ENVIRONMENTAL RESEARCH
COMMUNICATIONS

River pollution and social inequalities in Dhaka, Bangladesh

To cite this article: Sonia Ferdous Hoque *et al* 2021 *Environ. Res. Commun.* **3** 095003

IOP Publishing *Environ. Res. Commun.* **3** (2021) 095003 https://doi.org/10.1088/2515-7620/ac2458

Environmental Research Communications

OPEN ACCESS

RECEIVED
22 May 2021

REVISED
24 August 2021

ACCEPTED FOR PUBLICATION
7 September 2021

PUBLISHED
16 September 2021

PAPER

River pollution and social inequalities in Dhaka, Bangladesh

Sonia Ferdous Hoque[1], **Rebecca Peters**[1], **Paul Whitehead**[1], **Robert Hope**[2] **and Mohammed Abed Hossain**[3]

[1] School of Geography and the Environment, University of Oxford, United Kingdom
[2] School of Geography and the Environment and Smith School of Enterprise and the Environment, University of Oxford, United Kingdom
[3] Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Bangladesh

E-mail: sonia.hoque@ouce.ac.uk

Keywords: Bangladesh, sustainable development goals, urban rivers, inequalities, pollution exposure

Supplementary material for this article is available online

Abstract

River pollution through the discharge of untreated sewage and industrial effluent is a perverse outcome of rapid urbanisation and economic growth across Asia. To understand the socio-spatial and seasonal inequalities in pollution risks, we designed a direct observation method to record people's daily river use activities across dry and wet seasons, complemented by monthly monitoring of river water quality, heavy metal and biotoxicity assessment a large-scale household survey along a 25km stretch of the Turag River and Tongi Khal in Dhaka, Bangladesh. We found very high ammonia and almost zero dissolved oxygen during the low flow season, further exacerbated by heavy metals from the annual Bishwa Ijtema gathering and downstream industrial zones. Pollution exposure through domestic activities prevailed throughout the year, particularly for women and girls along low-income settlements lacking adequate water and sanitation facilities. Swimming peaked among men and children in the monsoon, risking exposure to pathogen pollution. Recognising the social inequalities in risk can support the sequencing of policy action involving short-term adaptation (improved services, education, advocacy) and long-term mitigation (effluent treatment, regulation and enforcement) responses.

1. Introduction

River pollution through discharge of untreated wastewater has plagued developing economies since the dawn of the industrial revolution (Parker 1932, Hostetter 2006). While high income countries in Europe and North America today treat 70% of their wastewater before discharge, urban river pollution remains a major challenge in low- and lower-middle income countries in Asia, where only 8% and 28% of the wastewater is treated (UNEP 2016, WWDR 2017, Kookana *et al* 2020). Weak enforcement of environmental regulations on polluting industries, coupled with the inability of municipalities to extend basic housing, water and sanitation services to growing urban populations, have led to severe degradation of water resources—stretching from the Citarum (West Java province, Indonesia) (Fulazzaky 2010) and Dong Nai rivers (Ho Chi Minh, Vietnam) (Nguyen *et al* 2019) in Southeast Asia to the Buriganga (Dhaka, Bangladesh) (Kamal *et al* 1999, Whitehead *et al* 2019) and the Yamuna rivers (New Delhi, India) (Mandal *et al* 2010) in South Asia. The global target to minimise the disposal of hazardous substances and maintain healthy river systems, as articulated in the Sustainable Development Goal (SDG) target 6.3, require interventions that manage the political, economic and social trade-offs in reversing environmental degradation, supporting economic growth and reducing population exposure to pollution (UN General Assembly 2015).

While there is an extensive body of literature on the nature and distribution of pollutants across urban river systems, the social inequalities in exposures have received little attention. Geospatial analysis at city or regional scale, through superposition of socio-demographic indicators on pollution parameters, often found the location of polluting factories and waste facilities to be associated with a higher proportion of socially disadvantaged populations, such as scheduled caste and tribes (Chakraborty and Basu 2019, Morandeira *et al* 2019). However, these analyses reveal little about the daily risks faced by riverine communities who come into contact with toxic pollutants through domestic, productive, and leisure activities. In addition to direct health impacts such as gastro-enteritis and dermal diseases from contact or immersion in polluted water (Prüss 1998, Turbow *et al* 2003), and consumption of heavy metals accumulated in fish and crops (Wang *et al* 2005, Khan *et al* 2008), there are wider impacts on wellbeing arising from poor visual amenities, unpleasant odours, limited recreational opportunities and stigmatisation of communities (Damery *et al* 2008). Unlike the disease burden from unsafe drinking water—estimated to cause 1.3 million deaths globally in 2015 (Landrigan *et al* 2018), the risks of ambient water pollution are difficult to assess due to the multiple pathways of exposure and the undefined spatial and temporal scales of observable impacts.

Here we present the first longitudinal analysis of the socio-spatial and seasonal dynamics of exposure to urban river pollution, by systematically documenting who interacts with the river and for what purpose, and how these activity patterns vary with the state water and sanitation facilities, river water quality, time of the year and sociodemographic characteristics. We designed and implemented a river use observation study, generating 7900 unique observations over 33 days across two seasons along the Turag River and Tongi Khal in Dhaka—one of the world's most densely populated megacities. This is supported by 12 months of river water quality data that illustrate the extent of pollution to which people are exposed, and surveys of over 1800 households along the riverbanks. While evaluating the health impacts from pollution exposure is outside the scope of this study, we identify individuals and groups at greatest risk with a view to prioritise spatial and temporal interventions for the urban poor often marginalised by trade-offs between economic growth, river health and poverty reduction.

2. Background

2.1. Surface water pollution in Dhaka

Dhaka is one of the fastest growing urban agglomerations in the developing world, home to over 17 million people spread over an area of 307 km^2. The city is surrounded by six interconnected river systems—the Buriganga and Dhaleshwari in the southwest, Turag and Tongi Khal in the north, and Balu and Sitalakhya in the east—which support trade, transport, and stormwater drainage. However, in the past three decades, the water quality in the rivers surrounding Dhaka has been severely degraded due to indiscriminate discharge of untreated sewage, solid waste, and industrial effluent. Dhaka's sewer system covers only 20% of the city, and feeds into one sewage treatment plant operating at one-third of its capacity (DWASA 2019). In addition to the organic and pathogen pollution load from the 1.2 million m^3 of untreated sewage, the rivers receive about 60,000m^3 of industrial effluent every day from nine major industrial clusters. There are an estimated 500–700 wet processing and dyeing textile factories releasing a range of chemicals including salts, dyes and bleaches, and 155 tanneries discharging heavy metals, including chromium (Sagris and Abbott 2015). The biological oxygen demand (BOD) and chemical oxygen demand (COD) of the textile wastewater are estimated to be 480 $mg\,l^{-1}$ and 696 $mg\,l^{-1}$ respectively, compared to a BOD of 2000 $mg\,l^{-1}$ and COD of 4500$mg\,l^{-1}$ for tannery effluent (Sagris and Abbott 2015).

The textile and leather industries are critical to Bangladesh's economic growth, with an average annual gross domestic product (GDP) growth rate of 6.5% in the fiscal years (FY) from 2009 to 2018 (World Bank 2019). As a subset of the textiles industry, ready-made garments accounted for 83.5% of the country's export revenues and 11.2% of the GDP in FY2017-18 and employs about 4 million people. The leather industry, which contributed to 3.5% of annual exports and 0.35% of GDP in FY2017-18, is also of strategic importance as the country is seeking to diversify its manufacturing export base to sustain the growth trajectory (Hong 2018). While environmental regulations, as articulated in the Environmental Conservation Act (1995), require these 'red category' factories to treat their wastewater, not all factories comply and many do not run their effluent treatment plants due to gaps in financing for infrastructure and technology upgrades, or cost savings associated with the treatment chemicals and electricity needed to run the system (Haque 2017, Restiani 2017). In December 2017, following decades of domestic and international pressure to curb pollution, the tanneries in Hazaribagh (along the Buriganga River) were relocated to a new 200-acre industrial park in Savar along the Dhaleshwari River. The park is equipped with a centralised effluent treatment plant (CETP) with a daily capacity of 25,000m^3 compared to 40,000 m^3 of wastewater being generated. As of August 2021, it is estimated that the tanneries dumped more than 16.4 million m^3 of untreated wastewater over the past three years, causing a parliamentary standing committee to order temporary closure of the industrial park (Hasan 2021).

