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Exploring Water Pollution in the Padma, Meghna and Jamuna River: Focusing Health and Environmental Impact Assessment

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Abstract: The three main rivers in Bangladesh—the Padma, Meghna, and Jamuna—have recently become severely contaminated. The purpose of this study is to examine the situation of water pollution and its effects on the environment and human health. After being meticulously gathered, 27 samples—9 water, 9 sediment, and 9 soil samples—were analyzed to determine various physicochemical properties. Wet digestion was used to evaluate the metals, and an Atomic Absorption Spectrophotometer (AAS) was used to ascertain the results. The ranges of pH, EC, TDS, DO, BOD, COD, SS, and alkalinity in three rivers were 6.5-7.7, 38-590 mg/L, 30-572 mg/L, 4.2-8.5 mg/L, 6.2-9.2 mg/L, 6-1560 mg/L, 5-62 mg/L, and 36-212 mg/L, respectively. Particularly in Padma Rivers, the majority of the results found in this study were above the permitted range, which is unacceptable. With the exception of Zn in Padma and Ni, which was not found in Meghna water, the mean concentrations of Cu, Fe, Pb, Cd, and Cr in Padma, Meghna, and Jamuna river water above the standard value in accordance with USEPA rules. While heavy metal concentrations in soil samples were all under the allowable range, except Cd in soil near Meghna, sediment samples from all three rivers showed significantly higher levels of Fe and Cd. Almost equal numbers of the 750 survey participants came from three carefully chosen areas in Bangladesh. Although the majority of respondents claimed to be in good health, the results showed that various ailments had occurred, prompting them to seek medical attention. Thankfully, most of them typically visited clinics or hospitals where they received medical care from trained professionals and were prescribed medication. However, the respondents knew very little about the entire issue of heavy metal contamination of river water and how it affects both the ecosystem and people.

1. Introduction

The Padma, Meghna, and Jamuna are the three main rivers of Bangladesh. The Jamuna flows south and joins the Padma River, near Goalundo Ghat, then flows into the Bay of Bengal as the Meghna River after its confluence with the Meghna River near Chandpur (Allison, 1998). The rivers are significant for navigation, irrigation, fisheries, industrial usage, and drinking water sources but anthropogenic and human development activities like industrialization and urbanization are deteriorating river water quality gradually threatening human health and the sustainability of the aquatic ecosystem (El Hammari *et al.*, 2022; Benkaddour *et al.*, 2020; Salam *et al.*, 2019; Kazi *et al.*, 2008). The accumulation of heavy metals in aquatic environments has become a serious problem in developing countries (Errich *et al.*, 2020; Ahmed *et al.*, 2015a) due to their toxicity, persistence, and non-degradability (Brunner *et al.*, 2008; Idris *et al.*, 2007).

Both natural and anthropogenic activities are considered accountable for the heavy metal abundance in the environment (Wilson and Pyatt 2007; Khan *et al.*, 2008). Geological weathering, waste from the municipality, industry, and agriculture, the disposal of metals and metal components; and leaching of metals from garbage, solid waste heaps, and animal and human excreta discharge huge quantities of heavy metals (Shanbehzadeh *et al.*, 2014). River sediments are a major carrier of heavy metals in the aquatic environment which have been extensively regarded as environmental sinks in the watercourse (Islam *et al.*, 2015a) because metals tend to amass in bottom deposits (He *et al.*, 2009; Nobi *et al.*, 2010). The chemistry of heavy metals in an aquatic environment depends profoundly on the behavior of water physicochemical parameters. The behavior of water physicochemical parameters such as pH temperature, salinity, electric conductivity, TDS, and turbidity profoundly affect the chemistry of heavy metals such as composition and toxicity level (Zhang *et al.*, 2009). However, increasing contamination by heavy metals has significant adverse effects on humans and aquatic organisms upon exposure (Islam *et al.*, 2015b).

The human body can be exposed to toxic heavy metals through several pathways e.g. ingestion, dermal contact, and inhalation (Alaqarbeh *et al.*, 2022; Ahmed *et al.*, 2021; Hossain *et al.*, 2021). Using such contaminated water causes health effects; if people use it for a long time, numerous types of acute and chronic health problems occur (Errich *et al.*, 2023; Singh *et al.*, 2017). Thereby, various long-lasting chronic impacts like liver damage, respiratory failure, blood circulation, and skin cancer can occur that can lead to even death (Wei *et al.*, 2014). In Bangladesh, the three major rivers become victims of industrial pollution, siltation, and many other man-made factors. Industrialization and unplanned urbanization have affected all fish and most aquatic animals to death, disrupting food chains, critical diseases to humans, and destruction of ecosystems of the river area (Nasri *et al.*, 2024; Nahar, 2009).

Therefore, the present study aimed to assess the physicochemical parameters and heavy metal contamination aspects in the water, sediments, and surrounding soil of three selected rivers, and also to explore the health and environmental impact of river water pollution.

2. Methodology

2.1 Study area

The study was conducted in the three major rivers Padma, Meghna, and Jamuna Rivers in Bangladesh where nine sampling sites were selected (three from each) based on higher pollution intensity. In the case of the Padma River, the study was conducted near Rajshahi, for the Meghna River, Kishoreganj was selected and for the Jamuna River, the study was conducted at Sirajganj. Both the Padma and Jamuna River convergence receive around 85% water flow from the North-West latitude, while the residual 15% flow is received from the Meghna River from the North-East latitude of Bangladesh (Syed *et al.*, 2018). The average and maximum depth of the Meghna river is 308 m and 490 m, while the Padma river's average and maximum depth are 295 m and 479 m, respectively (Ahmed *et al.*, 2019).

