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RESEARCH ARTICLE

Microplastics pollution in the river Karnaphuli: a preliminary study on a tidal confluence river in the southeast coast of Bangladesh

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Abstract

Bangladesh is a deltaic country in Asia, and its riverine systems ultimately drain into the Bay of Bengal. Plastic is a severe environmental issue for coastal-marine ecosystems due to the indiscriminate usage and discarding of plastic items in the upstream river that eventually find their route into the Bay of Bengal. Microplastics (MPs) are widespread pollutants in almost all environmental compartments, including aquatic environments. This study aimed to quantify and understand the distribution of microplastics in surface water and sediments of the river Karnaphuli, a tidal confluence river adjacent to the Chattogram seaport city of Bangladesh, a highly inhabited and industrial area on the southeast coast of the Bay of Bengal. A manta trawl net (300-µm mesh size) was used to collect surface water samples, while an Ekman dredge was used to collect sediment samples. The concentrations of microplastics in the surface water of the river Karnaphuli during late monsoon, winter, and early summer were recorded to be 120,111.11, 152,222.22, and 164,444.44 items/km^2, respectively, while in sediments, those were recorded to be 103.83, 137.50, and 103.67 items/kg, respectively. A higher abundance of microplastics was observed in downstream surface water (228,888.88 items/km^2) and sediments (164.17 items/kg). Smaller sizes (0.3 to 0.5 mm) of microplastics were predominant, fibers or threads were the frequent types, and black was the most common color in the river Karnaphuli. The Fourier transform infrared analysis revealed that polyethylene terephthalate (surface water: 22%, sediments: 19%), polyamide (surface water: 15%, sediments: 13%), polyethylene (surface water: 12%, sediments: 18%), polystyrene (surface water: 13%, sediments: 11%), and alkyd resin (surface water: 13%, sediments: 10%) were the most prevalent polymers in the river Karnaphuli. Moreover, there was a moderate positive correlation between MPs abundance in surface water and sediments. Therefore, improved long-term research (in different seasons with horizontal and vertical monitoring) is necessary in order to accurately determine the flux of microplastics from the river Karnaphuli to the Bay of Bengal.

Keywords Plastic pollution · Spatial–temporal distribution · Surface water · Sediments · River ecosystem · Asia

Introduction

Plastic production and consumption have expanded significantly from the initial commercial manufacture of plastics in the 1940s (Cole et al. 2011), with around 368 million tonnes of plastic manufactured in 2019 (Plastics Europe 2020). Plastic debris can be dispersed over large distances by oceanic currents, tides, winds, river discharge, and drift (Ng and Obbard 2006; Barnes et al. 2009; Martinez et al. 2009), including islands of the mid-ocean (Ivar do Sul et al. 2009; Rey et al. 2021), the sea around Antarctica (Barnes et al. 2010; Leistenschneider et al. 2021), and the deeper Atlantic region (Lozano and Mouat 2009; Reineccius and Waniek 2022). As a consequence, one of the most prominent types of anthropogenic litter found in the marine ecosystem is plastic debris (Gregory and Ryan 1997; Barnes et al. 2009; Thushari and Senevirathna 2020).

Microplastics (MPs), typically described as bits of plastic in the dimensional range of 1 µm and 5 mm, are one subclass of plastic that has sparked significant concern (Arthur et al. 2009; Fendall and Sewell 2009; Napper et al. 2021). MPs are classed as either primary (directly released from the

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Extended author information available on the last page of the article source, e.g., resin pellets, cosmetic scrubbers) or secondary (produced by the breakdown of larger plastic products, e.g., plastic bottles, toys) and can come from a variety of sources such as household waste and industrial waste (Andrady 2011; Cole et al. 2011; Hidalgo-Ruz et al. 2012). Additionally, various chemicals are utilized as plasticizers and flame retardants to improve the performance of plastic objects. These chemicals may be released into the environment by MPs, raising several environmental issues (e.g., causing toxicity to aquatic biota) (Liu et al. 2019). Furthermore, MPs adsorb hydrophobic pollutants such as polychlorinated biphenyls (PCBs), dichlorodiphenyldichloroethylene (DDE), and dichlorodiphenyltrichloroethane (DDT) (Laist 1997; Teuten et al. 2009), impacting aquatic habitats and the organisms within them.