Recognising the severity of pollution, four of the rivers surrounding Dhaka—Buriganaga, Sitalakhya, Balu and Turag—have been declared as ecologically critical areas in 2009 by the Department of Environment (DoE) (The Daily Star 2009), with the Planning Commission labelling them as 'unsuitable for any human use' (General Economics Division 2015, p.423). In 2016, DoE reported that the mean dissolved oxygen (DO) in dry and wet seasons ranged from 0. 17–2.98 $mg\,l^{-1}$ for Buriganga, 4.14–4.25 $mg\,l^{-1}$ for Sitalakhya, 0.4–4.51 $mg\,l^{-1}$ for

Turag, and 2.75–6.05 mg l^{-1} for Dhaleshwari, compared to the environmental standard of >5mg l^{-1} for fisheries, irrigation and recreational uses (DoE 2017). Heavy metals contamination in surface water and their accumulation in vegetables (Rahman *et al* 2017) and fisheries (Ahmed *et al* 2016, Rashid *et al* 2017) in areas surrounding industrial clusters have been documented. Hasan *et al* (2019)'s analysis of hair and nail samples reflected significantly higher chromium accumulation in leather factory workers and residents in Hazaribagh compared to non-exposed people in a control village. The pollution also has significant implications for the city's growing water demand, 87% of which is currently sourced from groundwater as the extreme contamination makes surface water treatment economically and technologically unfeasible (Arfanuzzaman and Rahman 2017).

2.2. Water and sanitation challenges in low-income settlements

The industrial clusters in Dhaka are often interspersed with low-income residential areas or slums that accommodate workers and their families. The underdeveloped water and sanitation facilities in slums, home to 35% of the urban dwellers in Bangladesh, counteracts the 'urban health advantage' often generated from better employment and health care services compared to rural areas (Vlahov *et al* 2005). The Bangladesh Urban Informal Settlements Survey 2016 (Yanez-Pagans 2016), which included a representative sample of 588 households across small, medium and large slums in Dhaka, showed that 68% of the households accessed piped water through a shared connection within the slum compound, with the poorest households sharing a waterpoint with 43 other households on average compared to 23 sharers among the richest households (Haque *et al* 2020). Landlords were the main providers of water infrastructure in small and medium slums on privately-owned land. In large slums on government owned land, about 27% and 21% of the waterpoints were installed by the Dhaka Water Supply and Sewerage Authority (DWASA) and NGOs, respectively. More than half of the households also reported being exposed to flooding in the past year, which disrupted access to a functional water source for 10 days on average.

In terms of sanitation, only 8% of the slum households had access to a flush toilet connected to a septic tank, while 78% used improved pit latrines and the remaining 10% depended on hanging latrines (Haque *et al* 2020). A toilet facility was shared among 16 households on average. Among those with improved sanitation facilities, about 68% reported never emptying their pits or septic tanks, while 20% mentioned disposing the faecal sludge directly to drains or nearby waterbodies. Amin *et al* (2020)'s study in two low-income neighborhoods in Dhaka showed extensive *V.cholerae, NoV-GII, Giardia,* and *Shigella*/EIEC contamination in effluent from on-site sanitation systems, to which children and adults may be exposed in their immediate residential environment. A larger study of environment faecal contamination across 10 neighbourhoods found significantly higher *E. coli* concentrations in non-municipal drinking water, bathing water, surface water, and soil samples in low-income neighborhoods compared to high-income neighborhoods, indicating poor drainage systems, improper child faeces disposal, and poor faecal sludge management in low-income neighbourhoods as the potential contamination routes (Amin *et al* 2019).

Consequently, many of the immediate environmental burdens of pollution are borne by these low-income residents. Longitudinal observations from hospital visits between 1993 and 2012 showed that children under five living in densely populated slums were significantly more prone to diarrhoeal diseases from *Vibrio cholerae* and severe dehydration compared to those in non-slum settings (Ferdous *et al* 2014). In Kamrangirchar, the largest slum in Dhaka and home to about 600,000 people who generated income from the tanneries in adjacent Hazaribagh area for wages, occupational and environmental exposure to toxic heavy metals, coupled with low living standards and poor health seeking behaviour, contributed to high disease burden, including contact dermatitis, work-related asthma, peptic disease, low back pain, malaise and injuries (Muralidhar *et al* 2017, van Puijenbroek *et al* 2019).

3. Materials and methods

Our study area covers a 25 km stretch along the Turag River and Tongi Khal flowing along the borders of Dhaka and Gazipur districts. We divided our study area into four zones, covering up to 1km on both sides of the riverbank (figure 1). Zone-1 stretches about 6km along the upper reaches of the Turag River and includes the Konabari-Kashimpur industrial cluster of knitting and dyeing factories, brick kilns and the Konabari settlement built on private land along the river. Zone-2 covers six peri-urban settlement clusters along an 8km river stretch, while Zone-3 includes a 6km stretch of the Tongi Khal passing through the Tongi industrial cluster with three densely populated slums built illegally on government land. Since 1967, the Bishwa Ijtema, an annual gathering of 3 million Muslims over three days in January, has been held along the Tongi Khal in Zone-3. Zone-4, the final 5km stretch of the Tongi Khal, includes part of the Tongi industrial cluster on the northern bank of the river, with is a relatively quieter neighbourhood and a boat terminal on the southern bank.

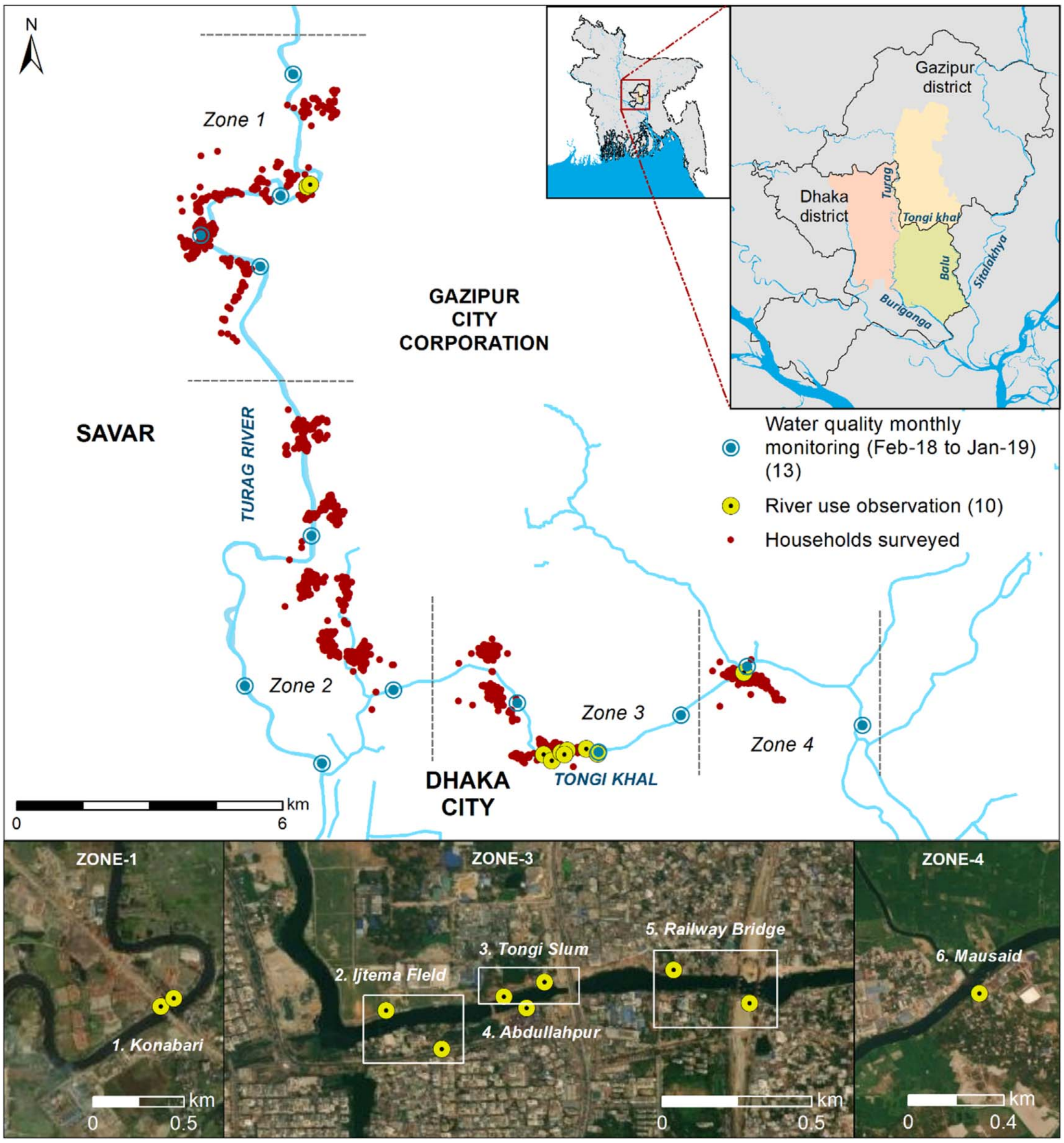


Figure 1. Map of Turag River and Tongi Khal showing locations of households surveyed, river use observation points and water quality sampling points, clustered into four zones.

