Pradesh, that is, Narora and Unnao, lie in Segment IIIA whereas those in West Bengal, that is, Jangipur and Tribeni, lie in Segment IVB (CPCB, 2015). Along with the socio-economic survey, we also conducted water experiments in the respective river stretches. The segment-wise water quality has been discussed in this chapter in order to understand the suitability of the river water for aquatic life and bathing, and also to subsequently identify the major pollution hotspots in the selected stretches of the river.

6.1. The Narora Water Experiment

6.1.1 Background

Narora is a small town located on the right bank of the river Ganga in the Bulandshahr district of Uttar Pradesh. It falls under Segment IIIA; the study area has the Narora Atomic Power Station (NAPS) close to the river bank, along with the bathing *ghat*s and temples on the right bank. However, sediment is deposited on the left bank of the river where agricultural activities are prominent. Just at the upstream of the main *ghat* is the Narora barrage, which diverts river water for irrigation through the canal. This opening and closing of the barrage gate has a significant influence on both the river flow and its water quality. A total of six boat rides were conducted here, and in each of the boat rides we covered an area of 6.5 km, and measured various water quality parameters, including pH, dissolved oxygen (DO), electrical conductivity (EC), turbidity, temperature, Chlorophyll-a (CHL-A), tryptophan, and coloured dissolved organic matter (CDOM), using the field sensors. The general river water quality in the area was found to be good. Apart from the field parameters, we also collected 12 samples from the river and tested them in the laboratory (Figure 6.1).

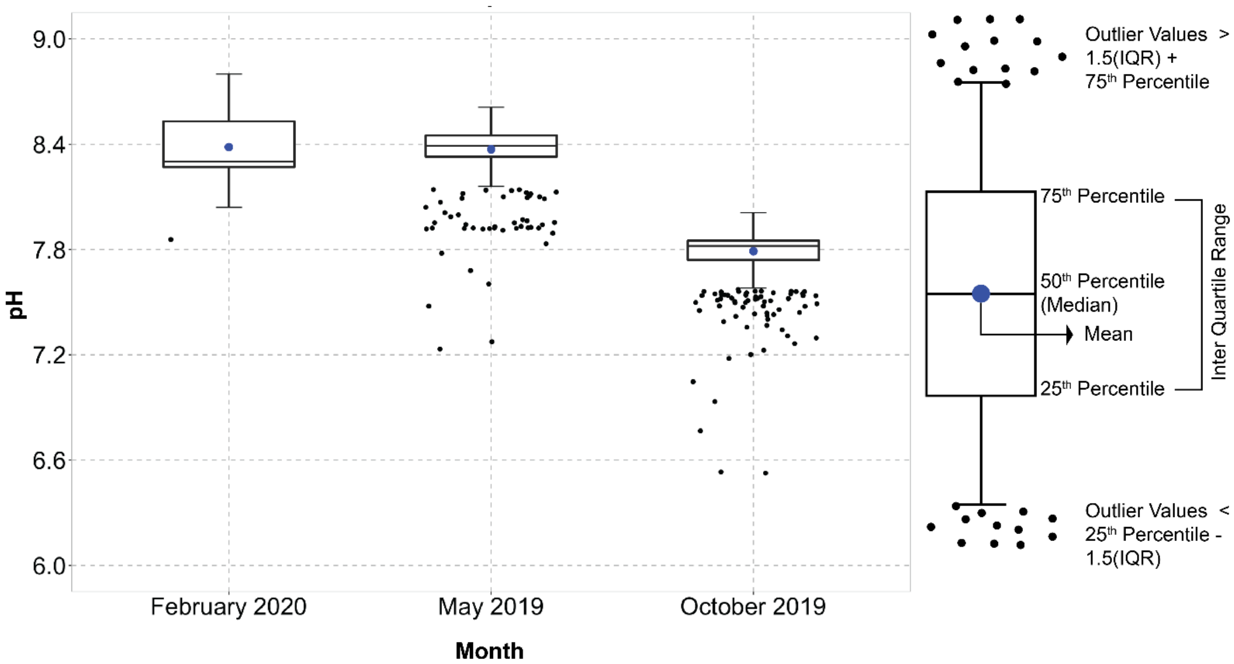
Figure 6.1: Boat Ride Route for Narora along with the Sample Collection Points

Source: Sampling points plotted on Google Earth by the 'Water to Cloud' team.

6.1.2 River Water Quality: The Boat Experiment

The boat rides for data collection start from the Gandhi *ghat* near the Narora barrage, and go up to 6.81 km downstream. Approximately, 1020 points were collected in the months of May and October 2019, and in January and February 2020, using multipara meter sensors. In addition to the field testing, 12 water samples were collected per boat ride per laboratory analysis. A summary of the descriptive analysis (Table 6.1) shows that the river water is within the CPCB standards for outdoor bathing, irrigation, and propagation of wild life and fisheries based on the average value of pH, DO, and EC (CPCB, 2003). The standard deviation for turbidity and CHL-A is high as compared to the other parameters, implying that the value of turbidity and CHL-A are changing the most. The maximum and minimum temperatures recorded were 32.63°C and 14.81°C during the months of May and January, respectively. The DO values were low in January, falling to a minimum of 5.52 mg/l, which is within the standard limits for the survival of aquatic life. The relatively stable levels of DO >5.52 mg/l indicate that the river has enough DO to support aquatic life in it.

Figure 6.2: Monthly Variations in pH at Narora (except in January 2020)



Source: Authors' estimates from water experiments conducted during the study.

When the pH of the Ganga river in Narora was measured, it ranged from 6.53 to 8.61. Although a pH of 7.4 is considered optimal in the river, the measured pH values still fall in the suitable range for supporting most of the river life (Figure 6.2). CHL-A is predominant in green plants and algae, as it allows plants (including algae) to photosynthesis, that is, use sunlight to convert simple molecules into organic compounds. Since there are no defined limits for CHL-A in rivers, the values obtained are similar to those seen in oligotrophic lakes (that is, with low nutrients) in terms of chlorophyll concentration. The river water has a low level of nutrients and high oxygen content throughout the stretch, suggesting that its water is suitable for the survival of aquatic life.

Table 6.1: Descriptive Statistics of Water Quality Parameters at Narora

	Temper-ature	pH	EC	DO	Turbi-dity	CHL-A	Tryptophan	CDOM
Narora, May 2019								
Mean	31.22	8.3	152.24	8.61	69.89	NA	NA	NA
Std. Dev.	0.49	0.1	4.13	0.9	137.54	NA	NA	NA
Max.	32.63	8.6	161	10.48	1000	NA	NA	NA
Min.	30.13	7.2	104	5.52	25	NA	NA	NA
Narora, October 2019								
Mean	25.61	7.8	158.05	8	156.96	408.27	25.29	170.31
Std. Dev.	0.35	0.1	67.52	0.48	86.4	88.21	6.54	46.08
Max.	26.43	8.0	1514	9.67	985	1361.6	94	602.92
Min.	24.07	6.5	7	6.39	93.7	12.8	8.96	0
Narora, January 2020								
Mean	15.56	NA	208.76		44.17	143.11	29.87	199.03
Std. Dev.	0.55	NA	8.11		21.27	40.37	4.03	34.71
Max.	18.08	NA	216		126	643.96	45.96	294.16
Min.	14.63	NA	150		10.6	0	0	0
Narora, February 2020								
Mean	20.39	8.3	199.09	7.38	73.34	768.51	33.55	206.63
Std. Dev.	0.85	0.1	5.74	0.2	54.33	132.63	4.84	13.88
Max.	25.67	8.8	207	8.08	897	1254	98	241.2
Min.	19.46	7.8	100	7	13.1	203.6	15.36	67.36

Source: Authors' estimates from water experiments conducted during the study.

6.1.3 Association between Field Parameters

A correlation analysis has been performed to understand the association between the sensor parameters. The results suggest that pH is strongly correlated with the temperature. With increase in temperature, increase in photosynthesis is observed, which leads to increase in the pH. Temperature shows moderate positive association with CHL-A, however, positive but not much significant association with DO, as shown in Table 6.2. The pH and DO have positive correlation on 0.46, but as it has been documented that oxygenation of water is not proportional to the pH (Hyslope et al., 2015) and external factors are likely to account for this apparent correlation. The study area does not have any major drains coming into the river, and the barrage gates are opened and closed frequently, which might lead to a washout of the pollutant when the gates are opened.

Table 6.2: Correlation between Water Quality Parameters at Narora

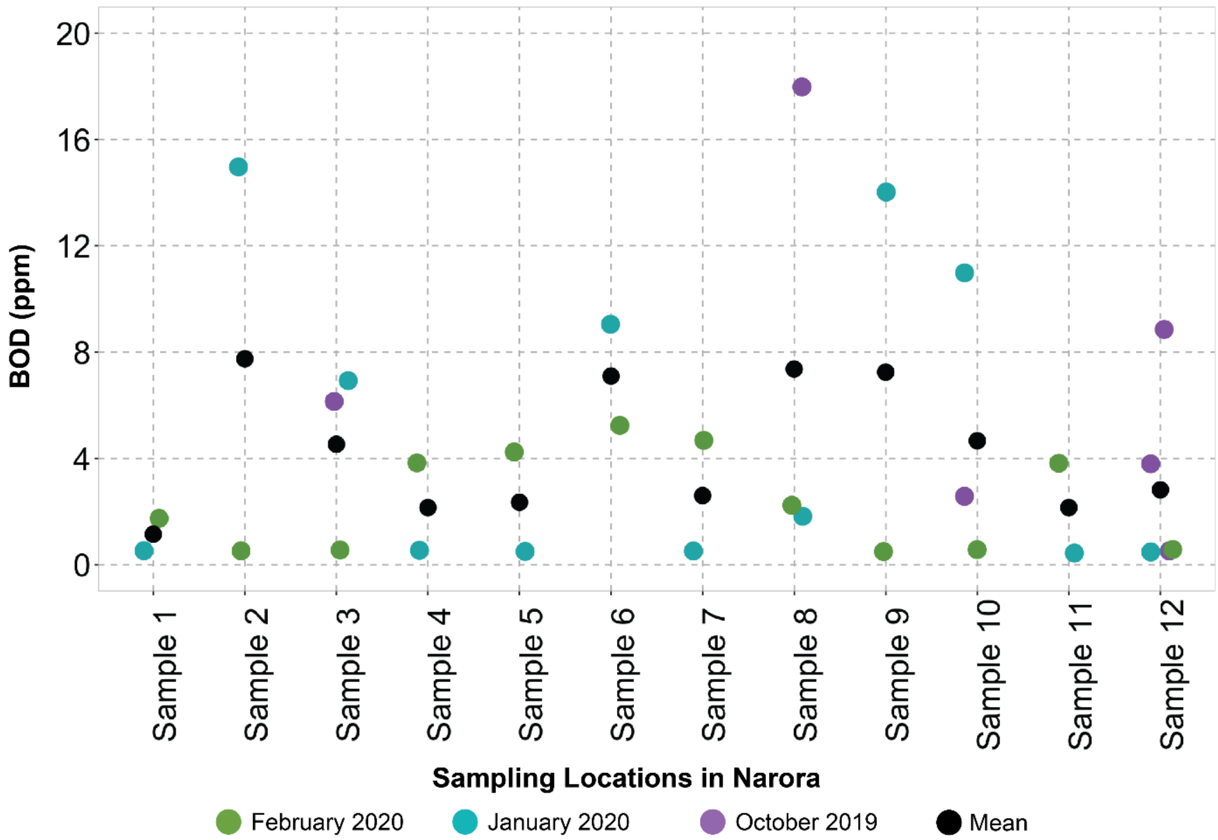
	Temp	pH	EC	DO	Turbidity	CHL-A	CDOM	Tryptophan
Temp	1							
pH	**0.94**	1						
EC	-0.14	-0.06	1					
DO	0.39	0.46	0.07	1				
Turbidity	-0.2	-0.27	0.2	0.06	1			
CHL-A	**0.62**	0.12	-0.23	-0.31	0.09	1		
CDOM	-0.2	0.02	0.02	-0.03	-0.16	-0.08	1	
Tryptophan	-0.2	-0.27	-0.01	0.1	0.04	-0.11	-0.05	1

Source: Authors' estimates from water experiments conducted during the study.

6.1.4 Water Quality of the Grab Samples

The river water samples were collected from 12 sampling locations and the samples were taken to the laboratory for analysis (Figure 6.1). The samples were analysed for EC, pH, turbidity, DO, nitrate (NO_3), nitrite (NO_2), sulfate (SO_4), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), faecal coliform (FC), and Total coliform (TC). The samples were collected in the months of October, January and February 2020. Based on the laboratory results, the water quality was found to be adequate for the survival of aquatic life, as all the parameters except BOD were found to be within the limits for both outdoor bathing and aquatic life (>3 mg/L). A high BOD was found throughout the sampling area in October 2019 but in January and February 2020, five out of 12 samples had high BOD values (Figure 6.3). Not all the barrage gates are open most of the time, which restricts the volume/flow of water and provides ample time for microbial growth, resulting in a high BOD level. High levels of BOD also point to high microbial activity, resulting in a rapid fall in the DO, with a potential threat to the aquatic biodiversity.

Figure 6.3: Spatial and Monthly Variations in BOD Concentrations at Narora



Source: Authors;' estimates from water experiments conducted during the study.

6.2. The Unnao Water Experiment

6.2.1 Background

Unnao is located on the left bank of the Ganga river, which separates the Kanpur and Unnao districts in Uttar Pradesh. The sampling site for the experiment falls under Segment III B of the Ganga river; it covers a total length of about 5.16 km, which includes the banks of the river in the Kanpur and Unnao districts (Figure 6.4). A total of seven boat rides were conducted, but due to the unavailability of motor boats, a hand-driven boat was used for experiments, collecting about 390 sample points, on an average, per boat ride using sensors. In addition, five water samples were collected for laboratory tests from pre-decided (Table 6.3). The study site contains an ordinance equipment industry, *ghat*s (for cremations and bathing), and agricultural and household areas. The barrage at the upstream of the river has a major influence on the river water quality and flow of the river. The deposited sediment (sand belts) in the middle of the channel bifurcates the main stream (Figure 6.4). This sand bed has a major influence on the river flow, as the stream on the Kanpur side has a relatively low width and less flow as compared to the one on the Unnao side.

6.2.2 River Water Quality: The Boat Experiment

The concentration of field parameters, including temperature, pH, EC, DO, turbidity, CHL-A, CDOM, and tryptophan were collected and analysed during the months of January, May, and December, 2019 and January and February, 2020. A summary of the descriptive analysis shows that the river water quality is within the CPCB standards for outdoor bathing, irrigation, and propagation of wildlife and fisheries based on the average values of pH, DO, and EC.

