Title: Assessing the Health of Karnaphuli River, Bangladesh: A Comprehensive Study of Macro Plastic Pollution, Water Quality, and Community Perspectives

Authors: Ariful Anwar Khan[1], Sreebash Chandra Bhattacharjee[2], Masuma Wahab[1], Joy Bardhan[1], Puja Bhattacharjaa[1], Abu Hena Sajib[1], Abdul Kader[1], Abdul Hasib Mollah[3,*]

1. *Department of Zoology, Government Hazi Muhammad Mohsin College, Chattogram, Bangladesh.*
2. *BCSIR Chattogram Laboratory, Chattogram, Bangladesh.*
3. *University of Barishal, Barishal - 8200, Bangladesh.*

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A B S T R A C T

Background: Plastic pollution has emerged as a critical environmental challenge in riverine ecosystems, particularly in rapidly urbanizing regions. The Karnaphuli River, a vital waterway in southeastern Bangladesh, faces escalating pollution pressures from industrial, residential, and commercial sources. Understanding the magnitude, sources, and community perception of this issue is essential for effective management and policy intervention.

Materials and Methods: This study employed a multidisciplinary approach combining field-based macro plastic collection from six strategically selected sites, water quality analysis, and a structured survey of 150 local residents. The sites represented varying pollution sources, including industrial, urban, and commercial zones. Statistical analyses were performed to identify relationships among physicochemical parameters, and thematic analysis was used to interpret community responses.

Results: A strong and statistically significant correlation was found between biochemical oxygen demand (BOD) and chemical oxygen demand (COD) ($r = 0.951$, $p = 0.004$), suggesting high levels of organic pollution. Urban and commercial zones were the dominant contributors to macro plastic accumulation. Survey findings indicated that while 80.8% of respondents were aware of river pollution, only 38% recognized associated health risks, and merely 6% expressed confidence in government actions. Key pollution sources included household waste, market runoff, and pluvial flow during rainfall events.

Conclusion: The study underscores the urgent need for targeted policy reforms, improved municipal waste management systems, and enhanced public environmental awareness. These findings contribute valuable insights for sustainable river management and plastic pollution mitigation strategies in South Asia.

Keywords: Macro plastic pollution; Karnaphuli river; Water Quality Index; Community perspectives; Environmental management

Introduction

Bangladesh is a riverine territory containing approximately 700 large and small rivers and channels including tributaries and canals across the country (Chowdhury et al., 2021)**.** Over the past two to three decades, many rivers passing through major cities have become increasingly polluted due to anthropogenic activities, with plastic pollution emerging as one of the most pressing concerns (Howladar et al., 2021; Chowdhury et al., 2021; Rakib et al., 2022; S. Hossain et al., 2021). Among these rivers, the Karnaphuli River holds particular significance. It is the most significant and vital watercourse in the Chattogram region, playing an essential role in agriculture, industry, transportation, and the daily lives of millions of people and wildlife (M. R. Islam et al., 2017; Hossen et al., 2019). The Karnaphuli River spans approximately 180 to 270 kilometers and flows through the port city of Chattogram, serving as a key economic artery by supporting the operations of the Chattogram port (Sadi et al., 2024; Saad et al., 2022). It provides water for drinking, irrigation, aquaculture, and household use, thus sustaining both urban and rural livelihoods. However, this vital river is now severely threatened due to escalating pollution levels. River pollution in Bangladesh is primarily attributed to municipal sewage, industrial discharges, agricultural runoff, and urban expansion (Yuceer, 2016; Blettler et al., 2017). Such contamination degrades water quality, disrupts aquatic ecosystems, and poses serious risks to public health. Plastics, in particular, are now recognized as some of the most pervasive pollutants in marine environments (van Emmerik et al., 2022; Khan, 2020a). Plastic pollution especially in microplastics and macro plastics has become a serious environmental challenge, with profound implications for biodiversity and ecosystem health (Khan, 2020; Kasavan et al., 2021).). Over the past several decades, declining trends in annual rainfall have been observed across Bangladesh, potentially affecting the discharge and morphological characteristics of rivers such as the Karnaphuli (Abdullah et al., 2022) The Karnaphuli exemplifies this crisis. Once considered a region's lifeline, the river now faces alarming pollution levels from plastic bags, pharmaceutical waste, personal care product residues, and other discarded items (Alam et al., 2023). These pollutants, often entering the river through industrial effluents, domestic sewage, and urban runoff, silently poison the water and threaten the health of aquatic life and local communities (Bio Publisher Chronicles, 2023; Das et al., 2024). Macro plastic pollution, in particular, poses a critical environmental concern. Industries along the Karnaphuli River often discharge untreated wastewater containing plastic waste directly into the river (Shimul et al., 2023). These large plastic items accumulate in riverbeds, interfere with navigation, entangle aquatic organisms, and gradually break down into harmful microplastics, exacerbating the ecological crisis. In response to this growing concern, the present study aims at a comprehensive assessment of macro plastic pollution in the Karnaphuli River, integrating physical water quality measurements with a socio environmental perspective. A community-based approach was adopted to understand better local awareness, practices, and perceptions of plastic use and disposal. Structured questionnaires were administered to residents living near the riverbanks, enabling the identification of socio-economic and behavioral drivers of plastic pollution.

This river's deterioration of water quality has been linked to significant ecological imbalances and negative impacts on fisheries, agriculture, and public health. Plastic pollution has emerged as a global environmental crisis, with microplastics and macro plastics being widely reported in freshwater and marine ecosystems. These plastics can obstruct waterways, harm aquatic life through ingestion or entanglement, and serve as vectors for toxic chemicals. In the context of Bangladesh, plastic consumption has risen dramatically in recent decades, leading to increased plastic waste generation. Additionally, informal settlements and inadequate sanitation infrastructure near the river contribute to unregulated plastic disposal. The environmental consequences are far-reaching: macro plastics degrade into microplastics, enter the food chain, and pose long-term threats to aquatic and human health. Plastic pollution in rivers affects biodiversity and the health and livelihood of communities dependent on these water resources. Aquatic organisms often ingest plastics, mistaking them for food, which can lead to internal injuries, reproductive issues, and death (Akhtar, 2024). In turn, these contaminated organisms pose a risk to human consumers, particularly in communities reliant on river based fisheries. Furthermore, plastics in rivers can absorb and concentrate toxic substances such as heavy metals and persistent organic pollutants (POPs), further intensifying ecological and human health risks (Ali et al., 2025). The accumulation of plastics in riverbeds and along banks also reduces the rivers' aesthetic and recreational value. It increases the risk of flooding by clogging drainage systems during monsoon seasons. Recent environmental studies emphasize integrating community knowledge and perceptions into pollution assessment and mitigation efforts. Community based research allows a more nuanced understanding of local behaviors, challenges, and practices contributing to environmental degradation (Zikargae et al., 2022; Mishra, 2025). Participatory approaches are especially valuable in developing countries like Bangladesh, where informal waste management and socio-economic disparities influence environmental outcomes. Studies have begun exploring how community awareness, attitudes toward plastic use, and waste disposal habits influence river pollution (Miguel et al., 2024). These findings highlight the necessity of behavior change interventions alongside policy reforms. Involving local stakeholders in data collection, awareness campaigns, and cleanup initiatives has proven effective in fostering ownership and long-term commitment to environmental stewardship.

Materials and methods

Study area and period

The study area covers the midstream to downstream stretch of the Karnaphuli river in Chattogram, spanning from Shikalbaha Ghat (upstream) through Anwara 11 No. Ghat (downstream). Six consecutive sampling sites were strategically selected along the river, considering diverse pollution sources, human activities, industrialization, and surrounding infrastructural developments. The Karnaphuli River originates from the Lushai Hills of Mizoram, India, and flows approximately 270 km through the Chattogram Hill Tracts before emptying into the Bay of Bengal. It plays a vital role in supporting ecological diversity and sustaining economic activities in southeastern Bangladesh (Banglapedia, 2025). Over the past several decades, declining trends in annual rainfall have been observed across Bangladesh, potentially affecting the discharge and morphological characteristics of rivers such as the Karnaphuli (Abdullah et al., 2022). The sampling campaign covered an approximately 70 km stretch of the Karnaphuli River, from upstream (Site 1) to downstream (Site 6), capturing diverse pollution sources including residential areas, industries, markets, and ferry operations. Data were collected from 5 January to 13 February 2025.during the dry season to minimize hydrological variability and ensure consistent assessment of water quality and plastic debris.To visualize spatial variations in pollution along the Karnaphuli River, six strategic sampling sites were selected based on land use, industrial activity, and proximity to human settlements. The spatial data analysis and map preparation were carried out using ArcGIS Desktop (version 10.8, ESRI, Redlands, CA, USA) to ensure precise spatial representation and visualization of the study sites (Figure 1).