We designed an interdisciplinary research approach, combining water quality monitoring, household surveys and direct observation of river use behaviour to collect empirical evidence on the state of water pollution, socio-economic profiles and water and sanitation challenges in riverbank settlements, and spatial and seasonal variations in people's interactions with the river water (table 1). Ethical approval for the surveys and observations was granted from Oxford University's Central University Research Ethics Committee (SOGE 18A-6, November 2017).

3.1. Water quality analysis

We collected water samples from the Turag River and Tongi Khal as part of two sub-studies: (1) monthly monitoring of 21 physiochemical parameters at 13 sampling points along the river from February 2018 to January 2019 (figure 1); (2) analysis of 18 heavy metals and biotoxicity at 22 sampling points in December 2017 and January 2018 (figure 3). Samples were collected from a boat at 2m depth, followed by field analysis of temperature, pH, dissolved oxygen, oxidation reduction potential, electrical conductivity, and total dissolved solids using HACH HQ40d multiparameter device and turbidity with VELP Scientifica TB-1 portable Turbidimeter.

Laboratory analysis of colour, alkalinity, dissolved organic carbon, ammoniacal nitrogen, nitrate, phosphate, iron (ferrous), chloride, sulphate, and sulphide ions, and pathogens (total coliforms and *E. coli*) were conducted at Bangladesh University of Engineering and Technology (BUET). Concentrations of heavy metals

Table 1. Outline of research methods and sampling across four study zones along Turag River and Tongi Khal.

Method		Total	Zone-1	Zone-2	Zone-3	Zone-4
Water quality analysis	Monthly monitoring of physiochemical parameters (Feb-18 to Jan-19)	13 sampling points	4	4	3	2
	Heavy metal and biotoxicity assessment (Dec-17 and Jan-18)	22 sampling points	8	7	4	3
Household survey (Dec-17)		1826	446	730	510	140
Direct observation of river use behaviour (Feb-19 and Aug/Sep-19)		10 observation points grouped into six sites	2 points grouped as 1 site (Konabari)	None	7 points grouped as 4 sites	1 point (Mausaid) (2 in Ijtema, 2 in Tongi slum, 1 in Abdullahpur, and 2 in Railway Bridge)

were analysed at the Department of Earth Sciences, Oxford University through Inductively Coupled Plasma Mass Spectrometry (ICP-MS) using a PerkinElmer NexION 350D ICP-MS. The heavy metal data was previously used for a separate study by Oxford Molecular Biosensors, which developed bacterially derived sensors to detect the bioavailability of specific chemicals and their overall cell damage toxicity (refer to Rampley *et al* (2020) for further details). Speciation analysis of few samples during the Ijtema preparatory phase in January 2018 were done using Visual Minteq ver. 3.1 (May 2020 Edition).

3.2. Household survey

We conducted a household survey in December 2017, in collaboration with the University of Dhaka, to collect baseline data on socio-economic and demographic profiles, indicators of multidimensional poverty, the state of water and sanitation facilities, itemised household expenditures and general development concerns. The survey was conducted in Bangla by 15 trained local enumerators using a semi-structured questionnaire on ONA, a mobile data collection platform (https://ona.io/). We covered all settlements within 1km buffer zone along the river, using a random walk method to select every 10th household within each settlement. If no consenting adult was present at the time of visit, the next household was chosen instead. A total of 1826 households were surveyed, of which 446 households were in Zone-1, 730 in Zone-2, 510 in Zone-3, and 140 in Zone-4. Data analysis involved generation of zone-wise descriptive statistics and calculation of a multidimensional wealth index through principal component analysis (PCA) of 11 variables on housing materials, education, and asset ownership (see table B1 in appendix (available online at stacks.iop.org/ERC/3/095003/mmedia)). A k-means cluster analysis was then applied to the factor scores of the first principal component (PC_1) to disaggregate the households into four wealth classes.

3.3. Direct observation of river use

We designed and implemented a 'structured direct observation' study to monitor the gender- and age-disaggregated daily river water use practices in relation to the spatial and temporal variations in water quality risks. Direct observation is an established method in social science research whereby the researcher uses a pre-designed questionnaire to collect standardised quantitative information on the research subjects in their usual environment without any alterations. Early examples of direct observation can be found in the medical anthropology literature, where researchers observed the patterns of human contact with water bodies to evaluate the pathways of schistosomiasis transmission (Dalton 1976, Dalton and Pole 1978, Slootweg *et al* 1993) with more recent applications is monitoring handwashing behaviour in rural South Asia (Halder *et al* 2010, Ram *et al* 2010).

We conducted our study in two phases. The first phase was carried out over an 18-day period in the dry season (9–26 Feb 2019) which coincided with the Bishwa Ijtema held in two groups of three consecutive days. The second phase was conducted for a 15-day period in the wet season (20 Aug–3 Sept 2019). We selected ten observation points, two of which were in Zone-1, seven in Zone-3, and one in Zone-4. The site selection involved multiple scoping visits to the household survey areas to identify spots with observable river use activities, as well as ensuring spatial distribution, diversity of river interactions, accessibility and security for field team, and alignment with river water quality monitoring points. Zone-2 was excluded as we did not find any interactions with the river during our scoping visits, as the short river branch flowing through the bottom part of Zone-2 remains dry for part of the year. During analysis, as shown in figure 1, we merged results from the ten observation points into six sites in three zones, namely, Konabari (Zone-1), Ijtema field, Tongi slum, Abdullahpur and Railway Bridge (Zone-2) and Mausaid (Zone-3).

Each observation day comprised three 3-hour slots: 7–10 am (morning); 10.30–1.30 pm (midday); and 2.30–5.30 pm (afternoon) during which enumerators recorded their observations in an electronic form in a tablet, whereby an 'observation' is defined as any activity conducted by an individual or group visible within the enumerator's field of view (refer to appendix C for detailed observation schedule). Thus, each slot comprised several observations, with each observation including one or more activities. Over the 33 study days, we recorded about 7900 observations for 852 slots. River users were visually categorised as children and adolescents (<16 years of age) and adults, as male and female, and also as groups and individuals. Differentiation of age was based on enumerators' judgment; some adolescents and young adults may have been misclassified. Activities were listed as drinking, food washing, water collection, dish washing, laundry, washing oneself, bathing, using hanging latrine, open defecation, urination, fishing, swimming, boating and other. These activities were listed as multiple-choice questions, as multiple tasks were often conducted by different individuals in a group. Enumerators were given clear guidelines for certain activities; for example, if fishing was done on a boat, the activity was recorded as fishing and not boating. Enumerators also took a photo for each observation, following approved ethical guidelines, which were inspected by the lead author to resolve issues in data entry.