The sites of sampling sections are shown in Figure 1 and Table 1, Table 1 details locations with their latitude and longitude.

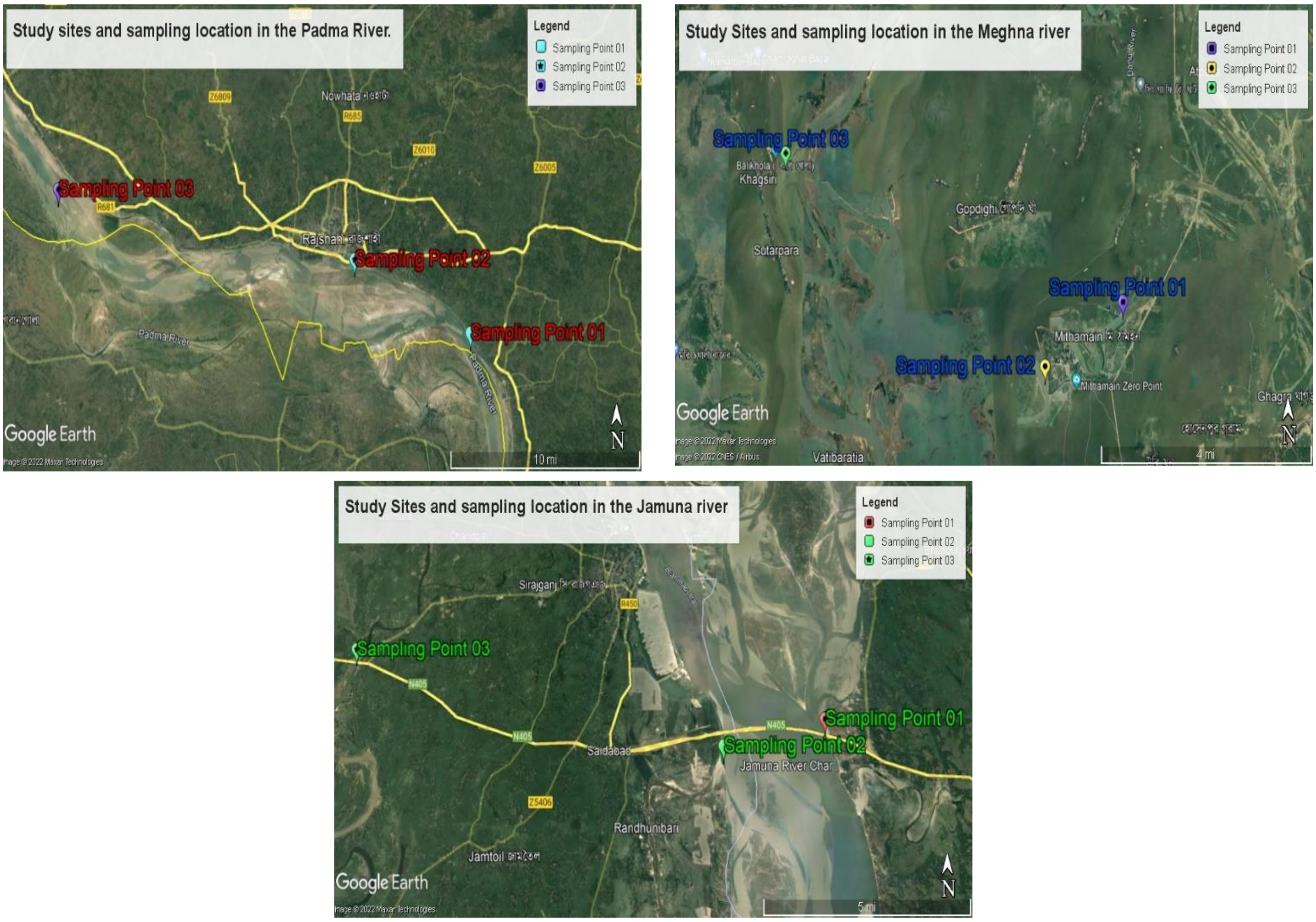


Figure 1. Map showing the study sites and sampling locations of three rivers (Source: Google Earth satellite image, 2022)

Table 1. Geographic location of the sampling sites

River Name	Points	Latitude	Longitude
Padma River	Sampling Point 01	24°23'35.60"N	88°22'1.70"E
	Sampling Point 02	24°21'9.43"N	88°36'54.11"E
	Sampling Point 03	24°18'35.97"N	88°42'43.04"E
Jamuna River	Sampling Point 01	24°23'48.97"N	89°47'52.22"E
	Sampling Point 02	24°23'46.79"N	89°45'27.50"E
	Sampling Point 03	24°25'18.95"N	89°35'29.97"E
Meghna River	Sampling Point 01	24°25'22.82"N	91° 4'16.74"E
	Sampling Point 02	24°24'34.82"N	91° 2'50.00"E
	Sampling Point 03	24°27'16.71"N	90°57'58.58"E

2.2 Collection of water, sediment, and soil samples

2.2.1 Water sampling

A total of 9 water samples were collected from the three rivers Padma, Meghna, and Jamuna in 500 ml plastic bottles. Before sample collection, all the bottles were cleaned properly with diluted acid followed by distilled water. During sampling the bottles were rinsed thrice with water to be sampled then filled to their brims and sealed immediately to avoid air bubbles. Samples were acidified with 5 ml 1M nitric acid to protect water from pathogenic attack. The bottles were labeled separately with a unique identification number with necessary information such as collection date, location, time, etc., and placed in an ice box. The samples were then carefully carried to the Laboratory of Environmental Science, BAU, Mymensingh.