Table 6.3: Details of the Location Selected for Collection of Samples for Laboratory Analysis

Site Name	Details of the Sample Sites
Start/End-point	Point where boat ride is started or ended in Shuklaganj, Unnao.
Burning *Ghat*	Point where cremations take place and a multiple household wastewater outlet is present
River Upstream	Upstream of the river
Sisamau *Ghat*	Point where a multipurpose *ghat* is present, and religious activities, bathing, and washing take place
Guptar *Ghat Nala*	Outlet of the drain

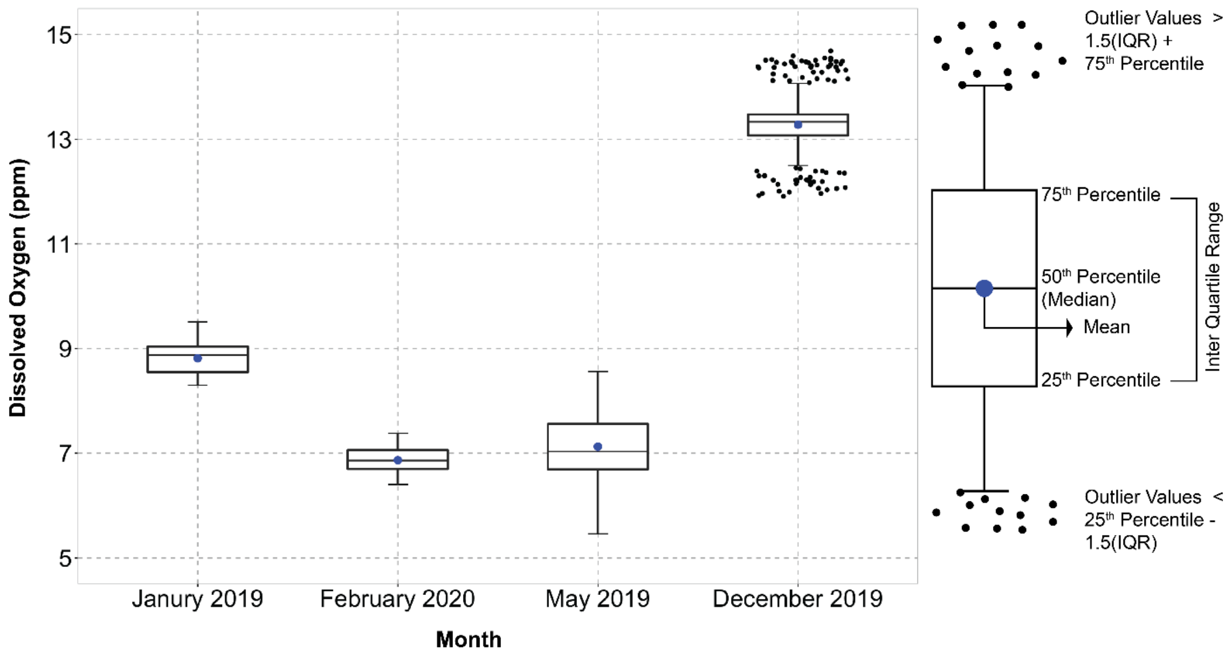
The average temperature was relatively high in May 2019 and February 2020 but the average temperature in other months varied between 15°C and 16°C. While the month of May falls under the summer season, the temperature starts rising after mid-February, and the increase in the surface/air temperature influences the water temperature. The variation in temperature significantly affects other water quality parameters, including the DO concentration. An analysis of the average values of DO indicates that the lowest DO was observed in the winter months characterised by low temperature, whereas in summer, the DO was found to be high. With increasing temperature and longer hours of sunlight, there was also an increase in the rate of photosynthesis, which is responsible for the relatively high concentration of DO in the water bodies.

Figure 6.4: Sampling Location and Boat Route for Unnao

Source: Sampling points plotted on Google Earth by the 'Water to Cloud' team.

The value of DO was found to be > 5 mg/L throughout the sampling months, which suggests that water has an adequate quantity of oxygen to support the growth of aquatic life, including fish (Figure 6.5). The pH of the river tilts towards an alkaline scale, but still complies with average CPCB standards. A high concentration of pH in the river water has a significant impact on the solubility of ions and hardness (Şener et al., 2017). The average values indicate that the turbidity was high in December 2019 and low in February 2020. The barrage gates were open in December, which might have disrupted the surface sediment, whereas in February, fewer gates were open and the river had a stable flow, which allowed the particles to settle down, resulting in low turbidity.

Figure 6.5: Monthly Variations in the DO at Unnao (except in January 2020)



Source: Authors' estimates from water experiments conducted during the study.

The organic contaminants, including CHL-A and CDOM, were found to be high in January 2019 as compared to the other months. CHL-A is an indicator of the presence of an algal biomass and indicates the amount of photosynthetic community or algae in water. However, CDOM represents a large proportion of dissolved organic matter, including terrestrially derived humic and fulvic acids. Variations in CDOM are the result of natural processes, including changes in the amounts and frequency of precipitation, as well as human activities such as logging, agriculture, effluent discharge, and wetland drainage, which can affect CDOM levels in fresh water systems. The prevalence of high concentrations of CDOM and CHL-A, along with relatively high presence of DO in the river points to a high concentration of phytoplankton. The tryptophan values were found to be high in January 2020, but the lowest average tryptophan content was found in February 2020, which points to a high level of faecal contamination in January as compared to the other months.

6.2.3 Association between Field Parameters

The correlation analysis of sensor parameters shows a negative but strong association between temperature and the DO, which indicates relatively low photosynthesis and phytoplankton growth in the low-temperature seasons (Table 6.4). Temperature and tryptophan content have a good negative correlation with the DO. However, a negative association was also observed between the DO and EC; EC restricts the dissolution of oxygen, resulting in low DO in the water (Stiff et al., 1992). Since the solubility of oxygen and other gases decreases with an increase in the temperature, higher temperature lowers the DO. High tryptophan indicates presence of microbial communities, especially faecal coliforms, which consume dissolved oxygen, leading to a decrease in DO values. Turbidity, which indicates presence of suspended particles in water, is also inversely associated with DO as suspended particles absorb heat, which increases the water temperature and reduces DO values , in turn, lowers the DO levels. They also prevent sunlight from reaching the plants below the surface. This decreases the rate of photosynthesis, thus reducing the quantity of oxygen produced by plants. However, in the case of Unnao, turbidity had a good positive correlation with the DO. One of the reasons for the high turbidity and DO content could be the mixing of water/high flow rate, which increases the surface adsorption of atmospheric oxygen in the water. The moderate but negative association between DO and tryptophan points to high microbial activity, leading to the breakdown of faecal contaminants, resulting in a lowering of the DO concentration. The positive association between CDOM and CHL-A also indicates a similar origin of these organic contaminants (Table 6.4).

Table 6.4: Association between Field Parameters at Unnao

Parameters	Temp-erature	pH	EC	DO	Turbidity	CHL-A	CDOM	Tryptophan
Temp	1							
pH	-0.08	1.00						
EC	-0.39	**0.6**	1.00					
DO	**-0.63**	-	-0.43	1.00				
Turbidity	-0.46	-	-0.28	**0.71**	1.00			
CHL-A	-0.17	-	-0.18	-0.01	0.24	1.00		
CDOM	-0.27	-	0.03	0.07	0.19	**0.51**	1.00	
Tryptophan	0.12	0.10	0.17	**-0.59**	-0.43	0.25	0.27	1

Source: Authors' estimates from water experiments conducted during the study.

6.2.4 Water Quality of the Grab Samples

The river water samples were collected from five sampling locations and the samples were taken to the laboratory for analysis (Figure 6.4). The details of the sampling location are provided in Table 6.5. The samples were analysed for EC, pH, turbidity, DO, nitrate (NO_3), nitrite (NO_2), sulfate (SO_4), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Faecal Coliform (FC) and Total Coliform (TC). The samples were collected in January 2020. Based on the water quality parameters in January, the dissolved oxygen concentration across the sampling locations was found to be adequate for the survival of aquatic life. Apart from the DO, the other physical parameters, including EC and pH, were also found to be within the limits for both outdoor bathing and aquatic life. All the parameters except BOD were found to lie within the prescribed limits (Table 6.5). High values of BOD (>3 mg/l) were found at the Sisamau *Ghat* and close to the Guptar *Ghat Nala*, indicating high organic contamination at these locations, which, in turn, is responsible for the high BOD. The Sisamau *ghat* area is where religious activities, bathing, and washing take place. However, Guptar *ghat* has an outlet of a major drain coming from the city. This drain may be a major source of organic contaminants, and therefore, responsible for deterioration in the quality of water needed for the survival of aquatic life. Both these sites fall along the Kanpur side, and as discussed above, the flow of the river channel is relatively low, which does not allow the pollutants to disperse.

Table 6.5: Results of the Laboratory Point Samples Collected in January 2020 from Unnao

Parameters	Conductivity	pH	Turbidity	DO	NO_3	COD	BOD	NO_2	SO_4	TC	FC
Start/End-point	230	8.02	33	7.9	0.23	4	BDL	0.29	18.5	140	60
Burning *ghat*	296	7.98	23	7.8	0.15	8	1.3	0.29	19.67	170	70
River Upstream	254	7.96	24	7	0.17	4	BDL	0.3	19.41	110	60
Sisamau *ghat*	271	7.89	30	7.8	0.13	12	3.5	0.3	20	130	70
Guptar *ghat nala*	228	7.86	13	6.8	0.17	12	3.8	0.3	19.22	140	80

Source: Authors' estimates from water experiments conducted during the study.

6.3. The Jangipur Water Experiment

6.3.1 Background

Jangipur is situated along the right bank of the river downstream and falls under Segment IV-B, whereas Raghunathganj is situated along the left bank of the river (CPCB, 2015). In the absence of any major industries here, the potential sources of pollution are domestic wastes and human–river interactions such as fishing, bathing, cleaning, plying of motor boats, presence of temples, cremation, and other religious activities. The experiments were conducted using mobile sensors starting from the Jangipur main *ghat* to the Bishnathpur bathing *ghat* upstream and downstream at the Soijapur boat point (Figure 6.6). The total length of the boat ride was approximately 16 km. In order to examine the water quality in the *ghat* area, water samples were collected and tested in the laboratory. The sampling points were decided based on the characteristics of the waste discharged into the river from both its banks. We collected at least one sample for each type of potential pollution source from both the banks. We collected a total of 10 samples, including five from each bank, and the river at Jangipur was relatively clean, with no major industry/waste discharge seen along the river. Details of the selected sites are provided in Table 6.6.

Table 6.6: Details of the Point Samples Collected from Jangipur

Sampling No.	Details of the Location (Jangipur)
Sample 1	Water supply inlet
Sample 2	Bathing *gh*at and temple (Jangipur)
Sample 3	Stream meeting point
Sample 4	Bathing *ghat*, Baperpur
Sample 5	Jangipur cremation *ghat* and temple area
Sample 6	Soijapur boat point and bathing *ghat*
Sample 7	Piarapur burning/bathing *ghat*
Sample 8	STP outlet near bridge
Sample 9	Boat point Raghunathganj;
Sample 10	Bishnathpur bathing *ghat*

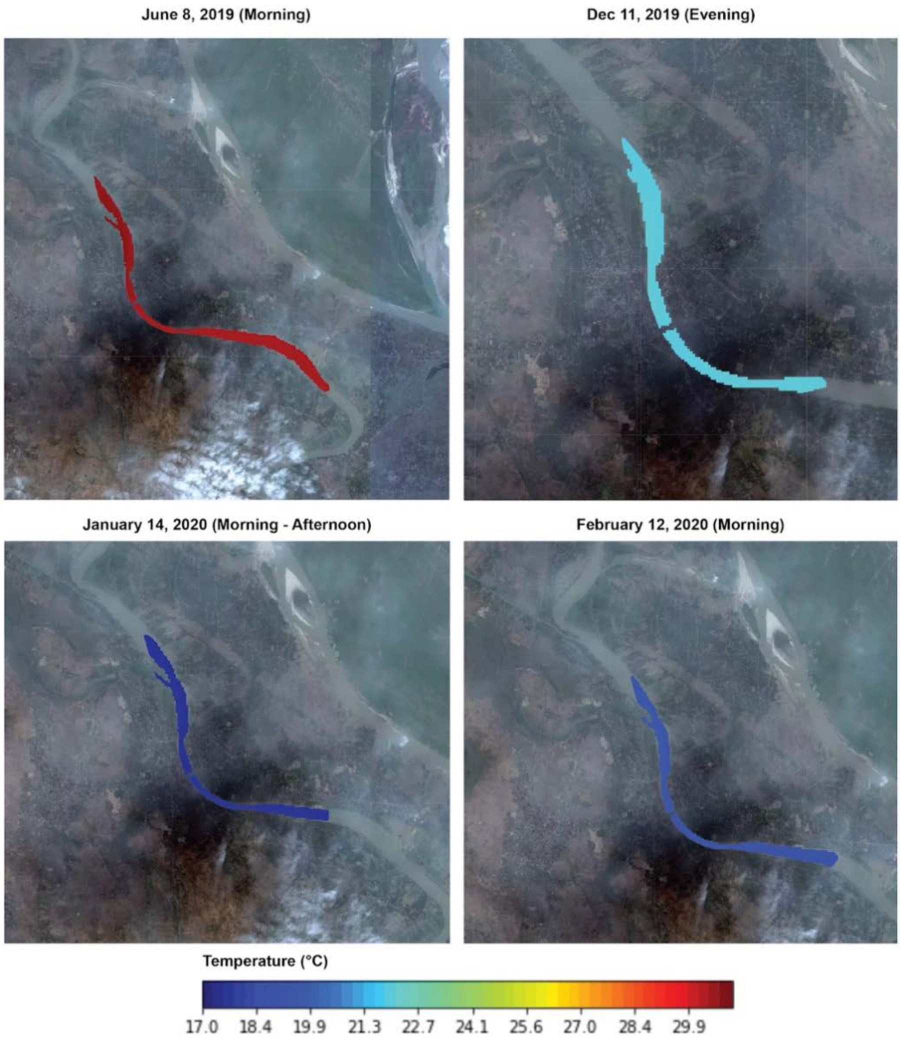
Figure 6.6: Boat Path and Locations of the Point Samples Collected from Jangipur

Source: Sampling points plotted on Google Earth by the 'Water to Cloud' team.

6.3.2 River Water Quality: The Boat Experiment

The concentration of field parameters, including temperature, pH, EC, DO, turbidity, CHL-A, CDOM, and tryptophan, was analysed in the months of June and December 2019, and January and February 2020. The temperature of the river water was found to be relatively high in June 2019 as compared to the other months due to the seasonal effect (Figure 6.7). The surface/air temperature varies from 30°C to 45°C in summer (March-mid June), which influences a corresponding increase in the river water temperature during this period. However, the lowest average temperature, 17.45°C, was found in January 2020. Temperature has a significant impact on other water quality parameters, especially on the concentration of dissolved oxygen. High temperature results in a low DO, which adversely affects fish, insects, zooplankton, phytoplankton, and other aquatic species in the water bodies.