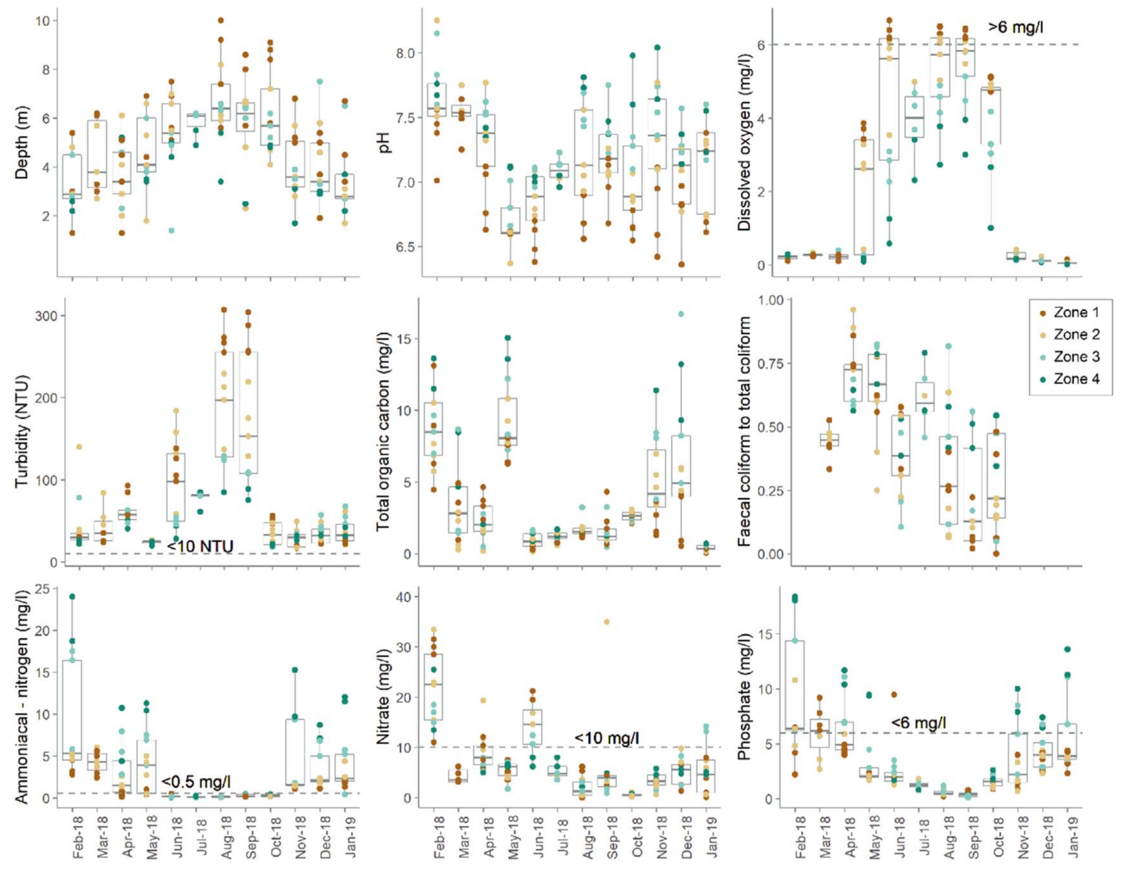


Figure 2. Physiochemical properties of Turag River and Tongi Khal in comparison to Bangladesh Environmental Quality Standards (MoEF 1997). Note: Boxplots show data from all 13 sampling points across the four zones, except for months with missing data for certain parameters (see table A1 in appendix). The figure is adapted from Murgatroyd *et al* (2021).

4. Results

4.1. Spatial and seasonal variations in river water quality

Monthly analysis of water quality along the Turag River and Tongi Khal shows extreme spatial and temporal variation in physiochemical parameters and heavy metal concentrations, with Zone-3 and Zone-4 exhibiting the worst conditions (figure 2). During the dry season, DO levels are so low that the waters and sediments may be presumed to be anoxic, with some metals from bound sediments and gases such as methane, ammonia, and hydrogen sulphide being released. Organic pollution, as indicated by the total organic carbon (TOC), is highest in January owing to the dumping of faecal and food waste in the Tongi Khal during Ijtema. TOC reduces as monsoon approaches, albeit a spike in May from dredging activity undertaken during the sampling period. Increase in temperature and DO, coupled with addition of different genre of coliform bacteria from the monsoon runoff, also reduces the relative proportion of faecal coliform (*E. coli)* to total coliform. Likewise, the concentrations of ammoniacal-nitrogen, nitrates, and phosphate decreases to below national standards in monsoon, except for the spike in nitrates in June from rainwater accumulating on the surface during the sampling. There is, however, diffuse runoff from the waste tips and polluted soils adjacent to the rivers and, during storm events, there is significant local storm runoff from urban and industrial areas into the streams and rivers, which is evident from elevated turbidity levels in rivers throughout the monsoon season.

The concentrations of heavy metals increased from December 2017 to January 2018 in general (figure 3) due to combined effects of decreased river flow, resuspension of sediments caused by the disturbance of riverbed during Ijtema preparatory work, and subsequent dissolution of metals due anaerobic condition. This sediment disturbance continues throughout the Ijtema event with addition of different metals, such as aluminium, chromium and iron from washing utensils, selenium from the likely consumption of medicines, lithium from battery disposal, and manganese from fish residues. Chromium, lithium, lead and selenium contribute to cellular toxicity to most microbes, while copper shows toxicity to bacteria and algae in mostly free ion form.

The heavy metal concentrations presented here, however, indicate the total concentration of each metal instead of their availability as free cations. Most metals are bound in organic and inorganic complexes with dissolved organic matter, sulfide and ammonia dictating complexation. Chromium and copper bind almost

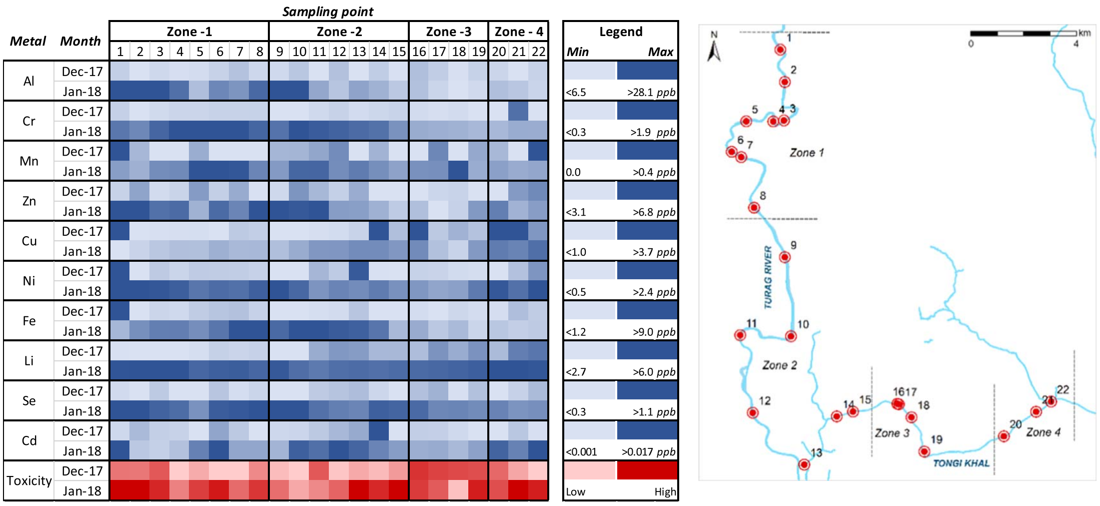


Figure 3. (a) Heatchart showing variation in heavy metal concentrations between December 2017 and January 2018, along with cell damage toxicity measured by Rampley *et al* (2020); (b) Map showing the 22 sampling points along Turag River and Tongi Khal.

exclusively to organic complexes, and aluminium, manganese, cadmium, lead, selenium and lithium all show considerable inorganic complexation to oxyhydroxides, chloride and ammonia. Lithium, selenium and zinc also tend to be in free ionic forms. A speciation analysis of samples in January 2018, through Visual Minteq 3.1 confirmed high levels of organic complexation for copper and chromium near Ijtema sites. Similar organic complexation was found for most metals except for selenium and lithium which had free ions as dominant species. A parallel study using this dataset and involving the co-authors of this paper found that high level of cellular toxicity was particularly associated with increased concentrations of selenium, zinc and chromium (Rampley *et al* 2020). Hence, despite the overall increase in metal concentrations, the simultaneous dumping of organic waste results in lower availability of free ions, which in turn lowers the toxicity in the samples collected during the Ijtema.

4.2. Social inequalities in water and sanitation services

Zone-1 comprises land privately-owned by a few families descending from early settlers, as well as long-term lease holders, who built and rented out houses to families and individuals working in nearby brick kilns, garment factories, and as day labourers. In comparison, settlements in Zone-3 are on government-owned land, with most tenants and homeowners lacking legal ownership, putting them at risk of eviction. Our survey reveals a high clustering of poverty in Zone-3, with 41% of the households belonging to the poorest wealth class, compared to 23% and 18% in Zone-1 and Zone-2 respectively (table 2). About 20% of adult women in Zone-3, equivalent to half of those in paid employment, work in one of the many garment factories nearby, while the men are engaged in small businesses (22%), casual labour (22%) and garment factories (19%). Zone-4 is a relatively well-off area, with 66% in the top wealth quartile and having the highest proportion of adults working in the service sector (14% men and 6% women). The average household monthly expenditure in Zone-4 is BDT 25,500 (USD 307), which is significantly higher than Zone-1, Zone-2 and Zone-3, with mean expenditures of BDT 13,500 (USD 162), BDT 16,300 (USD 196), and BDT 14,700 (USD 177) respectively. When disaggregated by wealth class, the average monthly expenditure ranges from BDT 12,000 (USD 145) for the poorest to BDT 25,000 (USD 301) for the richest class across all zones (Table B3 in appendix).

Households in Zone-1 and Zone-2 access water from motorised tubewells installed by NGOs, either through pipelines drawn inside their dwelling or through shared taps in communal spaces. Those living on the southern bank of the Tongi Khal in Zone-3 have access to piped water from DWASA, whether legally or illegally, while people on the northern bank rely on community tubewells. While they have access to an improved source within a few minutes of walking distance, water is often only available at certain times during the day, creating long queues for a limited quantity that is prioritised for drinking and cooking. About 68% of the households in Zone-3 reported sharing their water source with at least five other households. Households in Zone-4 usually have their own tubewells, with only 25% sharing it with 5–10 households in the same compound.