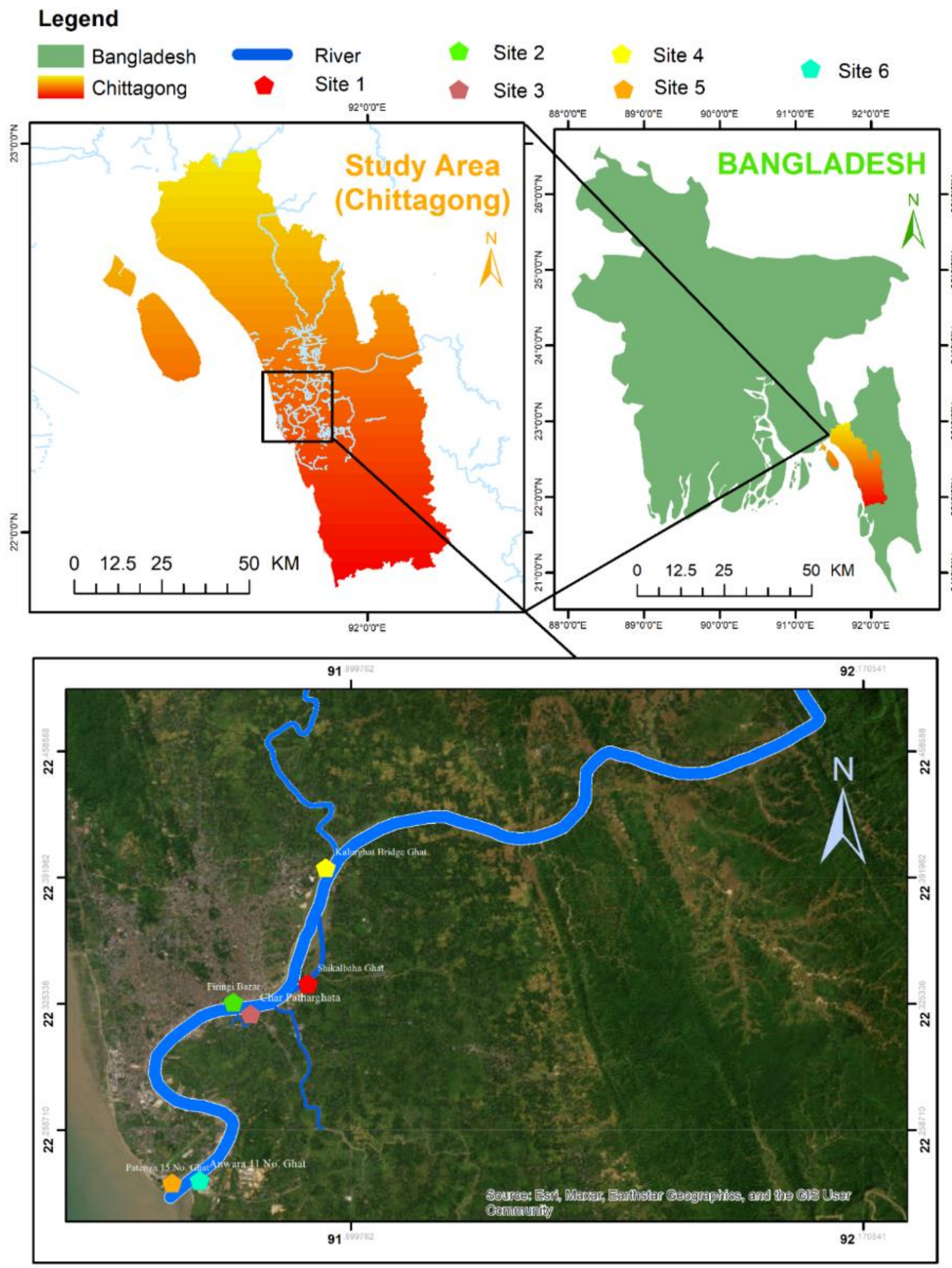

Figure 1: GIS map showing the geographical location of six sampling sites (1–6) along the Karnaphuli River, Chattogram, Bangladesh, where water and plastic debris samples were collected between January and February 2025.Sites include: Site 1 – Shikalbaha Ghat, Site 2 – Firingi Bazar Feri Ghat, Site 3 – Char Patharghata Bridge Ghat, Site 4 – Kalurghat Feri Ghat, Site 5 – Patenga 15 No. Ghat, Site 6 – Anwara 11 No. Ghat

The geographical distribution of the six sampling sites along the Karnaphuli River in Chattogram, Bangladesh. The upstream-to-downstream progression includes:

Site 1 – Shikalbaha Ghat, Site 2 – Firingi Bazar Feri Ghat, Site 3 – Char Patharghata Bridge Ghat, Site 4 – Kalurghat Feri Ghat, Site 5 – Patenga 15 No. Ghat, Site 6 – Anwara 11 No. Ghat. This selection of locations was made to depict a gradient of environmental conditions, beginning with somewhat less disturbed upstream areas and progressing to heavily urbanized and industrialized zones further downstream. Visualizing pollution patterns peculiar to a site and gaining knowledge of the impact of anthropogenic activities in the surrounding area are made easier by the GIS map.

To enhance the geographical representation, on-site images were captured to visually record the environmental conditions and adjacent activity at each sampling site in Error! Reference source not found.. These photos offer qualitative insights into land use patterns, infrastructure, and observable pollution along the riverbanks.

Figure 2. Photographic views of the six sampling sites (1–6) along the Karnaphuli River, Chattogram, Bangladesh. Sites include: Site 1 – Shikalbaha Ghat, Site 2 – Firingi Bazar Feri Ghat, Site 3 – Char Patharghata Bridge Ghat, Site 4 – Kalurghat Feri Ghat, Site 5 – Patenga 15 No. Ghat, Site 6 – Anwara 11 No. Ghat.

From upstream at Shikalbaha Ghat (Site 1) to downstream at Anwara 11 No. Ghat (Site 6), the photographic perspectives of the six selected sampling locations along the Karnaphuli River reveal distinct site characteristics. These include visible industrial discharge points, residential settlements, ferry terminals, fish markets, and floating debris. Such visual evidence reinforces the rationale behind site selection and helps validate the observed spatial variations in plastic pollution and water quality across the study area. In addition to quantitative data collection, comprehensive visual observations were made at each of the six chosen sites (Table 1) to better understand the local environment influencing plastic pollution and water quality. These observations focused on the physical environment, human activity, water appearance, sediment composition, and visible signs of environmental degradation. Placement categories were defined as “Far from human residence” (~200 m) and “Near human residence” (~50 m). Water appearance was classified as “Low turbid” (relatively clear), “Highly turbid” (opaque with suspended particles), or “Seems dirty” (floating debris, discoloration, or odor).

Table 1: Physical, Infrastructural, and Environmental Observations at Six Sampling Sites (1– 6) Along the Karnaphuli River, Chattogram, Bangladesh, During Fieldwork Conducted January–February 2025. Observations Include Proximity to Human Settlements, Industrial Areas, Ferry Crossings, Fish Markets, Human Activities, Water Appearance, Sediment Conditions, Bank Status, Pollution Status, and Floating Plastic Debris.

Visual Observation	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Placement						
Far from human residence				+	+	
Near human residence	+	+	+			+
Near ferry cross				+		+
Close to factory	+	+	+	+		+
Close to riverside fish market			+			
Adjacent to cement bag washing and recycling factory			+			+
Human Activities						
Fishing	+	+	+	+		
Bathing and washing clothes		+	+	+		
Dumping domestic waste	+	+	+	+	+	+
Washing utensils of the fish market			+			
Dumping waste of fish market			+			
Cement and plastic sack washing			+	+		
Dumping of nearby market waste		+	+			
Water Appearance						
Low turbid	+				+	+
Highly turbid				+		
Seems dirty		+	+			
Sediment Condition						
Sandy clay	+			+		+
Sandy and rocky			+			
Mostly clay		+			+	
Bank Status						
Natural				+		+
Both natural and artificial	+	+	+		+	
Pollution Status						
Low					+	+
Moderate			+	+		
High	+	+				
Environment Issues						
Vegetation			+	+	+	+
Floating of plastic Debris	+	+	+	+	+	

Visual observations indicate that Sites 4 and 5 are far from human settlements, while Sites 1, 2, 3, and 6 are near residential areas, increasing the probability of household waste influx. Site 3 has a distinctive sandy and rocky sediment composition, whereas Sites 2 and 5 are predominantly clay, potentially affecting pollutant retention. Industrial influence is considerable at Sites 1, 2, 3, 4, and 6, with Sites 3 and 6 located near cement bag washing and recycling operations, which may contribute to microplastic and chemical contamination. Site 4 exhibits elevated water turbidity, likely due to ferry operations, while floating plastic debris was observed at all locations, particularly Sites 1–5. These physical and environmental disparities explain the observed regional variations in pollution levels among the sampling sites and highlight the combined impact of human activity, industrial discharge, and river hydrodynamics on local water quality.