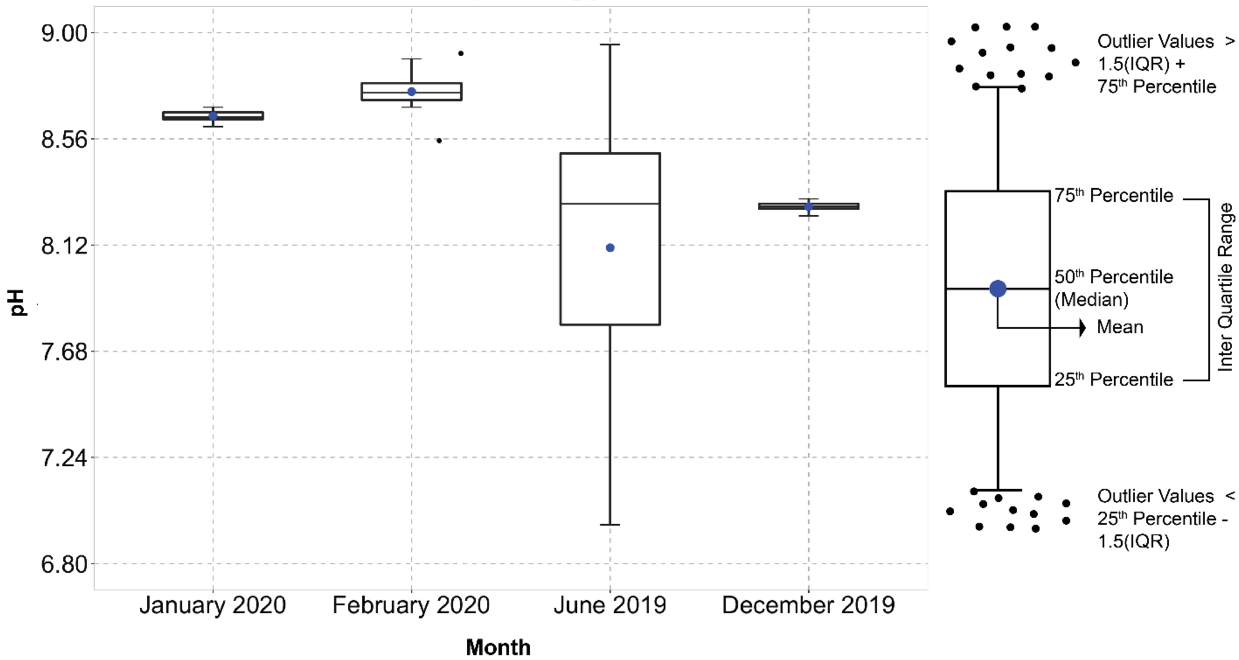
Figure 6.7: Monthly Change in Water Temperature Using Field Sensors at Jangipur



Source: Heat maps prepared by the 'Water to Cloud' team (http://thoreau.uchicago.edu/).

According to the CPCB guidelines, water should not have any odor for outdoor bathing standards. But the range of pH for water should be between 6.5 and 8.5. However alkaline pH might also affect the concentration of ammonia in river water. A low pH of <6.5 could influence the growth of invasive aquatic species of planktons and lead to the disappearance of fishes or smallmouth bass. While a wide range of pH values has been observed at Jangipur, the average pH values were found to be within the CPCB's permissible limits in June and December 2019. However, in January and February 2020, the average pH values exceeded the CPCB range of 8.5 (Figure 6.8). The pH exceeding the range could affect aquatic life, especially the adult fish, as it may cause damage to the outer parts of their bodies, including the gills and eyes. An increase in pH with an increasing temperature in the surface water bodies is often associated with photosynthesis. During the months of January and February 2020, the average concentration of the photosynthetic pigment, that is, chlorophyll, was also found to be high. A high rate of photosynthesis results in precipitation of carbonates of calcium and magnesium from bicarbonates imparting alkalinity in the surface water bodies (Omer, 2010; Rai et al., 2011).

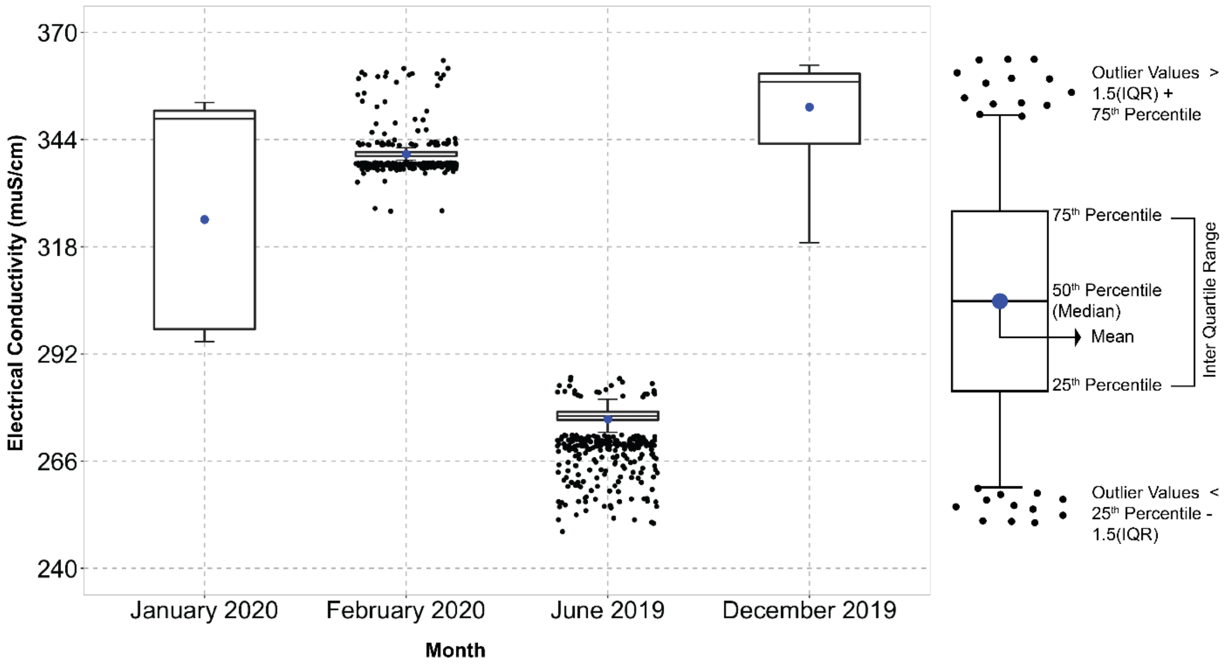
Figure 6.8: Box Plot Representing Monthly Variations in pH at Jangipur



Source: Authors' estimates from water experiments conducted during the study.

The fact that the DO was found to be above 5 ppm indicates that the quality water is good enough to support the survival of aquatic organisms. Based on the average concentrations, the highest EC figures were recorded in December 2019, followed by that in January 2020, February 2020, and June 2019 (Figure 6.9). The low EC figures during the pre-monsoon months or in summer point to a low level of ionic activities in the river. However, the maximum values of TDS were found in February 2020, followed by December 2019, January 2020, and June 2019. The values of TDS and EC were found to be within the permissible CPCB limits, which allow for outdoor bathing and enable aquatic life to flourish. Interestingly, like TDS, high level of turbidity was also observed in February 2020. An interesting observation from the field pertained to the construction of a concrete *ghat* during the months of January and February 2020. The flow of the river was low as the gates of the Farakka barrage were closed, and boulders, pebbles, and sand were deposited on the river bank. The dissolution of these deposits on the bank of the river and the presence of a high level of organic matter could be two of the reasons for the high turbidity and TDS in the river in February 2020.

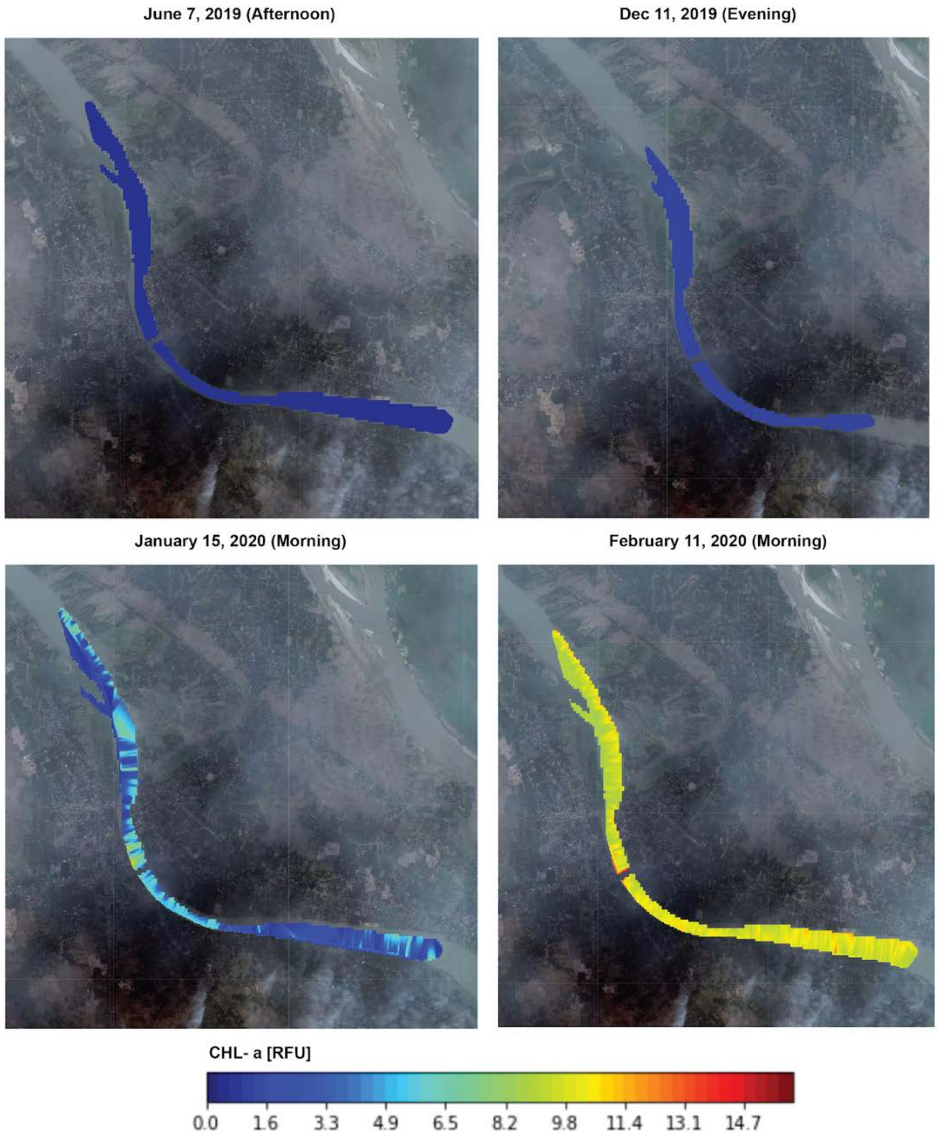
Figure 6.9: Box Plot Representing Monthly Variations in Electrical Conductivity at Jangipur



Source: Authors' estimates from water experiments conducted during the study.

The levels of organic contaminants, including CHL-A and CDOM, were found to be high in February 2020 as compared to the other months (Figure 6.10). The concentrations of CHL-A and CDOM are indicators of the growth of phytoplankton and concentration of organic matter in the river water. The high concentrations of CDOM and CHL-A along with relatively high DO levels also suggest high phytoplankton activity. The gates of the Farakka barrage were open for bank construction, resulting in a low flow and conducive environment for growth of phytoplankton, resulting in an increase in the DO levels. The growth of water hyacinth near Roshan Bridge also points to the high growth of phytoplankton in the river, which may have also impacted organic contaminants in the river. In addition, leaves from the trees along the river bank and agricultural run-off could also be responsible for the presence of high organic indicators in the water. High concentrations of tryptophan were also observed in the months of January and February 2020, indicating a relatively high microbial activity and faecal coliform concentration.

Figure 6.10: Spatial Distribution and Monthly Variability of CHL-A at Jangipur



Source: Heat maps prepared by the 'Water to Cloud' team (http://thoreau.uchicago.edu/).

6.3.3 Association between Field Parameters

The correlation analysis of the field parameters suggests a negative but strong association between temperature and EC/TDS. Low EC and TDS levels were observed in June, which has a relatively high temperature as compared to the other months. Temperature has a strong positive relation with the DO, which suggests a high degree of photosynthesis by phytoplankton, but the reasons for the negative relation with CHL-A and CDOM are not well understood. In ideal conditions, temperature should have a positive relation with these parameters as an increase in the temperature leads to an increase in both growth and photosynthesis, which, in turn, should lead to high values of CDOM and CHL-A. However, it is possible that anthropogenic activities may have affected this association. Apart from temperature, the EC value, as well as the CHL-A and CDOM values, also have a significant negative association with the DO. The EC has a positive association with organic load indicators, though the association with tryptophan and CHL-A is not very significant, indicating that the major ionic activities in the river may be attributed to organic pollutants. A high concentration of organic wastes increases the demand for DO, thereby resulting in a decrease in the DO concentration (Table 6.7).

Table 6.7: Association between Field Parameters at Jangipur

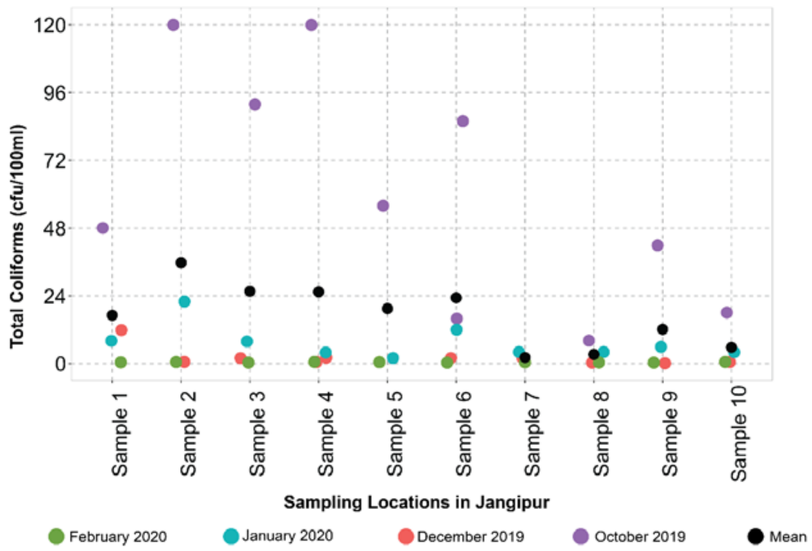
	Temperature	pH	EC	TDS	DO	Turbidity	CHL-A	CDOM	Tryptophan
Temperature	1								
pH	-0.49	1							
EC	**-0.95**	0.46	1						
TDS	**-0.95**	0.46	1	1					
DO	**0.71**	-0.37	**-0.73**	**-0.73**	1				
Turbidity	-0.32	-0.02	0.41	0.41	-0.18	1			
CHL-A	**-0.64**	0.43	0.42	0.42	**-0.58**	-0.09	1		
CDOM	**-0.79**	0.43	**0.66**	**0.66**	**-0.61**	0.02	**0.77**	1	
Tryptophan	-0.4	0.39	0.24	0.24	-0.48	-0.11	**0.77**	**0.63**	1

Source: Authors' estimates from water experiments conducted during the study.