2.2.2 Sediment and soil sampling

The sediment and soil samples were collected from previously selected 9 sites, basically from the river and farmer's fields (crops, vegetables, home garden, etc.) where river water is used for irrigation. Sediment and soil samples were kept in polythene bags (500 gm) subsequently proper labeling and sealing. The collected samples were digested properly before analysis.

2.3 Physicochemical measurements of the samples

Water pH, electrical conductivity, total dissolved solids, dissolved oxygen, biological oxygen demand, chemical oxygen demand, and suspended solids were evaluated using portable multimeters, respectively (**Table 2**). Biochemical oxygen demand (BOD) was measured using the 5-Days BOD test (Rikta, 2016), while alkalinity by Titration method (Hem, 1984).

Table 2. Instruments used during the physicochemical analysis of the collected samples

Parameters	**Instruments**
pH	Digital pH meter(pHep+)
EC (µS/cm)	EC meter (HACH SensIon TM+EC5)
TDS (mg/L)	TDS meter (HM digital, Germany)
DO (mg/L)	DO meter (Hanna -HI98194)
BOD (mg/L)	DO meter (Hanna -HI98194)
COD (mg/L)	Portable photometer (Hanna-HI97106)
SS (mg/L)	TSS meter (HACH)
Alkalinity (mg/L)	Titration (Methyl-orange indicator)
Heavy metals	AAS (Model- PG-990, Made in England)

2.4 Analysis of heavy metals in the samples

At initial, 100 ml water sample was taken in a beaker and then 4 ml HNO_3 was added. After mixing, the solution was kept on a hot plate for evaporation until the volume became 50ml. Then it was transferred into a 100 ml volumetric flask where 100 ml volume was done by adding distilled water (Afrin *et al.*, 2014). The concentrated sample was filtered and kept for analyzing heavy metals (Pb, Cr, Cd, Cu, Ni, and Zn) with the help of Atomic Absorption Spectrophotometer (AAS).

In the case of sediment and soil samples, the samples were dried in the laboratory at 104℃ for 48 hours, ground to a fine powder, and sieved through 106 µm stainless still mesh wire. The samples were then stored in a polyethylene container ready for digestion and analysis. About 0.5 grams of sample was put into the reference vessel. Then 25 ml of mixture (HCL: H_2SO_4: HNO_3 = 3:2:2) were added to reaction vessel which will be inserted into the microwave unit. The digested solution was cooled and filtered. The filtered sample was then made up to 50 ml with distilled water and stored in special containers (Al-Hetty *et al.*, 2021). AAS (Atomic absorption Spectrometry) instrument was used to detect and measure heavy metal content in the sediment and soil samples.

2.5 Data collection

The proposed study was done based on data collected through survey, observation, discussion, and structured and semi-structured questionnaires with limited participation of the people. A standard questionnaire was used for data collection with simple and appropriate words trying to convey the message of the issue intelligible to them. Respondents were selected from the affected community randomly from both males and females and were interviewed through a structured questionnaire. The generations who were young could not see the pollution-free water of those rivers. So, most of the respondents were selected with the age group of a minimum of 30-45 years. The key informants were interviewed through semi semi-structured questionnaire.

2.5.1 Sample size determination

The precision-based sample size n is determined using the following formula:

$$n = \frac{Z(c/100)^2 \times p(1-p)}{d^2} \times DE \times NR \qquad \textbf{Eqn.1}$$

where p is the proportion of responses we are interested in, d is the margin of error, Z(c/100) is the critical value for the confidence level c' DE is the design effect and NR is the non-response rate. Considering c = 95%, p =0.50, d = 6%, DE =1.5, and NR = 5%, the probable number of total respondents, 20%.

The principal considerations in selecting the sample respondents included time and accessibility. Thus, based on the formula and circumstances, the total number of respondents was 750 (for 3 rivers coverage) and the primary data were collected from those respondents of purposively selected 3 districts (Rajshahi, Kishoreganij, Sirajganj) of Bangladesh as a target population area because a large number of people are engaged in fishing, boating and agricultural activities in those rivers.

2.6 Statistical analysis

The collected analytical data were compiled and tabulated properly and subjected to statistical analysis. The Microsoft Office Excel 2016 software was used to present and interpret the collected data. The data collected through interviews were articulated in tabular form, analyzed through SPSS software, and presented by graphs/charts/tables transcribed into texts. A relationship between data and variables was established by interpreting statements. Results were presented through narrative text, simple computations logical reasoning.