Although none of the households are connected to formal sewerage infrastructure, 79% households in Zone-4 use a flush toilet with a septic tank and 86% do not share their toilet with others. The sanitation conditions are worst in Zone-3, with 27% reportedly using hanging latrines or practicing open defecation, with the faecal waste discharging into the river. About half of the households in Zone-3 share their toilets with at least

Table 2. Characteristics of households living along the Turag-Tongi Rivers in Dhaka.

Household characteristics		Zone-1	Zone-2	Zone-3	Zone-4
WEALTH QUARTILES	1 (Poorest)	23%	18%	41%	4%
	2	26%	28%	28%	11%
	3	30%	26%	20%	18%
	4 (Richest)	21%	28%	11%	66%
MAIN SOURCE OF DRINKING WATER	Piped water into dwelling/ yard	20%	6%	55%	1%
	Motorised tubewell	73%	92%	42%	96%
	Others	7%	2%	2%	3%
WATER SOURCE SHARING	Not shared	44%	26%	11%	75%
	Less than 5 households	33%	33%	21%	20%
	5–10 households	14%	15%	27%	5%
	More than 10 households	9%	26%	41%	0%
SANITATION	Flush to septic tank	19%	41%	26%	79%
	Improved pit latrine	68%	45%	43%	20%
	Unimproved pit latrine	3%	2%	5%	1%
	Hanging toilet/ Open defecation	10%	12%	27%	1%
TOILET SHARING	Not shared	61%	47%	20%	86%
	Less than 5 households	27%	25%	33%	13%
	5–10 households	9%	9%	25%	1%
	More than 10 households	4%	19%	22%	0%
GENERAL CONCERNS	Clean environment	3%	3%	25%	11%
	Water supply	6%	8%	17%	0%
	Sanitation	3%	2%	16%	4%
	Healthcare	23%	6%	7%	24%
	Roads and transportation	35%	33%	2%	37%
	Gas supply	7%	32%	5%	6%
	No concerns	1%	2%	13%	9%
	Others	22%	14%	16%	9%

five households, suggesting the lower living standards and increased likelihood of spreading pathogens. Improved pit latrines are more common in Zone-1 (68%) and Zone-2 (45%), followed by flush toilets with septic tanks (19% and 41%).

The variations in living standards are also reflected in the concerns expressed by the surveyed households. For households in Zone-3, clean environment (25%) ranked as the topmost concern, followed by water services (17%) and sanitation (16%). In comparison, households in Zone-1, Zone-2 and Zone-4 prioritised roads and transportation (35%, 33% and 37% respectively), followed by healthcare services or gas supply. However, when surveyed households were specifically asked about their environment-related concerns, 50%–60% across all zones mentioned the river being dirty as their main concern.

4.3. River use behaviour and pollution exposure

The types and intensities of river use activities were closely linked to the socio-demographic contexts of the studied populations and the water quality. Direct contact with river water, through dish washing, laundry, cleaning fish and vegetables, and personal washing was high in Zone-1 and Tongi slum in Zone-3 (figures 5 and 6), with averages of 14 and 15 people observed per 3-hour slot during the dry season, of which 10 people in each site were women and girls (Table C3 in appendix). These sites were close to residential clusters, where overcrowding at community water points and restricted supply only at certain times during the day, led to high usage of river water for domestic activities. We also observed several boat dwellers along the Tongi Khal in Zone-3, who used the river for almost all purposes other than drinking (figure 4). Domestic activities were relatively fewer in Zone-4, owing to the better socio-economic status of residents in this area.

During the wet season, we observed a slight decrease in domestic activities in Zone-1 and Tongi slum in Zone-3 (figure 5). In Zone-1, construction of new houses along the bank which partially deterred the local residents from accessing one of the observation sites, while in Zone-3, around 60 houses were evicted as part of the government's drive to control river encroachment. However, we recorded a steep increase in swimming and bathing activities in Zone-1 and Tongi slum in Zone-3, which changed the overall observation counts to 11 and 27 people observed per 3-hour slot. Recreational swimming was more prevalent among adult men and male children, as cultural norms sometimes refrained women from sharing the same public space with men for recreation (figure 6). This increased river interaction by men, along with the reduction in women carrying out domestic activities, led to equal proportions of both genders observed per 3-hour slot. The rise in bathing and

Figure 4. (1) Aerial view of Konabari settlement (Zone-1); (2) Boat dwellers and hanging latrines along Tongi slum (Zone-3); (3) Woman collecting plastic bottles from Tongi Khal (Zone-3); (4) People washing dye packaging near Konabari (Zone-1); (5) Children swimming in the Tongi Khal in monsoon (Zone-3); (6) People washing denim under the Railway Bridge (Zone-3); (7) Man fishing in the river at Mausaid (Zone-4); (8) Men washing and disposing food waste along the river bank during Ijtema (Zone-3); and (9) Temporary urinals for Ijtema participants (Zone-3).

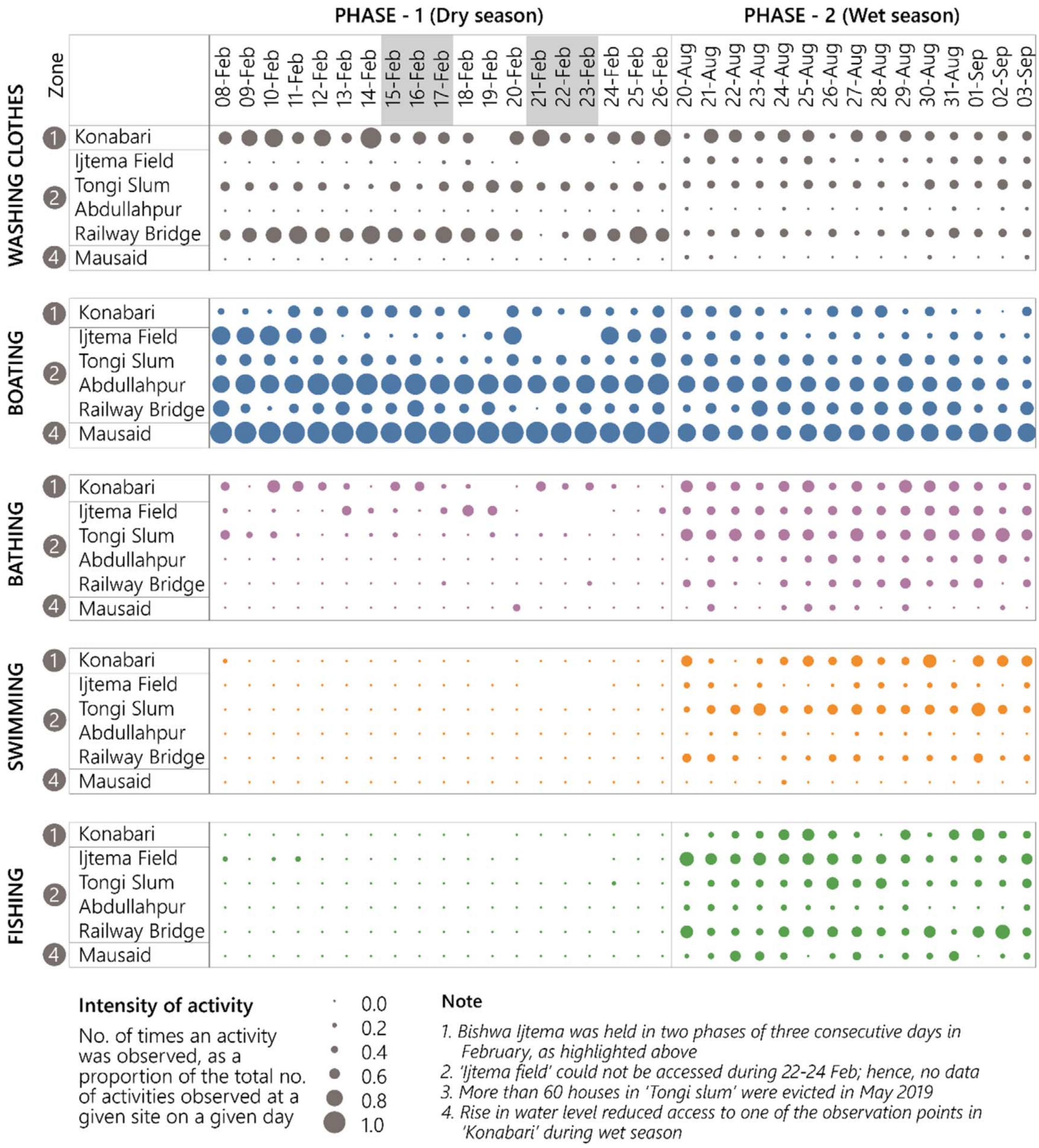
swimming, which was also prevalent in other sites, can be attributed to the warmer weather and perceived improvement in water quality.