6.3.4 Water Quality of the Grab Samples

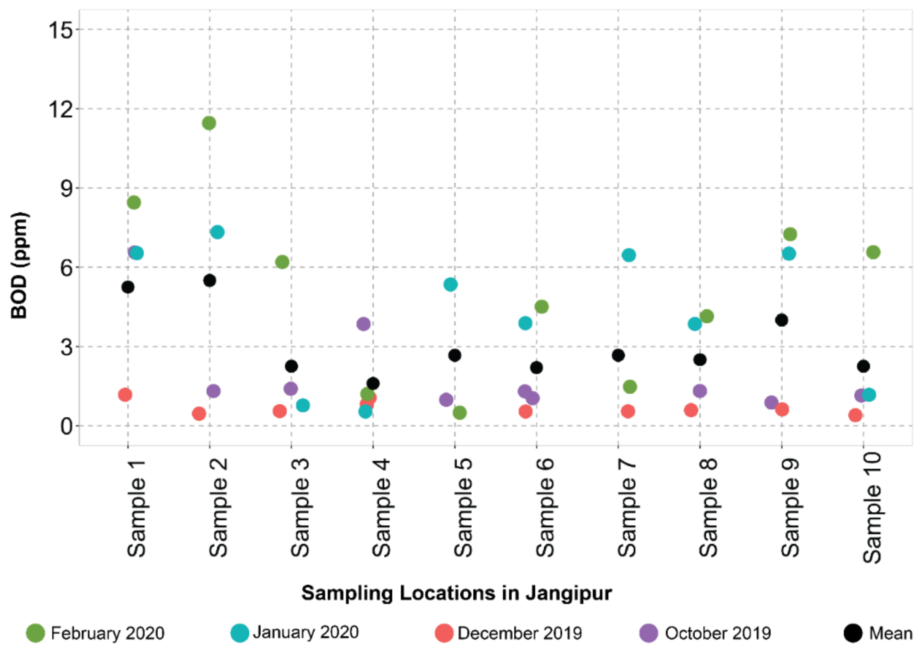
The river water samples were collected from ten sampling locations during the months of October and December 2019, and January and February 2020, and the samples were taken to the laboratory for analysis (Figure 6.6). The samples were analysed for EC, pH, turbidity, DO, nitrate (NO_3), nitrite (NO_2), ammonia (NH_4) Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), faecal coliform (FC), and Total coliform (TC). The results from the laboratory analysis showed that two sampling points, that is, two bathing *ghats* near the temple at Jangipur and at Soijapur, respectively, had high TC values in October 2019, which were above the recommended limits for outdoor bathing (Figure 6.11). High BOD levels of >3 mg/L and FC (not above the recommended limits) were also observed at these locations, indicating a high load of organic contaminants at these points. Since October is a post-monsoon month, the run-off from the adjoining areas could be one of the reasons for the presence of a high organic load. Moreover, October is also a month of festivals in the study region, and the disposal of festival-related wastes containing fruits, flowers, and other organic material at these points could be one of the reasons for the prevalence of high TC and BOD levels. The other sampling locations were respectively safe for bathing and other uses. All the parameters were found to fall within the range in December 2019, which suggests that the water was usable for bathing and other human use. However, in January and February 2020, high BOD levels were observed at most of the sampling locations (Figure 6.12). The low flow in the river due to the closing of the barrage gate for the construction of a concrete *ghat* be one of the reasons for high microbial activities and organic load in the river. A high DO content > 5 mg/l was found along with significant amounts of NO_3 and SO_4 with low levels of NH_4 and NO_2, which suggests that the river had adequate oxygen for the survival of aquatic life.

Figure 6.11: Spatial and Monthly Variations in Total Coliform Concentration at Jangipur



Source: Authors' estimates from water experiments conducted during the study.

Figure 6.12: Spatial and Monthly Variations in BOD Concentrations at Jangipur



Source: Authors' estimates from water experiments conducted during the study.

6.4 The Tribeni Water Experiment

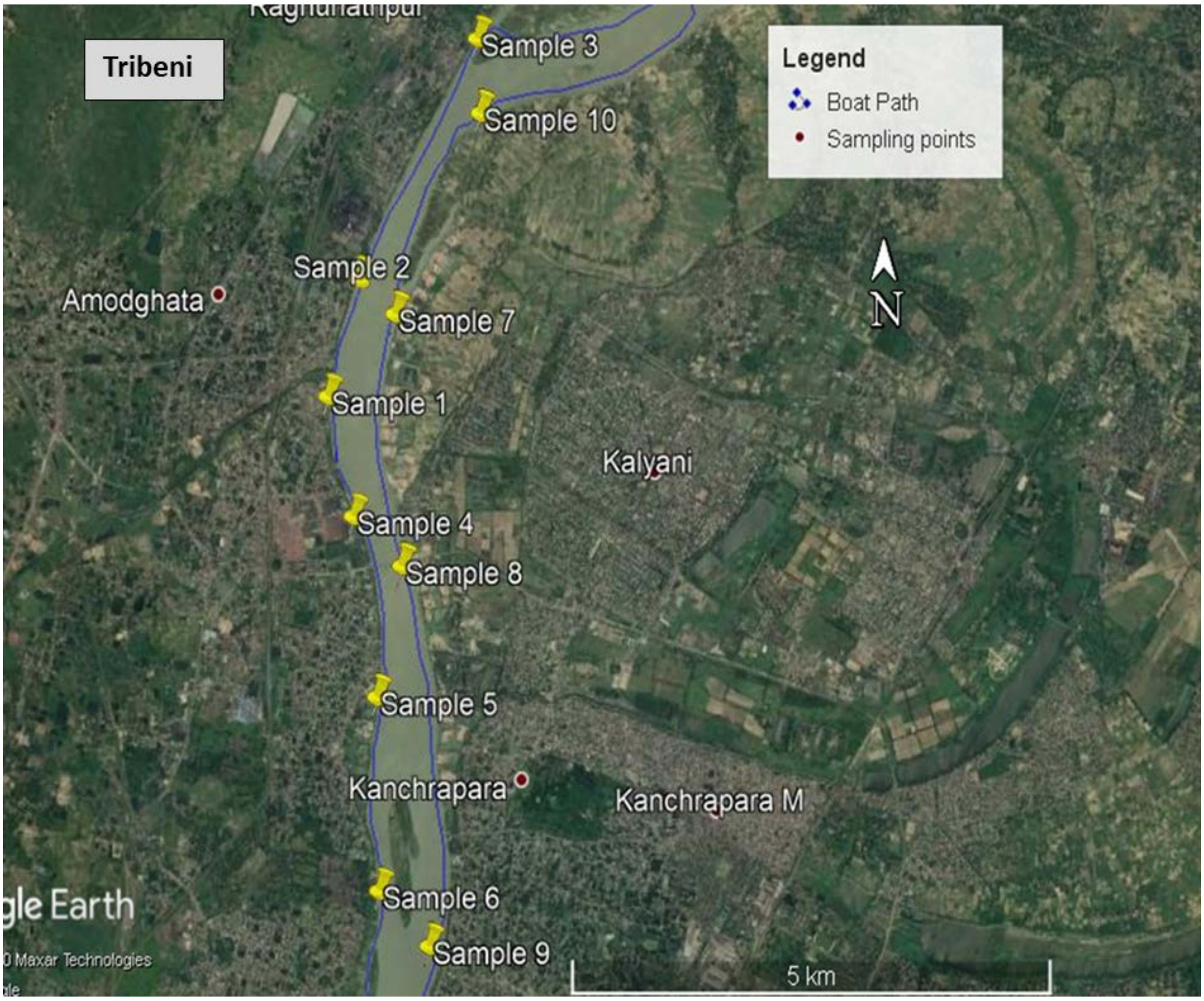
6.4.1 Background

Tribeni, a small town situated on the right bank of the river, is a religious destination. Kalyani city is situated on the left bank of the river. On the right bank of the river, that is, on the Tribeni side, there are various commercial outlets such as dye industries, a jute mill, and a thermal power plant, along with the human settlement. The major anthropogenic activities upstream of the left bank of the river are brick kilns and clay cutting units, but settlement is mostly found downstream of the river. The study area is a part of the estuary, which accounts for the fast flow of the river and the impacts of the tide can be easily experienced. During high tide, the water from the Bay of Bengal enters into the river whereas during low tide, fresh water from the river flows into the Bay of Bengal. The seasonal variation in the tide has a significant influence on the water quality (Fortune and Mauraud, 2015). The occurrence of a bore tide, that is, a sudden vertical rise of water just after low tide, is a notable feature in the Hooghly river and can be observed at Tribeni as well. Along India's Sundarbans estuarine system, the highest mean rise of the tide of about 16 feet (4.9 m) occurs in summers, but it declines in the rainy season to about 10 feet (3.0 m), whereas the minimum rise of 3.5 feet (1 m) is observed in winters (Gole and Vaidyaraman, 1967; Chatterjee et al., 2013). The navigation of ships can be frequently seen during tides. Additionally, fishing boats are also used to carry clay cuttings from the river bank to the brick kilns. Drains are found along both sides of the bank, and the area is under tidal influence. Activities symbolising human–river interaction, including fishing, bathing, cleaning, temple worship, cremation, and other religious activities are often seen in this region, which, along with domestic wastes and the discharge of effluents by industries, are the major sources of pollution here. The total length of every boat ride was approximately 25 km (Figure 6.13). The sampling points have been decided on the basis of the characteristics of the waste discharged into the river from both banks. We collected at least one sample from each type of potential pollution source from each side (Table 6.8).

Table 6.8: Details of the Sampling Points Selected for Laboratory Analysis at Tribeni

Sampling No.	Details of the Location (Tribeni)
Sample 1	Tribeni main bathing *ghat*, close to the cremation area
Sample 2	Thermal power plant outlet
Sample 3	Coloured water outlet from the jute mill
Sample 4	Drain close to the bridge
Sample 5	Water supply in the Tribeni area
Sample 6	Boat point
Sample 7	Brick kiln area
Sample 8	WTP
Sample 9	Bathing *ghat* near the major drain and boat point
Sample 10	Clear water upstream

Figure 6.13: Sampling Location and Boat Path at Tribeni

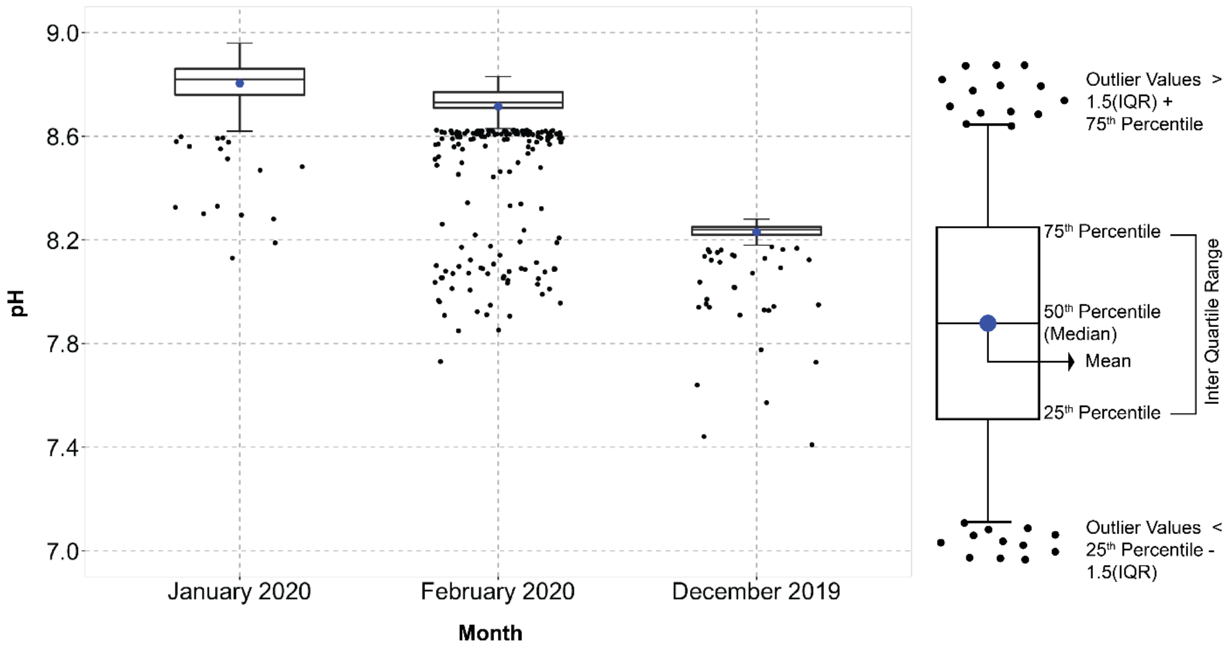


Source: Sampling points plotted on Google Earth by the 'Water to Cloud' team.

6.4.2 River Water Quality: The Boat Experiment

The concentration of field parameters, including temperature, pH, EC, DO, turbidity, CHL-A, CDOM, and tryptophan had been analysed in the months of July and December 2019, and January and February 2020. The temperature of the river water was found to be relatively high in December 2019, after which it fell in January 2020, and then showed a subsequent increase again in February 2020. The change in temperature in the study area could be attributed to seasonal effects as the month of January is relatively colder than the other months in the study area. As per the CPCB outdoor bathing standards, the pH of the water should be in the range of 6.5-8.5. The mean pH values of the water, except in the month of December 2019, exceeded the maximum recommended limits (Figure 6.14). The excess concentration of pH could be due to the tidal influences. During high tide, the water from the sea enters into the river, which leads to an increase in the volume of water in the river. Sea water is more alkaline and has a high ionic concentration as compared to the river or inland water, which may be one of the reasons for the prevalence of high pH levels (Fortune and Mauraud, 2015). Apart from the activity of bathing, alkaline pH may also affect the concentration of ammonia in the river water. If the pH levels exceed the normal range, it may adversely affect aquatic life, especially the adult fishes, by causing damage to their outer organs, including the gills and eyes.