Acquisition of water samples

Water samples were collected from each of the six designated sites along the Karnaphuli River, specifically from the midsection of the river at each location, maintaining a consistent depth of 21 cm below the surface. At each site, 500 mL of surface water was collected using pre-cleaned glass bottles to minimize contamination. Immediately after collection, the bottles were sealed with aluminum foil to prevent exposure to airborne particles and sunlight. The samples were thereafter maintained in an icebox at a low temperature to preserve their physicochemical integrity during travel by the standard protocols specified by the U.S. Environmental Protection Agency (EPA Method 1669) (Viet et al., 2021). All collected samples were subsequently transported to the Bangladesh Council of Scientific and Industrial Research (BCSIR) Laboratory in Chattogram for further physicochemical analysis. Surface water temperature and pH were measured directly at each sampling site along the Karnaphuli River to ensure site-specific accuracy. Temperature was recorded using a digital thermometer probe, while pH was measured with a calibrated HANNA pHep HI98107 portable pH meter. All measurements were conducted on site immediately after sample collection to minimize variability and ensure data reliability.

Plastic debris collection from sampling sites

Macro plastic samples were collected from the riverbank during low-tide conditions to ensure maximum exposure of the sediment, adopting and modifying the methodology of (Blettler et al., 2019). Three transects, each measuring 15 m × 5 m (75 m²), were established parallel to the water line on the exposed riverbank and sampled in triplicate, yielding a total sampled area of 225 m² per site. This approach focuses on stranded macroplastics deposited by river dynamics. Transect placement was systematic and based on site-specific features identified during preliminary surveys including proximity to residential areas, industrial discharge points, markets, and ferry crossings to capture local heterogeneity in contamination. All visible macro plastic items (>5 mm) within the transects were collected manually, washed to remove sediment, and dried prior to categorization to ensure complete recovery of debris.

Categorization of plastic items and weight measurement

Categorization of Plastic Items and Weight Measurement Collected plastic items were brought back to the laboratory facilities of the Faculty of Chemistry , Bangladesh Council of Scientific and Industrial Research, and macro plastics were visually categorized based on their functional origin and composition following the NOAA classification (Djaguna et al., 2019). Plastics from different categories were separately weighed to calculate the abundance of macro plastics at each sampling site. Each site was sampled in triplicate along three transects to ensure representative coverage, and all visible macro plastic items were counted and categorized. Sampling was conducted under low-tide conditions, and prior weather conditions were noted to avoid bias from recent rainfall or flooding events. During the entire procedure, strict safety precautions were followed to prevent contamination of the collected plastic debris.
Macro plastic samples were analyzed using FTIR spectroscopy at BCSIR, Chattogram. Spectral data were compared with reference libraries to reliably identify polymer types (PE, PP, PS, PET).

Calculation of pollution index

The water pollution index (WPI), was computed by using the recorded water quality parameters (temperature, pH, salinity, DO, TDS and conductivity) and compared with the standard limits in the freshwater systems (M. Hossain & Patra, 2020; Galal Uddin et al., 2017).

The WPI was calculated using the following equation.

$$WPI = \frac{1}{n}\sum_{i=1}^{n} PLi\ ,$$

Where n is the number of parameters and PLi is the total pollution load of each parameter (*A-Water-Quality-Index-Do-We-Dare-BROWN-R-M-1970*)
The Table 2 shows the limits of the rating classes in the water pollution index.

While scores between 0.5 and 0.75 show good but somewhat influenced conditions, a WPI score of < 0.5 implies excellent water quality with low pollution. Values between 0.75 and 1.0 indicate mild pollution, indicating possible ecological stress. Extreme pollution indicated by a WPI of ≥ 1 results from significant water quality degradation and perhaps hazards to aquatic life and human health. This classification system helps one comprehend the degree of contamination at several sampling sites more fully.

Social survey for source identification and public awareness towards plastic pollution in the Karnaphuli river

Table 2: Justification of Water Pollution Level Based on WPI Scores(Sarker et al., 2015)

Value	Status
≤ 0.5	Excellent
0.5-0.75	Good
0.75-1	Moderately polluted
≥ 1	Extremely polluted

A field-based social survey was conducted to identify the potential sources of riverine plastic pollution and assess public awareness and attitudes towards plastic waste management in the Karnaphuli River. A standard structured questionnaire was developed, and data were collected through direct, face-to-face interviews using a combination of quantitative and qualitative approaches. The survey covered six different sites along the Karnaphuli River, with approximately 25 participants from each site, resulting in a total of 150 adult participants. Participants were recruited using a convenience sampling approach from the six study sites, focusing on individuals residing near the riverbanks or engaged in river-related activities. Interviews were conducted at their residences or in nearby public areas such as markets. Efforts were made to include participants from diverse professions (e.g., fishers, factory workers, vendors, and homemakers) to capture a broad range of community perspectives.The questionnaire included both closed-ended and open-ended questions designed to extract information on: Perceived sources and severity of plastic pollution, Impacts of river pollution on livelihoods and local biodiversity, Attitudes and behaviors toward plastic waste disposal and management, Public engagement in awareness or community action efforts. The closed-ended questions in the survey addressed key areas such as: 1. Perceptions of increased pollution in the Karnaphuli River in recent years, 2. Descriptions of current pollution levels, 3. Impacts of river pollution on participants' professions or livelihoods, 4. Changes in daily river use due to pollution (e.g., bathing, washing), 5. Views on the effects of plastic pollution on local wildlife (e.g., fish), 6. Evaluation of governmental action to control pollution, 7. Awareness of local education or awareness programs, 8. Willingness to participate in community efforts to reduce pollution, 9. Public understanding of the long-term environmental impacts of plastic waste, 10. Need for increased awareness campaigns on plastic reduction, 11. Individual or community steps taken to reduce plastic pollution, 12. Availability of waste management services in the area, 13. Personal plastic waste disposal practices. In addition to the structured responses, the survey also incorporated open-ended questions to gather qualitative insights. One such question asked participants: "What change do you think should be made to the waste disposal system in your community regarding plastic waste?" This question allowed participants to freely express their opinions, suggest practical improvements, and share personal experiences or challenges regarding plastic waste management. These narrative responses revealed key themes such as the need for improved waste collection infrastructure, stricter enforcement of dumping regulations, increased recycling efforts, and more public education on responsible plastic use. Each interview session lasted approximately 20–30 minutes. In certain cases, assistance from local representatives or language interpreters was used to overcome regional language barriers. All collected field data were curated, and incomplete or invalid responses were excluded from the final analysis. The valid responses were then processed and analyzed using both statistical and thematic methods, and the findings were visualized through graphs and diagrams to provide a comprehensive overview of public awareness and the potential sources of plastic pollution in the Karnaphuli River.

Data processing and statistical analysis

All raw data were initially processed and organized using Microsoft Excel (Office 365) for cleaning, calculation of percentages, and basic formatting. Descriptive and inferential statistical analyses were performed using SPSS software, applying one-way ANOVA at a significance level of $p < 0.05$ to assess variations among sampling sites. Graphs and line diagrams were constructed using Excel charting tools, often based on the outputs from SPSS. For multivariate analysis, Principal Component Analysis (PCA) was performed using PAST software v4.03, and scatter biplots were generated based on principal component scores and loading plots.

Results and Discussion

Physicochemical characteristics of water

Table 3 outlines the physicochemical characteristics of water collected from six sampling sites, benchmarked against standard water quality parameters. Significant spatial variations ($p < 0.05$) were observed across all measured parameters, confirming heterogeneous environmental influences on water quality.