3. Results and Discussion

3.1 Physicochemical properties of water samples

The physicochemical parameters of water in the Padma, Meghna, and Jamuna Rivers obtained from the analysis are described in **Table 3**. Firstly, the pH of the Padma, Meghna, and Jamuna rivers ranged 6.8-7.7, 6.5-7.4, and 6.5-7.6, respectively. The values were all within the permissible limit, which indicated its suitability for fisheries, agriculture, and recreational activities. Similar results pH 7.87 was found during the monsoon season in Padma River (Islam *et al.*, 2014) and 7.67 at Paturia ghat, Manikganj (Rahman and Huda, 2012). The pH 7.2-7.5 was found in Meghna river (Bhuyan *et al.*, 2017). Begum *et al.* (2019) reported the pH ranging from 7.72-7.91 in their study. In pH average value of samples were found 8.63 and 8.9 in Jamuna River (Uddin *et al.*, 2014). From the surface and groundwater quality report 2022 by DoE, the maximum and the minimum pH of Jamuna river was 8.57 in December and 7.14 in September, while its range varied from 7.44 to 8.27 in 2019. pH standard range for fisheries was 6.0 to 9.0. Electrical conductivity (EC) measures the mineral constituents' concentration in water. In a water body, higher electrical conductivity means higher pollution. The electrical conductivity found in Padma River ranged from 215 to 561 μS/cm, in Meghna River from 38 to 136 μS/cm and in Jamuna River it ranged from 120 to 590 μS/cm. The wide ranges of EC measured in the studied water samples (38-590) (**Table 3**). The highest EC was found in Jamuna River followed by Padma, both were beyond the admissible limit set by WHO. Almost the same result of EC 258 µS/cm was observed during the post-monsoon season (Islam *et al.*, 2014), also from different study it was observed that the EC in Padma ranged from 162.17-390 mg/l (Rahman and Huda, 2012; Alam *et al.*, 2016). EC concentrations in water samples were found to be 115.8-220 μS/cm (Bhuyan *et al.*, 2017), 284.5-466 μS/cm (Flura *et al.*, 2016), 525-714 μS/cm (Begum *et al.*, 2019). The EC values in those works were much higher than what we found in our study which has a potential effect on seed germination and crop yields (Afrin *et al.*, 2014).

Total dissolved solids (TDS) in the rivers Padma, Meghna, and Jamuna River ranged from 140-295, 30-101, and 80-572 mg/L, respectively. Other than one sample of Jamuna River all of them were within acceptable limits. Similar TDS values were found at various points of Padma River such as Bheramara point, Kushtia; Paturia Ghat, Manikganj, Mawa, Godagari, and Paksi (Islam *et al.*, 2014; Rahman and Huda, 2012; Alam *et al.*, 2016). The TDS concentrations were higher in the previous studies than the present which were 160.4-229.9 mg/L (Flura *et al.*, 2016) and 113-197.67 mg/L (Begum *et al.*, 2019). For Jamuna River, the highest and the lowest TDS was 231 mg/L in March Tarakandi Down point and 59.1 mg/L in June at Kakua. In 2019, TDS range varied from 118.6 mg/L to 192.8 mg/L (DoE, 2022).

Dissolved oxygen (DO) is mainly involved in maintaining the oxygen balance of the aquatic system and an indication of healthy status. Its value over 5 mg/L is considered suitable for supporting life. It is evident from Table 3 that the limits of Padma varied from 5.2 to 8.5 mg/L, Meghna ranged from 4.8-7.2 mg/L, Jamuna 4.2-5.8 mg/L. The highest DO value was observed in Padma River (8.5 mg/L) and the lowest in Jamuna River (4.2 mg/L). The DO of the three main rivers from the three districts was found to be between 4.2 and 8.5 mg/L. In the Padma River, the greatest DO of 7.59 mg/L was recorded during the monsoon and post-monsoon seasons (Islam *et al.*, 2014). The Meghna River's DO concentration in water samples ranged from 4.2 to 6.71 mg/L (Bhuyan *et al.*, 2017). The EQS for DO for fisheries was ≥5 mg/L, while the greatest and lowest DO values were 11.5 mg/L in December at Kakua Point and 4.6 mg/l in March at Tarakandi Up Point. The DO range in 2019 was between 5.6 and 7.4 mg/l (DoE, 2022).

Biochemical Oxygen Demand or BOD measures the quantity of oxygen microorganisms consume during the decomposition of organic matter. The ranges of BOD of Padma, Meghna, and Jamuna Rivers were 7.7-8.8, 7.0-8.6, and 6.2-9.2 mg/L, respectively, which indicates the poor condition of the water (Table 1). The standard value of BOD for fisheries activities is 6 mg/L or less. Then again, BOD of more than 10 mg/L is considered very polluted and harmful. In this study, BOD of major three rivers from three districts were 6.2-8.8 mg/L. The concentration of BOD 3.21 mg/L was observed during monsoon and post-monsoon in Padma River water (Islam *et al.*, 2014) is much lower than present study. BOD concentration in water samples were found to 0.67-3.71 mg/L in Meghna river (Bhuyan *et al.*, 2017). BOD values 2-6.2 mg/L in 2022, 2-3 mg/L in 2019 were found in Jamuna River (DoE, 2022). BOD is an index of the biodegradable organics present (Clesceri *et al.*, 1998). It is important to understand that BOD is not a measure of some specific pollutant but it is very important phenomenon for limn logical studies (Vesilind *et al.*, 1990).

Chemical Oxygen Demand is defined as the amount of specified oxidant that reacts with the sample under controlled conditions (Clesceri *et al.*, 1998). The COD of Padma, Meghna, and Jamuna Rivers were 160-1560, 4-22, and 6-16 mg/L respectively (**Table 3**). According to WHO the permissible limit for COD is 10-20 mg/L so Meghna and Jamuna Rivers were suitable for those purposes but the condition of Padma River was not good in the present study. COD is one of the most important parameters for assessing the quantity of chemically oxidizing matter in water. It measures the oxygen required for the oxidation of mainly organic matter by a strong chemical oxidant (Zhao *et al.*, 2004).

The suspended solids (SS) in three major rivers ranged from 6-62, 5-44, and 7-25 mg/L during the study period. The highest value was observed in Padma (62 mg/L) succeeding Meghna (44 mg/L), which exceeded the admissible limit set for SS. Rahman and Huda (2012) observed SS of an average 120.82 mg/L. Ahmed (2004) reported TSS values ranging from 147.1-298.2 mg/L. Suspended solids can be coarse, floating fine or colloidal particles as a floating film which causes ecological imbalance in the aquatic ecosystem by mechanical abrasion.