Small-scale productive uses were also observed at some sites in Zone-3. These included washing and dyeing denim, washing fish baskets or plastic sheets, collecting plastic waste and fishing. Denim washing was mostly carried out by men, under the pillars of the railway bridge on the Tongi Khal (figure 4). During the wet season, the platforms of the pillars were flooded which resulted in a decrease in this observed activity, which likely shifted to another site not included in our study. Informal waste pickers could be spotted wading through the river on a boat, collecting plastic bottles for resale while others were seen washing plastic sheets either on the banks or in waist deep waters. These indigo tainted sheets are waste products from dye packaging, which serve as an income source for these marginalised citizens. One of our observation sites in Zone-3 was near the local fish market, where traders regularly used the river to wash their fish and the fish baskets. Fishing, with or without a boat, was commonly observed across all sites during the wet season. In Zone-1, the abundance of fish along the banks meant that women and children could easily catch these with their bare hands.

The river was heavily used for boating, mainly for transportation and sometimes for recreation. Boating increased significantly in Abdullahpur and Ijtema field in Zone-3 and in Zone-4 during the Ijtema period in February 2019 for transportation of people, food and construction materials. While temporary sanitation facilities with faecal sludge containment was provided for the Ijtema devotees, urinating into the river was commonly practiced, along with the disposal of organic food waste (figure 4).

5. Discussion

River pollution is a perverse though predictable outcome of economic growth in Asian cities. Our longitudinal river use observation, supported by water quality monitoring and household surveys, reflect three main findings. First, river water quality and usage behaviours are highly dynamic and contextualised, and while it is neither straightforward nor desirable to quantify correlations, we observe that the spatial co-location of multiple deprivations can increase pollution exposure (figure 7). For instance, despite having similar pollution levels,



Note

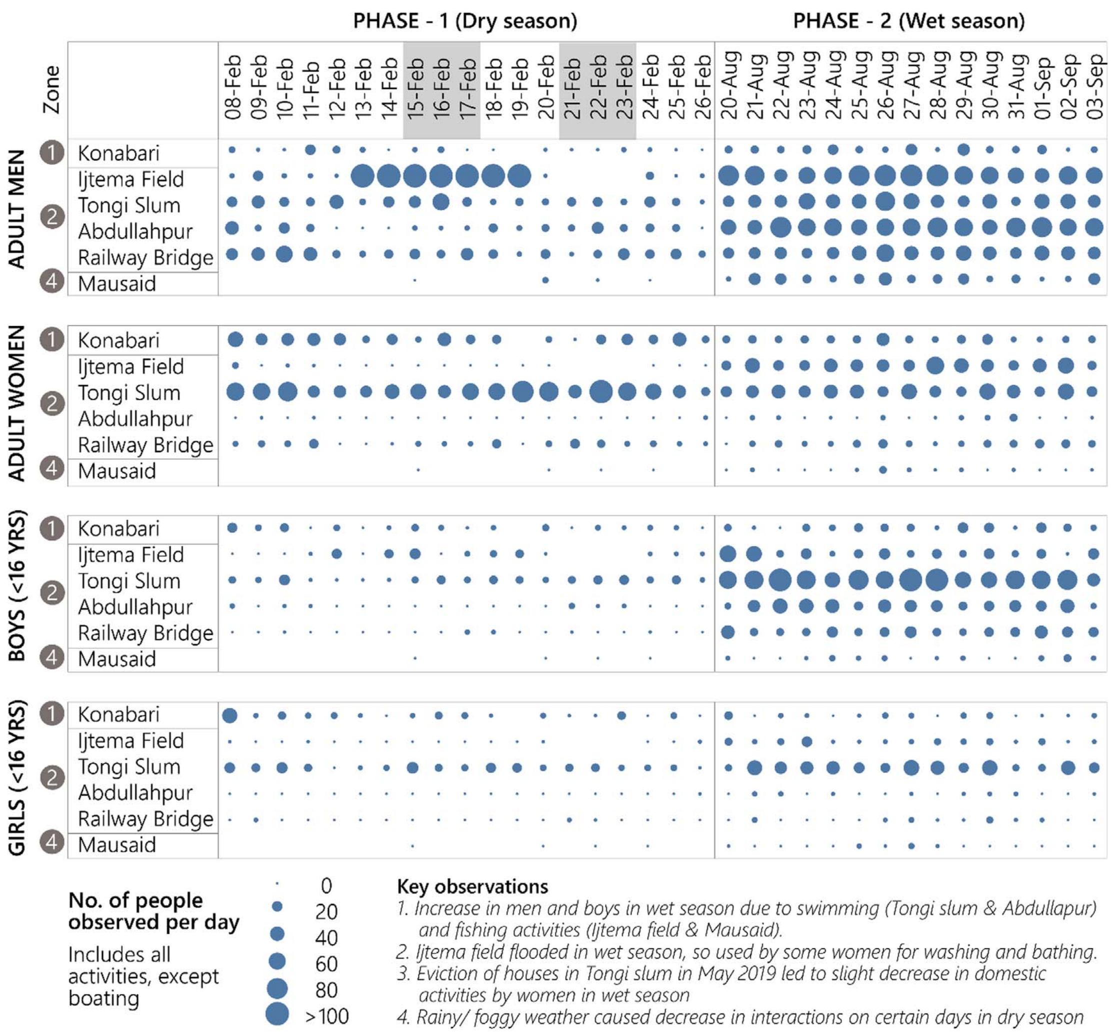
1. Bishwa Ijtema was held in two phases of three consecutive days in February, as highlighted above
2. 'Ijtema field' could not be accessed during 22-24 Feb; hence, no data
3. More than 60 houses in 'Tongi slum' were evicted in May 2019
4. Rise in water level reduced access to one of the observation points in 'Konabari' during wet season

Figure 5. Intensity of river use activities disaggregated by zone and observation site.

direct use of the river was substantially higher in Zone-3 than Zone-4, due to higher poverty levels and inadequate water and sanitation facilities in the former. Second, the nature and timing of river interaction is differentiated by gendered roles and cultural norms, with women and girls risking direct contact through washing dishes, clothes, and other chores throughout the year, while perceived improvement in water quality in monsoon led to increased swimming and bathing among men and children. Third, the Bishwa Ijtema gathering increased concentrations of many heavy metals, though simultaneous disposal of organic waste may alter availability of metal in their free ionic forms. However, given the anoxic conditions that already prevail during the dry season, the additional toxicity contributed by the Ijtema may not be significant. Our study illustrates how future monitoring systems can combine biophysical and social data to provide a more integrated framework for the government's planning cycles.

5.1. Poverty and pollution risks

Regardless of sampling location and season, the rivers have severe pathogen pollution, as indicated by the faecal coliform count that is several hundred times higher than the recommended national and international standards of $<$200cfu/1000ml for bathing and swimming (MoEF 1997, UNEP 2016). Swimming and bathing activities, which increase in monsoon, are likely to cause infectious diseases from accidental ingestion and contact with mucous membranes in eyes and ears. Results from a Quantitative Microbial Risk Assessment across three rivers



Key observations

1. *Increase in men and boys in wet season due to swimming (Tongi slum & Abdullapur) and fishing activities (Ijtema field & Mausaid).*
2. *Ijtema field flooded in wet season, so used by some women for washing and bathing.*
3. *Eviction of houses in Tongi slum in May 2019 led to slight decrease in domestic activities by women in wet season*
4. *Rainy/ foggy weather caused decrease in interactions on certain days in dry season*

Figure 6. Observations of river use disaggregated by gender and age.

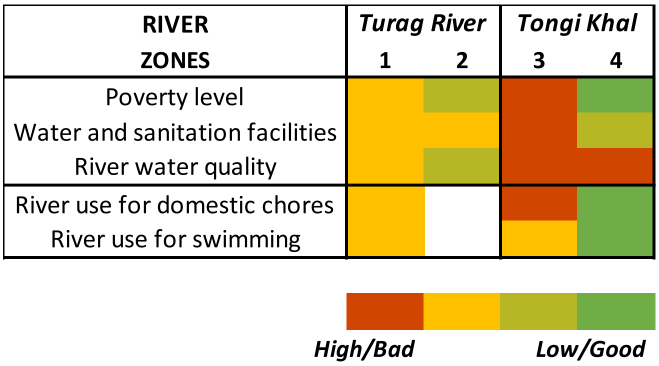


Figure 7. Qualitative assessment linking water quality, socio-economic conditions, and direct contact with river across the four study zones.

in southwestern Bangladesh show that the overall risk of illness for a single exposure of pathogens during bathing ranged from 9%–19% for children and 7%–16% for adults, which exceeds the USEPA acceptable risk of 3–6 illnesses per hundred bathing events (Islam and Islam 2020). Similarly, Hamner *et al* (2006) found significant associations between the use of the Ganges River in Varanasi, India for bathing, laundry, and washing utensils and the incidence of water-borne enteric diseases, with poor sanitation, low income and low education as confounding factors.