Table 3: *Comparative Physicochemical Properties of Water at Six Sampling Sites along the Karnaphuli River (Mean ± SE), with Statistical Significance and Reference Standards*

Sites	Temperature (°C)	pH	BOD (mg/L)	COD (mg/L)	DO (ppm)	TDS (ppm)	Conductivity (µS/cm)
Site 1	22.38±0.31 (a)	7.10±0.15 (c)	6.18±0.08 (a)	8.22±0.08 (a)	6.31±0.03 (a)	453.44±1.52 (c)	906.83±8.15 (c)
Site 2	22.24±0.20 (b)	6.64±0.24 (d)	4.32±0.11 (b)	7.12±0.21 (b)	5.88±0.31 (b)	390.40±0.84 (d)	780.81±0.88 (d)
Site 3	22.16±0.37 (b)	7.16±0.19 (c)	3.30±0.11 (c)	5.10±0.06 (c)	5.66±0.21 (b)	425.61±1.80 (c)	851.93±3.72 (c)
Site 4	23.08±0.32 (a)	8.20±0.30 (a)	4.05±0.17 (b)	6.88±0.11 (b)	2.97±0.06 (d)	610.88±1.04 (a)	1221.52±3.25 (a)
Site 5	22.40±0.22 (b)	8.44±0.16 (a)	2.40±0.07 (d)	3.20±0.08 (d)	3.68±0.08 (c)	305.12±1.92 (e)	610.24±3.74 (e)
Site 6	21.86±0.33 (c)	8.10±0.15 (b)	2.10±0.06 (d)	2.88±0.06 (d)	6.01±0.08 (a)	436.24±2.51 (b)	872.31±2.88 (c)
Standard	20–30	6.5–8.5	≤6	≤10	4–6	<400	800–1000

	(26)	**(25,27,28)**	**(29)**	**(29)**	**(28)**	**(27)**	**(28)**

Due to significant human activity and different sedimentological conditions, Site 4 and Site 5 had the greatest variances in numerous metrics of the six locations. Sandy clay soil and natural banks characterise Site 1, far from intensively inhabited regions. Despite minimal human influence, it had a low temperature and strong electrical conductivity. Temperature trend: Site 4 > Site 5 > Site 6 > Site 2 ≈, Site 3, with maximum conductivity at Site 4, followed by Site 5, indicating higher mineral and ionic content in downstream locations. Sites 4 and 5 have dramatically changed pH and DO. Site 4 had the biggest pH variability and lowest DO concentration (2.97 mg/L), indicating oxygen depletion. pH values were within acceptable limits (6.5–8.5). Site 4 had the highest pH fluctuation and lowest DO content (2.97 mg/L) among Site 4 and Site 5. TDS was highest in Site 4, followed by Site 5 and Site 6, indicating industrial and home waste inputs. Site 4 was more turbid and Site 5 more translucent, although both had significant TDS, suggesting coarser, suspended particles at Site 4 and fine, dissolved materials at Site 5. Sites with electrical conductivity between 610 and 906 µS/cm showed low to moderate mineralisation, mostly due to anthropogenic ion input. These findings match ferry turbulence, coastal erosion, and localised waste buildup field notes. Sites 4 and 5 had lower DO, higher TDS, conductivity, and sediment disruption indicators. Lower DO, higher TDS and conductivity, and sediment disruption factors clearly indicate increasing human activities and localised hydrological dynamics. The spatial changes imply local hydrology and human activity. Reduced dissolved oxygen, higher conductivity, and total dissolved solids at Site 4 and Site 5 indicate sewage, industrial effluent, and ferry effects. These patterns align with prior research demonstrating that human-induced discharges and bank erosion enhance organic loading and modify river oxygen dynamics (Lee et al., 2016).The water quality parameters listed in Table 3 were used to calculate the Water Pollution Index (WPI) shown in Figure 6; however, Table 3 itself does not display WPI values.

Categorization of macro plastics

A total of 11 categories of macro plastic items were identified in this study. Table 4 and figure 3 represents the types of macro plastic items, their associated polymer types, and their distribution across six sampling sites along the Karnaphuli River. The recorded macro plastic categories included food and fruit wrappers, polythene bags and sheets, beverage bottles (predominantly soft drink, oil, and water bottles), personal care product packaging (e.g., toothpaste tubes and shampoo bottles), pharmaceutical-related plastics (medicine packets and containers), various single-use plastic products (glasses, plates, straws, spoons, cups), disposable shoes, plastic tablecloths, old cassette reels, foam and cork sheet pieces, and plastic ropes and electrical wires. The most frequently detected polymer types were LDPE, HDPE, PET, PP, and PVC, with varying distribution across the sampling sites. Notably, Site 1 showed the highest total weight of macro plastic waste (650 gm) but had the lowest number of plastic categories. In contrast, Site 4 exhibited the highest diversity of plastic categories, followed by Site 5, despite their lower plastic weights (14 gm and 128 gm, respectively). These results show that macro plastic contamination is different not just in amount but also in type, depending on how the land is used around it. Residential and factory-adjacent areas (e.g., Site 1) seem to produce a lot of plastic waste connected to homes, whereas industrial and commercial centres (e.g., Site 4, Site 5) produce a wider range of waste types, such as packaging, foam, and electrical plastics. This graph shows how the kinds and amounts of macro plastic waste that get into rivers are affected by what people do for a living in the area (Hoellein et al., 2024).

All six sampling locations along the Karnaphuli River were subjected to photographic documentation of macro plastic debris, as shown in Figure . This was done to provide visual evidence in support of the findings of the field survey. These photographs capture the variety of plastic products that have been put or disposed of at the individual places, their condition, and the relative number of those items.

Figure 3: Different types of plastic items collected across the six study sites (1–6) along the Karnaphuli River, Chattogram, Bangladesh, during January–February 2025, showing the composition and relative abundance of plastic debris categories. The sites include: Site 1 – Shikalbaha Ghat, Site 2 – Firingi Bazar Feri Ghat, Site 3 – Char Patharghata Bridge Ghat, Site 4 – Kalurghat Feri Ghat, Site 5 – Patenga 15 No. Ghat, Site 6 – Anwara 11 No. Ghat.

This figure 3 displays a composite visual representation of macro plastic debris gathered from the six study locations, extending from upstream (Site 1) to downstream (Site 6). Figure 3 illustrates the predominant categories of plastic materials present at the respective locations, encompassing single-use packaging, food wrappers, plastic bottles, bags, containers, and industrial plastics. Figure 4 illustrates the sources of waste input across all sites. Common sources included residential dumping, ferry operations, market refuse, and industrial effluents, though their intensity differed—household waste was higher upstream (Site 1), ferry and market inputs midstream (Site 3, Site 6), and industrial inputs downstream (Site 4, Site 5). These photographic evidences of figure 3 elucidate geographical variations in pollution intensity and substantiates the quantitative study of macro plastic dispersion.

The collected items were categorized according to the type of polymer they were made of, which aligned with the standard frameworks for categorizing plastics in Table 4. This was done better to understand the composition and spread of macro plastic pollution. The application of this classification can provide a better understanding of the origin, utilization, and persistence of numerous plastic contaminants in the riverine environment.

Table 4: Categorization of macro plastic , polymer Types (M. N. Uddin et al., 2014; BWDB, 2025) and Availability at Different Sampling Sites

Plastic Category	Polymer Types	Site1	Site2	Site3	Site4	Site5	Site6
Food Wrappers	LDPE, HDPE, PP, PET	✓	✓	✓	✓	✓	✓
Polythene Bags/Sheets	LDPE, HDPE	✓	✓	✓	✓	✓	✓
Beverage Bottles	PET, LDPE, HDPE, PS	✓	✓	✓	✓	✓	✓
Personal Care Products	HDPE, PET, PP, PC, PE	✓	✓				
Pharmaceutical Products	PET, HDPE, PVC	✓	✓	✓			
Single-Use Plastic Products	LDPE, HDPE, PS, EPS	✓	✓		✓	✓	
Plastic Tablecloth	PVC			✓	✓		
Shoes	PU, PVC, EVA	✓		✓	✓	✓	
Cassette Reel	PVC,				✓		
Foam and Cork Sheet	EPS, PP, PU	✓		✓			
Plastic Wire and Rope	LDPE, HDPE, EPR, PP, PA, PVC	✓	✓	✓	✓		✓

Table 4 presents the categorization macro plastic debris based on polymer composition, including common types such as LDPE, HDPE, PET, PVC, and others. The table highlights the presence of these plastic types across the six sampling sites along the Karnaphuli River. Universally found items included food wrappers, polythene bags, and beverage bottles composed primarily of LDPE, HDPE, PET, and PS, indicating widespread use and improper disposal of daily-use plastic products. Items like personal care packaging and pharmaceutical plastics were more concentrated in upstream and midstream sites (Site 1 to Site 3), suggesting proximity to residential or healthcare-related activities. Meanwhile, downstream sites such as site4 and site5 exhibited a broader variety of plastic types, including industrial waste (e.g., plastic tablecloths, cassette reels, and foam sheets), reflecting the influence of industrial discharge and market-related waste streams. The polymer-based classification identified common types such as LDPE, HDPE, PET, and PVC present across sites. While Table 4 categorizes macro plastic debris based on polymer types, Figure 5 complements this by illustrating the relative proportions of major item categories (e.g., polythene bags, bottles, wrappers) across the six sites. Together, these provide both material-level and item-level perspectives on macro plastic pollution along the Karnaphuli River.