Many pieces of evidence indicate that MPs are ubiquitous, and their long-term existence may pose a substantial threat to the health of aquatic ecosystems (Murray and Cowie 2011; Farrell and Nelson 2013; Setälä et al. 2014; Kühn et al. 2015; Gall and Thompson 2015; Biginagwa et al. 2016). MPs have been reported to affect aquatic creatures through toxicological effects, tissue inflammation, physical blockages, digestive impairment, and functioning as a potential affluent for the transfer of other hazardous components (Rosenkranz et al. 2009; Moos et al. 2012; Besseling et al. 2013; Lambert and Wagner 2018). MPs have been found in a variety of marine environments, including beach sediments (Costa et al. 2010; Martins and Sobral 2011; Jayasiri et al. 2013; Lee et al. 2013; Besley et al. 2017; Karthik et al. 2018), estuaries (Leslie et al. 2013), in surface, shallow, and deep water (Collignon et al. 2012; Hidalgo-Ruz et al. 2012; Ivar do Sul et al. 2013; Cutroneo et al. 2022). MPs have also been found in the sediments and surface water of various rivers throughout the world (Wang et al. 2017a, b; Ta et al. 2020; Wu et al. 2020; Chauhan et al. 2021; He et al. 2021; Napper et al. 2021).

Bangladesh is a deltaic country in Asia with 257 active rivers that eventually drain into the Bay of Bengal. Besides, oceanic currents also contribute to the relocation of MPs from other portions of the ocean. MPs are assumed to have entered the Bay of Bengal by draining water and sediments from various sources (Hossain et al. 2021). As a result, considering the indiscriminate usage and dumping of plastic items in aquatic surroundings that finally find their way into the Bay of Bengal, plastic is a serious environmental issue for coastal-marine ecosystems. Moreover, the widespread incidence of MPs in the world's oceans (which also serve as a sink for other harmful chemicals) can cause adverse ecological effects.

Variations in spatial–temporal patterns may significantly influence the incidence and distribution of MPs in tidal confluence rivers. Furthermore, temporal changes owing to precipitation may have a significant effect on the abundance of MPs in the aquatic environment (Lima et al. 2014, 2015). As a result, combining the study of MPs' spatial and temporal distributions would be beneficial in obtaining full information on MPs' sources and transit patterns (Lebreton et al. 2017). There have been a few studies in Bangladesh on MPs contamination for fish (Hossain et al. 2019; Ghosh et al. 2021), penaeid shrimp (Hossain et al. 2020), and sandy beaches (Hossain et al. 2021). However, to the best of our knowledge, no study has evaluated the abundance and distribution of MPs in the tidal confluence river of Bangladesh. Thus, we examined the spatial and temporal distribution of MPs in Karnaphuli river, a major tidal river system in the southeast coast of the Bay of Bengal, Bangladesh.

Materials and methods

Study area

Chattogram is a coastal seaport city and is known as Bangladesh's industrial capital, located in the southeast coast of the Bay of Bengal. The Karnaphuli is a transboundary river basin distributed between India and Bangladesh. This river was chosen due to its exposure to intense industrial contaminants and anthropogenic pressures, such as proximity to harbors, fishing ports, and large cities. This study focused on a 9-km stretch of the river Karnaphuli in Chattogram, Bangladesh (Fig. 1).

Surface water sample collection

Triplicate samples were taken from five sampling stations (S1, S2, S3, S4, and S5) during September 2019 (late monsoon in Bangladesh), January 2020 (winter), and March 2020 (early summer) (Table S1). Surface water samples (water depth 16 cm) were collected using a manta net (300-μm mesh, 60-cm opening width). MPs sampling from surface water was performed according to Kovač Viršek et al. (2016) with slight modifications. In brief, the manta net was launched from the port and starboard side of the research vessel, approximately 3–4 m away from the vessel. The action started to move in one straight direction with a ~ 2 knots speed for 15 min. Then, the research vessel was stopped, and the manta net was taken out of the water. The net was rinsed thoroughly from the outer side of the net with clean water from the vessel water reservoir. The manta net was rinsed in the mouth to the cod-end direction to concentrate all particles adhered to the net into the cod-end. After that, the cod-end was removed carefully, and the sample in the cod-end was sieved through a 300-μm mesh sieve. The cod-end was rinsed thoroughly from the outer side, and the rest of the sample was poured through the sieve. With the use of a funnel, the sieve was rinsed into a glass jar