The bioaccumulation of heavy metals in fish and vegetables have also been documented in previous studies (Ahmed *et al* 2016, Rashid *et al* 2017). Our observations show that fishing activities are prevalent in the monsoon season, indicating potential consumption of accumulated heavy metals by families consuming fish and nearby populations through the sale of caught fish at neighbourhood markets. Our study shows that women in low-income settlements are regularly exposed to contaminated water, even during the dry season, through washing clothes and dishes. Similarly, informal waste recyclers, standing in waist deep water to wash dye packaging, and casual workers washing denim in the river, are risking exposure on a daily basis. While Hasan *et al* (2019) found significantly higher concentrations of chromium in nails and hair samples of tannery workers, there has been no similar research on bioaccumulation of heavy metals in these riverine dwellers, despite the measured cytotoxicity potential of the river water. Systematic observation of human interaction with polluted river water is unprecedented, providing opportunities for adapting our method to quantify health risks. Recent studies also show high likelihood of heavy metal exposure through dermal contact, the risk being dependent on exposed body surface area and duration of activity (Zhao *et al* 2019). However, these assessments of 'total human exposure' are based on retrospective snapshots of human activity patterns from surveys, which are prone to recall and social desirability bias. In such cases, our method can be adapted in the future to include recordings of the proportion of body surface exposed and duration of activity.

The riverbank settlements studied here are home to thousands of factory workers and their families, living in dense, unsanitary conditions that they afford with their low wages. Though the aggregate benefits of economic growth are enjoyed by the wider population, the negative externalities of unregulated industries and unplanned urbanisation are disproportionately borne by those directly contributing to the growth process. While rural migrants are often habituated to use surface water for domestic activities, the lack of adequate water services and the resulting overcrowding at community waterpoints are key drivers of river usage for washing and bathing purposes. Such unequal water-citizenship in Dhaka slums 'is a daily reminder to the urban poor of their abjection and undesired status in the city' (Sultana 2020, p.1413). While aggregate statistics by JMP (2019) suggest that open defecation is non-existent in urban Bangladesh, the high prevalence of hanging latrines, as observed in this study and previous work by Haque *et al* (2020), reveals that the challenges of marginalised communities may be masked or ignored in the bigger picture.

5.2. Policy landscape and recommendations

While the export-oriented economic growth agenda has dominated the Government of Bangladesh's political and institutional approach since the 1990s, actions are being taken to curb river encroachment, reduce industrial and municipal pollution, and regulate water use, with the High Court bestowing rivers with the same rights as 'legal persons' in July 2019 (Islam and O'Donnell 2020). The ongoing construction of new sewerage treatment plants under the 'DWASA Masterplan 2011', and the recently approved 'Dhaka Sanitation Improvement Project', which includes plans to upgrade toilets and provide communal septic tanks in low-income communities (The World Bank 2020), are two of the planned large-scale interventions to reduce municipal pollution. The Water Resources Planning Organization (WARPO) in collaboration with United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) is drafting the Industrial Water Use Policy (UN ESCAP and WARPO (2019)), including the Greater Dhaka Watershed Restoration project to promote industrial wastewater treatment and reuse (2030WRG 2017). The relocation of the tanneries has been another major intervention, though in absence of a functioning centralised effluent plant, the pollution has merely shifted from the Buriganga to Dhaleshwari River (Hasan *et al* 2020).

The Government of Bangladesh has ambitious goals to dramatically increase ready-made garment exports; however, no equivalent bold environmental policies have been enacted to counter the potential harm from increased wastewater (Hossain *et al* 2018). Government plans to achieve SDG 6.3 tend to rely on the technocratic logic of dominant institutions, driven by physical interventions in manipulating river morphology through dredging (General Economics Division 2015: p. 423). Industry efforts, largely pursued by international brands sourcing from Bangladesh and donor institutions such as the World Bank and International Finance Corporation, focus on creating zones of 'cleaner production' that end up excluding the worst offenders that supply only to the domestic market from external scrutiny (Selim 2018).

However, even if all these initiatives are executed effectively, the portfolio of engineering, judicial, and institutional initiatives is likely to take years to translate into reduction of pollution risks for the most vulnerable. In the short-term, responses to curb pollution exposure, through provision of safely managed water and sanitation facilities and approaches like risk communication can minimise health risks of those living in riverine communities.

Acknowledgments

This document is an output from the REACH programme funded by UK Aid from the UK Foreign, Commonwealth and Development Office (FCDO) for the benefit of developing countries [Programme Code 201880]. However, the views expressed and information contained in it are not necessarily those of or endorsed by FCDO, which can accept no responsibility for such views or information or for any reliance placed on them.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

ORCID iDs

Sonia Ferdous Hoque https://orcid.org/0000-0001-7239-2312

References

2030WRG 2017 *Water for Growth, People and Environment - Bangladesh.* (The 2030 Water Resources Group) (https://www.2030wrg.org/wp-content/uploads/2017/11/WRG_Bangladesh-Fact-Sheet_09_11.pdf)

Ahmed M K, Baki M A, Kundu G K, Islam M S, Islam M M and Hossain M M 2016 Human health risks from heavy metals in fish of Buriganga river, Bangladesh *SpringerPlus* **5** 1697

Amin N, Liu P, Foster T, Rahman M, Miah M R, Ahmed G B, Kabir M, Raj S, Moe C L and Willetts J 2020 Pathogen flows from on-site sanitation systems in low-income urban neighborhoods, Dhaka: a quantitative environmental assessment *Int. J. Hyg. Environ. Health* **230** 113619

Amin N, Rahman M, Raj S, Ali S, Green J, Das S, Doza S, Mondol M H, Wang Y and Islam M A 2019 Quantitative assessment of fecal contamination in multiple environmental sample types in urban communities in Dhaka, Bangladesh using SaniPath microbial approach *PLoS One* **14** e0221193

Arfanuzzaman M and Rahman A 2017 Sustainable water demand management in the face of rapid urbanization and ground water depletion for social–ecological resilience building *Global Ecology and Conservation* **10** 9–22

Chakraborty J and Basu P 2019 Linking industrial hazards and social inequalities: environmental injustice in Gujarat, India *International Journal of Environmental Research and Public Health* **16** 42

Dalton P R 1976 A socioecological approach to the control of Schistosoma mansoni in St Lucia *Bulletin of the World Health Organization* **54** 587

Dalton P R and Pole D 1978 Water-contact patterns in relation to Schistosoma haematobium infection *Bulletin of the World Health Organization* **56** 417

Damery S, Walker G, Petts J and Smith G 2008 Addressing environmental inequalities: water quality *Science Report SC020061/SR2.* (Bristol, UK: Environment Agency)

DoE 2017 *Surface and groundwater quality report 2016.* (Dhaka, Bangladesh: Department of Environment, Ministry of Environment and Forest)

DWASA 2019 Environmental and social impact assessment (ESIA) of pagla STP and trunk mains *Dhaka Sanitation Improvement Project (DSIP)* (Dhaka Water Supply and Sewerage Authority, Ministry of Local Government, Rural Development and Co-operatives) (https://documents1.worldbank.org/curated/en/507721559627554397/pdf/Environmental-and-Social-Impact-Assessment-of-Pagla-STP-and-Trunk-Mains.pdf)

Ferdous F, Das S K, Ahmed S, Farzana F D, Malek M A, Das J, Latham J R, Faruque A S G and Chisti M J 2014 Diarrhoea in slum children: observation from a large diarrhoeal disease hospital in Dhaka, Bangladesh *Tropical Medicine & International Health* **19** 1170–6

Fulazzaky M A 2010 Water quality evaluation system to assess the status and the suitability of the Citarum river water to different uses *Environ. Monit. Assess.* **168** 669–84

General Economics Division 2015 *Seventh Five Year Plan (2016 - 2020) - Accelerating growth, empowering citizens.* (Dhaka: Planning Commission, Government of People's Republic of Bangladesh)

Halder A K, Tronchet C, Akhter S, Bhuiya A, Johnston R and Luby S P 2010 Observed hand cleanliness and other measures of handwashing behavior in rural Bangladesh *BMC public health* **10** 545