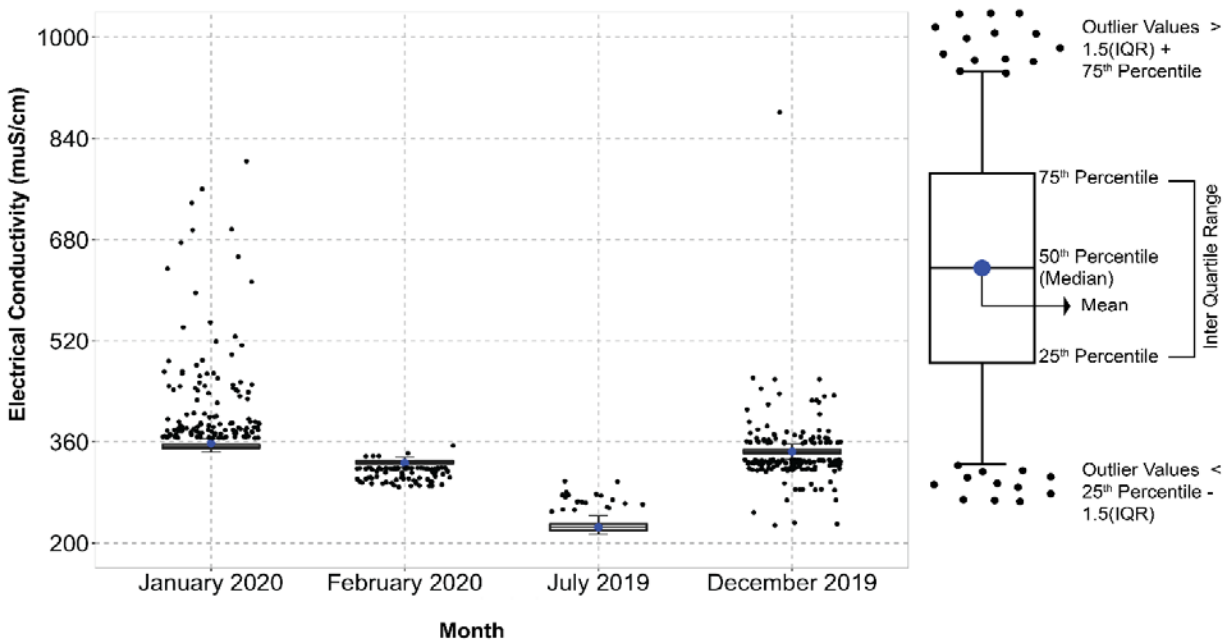
Figure 6.14: Monthly Variations in pH of the Water at Tribeni



Source: Authors' estimates from water experiments conducted during the study.

The turbidity, EC, and TDS values of the river water also point to a significant impact of tides on the river water quality. The lowest EC level was observed in July 2019, which falls under the monsoon season, and the rainwater, along with the run-off from the adjoining area, may be one of the reasons for high turbidity (Figure 6.15). The concentration of DO in water is the most important sign of health of the water body, as it indicates the ability of the water to support aquatic life. The presence of DO levels greater than 5 mg/L is considered suitable for the optimal functioning and highest carrying capacity of the ecosystem. The concentration of DO in the river varied from 4-9 to 11.5 mg/L, which suggests that the river water is conducive for the growth and survival of aquatic life. The major source of oxygen in water bodies is its absorption directly from the atmosphere or by aquatic plants and algae photosynthesis, but oxygen is removed from the water by respiration and the decomposition of organic matter. The amount of DO in the water depends on several factors, including temperature, the volume and velocity of the water flowing into the water body, and the amount of organisms using oxygen for respiration.

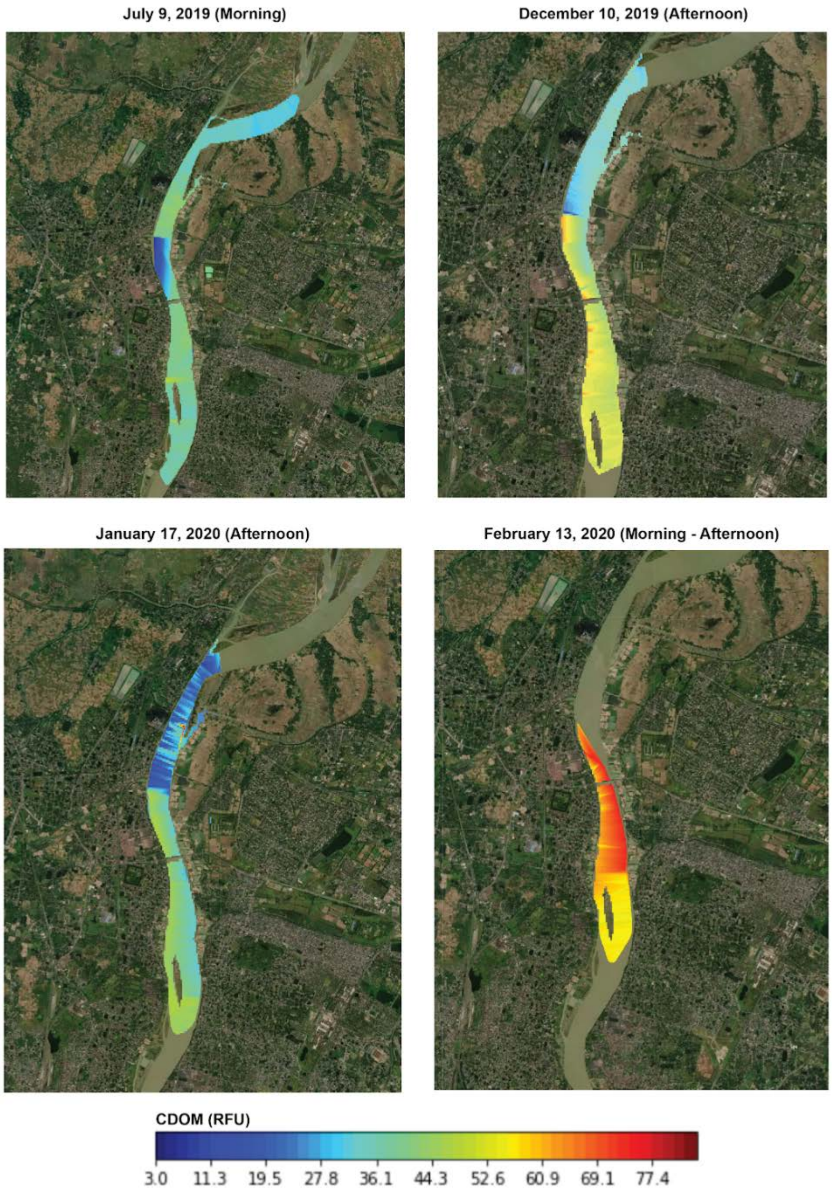
Figure 6.15: Monthly Variations in Electrical Conductivity at Tribeni



Source: Authors' estimates from water experiments conducted during the study.

The level of organic contaminants, including CHL-A and CDOM, was found to be high in the months of January and February 2020 as compared to the other months. The maximum average CHL-A values were observed in January 2020, followed by those in February 2020, December 2019, and July 2019. However, the concentration of CDOM did not follow a similar pattern. The highest mean value of CDOM was observed in February 2020, followed by the values in January 2020, Dec 2019, and July 2019, respectively (Figure 6.16). In natural conditions, the CHL-A shows a positive trend with increasing temperature, but in the tidal zone, sea water mixing may be one of the reasons for the presence of a high CHL-A content. In natural conditions, variations in the CDOM are the result of changes in the amount and frequency of precipitation, though human activities such as logging, agriculture, effluent discharge, and wetland drainage can also affect CDOM levels. At the upstream of the study area, agriculture is the prominent anthropogenic activity, and agricultural run-off along with the effluents from industries and clay cutting along the river bank could be the reasons for the presence of high CDOM levels. Tryptophan is an indicator of faecal coliform and microbial health. The concentration of tryptophan follows a similar trend as that of CDOM, pointing to the influence of anthropogenic activities on the river water, resulting in relatively high microbial activity and concentration of faecal coliform.

Figure 6.16: Spatial Distribution and Monthly Variations in CDOM Concentration at Tribeni



Source: Heat maps prepared by the 'Water to Cloud' team (http://thoreau.uchicago.edu/).

6.4.3 Association between Field Parameters

The correlation analysis of the field parameters suggests a moderate association between temperature and the EC/TDS values. Relatively low levels of EC and TDS were observed in December 2019, when the temperature was relatively higher than in other months such as January and February 2020, though we did not collect the temperature and pH values in July 2019. The pH value has a strong association with EC/TDS, which points to the influence of sea water, resulting in a subsequent increase in the pH and EC values. Apart from these, CHL-A and CDOM show strong positive association between them. Both these parameters also have positive association with temperature, however, it is not significant. The occurrence of anthropogenic activities, along with the influence of tide, may be the reasons for the relatively low association between these parameters (Table 6.9).

Table 6.9: Association between Field Parameters at Tribeni Parameters

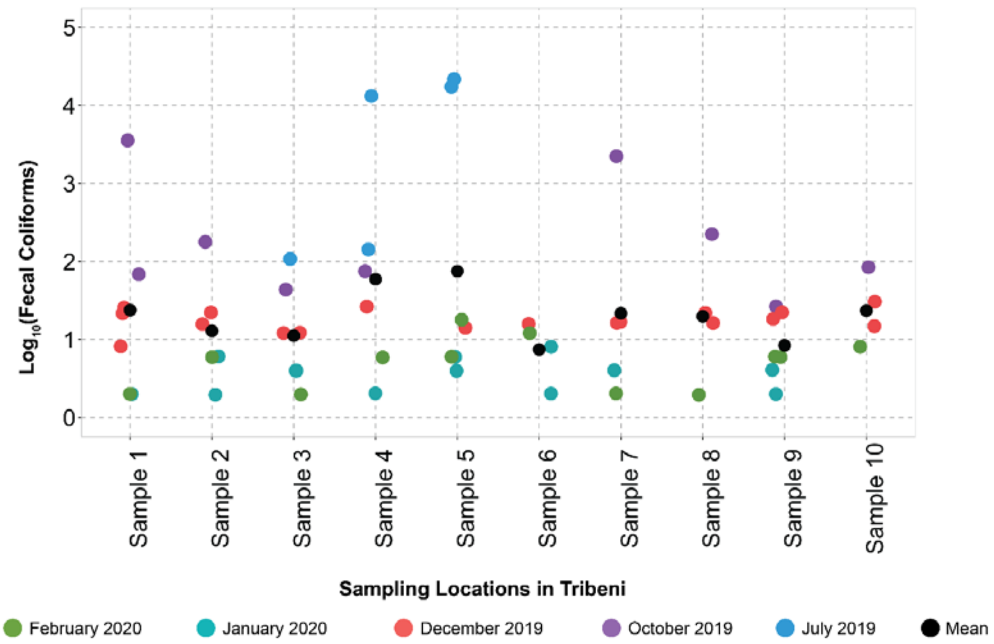
	Temperature	**pH**	**EC**	**TDS**	**DO**	**Turbidity**	**CHL-A**	**CDOM**	**Tryptophan**
Temperature	1.00								
pH	-0.32	1.00							
EC	**0.50**	-	1.00						
TDS	**0.50**	-	1.00	1.00					
DO	-0.20	0.46	-	-	1.00	-			
Turbidity	-0.02	0.01	0.01	0.01	-	1.00			
CHL-A	0.10	-	-	-	0.31	-0.21	1.00		
CDOM	0.09	0.08	-	-	0.49	-0.23	**0.73**	1.00	
Tryptophan	0.01	-	-	-	-	-0.05	0.08	0.22	1.00

Source: Authors' estimates from water experiments conducted during the study.

6.4.4 Water Quality of the Grab Samples

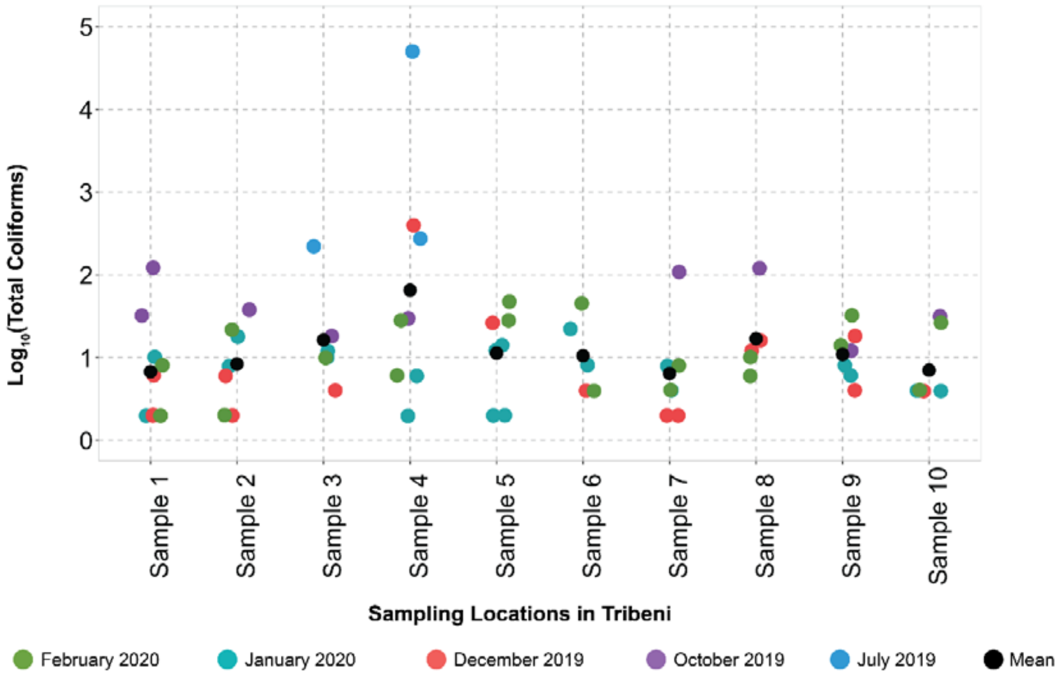
The river water samples were collected from 10 sampling locations during the months of July, October and December 2019, and January and February 2020, and the samples were taken to the laboratory for analysis (Figure 6.13). The details of the sampling locations are provided in Table 6.10**.** The samples were analysed for EC, pH, turbidity, DO, nitrate (NO_3), nitrite (NO_2), ammonia (NH_4) Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Faecal Coliform (FC) and Total Coliform (TC). Samples were collected in The results from the laboratory analysis in July 2019 showed that the FC and TC values were above the recommended limits near the water supply at Halisahar, and at the left bank, and near the major drain downstream of right bank (Figure 6.17). All these locations had sewage drain outlets coming from the city. July is a monsoon month and the run-off along with the sewage could be one of the reasons for the high organic contamination, resulting in high TC and FC values, thereby making river water unfit for bathing.