Total macro plastics concentration at sampling sites

The study found significant differences in macro plastic concentrations across six sampling sites ($p < 0.05$), indicating pollution loads vary spatially (Table 3). The largest concentration was found at site 1, near homes and a factory. The high macro plastic levels here may be from home garbage discharge and industrial plastic leaks. This was followed by site3, which is identical to site 1 and near a riverfront fish market and cement bag washing zone. These activities may generate plastic garbage, especially packaging and sacks. site6, similar to site3 but closer to a ferry crossing point, likewise had moderate macro plastic deposition, probably due to passenger activities and surrounding business operations. Residential site2 and site5, with similar environmental exposure, had intermediate macro plastic debris levels. Tukey's HSD post-hoc test showed no significant difference between these sites ($p > 0.05$). Their similar land use patterns and low business activity may explain their pollution levels. Despite being near homes, a ferry crossing, and a factory, site4 had the lowest macro plastic content. This anomaly may be caused by local waste management, natural dispersion, or hydrodynamic flow that reduces debris retention. Human activity, industrial proximity, and riverine influence significantly affect macro plastic dispersal across sites. Higher macro plastic concentrations were seen surrounding residential and business activities.

Figure illustrates the average macro plastic concentrations (g/m²) gathered from each of the six sampling locations along the Karnaphuli River, along with standard deviations and statistical classifications derived from significance testing ($p < 0.05$).

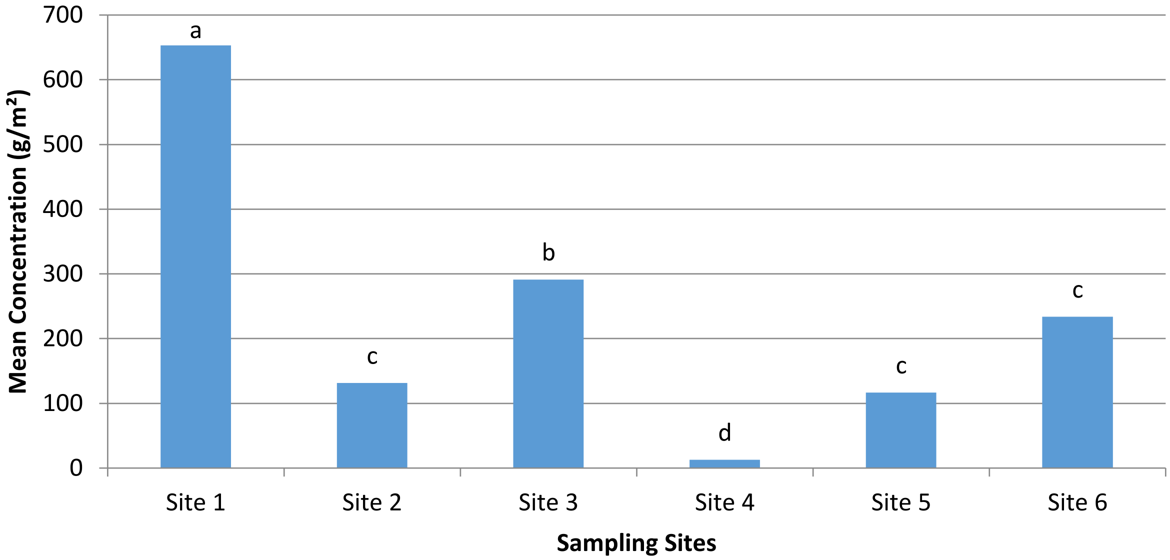

Figure 4: Mean macroplastic concentrations (g/m²) across the six sampling sites (1– 6) along the Karnaphuli River, with standard deviations. Different letters (a–d) indicate significant differences among sites ($p < 0.05$); sites sharing the same letter are not significantly different.

The highest concentration of macro plastics was observed at Site 1, measuring 653.36 g/m². This suggests significant waste input due to residential discharge and inadequate waste management practices. Site 3 exhibited a moderate concentration of 291.26 g/m², whereas Site 6 was not far behind with 233.80 g/m². Site 2 documented 131.52 g/m², while Site 5 indicated 116.68 g/m², demonstrating moderate plastic accumulation levels. Site 4 exhibited the lowest recorded concentration at merely 12.71 g/m², indicating either diminished dumping activities or increased plastic dispersion due to river currents. The differences among sites were statistically significant, as indicated by distinct superscript letters (a, b, c) based on one-way ANOVA followed by Tukey's HSD test ($p<0.05$; Figure 3). The highest concentration at site 1 is because it is close to homes and a factory, while the concentrations at site3 and site6 are because of riverside markets and ferry activities. The unexpectedly low abundance of macro plastics at Site 4 may result from localized waste disposal practices or hydrodynamic flushing in tidal and estuarine zones, where hydrological conditions strongly control accumulation patterns (Van Breukelen, 2007).

Pollution index debris composition

The present study revealed that the highest Water Pollution Index (WPI) values were observed at Sites site 1 and site 6, indicating extreme pollution levels according to standard classification thresholds (Table 3; Figure 6). Site2 was categorized as moderately polluted, while site 3, site 4, and site 5 were identified as comparatively less polluted locations.
Supporting these findings, the composition of macro plastic debris in Error! Reference source not found. showed a consistently higher proportion debris across all sites, with site 1 and site 6 exhibiting the greatest abundance of dominant plastic categories. These patterns underscore the influence of localized anthropogenic activities on pollution levels and plastic waste accumulation along the Karnaphuli River.

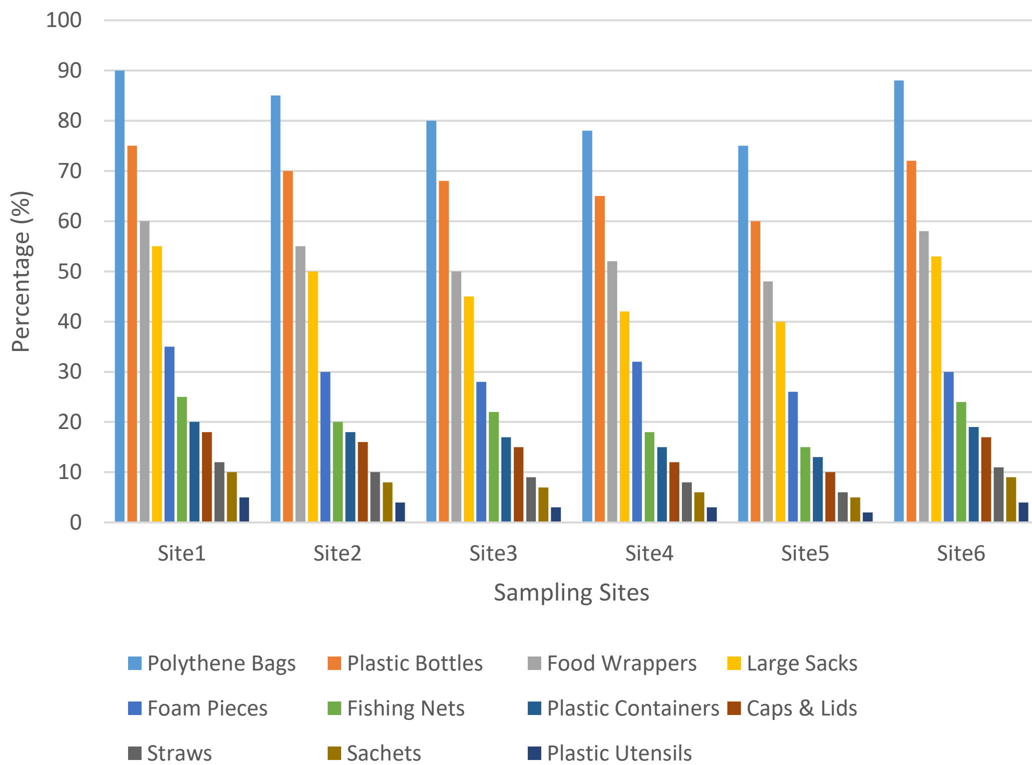

Figure 5: Proportions of different types of macroplastic items identified from the six sampling sites (Site 1 – Shikalbaha Ghat, Site 2 – Firingi Bazar Feri Ghat, Site 3 – Char Patharghata Bridge Ghat, Site 4 – Kalurghat Feri Ghat, Site 5 – Patenga 15 No. Ghat, Site 6 – Anwara 11 No. Ghat) along the Karnaphuli River, Chattogram, Bangladesh, based on samples collected during [5 January to 13 February 2025]. This figure provides an item-level composition of macroplastic debris, complementing the polymer-based categorization in Table 4.