The alkalinity of water is caused mainly by OH, CO_3, and HCO_3, ions and an estimate of water to resist change in pH upon the addition of acid (Mahanandda *et al.*, 2010). The maximum alkalinity of water samples was 212, 74, and 146 mg/L for Padma, Meghna, and Jamuna Rivers, respectively (**Table 3**) whereas the standard alkalinity value is 200 mg/L based on WHO. The measured alkalinity values were below the standard level except for Padma River which is exceptionally high and not satisfactory for the natural ecosystem and suitable for fisheries, and agriculture. The high alkalinity impacts water with an unpleasant taste and may be disastrous to human health (Jafar *et al.*, 2012).

Temperature, pH, TDS, EC, turbidity, DO, BOD, and COD were measured on the right bank at 25.450C, 6.85, 43.65 mg/L, 87.23 µS/cm, 14.97 FTU, 6.97, 5.3, and 57.31 mg/L, and on the left bank at 25.150C, 7.48, 43.69 mg/L, 87.34 S/cm, 11.61 FTU, 7.64, 4.34, and 66.68 mg/L, respectively of Bramhaputra River. The results indicated that there were no appreciable variations in the physical-chemical parameter values between the two banks. During the study period, the river water's temperature, pH, DO, TDS, and EC levels were all within the allowed range, but the turbidity, BOD, and COD levels were over it (Islam *et al.*, 2020). Then again, certain physicochemical parameters, such as TDS (704±8.54 mg/L), EC (1043±39.15 mg/L), BOD (22±3 mg/l), and alkalinity (311±6.56 mg/L), were found to be significantly higher in Balu river water than in Brahmaputra River water, while transparency (10±0.25 cm) and DO (1.7±0.36 mg/L) were found to be lower (Rahman *et al.*, 2016).

Table 3. Physicochemical characterization of water samples of major three rivers.

River	pH	EC (µS/cm)	TDS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	SS (mg/L)	Alkalinity (mg/L)
Padma	6.8-7.7	215-561	140-295	5.2-8.5	7.7-8.8	160-1560	6-62	50-212
Meghna	6.5-7.4	38-136	30-101	4.8-7.2	7.0-8.6	4-22	5-44	36-74
Jamuna	6.5-7.6	120-590	80-572	4.2-5.8	6.2-9.2	6-16	7-25	51-146
Permissible limit (WHO, 2011)	**6.5-8.5**	**400**	**500**	**6.0**	**10**	**10-20**	**30**	**200**

3.2 Concentrations of heavy metals

3.2.1 Heavy metals in river water samples

The results of heavy metals found in river water samples are presented in Table 4. The mean concentrations of heavy metals followed the decreasing order of: Fe ((179.06 mg/L)> Cu (20.92 mg/L)> Ni (7.05 mg/L)> Cr (2.80 mg/L)> Cd (2.16 mg/L)> Pb (1.42 mg/L)> Zn (1. 35 mg/L) in Padma River water. In case of Meghna river water samples, Fe (23.78 mg/L)> Zn (11.08 mg/L)> Cu (8.52

mg/L)> Pb (1.02 mg/L)> Cr (0.15 mg/L)> Cd (0.02 mg/L) order was observed where Ni was not detected. The order of metals contents in water samples of Jamuna River was Fe (98.44 mg/L)> Zn (18.32 mg/L)> Cu (13.20 mg/L)> Cr (3.50 mg/L)> Pb (2.45 mg/L)> Ni (2.25 mg/L)> Cd (0.32 mg/L). Therefore, it was observed that Fe is the most concentrated metal in the water of the three rivers (**Table 4**). Based on EPA permissible limits of metals in water, Fe and Cu contents were very much higher than permissible limits in all collected samples. Zn concentrations of Meghna and Jamuna River are much higher than the permissible limit but water of Padma River contains less than the permissible limit. The concentration of Cu, and Fe in Padma, and Jamuna were much higher than Meghna. Zn concentration was comparatively lower in Padma, and the highest was found in Jamuna. Pb in Padma and Meghna was almost similar whereas in Jamuna was higher (2.45 mg/L). Cd was present in a very small amount in Meghna, and Jamuna but relatively higher in Padma (2.16 mg/L). Ni in Padma, Jamuna were 7.05, 2.25 mg/L and not found in Meghna river water samples. Meghna river contained lowest Cr than Padma, and Jamuna still exceeded the standard value. Mean concentrations of heavy metals in Meghna river was observed lower than other two rivers in the present study. The concentrations of Zn, Pb, Cu, Cd, Fe, Cr, and Ni were 7.71, 2.21, 17.45, 1.62, 150.46, 2.61, and 8.78 µg/L, respectively in the Padma River (Toma *et al.,* 2024). The mean concentration of metals determined in the water samples ranged from 5.24–26.26 µg/L and the metals determined were Zn, Mn, Cu, Cd, Cr, Pb, and Ni, with mean concentrations of 9.65, 9.68, 13.33, 5.69, 15.94, 26.26, 5.24 (mg/L) in water, respectively.