Hamner S, Tripathi A, Mishra R K, Bouskill N, Broadaway S C, Pyle B H and Ford T E 2006 The role of water use patterns and sewage pollution in incidence of water-borne/enteric diseases along the Ganges River in Varanasi, India *International Journal of Environmental Health Research* **16** 113–32

Haque N 2017 Exploratory analysis of fines for water pollution in Bangladesh *Water Resources and Industry* **18** 1–8

Haque S S, Yanez-Pagans M, Arias-Granada Y and Joseph G 2020 Water and sanitation in Dhaka slums: access, quality, and informality in service provision *Water Int.* **45** 791–811

Hasan M M, Ahmed M S, Adnan R and Shafiquzzaman M 2020 Water quality indices to assess the spatiotemporal variations of Dhaleshwari river in central Bangladesh *Environmental and Sustainability Indicators* **8** 100068

Hasan M M, Hosain S, Poddar P, Chowdhury A A, Katengeza E W and Roy U K 2019 Heavy metal toxicity from the leather industry in Bangladesh: a case study of human exposure in Dhaka industrial area *Environ. Monit. Assess.* **191** (530) 1–9

Hasan R 2021 Shut down Savar tannery estate. *The Daily Star*, 24 August 2021

Hong S C 2018 *Developing the Leather Industry in Bangladesh.* (Asian Development Bank) *ADB Brief No. 102*

Hossain L, Sarker S K and Khan M S 2018 Evaluation of present and future wastewater impacts of textile dyeing industries in Bangladesh *Environmental Development* **26** 23–33

Hostetter M K 2006 The great stink of Paris and the nineteenth-century struggle against filth and germs *J. Clin. Invest.* **116** 2835–2835

Islam M M M and Islam M A 2020 Quantifying public health risks from exposure to waterborne pathogens during river bathing as a basis for reduction of disease burden *J. Water Health* **18** 292–305

Islam M S and O'Donnell E 2020 Legal rights for the Turag: rivers as living entities in Bangladesh *Asia Pacific Journal of Environmental Law* **23** 160–77

JMP 2019 *JMP WASH Data [Online].* (WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene) Available: (https://washdata.org/data/)

Kamal M M, Malmgren-Hansen A and Badruzzaman A 1999 Assessment of pollution of the River Buriganga, Bangladesh, using a water quality model *Water Sci. Technol.* **40** 129–36

Khan S, Cao Q, Zheng Y, Huang Y and Zhu Y 2008 Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China *Environ. Pollut.* **152** 686–92

Kookana R S, Drechsel P, Jamwal P and Vanderzalm J 2020 Urbanisation and emerging economies: issues and potential solutions for water and food security *Sci. Total Environ.* **732** 139057

Landrigan P J *et al* 2018 The Lancet Commission on pollution and health *Lancet* **391** 462–512

Mandal P, Upadhyay R and Hasan A 2010 Seasonal and spatial variation of Yamuna River water quality in Delhi, India *Environ. Monit. Assess.* **170** 661–70

MoEF 1997 *Environmental Conservation Rules 1997.* (Dhaka, Bangladesh: Ministry of Environment and Forest (MoEF), Government of People's Republic of Bangladesh)

Morandeira N S, Castesana P S, Cardo M V, Salomone V N, Vadell M V and Rubio A 2019 An interdisciplinary approach to assess human health risk in an urban environment: a case study in temperate Argentina *Heliyon* **5** e02555

Muralidhar V, Ahasan M F, Khan A M and Alam M S 2017 Basic occupational health services (BOHS) in community primary care: the MSF (Dhaka) model *BMJ Case Reports* **2017** (bcr2016218293) 1–6

Murgatroyd A *et al* 2021 *Water Security for Climate Resilience Report: A synthesis of research from the Oxford University REACH programme.* (Oxford, UK: University of Oxford)

Nguyen H D, Hong Quan N, Quang N X, Hieu N D and Thang L V 2021 Spatio-temporal pattern of water quality in the Saigon-Dong Nai river system due to waste water pollution sources *International Journal of River Basin Management* **19** 221–243

Parker A 1932 Water Pollution Research *Nature* **130** 761–3

Prüss A 1998 Review of epidemiological studies on health effects from exposure to recreational water *International Journal of Epidemiology* **27** 1–9

Rahman M, Rukshana F, Ghosh N, Moniruzzaman M, Shahabuddin M and Ahmed M 2017 Polluted river water enhances accumulation of heavy metals in soil and crops *Vegetos-An International Journal of Plant Research,* **30** 220–6

Ram P K *et al* 2010 Is structured observation a valid technique to measure handwashing behavior? Use of acceleration sensors embedded in soap to assess reactivity to structured observation *The American journal of tropical medicine and hygiene* **83** 1070–6

Rampley C P N *et al* 2020 River toxicity assessment using molecular biosensors: heavy metal contamination in the Turag-Balu-Buriganga river systems, Dhaka, Bangladesh *Sci. Total Environ.* **730** 134760

Rashid A, Siddika A and Rahman M T U 2017 Assessment the presence of Heavy Metal (HM) concentration in river water and fish species and associated human health hazard due to the fish consumption of Turag River in Bangladesh *15th Int. Conf. on Environmental Engineering, Held as part of the Canadian Society for Civil Engineering Annual Conf. and General Meeting 2017*

Restiani P 2017 *Water governance mapping report: textile industry water use in Bangladesh.* (Stockholm International Water Institute (SIWI) and Sweden Textile Water Initiative) (https://www.siwi.org/wp-content/uploads/2017/06/Water-governance-map)

Sagris T and Abbott J 2015 *An analysis of industrial water use in Bangladesh with a focus on the textile and leather industries.* (Washington DC, USA: 2030 Water Resources Group)

Selim S 2018 Environmental compliance opportunities in the Bangladeshi Ready Made Garments Industry: lessons from the Green High Achievers. UK Aid and Economic Dialogue on Green Growth

Slootweg R, Kooyman M, de Koning P and van Schooten M 1993 Water contact studies for the assessment of schistosomiasis infection risks in an irrigation scheme in Cameroon *Irrigation and Drainage Systems* **7** 113–30

Sultana F 2020 Embodied intersectionalities of urban citizenship: water, infrastructure, and gender in the global south *Annals of the American Association of Geographers* **110** 1407–24

The Daily Star 2009 4 rivers around city declared ecologically critical area. *The Daily Star*, November 24, 2009 (https://www.thedailystar.net/news-detail-115519)

The World Bank 2020 Bangladesh - Dhaka sanitation improvement project : ensuring better sanitation in Dhaka *Project Brief.* (Washington, D.C: World Bank Group)

Turbow D J, Osgood N D and Jiang S C 2003 Evaluation of recreational health risk in coastal waters based on enterococcus densities and bathing patterns *Environ. Health Perspect.* **111** 598–603

UN ESCAP, and WARPO 2019 *Workshop on Industrial Water Use Policy in Bangladesh - Concept note [Online] (Dhaka, Bangladesh)* (https://www.unescap.org/sites/default/files/Concept%20Note%20on%20Industrial%20Water%20Use%20Policy%20in%20Bangladesh_24_04_2019_0.pdf)

UN General Assembly 2015 Transforming our world : the 2030 Agenda for Sustainable Development (https://sdgs.un.org/2030agenda)

UNEP 2016 *A Snapshot of the World's Water Quality - Towards a global assessment.* (Nairobi, Kenya: United Nations Environment Programme (UNEP))

van Puijenbroek P J T M, Beusen A H W and Bouwman A F 2019 Global nitrogen and phosphorus in urban waste water based on the shared socio-economic pathways *J. Environ. Manage.* **231** 446–56

Vlahov D, Galea S and Freudenberg N 2005 The urban health 'advantage' *Journal of urban health : bulletin of the New York Academy of Medicine* **82** 1–4

Wang X, Sato T, Xing B and Tao S 2005 Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish *Sci. Total Environ.* **350** 28–37

Whitehead P, Bussi G, Peters R, Hossain M, Softley L, Shawal S, Jin L, Rampley C, Holdship P and Hope R 2019 Modelling heavy metals in the Buriganga River System, Dhaka, Bangladesh: Impacts of tannery pollution control *Sci. Total Environ.* **697** 134090

World Bank 2019 *World Development Indicators* [Online]. Available: (https://databank.worldbank.org/) [Accessed 22 February 2020

WWDR 2017 The united nations world water development report 2017 *Wastewater: The Untapped Resource.* (Paris: UNESCO)

Yanez-Pagans M 2016 *Bangladesh Urban Informal Settlements Survey 2016* ed T W Bank (The World Bank Microdata Library)

Zhao X, Li Z, Wang D, Li J, Zou B, Tao Y, Lei L, Qiao F and Huang J 2019 Assessment of residents' total environmental exposure to heavy metals in China *Sci. Rep.* **9** 1–12