Across all sites, polythene bags consistently dominated the waste composition, peaking at over 90% at Site 6 and remaining above 70% at Sites 1 through 5. Plastic bottles and food wrappers were also prevalent, especially at Sites 1 and 2, indicating familiar consumer waste sources. Large sacks and fishing nets showed moderate presence, with higher levels at Sites 1 and 3, likely linked to nearby industrial and fishing

activities. Less abundant items included foam pieces, plastic containers, caps and lids, straws, sachets, and plastic utensils, each contributing smaller proportions (generally under 20%) across the sites. Despite these lower percentages, their consistent presence across locations suggests wide usage and improper disposal practices. Notably, Sites 1 and 6 exhibited the highest abundance of dominant plastic categories, such as polythene bags, bottles, and wrappers, reflecting intensified anthropogenic pressures in these regions. The prevalence of polythene bags underscores the dependence on single-use plastics, a trend observed in South Asian rivers facing urban pressures (Mourshed et al., 2017). Elevated WPI values at site 1 and site 6 highlight the cumulative impact of household discharge, ferry traffic, and inadequate municipal services, whereas diminished indices at site 4 and site 5 indicate either improved dispersion or decreased dumping.
The Water Pollution Index (WPI) was computed in Figure to evaluate the surface water pollution levels at the six study locations and to identify geographic differences in water quality along the Karnaphuli River

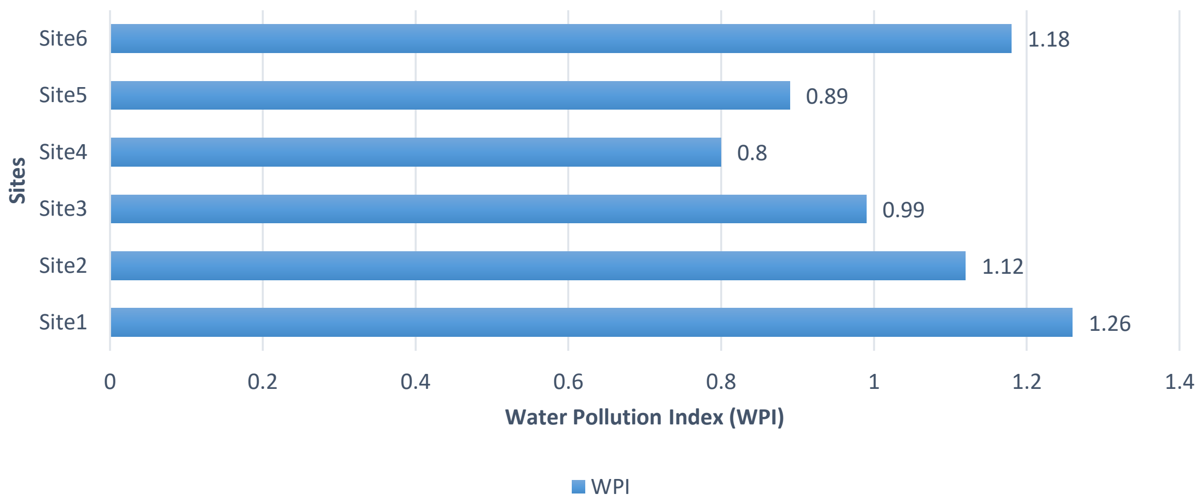

Figure 6: Water Pollution Index (WPI) at the six sampling sites (1– 6) along the Karnaphuli River, Chattogram, Bangladesh.

The WPI value of 1.26, which was recorded at Site 1, suggests substantial pollution, potentially due to the proximity to industrial runoff and upstream refuse inflow. Site 6 and Site 2 were the subsequent sites, with WPI values of 1.18 and 1.12, respectively. These values indicate that the pollution levels were likely elevated due to municipal discharges and ferry operations. Site 3 exhibited a moderate WPI of 0.99, indicating that the water quality is comparatively improved, albeit still on the cusp of concern. In contrast, Site 5 and Site 4 demonstrated the lowest WPI values, at

0.89 and 0.80, respectively. These lower indices suggest that the pollution levels in those areas are relatively lower, which may be due to improved water exchange dynamics or less direct discharge. The WPI results generally indicate
that pollution is variably distributed throughout the study area, with upstream and densely populated regions exhibiting higher contamination levels. It is crucial to understand that the WPI serves as a powerful quantitative evaluation of water quality, encompassing a variety of physicochemical parameters, and may not consistently correspond with the subjective visual assessments outlined in Table 1; for instance, Site 6 may have seemed visually pristine but boasted a significant WPI (1.18), indicating the presence of dissolved contaminants and upstream influences that are imperceptible through mere visual examination.

Correlation analysis of macro plastic and water quality

A pairwise correlation analysis was conducted to investigate the potential relationships between macro plastic pollution and key physicochemical parameters of the river water. The findings in explore the relationship between average macro plastic concentrations and the environmental variables assessed at the six study locations.

Table 5: Pairwise correlation matrix between mean macro plastic Concentrations and Physicochemical Parameters of water at the study sites (1–6)

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
(1) Mean Macro plastic Concentrations	1.000							
(2) Temperature	-0.339	1.000						
	(0.511)							
(3) pH	-0.448	0.275	1.000					
	(0.373)	(0.598)						
(4) BOD	0.616	0.350	-0.614	1.000				
	(0.193)	(0.497)	(0.195)					
(5) COD	0.370	0.482	-0.640	0.951	1.000			
	(0.470)	(0.333)	(0.171)	(0.004)				
(6) DO	0.700	-0.785	-0.707	0.280	0.148	1.000		
	(0.122)	(0.064)	(0.116)	(0.591)	(0.779)			
(7) TDS	-0.107	0.632	0.095	0.335	0.471	-0.295	1.000	
	(0.841)	(0.179)	(0.859)	(0.516)	(0.346)	(0.570)		
(8) Conductivity	-0.106	0.631	0.094	0.335	0.471	-0.295	1.000	1.000
	(0.841)	(0.179)	(0.860)	(0.516)	(0.346)	(0.571)	(0.000)	

A pairwise correlation (Pearson's r) analysis of mean macro plastic concentrations and seven water quality parameters temperature, pH, BOD, COD, DO, TDS, and electrical conductivity is shown in Table 5. The p-values of the correlation coefficients are provided in brackets. A strong positive correlation was observed between BOD and COD (r = 0.951, p = 0.004), confirming the relationship between chemically oxidizable and biologically degradable organic loads (Lee et al., 2016) Macro plastic concentrations showed a moderate positive correlation with BOD (r = 0.616, p = 0.193), suggesting that plastic debris often co-occurs with organic waste streams such as untreated sewage and market runoff (Hoellein et al., 2024). Unexpectedly, macro plastic abundance also exhibited a positive correlation with Dissolved Oxygen (r = 0.700, p = 0.122). While organic pollution typically depletes oxygen, this positive relationship in the Karnaphuli River likely reflects hydrodynamic influences rather than biological demand; areas with higher water turbulence or wind exposure tend to have higher atmospheric aeration, increasing DO while simultaneously driving floating debris onto riverbanks ,increasing macro plastic accumulation. Conversely, macro plastic content was negatively correlated with temperature (r = –0.339), pH (r = –0.448), and TDS (\$r = –0.107), though these associations were not statistically significant (p > 0.05). Electrical conductivity and TDS correlated perfectly (r = 1.000), indicating their strong physicochemical link. Although the limited number of sampling sites (n = 6) reduced statistical power, the observed patterns highlight the complex interaction between anthropogenic waste inputs and river hydrodynamics.