Table 4. Mean concentrations of heavy metals in river water samples

River	Metal concentrations (mg/L)						
	Cu	**Fe**	**Zn**	**Pb**	**Cd**	**Ni**	**Cr**
Padma	20.92	179.06	1.35	1.42	2.16	7.05	2.80
Meghna	8.52	23.78	11.08	1.02	0.02	ND	0.15
Jamuna	13.20	98.44	18.32	2.45	0.32	2.25	3.50
Permissible limit (USEPA, 2012)	**1.3**	**0.3**	**5**	**0.015**	**0.005**	**0.20**	**0.10**

The concentration of Ni was lowest in the Padma River water (Mortuza, 2024). In water, available Pb, Cu, Zn, and Mn contents were varied seasonally and spatially from 0.002 to 0.0.019, 0.00 to 0.026, 0.001 to 0.082 and 0.003 to 0.062 mg/L, respectively. The Zn was the most abundant in the water during dry season as Zn is normally associated with a variety of other metal activities and mining (Akter *et al.,* 2019). Fe>Mn>Zn>Cu>Ni>V>Se>Cr>Co>As>Cd with mean values of 1291.17, 891.93, 14.18, 3.36, 3.31, 2.5, 1.49, 1.40, 1.07, 0.45, and 1.07 µg L^{-1}, respectively, were determined in the water of the Someshwari river (Tuhin *et al.,* 2024). The detected quantities of Cd, Cr, Mn, and Zn in the Brahmaputra River water are lower than recommended levels, however, Fe is greater, according to research by Islam *et al. (*2020) where in every sampling site, Pb and Ni are found below the detection limit. The comparative analysis of Rahman *et al.* (2016) showed that the water from the Balu River had higher quantities of heavy metals than that from the Brahmaputra River. According to the findings, the Balu River's water was contaminated and unfit for aquaculture and human consumption. The Brahmaputra River's water, on the other hand, was suitable for irrigation and aquaculture but rapidly lost quality due to expanding industry and untreated municipal trash. These metals come from industrial effluents, urban run-off, sewage discharge and insect or disease control agents and from many others sources. Zhang *et al.* (2015) revealed that these toxicants from river water can enter into the nearby groundwater recharge system.

3.2.2 Heavy metals in sediment samples

The average concentrations of Cu, Fe, Zn, Pb, Cd, Ni, and Cr in Padma River sediment were 9.33, 327.4, 46.18, 11.44, 1.90, 13.22 and 36.32 ppm; in Meghna river 14.50, 366.20, 55.50, 14.32, 3.28, 22.46 and 54.20 mg/kg; in Jamuna River 8.20, 278.00, 36.80, 10.40, 0.48, 9.94 and 24.60 mg/kg, respectively. Present data indicated that Fe accumulation in the sediments of three rivers were the highest followed by Zn content. Among the measured metals Fe exceeded the permissible limit in all the sediment samples. Cu, Zn, and Pb contents were within the boundary values guided by USEPA. For Cd, and Cr only the Jamuna River had less compared to the standard limit while Ni contents found much higher in the Meghna River (**Table 5**). Similarly, sediments were highly contaminated for Ni according to sediment quality standards in the Bramhaputra river. With the exception of Ni, which is moderately contaminated, all of the sampling sites are low polluted for all of the heavy metals under study, according to the contamination factor (Islam *et al.*, 2020). The mean concentration of metals determined in sediments, the range was 10.13–38.21 mg/kg. The metals determined were Zn, Mn, Cu, Cd, Cr, Pb, and Ni, with mean concentrations of 21.30, 24.46, 28.26, 10.73, 32.72, 38.21, and 10.13 (mg/kg) in sediment, respectively. The concentration of Pb was highest in the sediment of Padma (Mortuza, 2024). Akter *et al.* (2019) stated that in sediments, diverse Pb, Cu, Zn, and Fe contents were seen seasonally and spatially from 6.34 to 20.46, 1.39 to 28.06, 81.30 to 98.90 and 2274.28 to 34.62.10 mg/kg, respectively. The Fe content in all sediment samples was above the EPA guideline whereas the content of Cu and Zn fall in the criteria of moderately polluted range. Therefore, the water of Meghna River is not completely safe for aquatic organisms regarding heavy metal pollution. on the other hand, the mean concentrations of As, Cd, Cr, Co, Cu, Pb, and Zn in sediment samples were 2.82, 1.13, 25.30, 8.63, 22.01, 4.58, and 68.82 mg/kg and 3.83, 1.48, 43.22, 13.86, 35.63, 8.48, and 100.27 mg/kg, in the summer and winter season, respectively. The mean concentrations of all elements were found lower than the sediment quality guidelines values of probable effect level (PEL). The findings concluded that the overall condition of the Jamuna River is a considerable threat to human health and living organisms (Kormoker *et al.*, 2024). The sediment from the Someshwari river has mean values (μg g^{-1}) of As, Cd, Co, Cu, Cr, Ni, Fe, Mn, Pd, Se, V, and Zn of 9.215, 0.441, 11.45, 10.58, 80.26, 87.26, 25166.67, 420.5, 11.47, 15.52, 56.53, and 34.25, respectively (Tuhin *et al.*, 2024).