Figure 6.17: Spatial and Monthly Variations in Faecal Coliform Concentrations at Tribeni



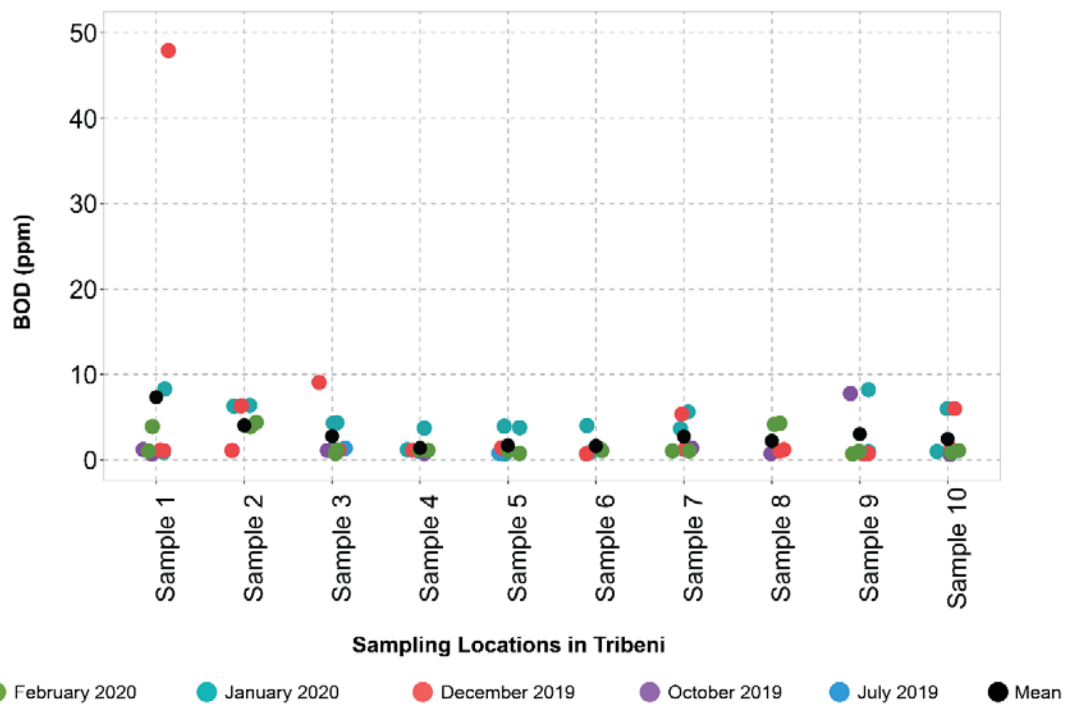
Source: Authors' estimates from water experiments conducted during the study.

Figure 6.18: Spatial and Monthly Variations in the Total Coliform Concentrations at Tribeni



Source: Authors' estimates from water experiments conducted during the study.

Figure 6.19: Spatial and Monthly Variations in BOD Concentrations at Tribeni



Source: Authors' estimates from water experiments conducted during the study.

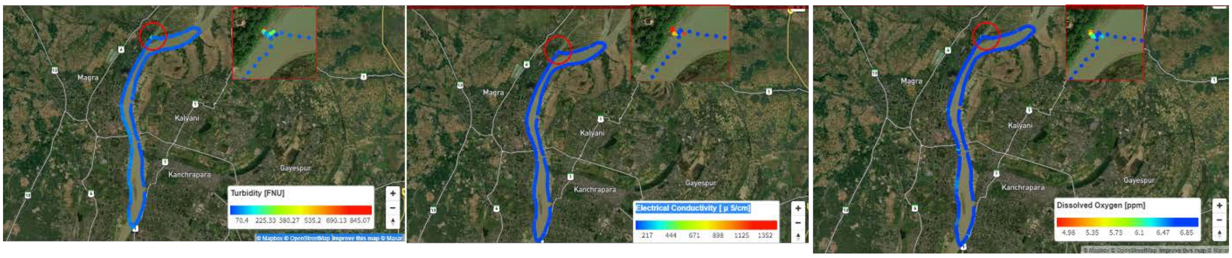
The values of TC were found to be high in December 2019 at two sampling points:the brick kiln area and the Tribeni main bathing or cremation *ghat* (Figure 6.18). Consistently high BOD (>3 mg/L) levels were observed at the thermal power plant area, the coloured outlet from the dying industry upstream, and at the Tribeni main *ghat* area (>3 mg/L), which point to high organic contamination at these locations, causing a high level of microbial activities (Figure 6.19). A high BOD content indicates a rapid fall in the DO with a potential threat to aquatic biodiversity. The major reason for a high BOD could be the prevalence of high levels of organic pollution, usually caused by poorly treated wastewater or high nitrate levels, which trigger high plant growth. In the case of drinking water, the BOD level should not exceed 6 mg/L, but a BOD level > 3mg/L is not found to be feasible for the growth and survival of fish and other aquatic life.

6.5. Segment-wise Water Quality Based on Field Experiments

The water quality parameters were tested at all our sites of the river Ganga, and were found to be within the permissible limits of the CPCB. However, for outdoor bathing, the water quality parameters are often dynamic and get influenced by regional and anthropogenic factors. In the current study, based on the sensor results, it has been observed that the water quality at Narora, which falls under Segment III-A, is much better as compared to that in the other three locations. The values of pH, EC, temperature, DO, CHL-A, CDOM, tryptophan, and turbidity were found to be low throughout the season. However, the standard deviation in the water quality parameters was also low, suggesting a low level of alteration due to external factors such as anthropogenic activities. Apart from religious activities and cremation that take place at the right bank of the river, agriculture is the most dominant anthropogenic activity here and residues from these activities could impact the water quality. However, the study site at Narora is very close to the barrage, and the boat ride is possible only when the gates are open and there is sufficient flow of water in the river for boat navigation. A high BOD level along the *ghat*s suggests high microbial activity. The fact that all the barrage gates are not opened allows for a longer residence time and lower water flow, thereby creating favourable condition for microbial growth. A high deviation in the water quality parameters was observed at Unnao, indicating significant alteration due to anthropogenic activities. The study site falls under Segment III-B. With the river being divided into two channels due the deposition of sand in the middle of the river, one channel receives less flow of water. This reduced flow in the river is observed at the right bank (on the Kanpur side) and two major sources of pollution, that is, Sisamau *ghat* and Guptar *ghat nala*, are located at this bank. The low flow in the river at one bank may allow for higher resident time for the pollutants, thus resulting in poor water quality. The point samples collected from the Sisamau *ghat* and Guptar *ghat nala* also indicate that the quality of the water at these locations is not suitable for bathing and survival of aquatic life.

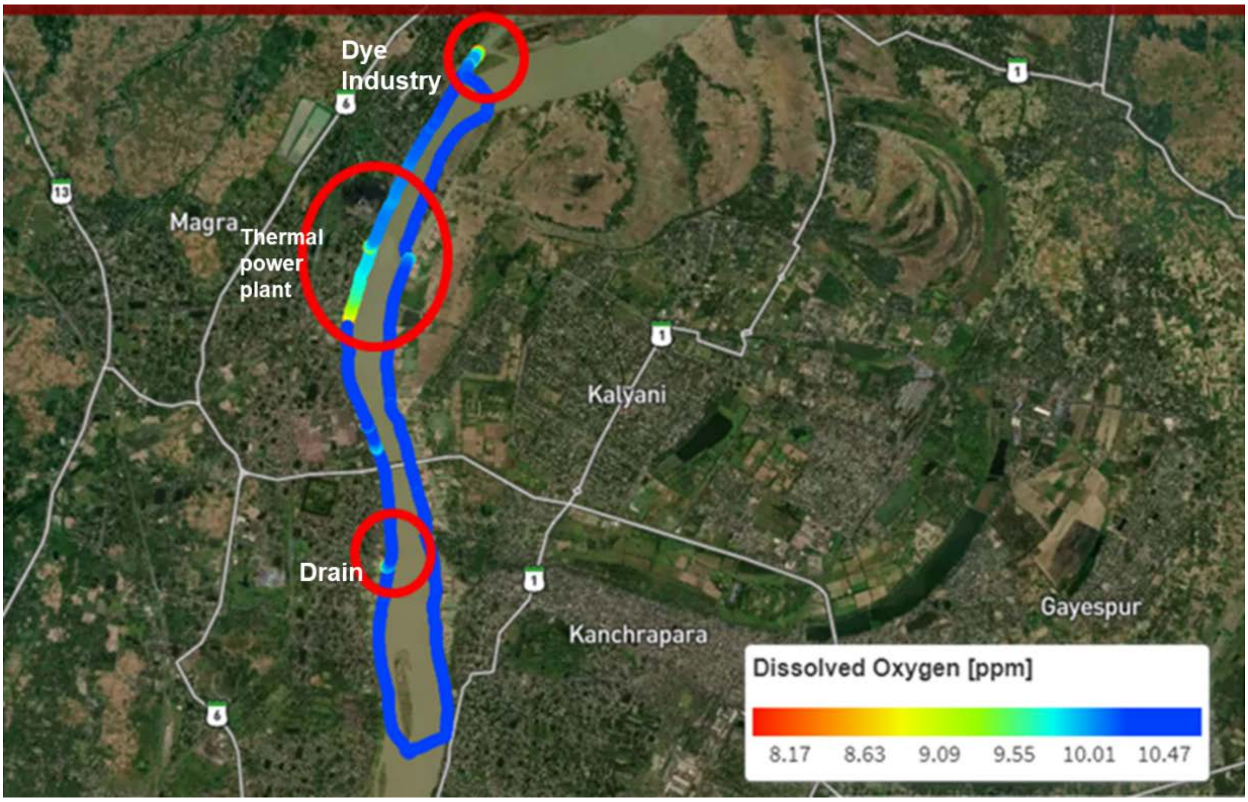
The rest of the two study sites, Jangipur and Tribeni, fall under Segment IV-A close to the mouth of the river before meeting the Bay of Bengal. Jangipur is located relatively upstream, but the Tribeni area is part of the estuary, and faces frequent tides. One of the major differences among these sites despite their falling in the same segment lies in the anthropogenic activities taking place around the bank of the river. The Jangipur area has no industries and the major source of pollution here is waste emanating from agriculture, bathing, religious activities, and small sewage drains. However, at Tribeni, apart from the above-mentioned activities, industrial effluent and major drains coming from both the banks are the major sources of pollution. All the water quality parameters at Jangipur were found to be within the permissible limits, but alteration in the water quality was observed in the months of January and February 2020, as the mean pH was found to be above the permissible limits. However, a significant increase in EC, turbidity, and CHL-A levels was also observed. An interesting observation was that of less flow in the river as the Farakka barrage upstream was closed for the construction of concrete *ghat*s, and clay boulders and pebbles were also kept on the bank of the river for this purpose. The closure of the barrage upstream had a significant impact on the water quality, and one of the major indicators of the low flow rate and increased phytoplankton growth was the presence of water hyacinth near the Roshan Bridge. Apart from that, the dispersal of leaves from the tree (due to the autumn season) along the river bank and agricultural run-off could also be responsible for the high level of organic pollution in the water. At Tribeni, a significant influence of tides was observed on the water quality, as the mean pH values of the water, except during the month of December 2019, exceeded the maximum recommended limits. Apart from pH, high CDOM and CHL-A levels along with turbidity also suggest that that water quality was influenced by tides because during high tides, water from the sea enters into the river channel. The outlets of drains along the Tribeni main *ghat* and outlets from the thermal power plants are found to be the major locations for the presence of high BOD levels due to an increase in organic contamination, as per the laboratory results.

Figure 6.20: Heat Map of Water Quality Parameters Representing the Sudden Change in River Water Quality due to Outlets from the Jute Mill at Tribeni



Source: Heat maps prepared by the 'Water to Cloud' team (http://thoreau.uchicago.edu/).

Figure 6.21: Change in the Dissolved Concentration at Major Pollution Hotspots



Source: Heat maps prepared by the 'Water to Cloud' team (http://thoreau.uchicago.edu/).

It may, however, be pointed out that most of the time, the overall water quality of the river is found to be suitable for bathing and aquatic life. Even if the overall water quality falls within the permissible limits of the CPCB, a minute change can be observed in the water quality parameters due to the anthropogenic activities, using the sensors data (Figure 6.20). The point marked as the circle is the outlet from the dye industry, and often the visible colour of the water is found to be different or greyer. The sensor collects data every 10 seconds and it can be seen that the effluents falling into the river bring about a significant change in the water quality. An increase in the turbidity and EC levels along with a decrease in the DO concentration can be observed in June 2019. The association between these parameters can also be well explained at this point as the outlet has high EC levels, which are inversely correlated with the dissolved oxygen concentration. In addition, the large amount of data collected from the river also provides a better understanding of pollution hotspots in the study area. In December 2019, a sudden decline in the DO concentration was observed at three different points (Figure 6.21). These three points, marked as red circles in the figure, are mainly located at the jute dye industry, the outlet of the thermal power plant, and a municipal wastewater drain entering into the river, respectively. This suggests that these locations are the sources of pollution in the study area and the water in these locations needs detailed monitoring and treatment.

6.6. Conclusion

This study was conducted at four different sites in Segments III-A, III-B, and IV, to understand the temporal variations in water quality and river health. The integration of field sensors and laboratory experiments has been used for assessing the water quality. It may be inferred from the results of this study that the overall water quality at all the four study sites is suitable for fishing and the survival of aquatic life. However, spatial and temporal variations in the water quality parameters were observed, which depend on external factors. The water quality at Narora was found to be consistent throughout the monitoring period with very less deviation, pointing to a low level of alteration and relatively better water quality. However, at Tribeni, the average concentrations of field parameters were very high with high deviation, suggesting that the sea water and anthropogenic activities had an influence on the quality of the river water. An analysis of the field parameters shows a major influence of anthropogenic activity at the right bank in Unnao, where the drain coming from the Kanpur side was found to be a major source of pollution. Anthropogenic activities leading to the discharge of industrial and municipal wastes are the major sources of pollution of the river water at Tribeni and Unnao, but the opening and closing of the barrage gate, a relatively low flow rate, and longer residence time, had a major impact at Narora. The water quality at Jangipur was found to be consistent throughout except in the month of February 2020, when the construction of banks was taking place. A significant influence of seasonal change was also observed on the water quality parameters; changes were observed in the pH, temperature, and DO levels. However, the overall impact of these external factors was not found to be very high, and the overall water quality parameters, including the DO levels, were found to be within a suitable range for survival of aquatic life.

The suitability of water quality along the *ghat* area was also assessed, and the findings suggest that the BOD levels in the river were significantly high, making the river water unfit for bathing. Most of the laboratory samples from Narora had high BOD levels, indicating the presence of high microbial activity at these points. The major reason for high BOD levels in *ghat* area is anthropogenic activity in the form of i.e. wastewater discharge, cremation, and other religious activities around the *ghat*s. However, in the case of Narora, the low flow of water in the river resulted in a longer residence time of water along the *ghat*s, which, in turn, supported microbial activities. Hence, proper cleaning and management of wastes along the *ghat* area is recommended. It is also suggested that continuous monitoring of the river and examination of its water quality using sensors should be done to identify the pollution hotspots and ensure efficient management of the river water.

Chapter 7: Conclusion and Recommendations

This study has been conceived as part of the 'Water to Cloud' project, in which water experiments are being conducted to map the quality of the Ganga river's water. The study entailed conduction of a primary survey and FGDs to examine if pollution has any long-standing impact on the lives of the riverine community, comprising mostly fisher folk. As a part of the study, we covered two locations in Uttar Pradesh, namely Narora and Unnao, and two in West Bengal, namely Jangipur and Tribeni.