Sources and pathways of plastic waste

To better understand macro plastic contamination's origin and transport pathways, Figure presents a schematic diagram highlighting the primary anthropogenic sources and mechanisms through which plastic waste enters the Karnaphuli River system.

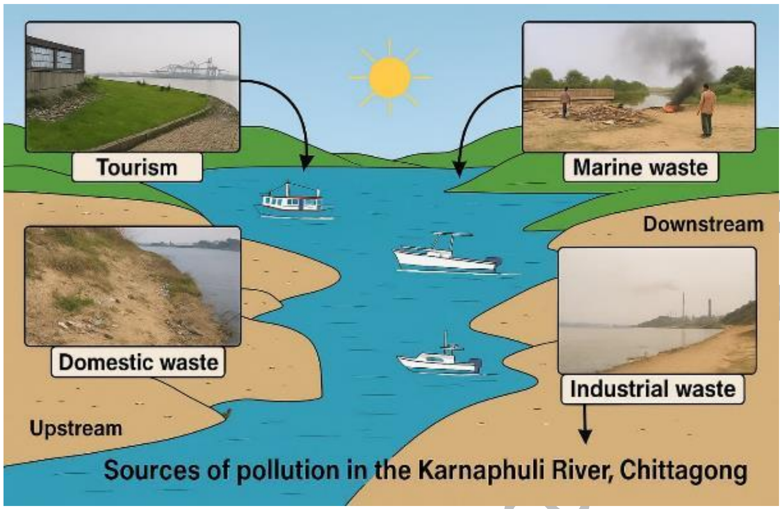

Figure 7: Representative photographs illustrating major anthropogenic sources and pathways of plastic pollution along the Karnaphuli River, Chattogram, Bangladesh, including domestic waste dumping, industrial discharge, and river-based transport. The images depict general pollution sources rather than specific quantified contributions.

Domestic garbage, industrial effluents, marketplaces, informal settlements, and ferry terminals all dump plastic into the river, as shown in the schematic. Human activities like plastic packaging disposal, fishing net losses, and commercial operations like fish markets and plastic processing facilities increase the plastic burden, as seen in the diagram. This graphic shows how sources and transport mechanisms interact, emphasising the need for comprehensive waste management, improved drainage infrastructure, and stricter plastic use and disposal regulations in the river catchment area. The distribution of found pollution sources in Error! Reference source not found. emphasizes how local land use, human activity, and population density help site-specific macro plastic contamination along the Karnaphuli River, illustrating the spatial variation in plastic pollution inputs over the study area.

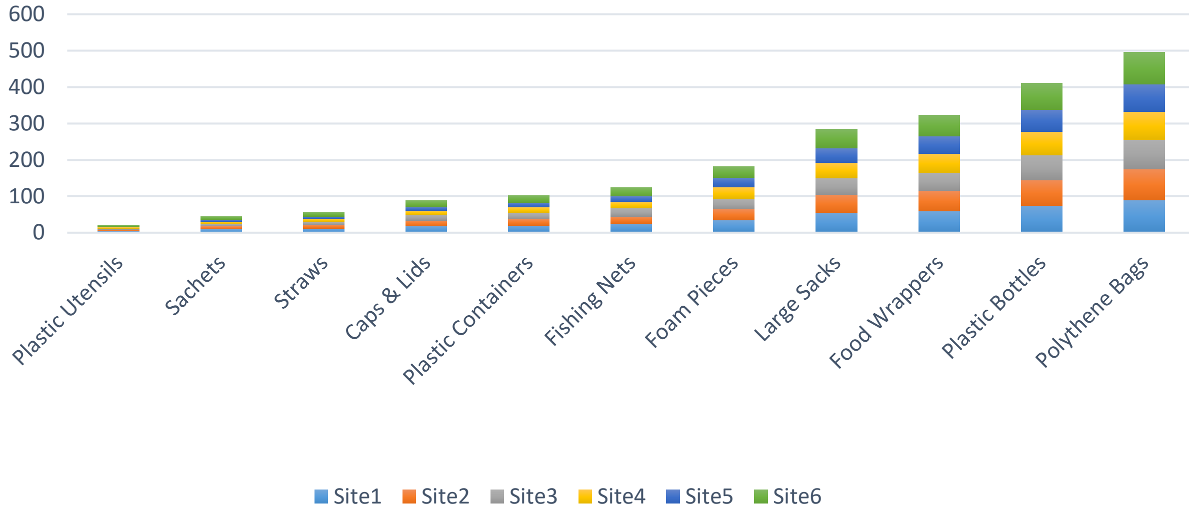

Figure 8: Sources of plastic pollution identified across the six sampling sites (1– 6) along the Karnaphuli River, Chattogram, Bangladesh, illustrating spatial differences between urban-driven inputs (household waste, commercial activity, river transport) and non-urban influences (beach dumping, industrial discharge).

Figure 8 presents the likely sources of plastic pollution along the Karnaphuli River, inferred from collected plastic items and field observations. Urbanized sites such as site 1, site2, and site 5 exhibited major contributions from household waste, commercial activities, and river-based transport. In contrast, sites like site 4 and site 6 showed higher impacts from industrial discharges and beach dumping. These spatial trends emphasize the necessity of site-specific management strategies to mitigate plastic pollution effectively. These schematic insights demonstrate that land use and livelihood structures determine localized plastic pressures. Pluvial runoff has been identified as a significant vector, particularly during monsoon seasons, aligning with findings from other Southeast Asian research on rainfall-driven plastic mobility (Zielonka & Liro, 2024). Enhancing waste management and storm water infrastructure is essential for addressing these pathways.

Community perceptions and awareness

presents the demographic and socioeconomic aspects of study participants. The survey sought community input on the main sources of macro plastic contamination of the Karnaphuli River system. Statistics indicate seven main sources: domestic plastic trash, market waste, municipal solid waste, industrial waste, upstream urban waste, pluvial flow, and fish-market plastic waste. All sites reported residential trash, local market runoff, and pluvial flow as the most prevalent. Participants' age, education, and occupation help explain how these impressions vary among social groups.

Table 6: Demographic and socioeconomic characteristics of survey participants and identified sources of plastic pollution.

Participant's Specification	Description	Percentage
Gender	Male	72.32
	Female	27.68
Age Group	18–30	26.5
	31–45	39.1
	46–60	27.2
	Above 60	7.3
Education	Illiterate	24.67
	Primary level	30.22
	Secondary level	31.56
	Tertiary level	13.55
Occupation	Boatman	19.9
	Fisherman	14.6
	Farmer	6.0
	Housewife	16.6
	Day laborer	4.0
	Job holder	0.7
	Driver	2.7
	Business holder	27.2
	Mechanic	1.7
	Student	1.3
	others	5.3

Male respondents made up 72.32% and female respondents 27.68%. The majority (39.1%) were 31–45, with 27.2% being 46–60. Most participants (31.56%) had secondary education, whereas 24.67% were illiterate. Business owners (27.2%), boatmen (19.9%), and housewives (16.6%) were the most common jobs. These profiles show varied market- and riverine-based workers. Based on community perspectives, the survey found that domestic plastic waste, local market contributions, and pluvial flow were the main causes of plastic contamination in the Karnaphuli.