Table 5. Mean concentrations of heavy metals in sediment samples

River	Metal concentrations (mg/kg)						
	Cu	**Fe**	**Zn**	**Pb**	**Cd**	**Ni**	**Cr**
Padma	9.33	327.40	46.18	11.44	1.90	13.22	36.32
Meghna	14.50	366.20	55.50	14.32	3.28	22.46	54.20
Jamuna	8.20	278.00	36.80	10.40	0.48	9.94	24.60
Permissible limit (USEPA, 1998)	**16**	**30**	**110**	**40**	**0.6**	**16**	**25**

3.2.3 Heavy metals in soil samples

In the farmer’s field, most of the farmers used water for irrigation from the nearest river. Since the water of rivers contains most of the metals at higher than acceptable limits such metal contents were assessed in the nearest farm/fields. Iron (Fe) measured higher than other metals in farm soils but no soil samples crossed the EPA permissible limit. Copper (Cu) and Zn contents in studied soils did not cross the WHO permissible limit also. Cu and Zn deficiency was observed after the assessment of the soil samples in this study (**Table 6**). The concentrations of Pb, Ni, and Cr were much lower in the soils but Cd (0.94 ppm) crossed the WHO permissible limit in one field's soil of Meghna (**Table 6**). Agricultural soil irrigated with Shitalakhya river water in Narayangonj presents elevated Pb (28.13 mg/kg), Cd (0.97 mg/kg), and Cr (69.75 mg/kg), which are higher than safe limits (Ratul *et al.*, 2018). Along with various other Bangladeshi cities, Islam *et al.* (2017) discovered that the soil of Dhaka was heavily contaminated with heavy metals. The average amounts of Cd, Cr, Cu, and As in water were found to be greater than the FAO irrigation water quality standard, and the sources of metals in agricultural soils are reportedly contaminated irrigation water and agrochemicals. In the Gazipur district, irrigation water was combined with wastewater from three industrial areas: textile, dye, agrochemical, paint, and ceramics firms. Both irrigation water and soil had significant quantities of Zn, Cu, Pb, and Cr, all of which were beyond allowable limits. A prevalent technique in many underdeveloped nations is irrigation using contaminated surface water (Chary *et al.*, 2008). In developing nations like Bangladesh, one of the most serious ecological and public health issues is the contamination of agricultural soil and vegetables by metals from contaminated irrigation water (Kashem and Singh, 1999).

Table 6. Measurement of metals in soils of field near to rivers

River	Metal concentrations (mg/kg)						
	Cu	**Fe**	**Zn**	**Pb**	**Cd**	**Ni**	**Cr**
Padma	4.48	10.00	0.32	1.46	ND	0.60	4.02
Meghna	6.88	8.00	0.96	0.58	0.94	ND	ND
Jamuna	1.60	43.00	0.23	0.64	0.32	1.03	6.96
Permissible limit (WHO, 1996)	**36.00**	**50.00**	**50.00**	**85.00**	**0.80**	**35.00**	**100.00**

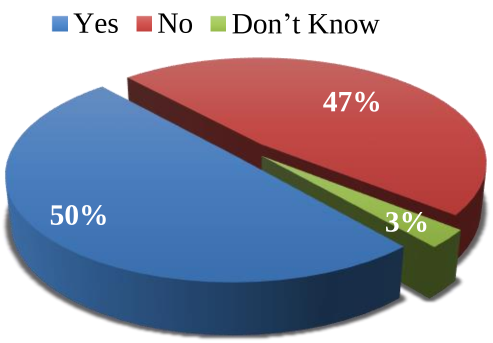
3.3 Impact of water pollution on human health

In Bangladesh, river water is essential to many areas, including household, agricultural, and industrial operations. Recent studies, however, show that the state of river water is alarming because of the alarming levels of heavy metals in the sediment and river water, which suggest possible contamination and provide hazards to aquatic ecosystems as well as human health (Gain *et al.*, 2025). Respondents were asked to rate their health condition according to themselves and results were presented in **Table 7**. In this regard, respondents rated their health condition as poor, fair, good, and excellent. Results showed that 43% of the respondents mentioned their health condition as good whereas 19% indicated poor health condition.

Table 7. Distribution of river water users and respondent's health condition

Respondents' health condition	Number	Percentage
Poor	140	19
Fair	209	28
Good	326	43
Excellent	75	10
Don't Know	0	0
Total	**750**	**100**

Figure 2 (a) shows whether respondents were suffering from (self-reported) any diseases. It was found that about half (50%) of the river water users suffered from diseases; however, 3% did not know about their conditions



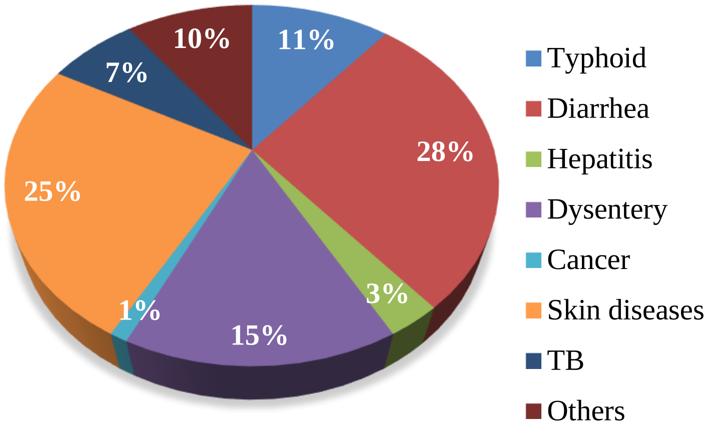


Figure 2. Information related to diseases (a) presence of any disease (b) sufferings from multiple diseases among river water users