Through our process of exploration emerged interesting stories relating to the property rights on the river, unregulated fishing practices, and the impact of river conservation drives on the livelihoods of the riverine communities. The stories of their gradual detachment from the general economic growth trends observed in the country highlights how these traditional inland fishing communities are not only being adversely affected by technological advancements in the rest of the country, but also being deprived of the benefits of economic growth. We found that there was no uniform law for fishing in the river Ganga. Various factors associated with fishing, including the fishing rights of fisher folk at a particular stretch, the availability of fishing licences, insurance mechanisms, and the formalisation of fishing as an occupation differ not only by States but also within States.

Along the course of the river, fishing is prohibited between Rishikesh and Bijnor, and between Bithoor and Varanasi, due to the religious importance of these places; between Bijnor and Garhmukteswar because this is a sanctuary area; and further down to the Narora barrage because it is a protected site and a Ramsar area. There are also different fishing regimes along these stretches. For instance, in some areas like Narora, fishing takes place under the cooperative system. We also found privately owned areas of fishing in Jangipur, and open access fishing without any permits in certain areas of Tribeni.

Under the cooperative system at Narora, fishing rights were awarded to the cooperative offering the highest bidding amounts. Only fishermen who were members of the said cooperative were allowed to fish in the auctioned river stretch. Thus, non-member fishermen had to look for alternate livelihood options. Similarly, in privately owned regimes, such as in Jangipur, the higher bidder got exclusive rights of fishing. He was further selling this right to other fishermen on a daily or monthly basis. In the open access regime, like in Tribeni, everyone was free to fish. The fishermen along the Unnao stretch seemed more destitute than others, as for the last two years, fishing had been banned in this area due to religious reasons. This ban had forced the fishermen to look for other job opportunities or to go in for poaching or illegal fishing. Hence, the riverine communities in Uttar Pradesh are trapped in this vicious cycle, where on the one hand, the need for environmental protection is used as a justification for the demarcation of river stretches as sanctuary or Ramsar sites, and on the other hand, the stretches considered important for religious reasons, are not open for fishing, leaving large clusters of fisher folk in the concerned villages unemployed. The fishermen residing alongside the river stretches where fishing is banned by authorities have not been provided with any alternative sources of employment. This, in turn, pushes them deeper down into financial vulnerability and even destitution. We found the inland fisher community at our study sites to be highly unorganised. These findings, in conjunction with the phenomenon of multiple ownership and stakeholder nature of the river stretches, have affected the livelihoods and occupational efficiency of the fisher community.

We also found the fishing occupation to be highly fragmented, both in terms of the amount of time spent on fishing and the frequent interruptions that this activity was subjected to. There were hardly any provisions for fishing licences for inland fisher folk even though fishing is their traditional occupation. There was no evidence of any formal documentation process for most of the fishing community. This prevents them from accessing any benefits or compensation for the negative impact of other activities on their livelihoods. The customary regulations and fragmentation observed with regard to the fishing activity also leads to a weakening of the rights of the fishing community. Low educational status and lack of unity further constrain their agency from acting against the misdoings that are rampant in fishing occupation. In the absence of the stringent implementation of laws, certain fisherman resort to the poisoning of fishes. Incidences of fish being killed from pesticides, ammonia fertiliser, and other toxic chemicals are common in all the study locations. All these malpractices are preventing the breeding of fishes in the river, which, in turn, leads to less catch and less income.

The economic status of the fishing community, whose members are involved in their traditional occupation, is very poor in all the States; about 48- 65 per cent of them earn a monthly income of only Rs 5,000. In order to meet their daily household needs, the family members of the fisher folk have to resort to practising subsidiary occupations such as agriculture or have to work as casual labourers. During our FGDs, some of the participants also talked about the occupational hazards of fishing. They said that one of the demands of this occupation was that they had to go for fishing even in the harshest of climates; many a time, they had to risk their lives, yet, even after making all these efforts, they could not achieve any progress in their economic and social standards. They also complained that the earnings from this occupation had significantly decreased over the years and were now barely sufficient to enable them to maintain a family. It was for all these reasons that a majority of the fishermen were vehemently opposed to their kin joining this occupation, and were considering finding '*land*' jobs for members of their next generation. However, high levels of illiteracy, at 40 and 64 per cent in West Bengal and Uttar Pradesh, respectively preclude the opportunity of securing higher income jobs for the fishing community.

A number of studies have found that the level of interaction with nature among traditional communities and their dependence on natural resources and experience of managing these resources help them promote local ecological knowledge (Ingold and Kurttila, 2000). We also mapped the respondents' knowledge of the causes and sources of pollution in the river water. The uniqueness of our study lies in the fact that we were able to compare the respondents' understanding of the river water quality with the actual water quality parameters. Our experiments show that most of the time, the water quality at all the four sites of the Ganga river was within the permissible limits of the CPCB for outdoor bathing and the survival of aquatic life. This is also reflected in the responses of the fisher folk. We found that more than 90 per cent of the fisher folk in West Bengal said that the water in the river was acceptable for fishing and bathing. Various water experiments showed that Narora was the most consistent in its water quality parameters, with very few deviations across the monitoring period, which was also reflected in our survey responses. During both the phases of the survey, a majority of the respondents in Narora (50 and 60 per cent, respectively, for the two phases) claimed that the water in the river was is acceptable for all purposes, including bathing and fishing among others. A similar trend was observed for Unnao too.

Although the water quality was mostly within the CPCB limits for the entire river stretch, the quality parameters are often dynamic and are influenced by the regional and anthropogenic factors. The major influences of anthropogenic activity were noted mainly in Unnao and Tribeni. The pollution hotspots, as identified from water experiments along these two downstream locations, match the ones identified by the fishermen during our FGDs. In Tribeni, the fishermen and the villagers highlighted this issue and spoke of the dye industry, which regularly drains black water into the river. In our RRA, they referred to the thermal power plant as continuously draining hot water into the river, which harms the fishes. The draining of the municipal wastewater and throngs of visitors taking baths in river at the Tribeni *ghat* on the religious occasion of *Makarsankranti* were also highlighted.

Similarly, in Kanpur, during our FGDs, we found that the participants were well aware of pollution due to the wastewater discharge. They could identify all the drains, mainly from the Kanpur side, which were discharging wastewater into the river from the Kanpur barrage to the Shuklaganj bridge stretch of the river. The H.D. College drain, which was discharging wastewater just downstream to the Atal *ghat*[13] and the Guptar *ghat nala* (on the Kanpur side) were two important drains identified as causes of pollution in the river, along with other small drain discharge points. The respondents clearly mentioned that they preferred to fish around the Unnao–Kanpur bridge. We also noticed that downstream to the Kanpur barrage, a large sand-belt divides the river mainstream into two parts—the Unnao side of the water with a higher water volume and flow, leaving the Kanpur side with a low water volume and comparatively no flow. The river steam on the Kanpur side is more polluted because of the low water volume and higher wastewater discharge.[14]

Given that the water quality standards are acceptable across all the survey sites, it is not surprising that the livelihood challenges cited by the respondents are caused by factors other than pollution in the river. Along with the fishing malpractices and the use of unregulated fishing nets, the fisher folk identified the low water volume in the river as a major cause for concern. Although most of the major carps were set on an upstream journey for breeding in the shallow areas, the low water volume and fragmentation in the streams were adversely affecting the breeding habitat of fishes, which were getting killed due to the minimum water flow in the riverine system (Joshi and Lal, 2017).

We also enquired about the health implications of the use of the river water on the riverine communities. About 40-50 per cent of the respondents across various sites reported incidences of water-borne diseases, but they mainly attributed their drinking water sources and not the Ganga river's water as the cause of the diseases. Even after we repeatedly enquired about any potential link between the adverse health implications and polluted river water, the respondents were not willing to associate their health adversities with the Ganga. However, medical practitioners at all the four survey sites emphasised that skin allergies are rampant among the local populations, and that extensive use of the Ganga river's water is one of the potential reasons for the

[13] This *ghat* has been newly constructed under the 'Namami Gange river front development drive', on the Kanpur side near the Ganga barrage.

[14] A sand belt in the river bed bifurcates the stream into two parts—the Kanpur side with a low water volume and the Unnao side with a higher water volume.

spread of these allergies. However, this can be regarded only as suggestive evidence since skin diseases were also found to be prevalent among other communities that were not in direct contact with the river water on a regular basis. The fisher folk further maintained that it was their regular contact with the river water that had made them immune to any health adversities.

Finally, we also found that the fisher folk understand the importance of community engagement in maintaining the sanctity of the Ganga river's water. A significantly higher percentage of respondents from both the States (90-98 per cent) were willing to participate in a cooperative society, which would ensure the preservation of the river water quality, but their lack of income and agency was preventing them from doing so. Also, almost the entire sample of respondents (90-100 per cent) across the four sites agreed that the Ganga was a living holy river. This belief also prevents them from taking compensation from the polluting agencies for the loss of their livelihoods. These findings, thus, highlight the willingness of the riverine community as a whole to protect both the water quality as well as the sanctity of the river.

Recommendations

- ***Recognition as an Integral Part of the Riverine System***

We found that irrespective of the regime system, the socio-economic condition of the riverine fisher communities is not satisfactory, as they are subject to a high degree of exploitation in both the cooperative and privately-owned regimes. Further, reserving a stretch of the river is important for religious or conservation purposes, but the absence of any alternate means of livelihood for the fisher community further pushes the latter to the margins of economic destitution. Thus, it is imperative to formalise their occupation by providing proper licence facilities to counter the challenge of loss of livelihoods. This recognition of their occupation through licensing will ensure implementation of policies targeted at the fishing community, may be in the form of cash transfers, imparting education, and setting up of awareness camps for the fishing population, as also the identification of alternative livelihood options for them during the lean seasons.

- ***Synchronisation of Local Ecological Knowledge and Scientific Knowledge***

This study found that the river is a lived reality for the people. Their traditional occupation has enabled them to generate local ecological knowledge, which can also be used for the sustainable management of the river resources. Bridging this experiential knowledge with scientific knowledge may help enhance the quality of programmes aimed at mitigation of pollution. Thus, we would recommend that these people, who are involved in traditional occupations related to the river, should be considered as stakeholders and their needs should be given preference during the implementation of the government's community programmes. They should also be trained in real-time pollution monitoring, which provides an opportunity to scientists, researchers, and the local people to interact with each other and fill the knowledge by sharing both their trained and untrained knowledge.

- ***Widening Scope of Participation***

During the course of our project, we also found that the primary stakeholders were willing to participate in the river cleaning programmes. However, most of them said that they could not afford to pay the costs entailed in setting up a local organisation. In this context, we propose that every riparian village should have a local governance platform/ cooperative, with a democratically elected executive body, and all the residents of that village should be made members of that body in order to monitor and manage the particular river stretch falling within the ambit of their village, and its resources. Further, in order to encourage the voluntary participation of the villagers in community programmes, they can be given incentives in the form of acknowledging and rewarding their efforts to keep the river stretch clean.

- ***Need to Ensure a Minimum Standard of Living***

During our discussions with the fishing community members, we found that apart from occupational hazards and livelihood challenges, they also face other problems such as the lack of basic necessities like suitable drinking water in almost all the survey areas. The incidences of illnesses and suggestive evidence about their causes indicate that the local authorities need to pitch in significantly to counter these challenges and ensure the maintenance of a minimum standard of living in these villages.

- ***Decentralised Power Structure in the Form of the Jal Police and Ganga Praharis***

There is a significant degree of social and economic fragmentation among the fishing communities inhabiting the Ganga river banks. This has led to rampant malpractices such as the usage of mosquito nets for fishing and the application of pesticides to kill fishes in all the surveyed locations. Although the marginalised fisher folk are mostly aware of these wrongdoings and also the culprits responsible for them, the lack of unity and organisation among these communities prevents them from taking any strict actions against these economically sound perpetrators. Thus, it becomes incumbent upon the *Jal Police* stationed at various locations to deal with the situation seriously and find solutions. We recommend that members of the fishing community could be given preference to be recruited as *Ganga Prahari*s (Ganga guards), and work in close coordination with the *Jal Police* to maintain law and order. By doing this, they can also keep an eye on those causing pollution in the river. These measures will not only control pollution and other malpractices prevalent along the Ganga river banks but also help to bridge the communication gap between the fishing communities and the local authorities in these areas.

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Appendix 1: Details of Water Quality Parameters

Parameter	What Does It Measure	Common Source	Sensor/Lab -based
Physical Parameters			
Temperature	Heat	Many	Sensor
Electrical Conductivity	Salinity, total dissolved salts	Inorganic salts coming from different sources	Sensor
pH	Concentration of hydrogen ions	Many	Sensor
Turbidity	Water clarity optically	Many	Sensor
Total Hardness	Amount of dissolved calcium and magnesium in water	Weathering of rocks and anthropogenic activities	Lab
Total Suspended Solids	Water clarity	Suspended particles can come from soil erosion, run-off, discharges, stirred bottom sediments or algal blooms	Lab
Dissolved Oxygen	Concentration of molecular oxygen	Atmosphere	Sensor
Chemical Oxygen Demand	Amount of oxygen required to oxidize organic pollutants in the water	Organic wastes from agricultural run offs and industries	Lab
Biological Oxygen Demand	Amount of oxygen required for bio degradable organic matter	Organic wastes from agricultural run offs and industries	Lab
Major Anions			
Nitrate	Concentration of Nitrate-N	Agricultural run-off, Industrial wastes and sewages	Sensor
Nitrite	Concentration of Nitrite-N	Acid rains, Agricultural run-off	Lab
Ammonium	Concentration of Ammonia-N	Agricultural runoff, Industrial wastes	Lab
Sulfate	Concentration of Sulfur oxides	Anthropogenic activities, sewage and waste	Lab
Microbiology			
Total Coliforms – MPN	Indicate the presence of other pathogenic organisms	Sewage	Lab
Faecal Coliforms	Indicate the presence of other pathogenic organisms	Sewage	Lab
Bio-chemical Parameters			
Tryptophan	Faecal Contamination	Sewage	Sensor
Chlorophyll-A	phytoplankton	Nutrient level in water; indicative of contamination from man-made activities.	Sensor
Colored dissolved organic matter (CDOM)	Organic carbon	Ag, industrial runoff, sewage	Sensor

Appendix 2: Questionnaires

send scanned copies at srchoudhury@ncaer.org

Version B

National Council of Applied Economic Research
Parisila Bhawan, 11-I. P. Estate, New Delhi - 110 002
Phone: 011-23379861-3 Fax: 011-23370164

Unique ID of the interviewer
Date: ________________

Name of the Respondent……………………………………. ……………….…………

Age ………………Sex…………

Primary Occupation……………………

Address…………………………**State**……………**City** ………………**Pin**…………

Phone/Mobile ………………………………………… **GPS Coordinates** ………...