Error! Reference source not found. illustrates community awareness and perception regarding the implications of river water pollution, specifically focusing on local understanding of pollution impacts on

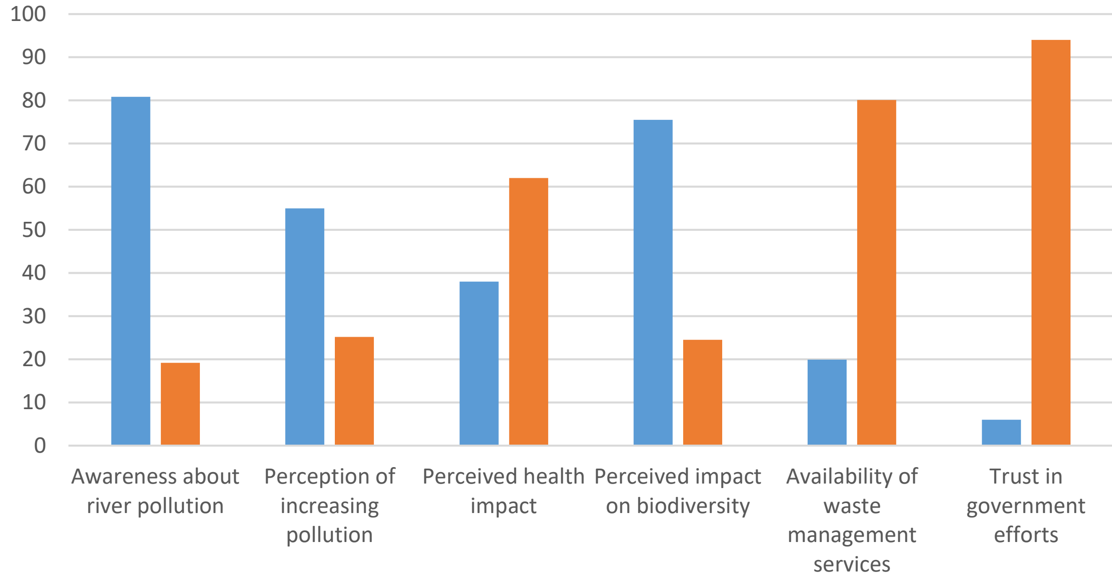

Figure 9: Community awareness and perception of river water pollution at six sampling sites (1– 6) along the Karnaphuli River, Chattogram, Bangladesh, illustrating local understanding of pollution impacts and perceived environmental consequences.

the Kar

figure highlights the level of environmental concern and perceived consequences among surveyed participants.

A 150-respondent survey provides valuable insights into public awareness and sentiments. River pollution was mentioned by 80.8% of respondents, demonstrating that most people are environmentally conscientious. Of the respondents 55% perceived Karnaphuli river pollution to be increasing, demonstrating a gap in awareness and acknowledgement of ongoing trends. River pollution was recognised as a health danger by 38% of respondents, while 62% did not, probably due to a lack of knowledge about waterborne diseases and contamination impacts. However, 75.5% of respondents thought river pollution harms biodiversity, showing greater environmental care. Only 19.9% said their location has acceptable waste management services, while 80.1% disagreed, indicating community unhappiness with the current infrastructure. Most alarmingly, 94% of respondents distrusted government efforts to limit river pollution, whereas 6% trusted them. The survey reveals a paradox: great general awareness but poor risk perception and very low trust in government. This reflects broader discoveries that environmental awareness may not always lead to behavioural change (Suárez-Varela et al., 2016). Weak institutional legitimacy and infrastructure gaps exacerbate waste management issues, causing households to use inconsistent and sometimes dangerous disposal procedures. Building community engagement through participatory government and culturally relevant awareness campaigns could assist to close this gap (Armansaputra et al., 2024).

To explore community perceptions and suggestions for improving local plastic waste management,

Table *7* presents a thematic analysis of responses to the open-ended survey question: "What change do you think should be made to the waste disposal system in your community regarding plastic waste?" Participants' statements were organized into key themes, reflecting positive and negative perspectives. This analysis provides valuable insights into local practices, environmental awareness, and perceived shortcomings of the current waste disposal system. The structure includes concise theme descriptions and illustrative quotes directly reflecting the respondents' voices.

Table 7: Thematic Analysis of Community Suggestions for Improving Plastic Waste Disposal Practices

Perspective	Theme	Description	Examples
Positive Perspective	Home-based disposal methods	Participants try to manage waste themselves using traditional or household methods	"We bury waste in the soil and later use it for gardening." "Sometimes we burn plastics to keep the area clean."
	Environmental awareness	Some show basic understanding of eco-friendly practices and act accordingly	"We separate organic waste and avoid throwing it on the road."
Negative Perspective	Irresponsible disposal habits	People throw waste anywhere without thinking about the consequences	"Everyone just dumps garbage wherever they want."
	Weak municipal services	Complaints about the inefficiency of city corporations in waste collection	"The city corporation rarely comes to collect the garbage."
	Lack of knowledge	Public unawareness about how harmful plastic is and how long it lasts in nature	"People don't know how dangerous plastic is for the environment."
	Overuse of single-use plastic	Observations on high dependency on disposable plastic products	"We still use plastic bags and bottles every day without thinking."

Table 7 classifies participant responses into positive and negative viewpoints concerning their communities' existing plastic waste disposal system. Positive themes encompass self-directed home disposal initiatives and an increasing recognition of sustainable practices. Some individuals reported burying waste for future gardening or incinerating plastics to uphold cleanliness. Negative themes underscore prevalent issues, including irresponsible waste disposal, insufficient municipal waste management services, limited public awareness regarding plastic pollution, and ongoing dependence on single-use plastics. Direct participant quotes enhance each theme, providing insights that could guide future community education, policy, and intervention strategies.

Conclusion

This study provides one of the first integrated assessments of macro plastic pollution in the Karnaphuli River, combining physical measurements of riverine plastics and water quality with community perceptions. Macro plastic concentrations showed moderate positive correlations with BOD ($r = 0.616$) and DO ($r = 0.700$), suggesting shared anthropogenic origins of plastic and organic waste. A strong correlation between BOD and COD ($r = 0.951$, $p = 0.004$) further indicates high organic loading. Urban and commercial areas emerged as primary accumulation zones, with household waste, market runoff, and monsoon-driven pluvial flow identified as key sources. Despite over 80% of surveyed residents recognizing the river's pollution problem, only 38% acknowledged associated health risks, and just 6% expressed trust in government action—highlighting a significant perception gap. These findings align with global evidence that urban rivers act as major conduits for plastics to marine systems, but they also reveal local drivers, such as concentrated market waste streams and seasonal runoff patterns, that are particularly relevant in monsoon-influenced South Asian contexts (Hurley et al., 2023; Hurley et al., 2025; Cleveland et al., 2025). To address this issue, policies should target both plastic and organic waste sources through strengthened municipal waste collection, enforcement of extended producer responsibility (EPR) schemes, community-based waste segregation, and culturally appropriate awareness campaigns. Building public trust and engagement is crucial for the success of any intervention.

Limitations

This study had several limitations that should be considered when interpreting the findings. First, sampling was limited to six sites during a single season, which may not capture seasonal or interannual variability in macro plastic loads and water quality. Given the influence of monsoon-driven flows on pollution transport, results might differ substantially at other times of year. Second, macro plastic collection focused on visible items (>5 mm), excluding microplastics, which likely underestimated the total plastic burden. Third, the water quality parameters measured represent point-in-time conditions and may not fully reflect daily or short-term fluctuations. Fourth, regarding the social survey, the reliance on convenience sampling may have introduced selection bias, as respondents were primarily those accessible in public areas, potentially excluding industrial stakeholders or working professionals. Additionally, participant responses regarding historical river conditions are subject to recall bias and may be influenced by recent environmental awareness rather than objective historical data. Finally, the community survey, although useful for capturing local perceptions, involved a relatively small sample size (n = 150) and may not fully represent all demographic groups, particularly women, transient populations, or those living in more remote riverbank areas. Despite these limitations, the combination of physical measurements and social data provides a robust initial assessment of macro plastic pollution and its perceived impacts in the Karnaphuli River. Addressing these constraints in future work will strengthen the reliability and generalizability of findings.

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Authors' contributions

All authors contributed to the conception, design, and execution of the study. Dr. Md. Ariful Anwar Khan provided supervision, validation, and contributed to writing, review, and editing. Dr. Sribash Chandra Bhattacharyya supported the study through supervision, provision of resources, and writing, as well as review and editing. Masuma Wahab led the conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing (original draft), and project administration. Joy Bardhan, Puja Bhattacharjaa, Abu Hena Sajib, and Md. Abdul Kader was involved in data curation, field investigation, and contributed to formal analysis. Abdul Hasib Mollah contributed to the statistical analysis and formatting of the manuscript.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. The authors are open to sharing the full dataset with researchers for non-commercial academic purposes. Interested individuals may contact the corresponding author, Masuma Wahab, at masumawahabk@gmail.com.

Declarations

All authors have read, understood, and have complied as applicable with the statement on Ethical Responsibilities of Authors as found in the Instructions for Authors.

Ethical approval

This research involved no clinical or biomedical procedures and did not require formal ethical approval. However, all procedures involving human participants (i.e., survey respondents) were conducted by the ethical standards of the institutional research committee and the 1964 Helsinki Declaration and its subsequent amendments.

Human ethics and consent to participate

The study did not involve medical or clinical procedures and thus did not require approval from a formal ethics board. However, informed consent was obtained from all individual participants involved in the survey component of this study, and participation was entirely voluntary.

Clinical trial registration

Not applicable.

Competing interests

The authors declare that they have no conflicts of interest or competing financial interests related to this research.

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