Again, **Figure 2 (b)** illustrates the kind of diseases the respondents encountered owing to river water pollution. About 28% respondents mentioned having diarrhea, 25% skin diseases, followed by dysentery (15%), typhoid (11%), and TB (7%). A very small portion stated having cancer (1%) may be due to the presence of heavy metals in water. Also, 10% listed other diseases which were not considered in the questionnaire. Human health directly related to the status of water pollution, where 94% peoples are use river water regularly for their livelihood. Most of the people (45%) are affected by Scabies, 4% are affected by diarrhoea, 6% are affected by dysentery, 20% of people are suffering from respiratory diseases and 4% are suffering from asthma (Hanif *et al.*, 2020). The region's illness pattern was reported by Kabir (2014). Thirty percent suffer from respiratory disorders, four percent have asthma, six percent have diarrhea, eight percent have dysentery, and the majority (54%) have skin illnesses. The Banshi River in Savar (Mukti, 2009) and the Buriganga River (Chakraborty *et al.*, 2013) both contain various industrial and other pollutants. For this reason, the majority of people (54%) suffer from skin conditions, followed by diarrhea (6%), dysentery (4%), respiratory disorders (30%), asthma (4%), and other conditions (2%). Additionally, the Turag River study region has gotten more polluted, with 80% of the population suffering from skin diseases, 75% from gastric ulcers and diarrhea, and 45% from cold coughs. The Turag River of Tongi Bridge in Dhaka has a disease pattern, according to Halder and Islam (2015). 75% of people have gastric ulcers and diarrhea, 45% have colds, and the majority (80%) have skin diseases. Both studies revealed that disorders of all kinds had a greater influence on human health than the chosen field of study. The information regarding the medical history of the respondents is presented in **Table 8**. About 67% of respondents suffering from diseases were diagnosed by a qualified doctor and 33% responded by going to the non-qualified doctor. The Majority of river water users (63%) took treatment from either hospital or clinic, and the remaining 37% of patients had taken their treatment from other places. Furthermore, most of the river water users (82%) were treated with medicines, on the other hand, 18% of patients did not have any medication history. In contrast, Pasha *et al.* (2023) found that 97.8% (44 people) of the respondents said that there are no health centers in the Buriganga river area, while only 2.2% (1 person) said that there are. This study suggests that it is difficult to control and identify new diseases because there aren't enough health centers in the area.

Table 8. Information regarding disease diagnosis and treatment of the river water users

Information	Number	Percentage
Diagnosed by doctor type		
Qualified doctor	504	67
Non-qualified doctor	246	33
Place of treatment		
Hospital/clinic	476	63
Other	274	37
Medication history		
Yes	612	82
No	138	18

3.4 Knowledge and perception of respondents on river water pollution

Many elements (mostly metals) are available in water, sediments, and soils. The knowledge related to elements contained in various samples is fundamental. Awareness of elements in used water among the respondents was investigated. Only 45% of respondents knew of metals' presence in water. Therefore, it was evident that more than half the respondents (55%) did not know about it (**Table 9**). Among the 750 users, about 70% of the respondents had no knowledge about elements present in soils which is a large part of our target population. The respondents were further asked about their knowledge of the names of chemical contents in soils. It was noted that 30% of the respondents indicated soils contain metals. As for the sources of their awareness about environmental pollution, the most popular was media such as newspapers and TV, which accounted for 65%, while 20% and 15% of respondents knew about water pollution from educational institutions and also from friends and family, respectively. The findings show that 20% of respondents, who were all farmers, stated that using water for agricultural purposes pollutes the soil. According to 80% of responses, soil cannot be impacted by non-use of this water (Hanif *et al.*, 2020). About 10% of respondents, or 100% of farmers, responded that using contaminated water for agricultural purposes pollutes the soil while 90% of respondents said that soil cannot be impacted by not using this water (Kabir, 2014). Nearly half of the respondents gave positive answers regarding the direct impact of industrialization on soil and water contamination (Chakraborty *et al.*, 2013). The impact of air pollution and awareness in Bangladesh also revealed that both urban and rural areas lacked this important awareness (Sarker *et al.*, 2018).

Table 9. Knowledge and perception of respondents on river water pollution

Question	Categories	Number	Percentage
Do you know what elements water contains?	Yes	339	45
	No	411	55
Do you know what elements the soil (surrounding river) contains?	Yes	228	30
	No	522	70
How did you know about environmental pollution?	Educational Institution	150	20
	Media (Newspaper, TV, etc.)	488	65
	Friends and Family	112	15

Conclusion

The goal of the current study was to understand the pollution levels of three significant rivers in Bangladesh with an emphasis on the effects on the environment and human health. A questionnaire survey and the meticulous collection and examination of water, sediment, and soil samples from nine locations along three rivers were used to evaluate a number of parameters, such as pH, EC, TDS, DO, BOD, COD, SS, and alkalinity, and compare them with standard values for drinking, irrigation, and aquaculture. The majority of the water quality metrics, particularly the Padma River, appeared to be over the required limit, according to the analysis of various parameters. The levels of heavy metals in water samples were found to be significantly higher than permitted. All of the elements were detected within standard limits in the soil, but, Fe, Cd, and Cr exceeded the recommended concentrations in the sediment samples. Meghna River showed comparatively better condition than Jamuna when all the parameters were taken into account, however, Padma River's state was the poorest in this study. The results of the survey showed that people were unaware of their health, even if the majority of respondents claimed to be in good health. They experienced a wide range of illnesses, primarily TB, typhoid, diarrhea, skin conditions, and dysentery. Some of them even pointed out that the list did not include ailments like cancer. That most of the respondents sought diagnosis and treatment from trained medical professionals and institutions, however, is a relief. The situation was brought on by relying on contaminated water that had high levels of heavy metals. Furthermore, the respondents knew relatively little about metal contamination of soil, sediment, and water. Even though the current level of pollution is not severe enough to endanger the ecological well-being of the river and the local population, if the current pollution trend continues, at least in the future, the river's quality will deteriorate further over the next few years, particularly during the summer. This river ecosystem's metal contamination can be controlled by implementing an appropriate management plan, maintaining a enough dilution flow, installing a sufficient sewage treatment network, and using other watershed management techniques.

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