Location	WB-Downstream	1
	WB- Upstream	2
	UP- Downstream	3
	UP- Upstream	4

Section A: General Perception (Ask to all)

A.1 How long have you been in this occupation (Primary occupation)?	< 5 years	Terminate survey	
	5-10 years	1	
	11-15 years	2	
	16-25 years	3	
	Since birth	4	
A.2 What are the major uses of the Ganga river? (Multiple uses)		A.2 Respondent	A.3 HH
	Fishing	1	1
	Bathing	2	2
	Drinking	3	3
	Recreation	4	4
	Washing cloths	5	5
	Agriculture	6	6
	Religious	7	7
	Others (specify)	8	8
A.3 How do you rate the quality of Ganga River water? (Multiple options)	Acceptable for bathing	1	
	Acceptable for drinking	2	
	Acceptable for washing	3	
	Acceptable for fishing	4	
	Acceptable for agriculture	5	
	None of the above	6	
	All of the above	7	
A.4 Please rate your extent of dependence on the river Ganga?	High dependence	1	
	Moderate dependence	2	
	Minimal dependence	3	

Section B: Livelihood Implications (Ask to all)

B.1 What is your primary occupation? (Tick one only)	Agriculture	1
	Fishing	3

	Others ……….(specify)	9
B.2 Monthly income from primary occupation (refer to last month income)	<5000	1
	5001-10000	2
	10001-20000	3
	20001-40000	4
	40001-60000	5
	>60000	6

Please give details of working/active months in a year and also mention you highest and lowest income month and amount from primary section

B.3 Working Months (Multiple)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B.4 Highest Income (Multiple)												
B.5 Lowest Income (Multiple)												

B.6 Is your earning through ………… (Primary occupation) sufficient?	Yes	1	
	No	2	
B.7 Number of household members involved in ………..(primary occupation)	………. (In nos.)		
			Ranking
B.8 What is the subsidiary source of earning of your household? (Rank from higher to lower)	No Subsidiary Income	1	
	Agriculture	2	
	Livestock	3	
	Fishing	4	
	Washer man	5	
	Priest	6	
	Causal Labour	7	
	Salaried	8	
	Others ……….(specify)	9	
B.9 Monthly income from subsidiary occupation (Refer to last month)	<5000	1	
	5000-10000	2	
	10001-20000	3	
	20001-40000	4	
	40001-60000	5	
	>60000	6	
B.10 Total investment on inputs you have incurred towards your primary occupation in previous year? (should be total of owned and borrowed)	<100	1	
	100-500	2	
	501-1000	3	
	1001-5000	4	
	5000-10000	5	
	>10000	6	
B.10 A Owned			

	…………………..(Rs)	
B.10B Borrowed	……………….. (Rs)	
B.11 Has your livelihood (income and occupation) been affected by river water pollution?	Yes	1
	No	2
B.12 Do you have days in a week without income? (in the last month)	Yes	1
	No	2
B.13 If yes, how many days, on an average, you do not have any income per week?	1-2 days	1
	3-5	2
	6-7 days	3
B.14 Do you think water pollution has been a health problem to you in the last 3 months? (If Yes, answer B.14A; If No answer B.14B)	Yes	1
	No	2
B.14A If yes. Explain in brief about the problem………………………..		
B.14B If No, what is the reason?	Habituated	1
	Developed immunity	2
	Others …………….	3
B.15 Have you ever changed your occupation due to river water pollution?	Yes	1
	No	2
B.15A If, yes, what was your previous occupation?	Farm labourer	1
	Construction worker	2
	Vendor	3
	Causal labour	4
	Others … (specify)	5
B.16 Is your next generation involved in the primary occupation?	Fully involved	1
	Not at all involved	2
	Partially involved	3
	Not Applicable	4
B.17 If No, which occupation your next generation is involved in? (Name the occupation)	Yes	1
	No	2
B.17.A Do you want your next generation to be involved in this occupation?	Yes	1
	No	2
B.18 Do the problems of pollution increase in magnitude during specific seasons? Summer-April, May, June Monsoon-July, August, September Post-Monsoon-October, November, December Winter-January, February, March	Summer	1
	Monsoon	2
	Post-monsoon	3
	Winter	4
	All of the above	5
B.19 Please choose the worst water quality period? (Tick one)	Summer	1
	Monsoon	2
	Post-Monsoon	3
	Winter	4
B.20 Please choose the best water quality period? (Tick one)	Summer	1
	Monsoon	2
	Post-Monsoon	3
	Winter	4

B.21 In the past years, when the river water quality was at its best?	Currently it is the best	1
	3 years back it was best	2
	5 years back it was best	3
	6+ years back	4
B.22 Do you think your earning from primary livelihood has decreased over the years due to river Ganga pollution?	Yes	1
	No	2
B.23 Please help us compare your income and work months before and after from your primary livelihood.	**A. Before (>5 years)**	**B. Now**
	…………. Number of months/year	………….. Number of months/year
	(iii) Yearly Rs ……….	(iii) Yearly Rs ……….

Section C: Fishing months and catch

C.1 How many active fishing months do you observe in a year?	< 3 months	1
	3-6 months	2
	7-10 months	3
	10-12 months	4
C.2 Do you have active days without any catch?	Yes	1
	No	2
C.3 If yes, how many days on an average every week you do not have any catch?	1-2 days	1
	3-5	2
	6-7 days	3
C.4 Does your fishing capital depreciate faster due to water pollution?	Yes	1
	No	2
C.5 Which method is used for determining the fish price? (Multiple options)	Market demand	1
	Auction	2
	Any Other	3
C.6 How does your fish reach the market? (Multiple options)	Self	1
	Cooperative	2
	Agents	3
	Others ………….	4 (specify)
C.7 Do you have a fishing licence?	Yes	1
	No	2
	Don't know about license	3
C.8 Do you think your fish catch has decreased over the last five years due to pollution?	**A. Before (5 years)**	**B. Now**
	……….. (kgs/day)	………. (kgs/day)
C.9 Species heterogeneity across times (types of fish species) Rank the species by the availability and number	**A. Before (5 years)**	**B. Now**

C.10 Changes in income over the years due to pollution (Oct, Nov, Dec) (compare approximate income during Oct-Nov-Dec now and 5 years)	**A. Before (5 years) / month**	**B. Now / month**
C.11 Do you think your investments towards fishing capital have increased over the years due to pollution?	Yes	1
	No	2
C.12 Do you drink the Ganga river water?	Yes	1
	No	2
C.12.1 Do you take bath in the river Ganga	Yes	
	No	

Section D- has been excluded in this phase.

Section E: Perceptions on water pollution (Ask to all)

	Strongly Agree (1)	Somewhat Agree (2)	Neither agree or disagree (3)	Disagree (4)	Strongly Disagree (5)
E.0 River ganga has divine quality					
E.1 Sewage from industrial activities leads to pollution					
E.2 Runoffs from agricultural activities leads to pollution					
E.3 Sewage from humans/city drains (Septic tanks, street runoffs) leads to pollution					
E.4 Pollution in Ganga river harms fish and other aquatic species					
E.5 Pollution in Ganga harms agricultural production					
E.6 Pollution in Ganga harms the livelihood of people dependent on Ganga (can be explained in qualitative survey)					
E.7 Bathing in Ganga river on a regular basis causes health problem					
E.8 Washing clothes in Ganga river on a regular basis causes health problems					
E.9 Ganga river water pollution adversely contaminates ground water					
E.10 Drinking Ganga river water causes health problems					
E10a Pollution of river water has a negative impact on its divine power					

E.11 Have there been any measures from the government about the problems of river water pollution? E.11A. Have you heard about the programs?	Yes	1	Namami Gange Ganga Action Plan
	No	2	
	Don't know	3	

E.12 What measures or policies regarding water pollution would you like to see?	Compensation against livelihood adversities	1
	Health facilities to address water related illnesses	2
	Policies addressing factory level pollution discharge	3
	Others …………………………	4

E.13 How effective is Namami Ganga in cleaning your stretch of river water?	Very effective	1
	Moderate effective	2
	Not effective	3
	Don't know	4

Section F: Health Status and Behaviour (Ask to all)

Now we would like to ask you some questions concerning your health and the health of other members of your household

F.1 How would you discuss your general health status?	Excellent	1
	Very good	2
	Good	3
	Fair	4
	Poor	5

F.2 According to you which are the months when you suffer with

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Whole Year
F.2A Most of the waterborne diseases													
F.2B Least of the health problems (related to waterborne diseases)													

F.3 Specify in general what are the medical issues you have faced during last year? (Rare events/chronic diseases like stones, cancer, TB etc.) ………………………………….

F.4 Specify what are the specific treatments you have undertaken in last 3 months for the F.3? ……………………….

F.5 Approximately, how much is spent on your medical treatments during the last three months? ……………….(Rs)

F.6 Do you think any of the medical issues you faced is because of your contact with polluted river water?	Yes	1
	No	2
F.7 How was the cost of the treatment met? (Cost of all illnesses irrespective of waterborne diseases) (Multiple answers up to major three)	Bank Account/Savings	1
	Borrowed from Friends/Relatives	2
	Selling Property	3
	Selling Jewellery	4
	Insurance (partly of the cost)	5
	Others	6
F.8 Which health care provider was consulted for treatment?	Private pharmacy/ drugstore/shop	1
	Private Clinics / hospitals	2
	Public dispensary / hospital	3
	Ayurveda / Homeopathy	4
	Traditional healer	5

	Self-Medication	6
F.9 On an average what is the monthly medical expenses of your family?	………………. (Rs)	

Types of diseases	F.10 Whether you have suffered from these diseases in last 3 months? (Yes=1; No=2)	F.11 How many days of work did you miss last month due to disease?		
		Last 1 month	Last 2 month	Last 3 month
A. Pneumonia				
B. Diarrhoea				
C. Cholera				
D. Cold and Cough				
E. Fever				
F. Skin disease				
G. Typhoid				
H. Hepatitis / Jaundice				
I. Others (Specify)				
F.12 Total number of days missed		…………………. (Must answer)		

Types of diseases	F.13 How many children (<5 years) in your household experience this disease in last 3 months?	F.14 How many members EXCEPT you (>5 years) in your household experience this disease in the last 3 months?	F.15 How many days of school did HH children miss last month due to the following diseases?
A. Pneumonia			
B. Diarrhoea			
C. Cholera			
D. Cold and Cough			
E.. Fever			
F. Skin disease			
G. Typhoid			
H. Hepatitis/Jaundice			
I. Others (Specify)			

Types of diseases (Tick accordingly)	F.16 History of infant mortality (<1 year) in your household in last one year?	F.17 History of child mortality (>1 year & <5 year) in your household in last one year?
A. Pneumonia		
B. Diarrhoea		
C. Cholera		
D. Cold and Cough		
E. Fever		
F. Typhoid		
G. Hepatitis/Jaundice		
H. Others (Specify)		

Section G: Contingent valuation survey (Ask to all)

[Enumerators will have to explain the script before asking the questions of this section]

Scenario -2: Willingness to accept compensation

G.5 Would you like to receive compensation from industries to participate in the compensation scheme?

Yes =1 / No=2

G.6 Are you willing to accept Rs……….. (per month) for compensation from industries or polluting source?

Yes =1 / No=2

G.7 What is the amount you will like to accept? ……………….

G.8 If not willing to accept why? …………………………….

Scenario 1: Willingness to pay

G.1 Do you want to participate in such type of a cooperative if that is available?

Yes =1 / No=2

G.2 Are you willing to pay Rs ……. per month (pick from the bid list provided) for clean water?

Yes =1 / No=2

G.3 What is the maximum amount you are willing to pay? ………………. (To be asked to all saying Yes to G.1)

G.4 If not willing to pay why? …………………………….

Section H: Demographics (Ask to all)

H.1 Ownership	Own house	1
	Rented house	2
	Own Agricultural land	3
	Own Livestock	4
H.2 Does your family financially dependent on you?	Yes	1
	No	2
H.3 Type of fuel used for cooking (Multiple codes)	Electricity	1
	LPG/Natural gas	2
	Fossil Fuel	3
	Others ……. (specify)	4
H.4 Average monthly income of the respondent.	<5000	1
	5000-10000	2
	10001-20000	3
	20001-40000	4
	40001-60000	5
	>60000	6
H.5 Education Level of respondent	Illiterate	1
	Primary level education completed (1-5)	2
	Middle education (Not passed Class 10)	3
	Secondary education completed	4

	Graduate	5
	Higher than graduates	6
H.6 Ethnicities	SC	1
	ST	2
	General	3
	Others	4
	OBC	5
H.7 What is the approximate monthly income of the household?	………………….	
H.8 Marital Status of the respondent	Married	1
	Unmarried	2
	Others	3
H.9 Total member in the household	(<5 years)	M …. / F …..
	(5- 18 years)	M …. / F …..
	(>18 years)	M …. / F …..
H.10 Does all school age children in your household go to school? [6-18 years]	Yes	1
	No	2
H.11 If yes, type of school they attend	Private	1
	Govt.	2
	Other	3
H.12 If they do not attend school, why?	Household /occupational requirement	1
	Children do not want to go to school	2
	Lack of school in the area	3
	Other_______________	4

Section I: WASH Facility (Ask to all)

I.1 Types of potable water connection in your house	Govt. Tap	1
	Hand Pump/Borewell	2
	Tankers	3
	Other	4
I.2 Access to potable water connection	In-house premise	1
	Outside house premise	2
I.3 How do you use water for drinking?	Direct use	1
	Boiled	2
	Use water purifier	3
	Other (buy water bottles)	4
I.4 Sanitation Facility	Individual household latrine	1
	Community Toilets	2
	Open defecation	3
I.5 Do you have sewer-line facility in your area	Yes	1
	No	2
I.6 Do you know, where wastewater generated in your house being disposed off?	Yes	1
	No	2
	Don't Know	3
I.7 If yes, Please mention where it gets disposed off?	Ganga river	1
	Nearby pond	2
	Community drainage	3
	Others (specify)……..	

Section J: Household Consumption (Ask to all)

Household Consumption Expenditure: Includes expenditure on the food and the non–food items consumed by all the members of household during the last one month or year preceding the date of survey.	
J.1 In the last one month (preceding the date of survey), how much did your household spend on food and non-food items?	**Values in Rupees (during last one month)**
A. Food items such as cereals, pulses, sugar, oil, spices, fruits, vegetables, milk & milk products, meat, egg, fish, tea, coffee, pan, tobacco, intoxicants, snacks and food from restaurants &Water Bottle	………………. (Rs)
Non-food items (B+C+D+E+F+G)	……………… (Rs)
B. Education (school/college fees, tuition fees, uniforms, books, stationary, transport, hostel etc.)	
C. Health (medicines, doctors' fees, tests, etc.)	
D. EMI – loans	
E. House rent	
F. Servants, cook, driver, sweeper, helper in occupation	
G. All other expenses	

Specific Observations of the day ……………………………………………………………..

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