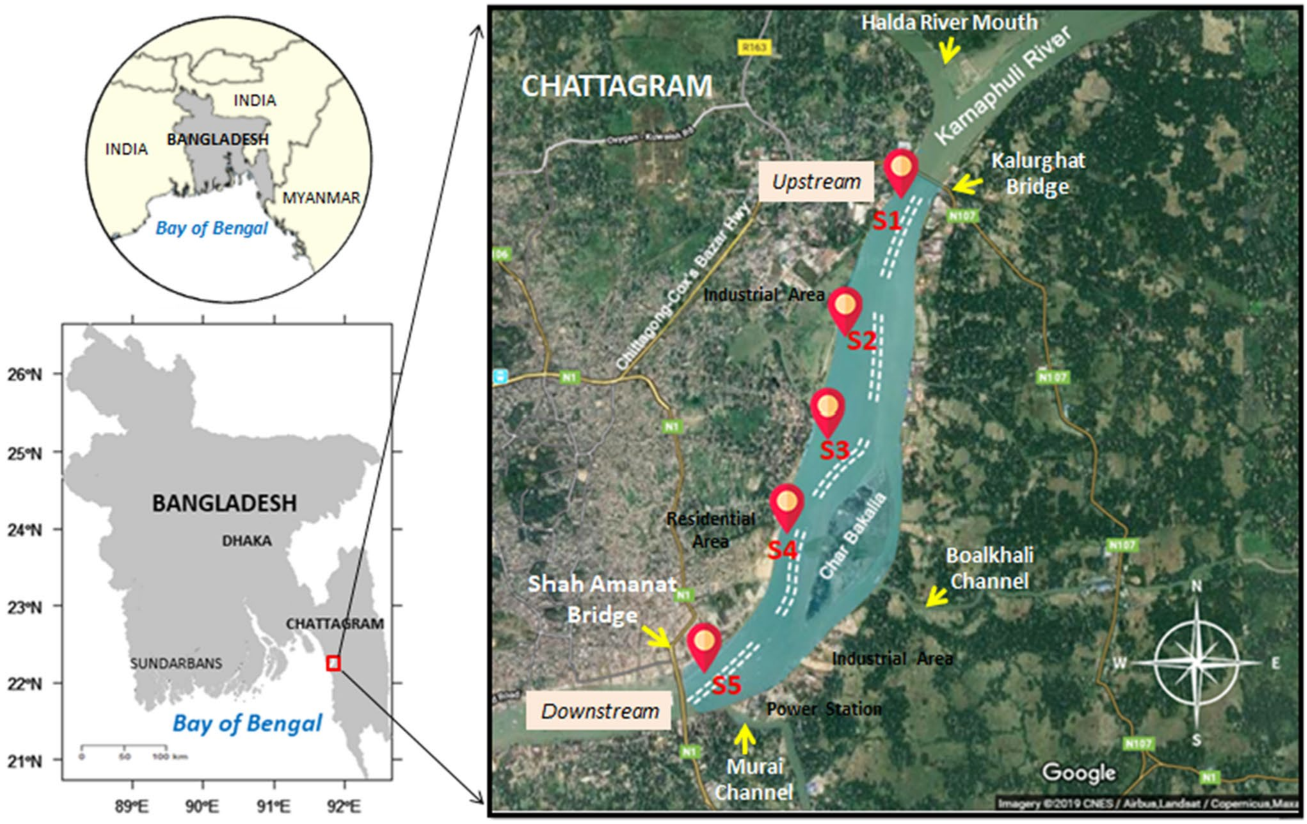

Fig. 1 Study area, sampling stations, and location

using 70% ethanol. The use of 70% ethanol is important to preserve the sample. Besides, in the step of visual inspection of the sample, ethanol helps to discolor the organisms; hence, colorful plastics become easier to find (Kovač Viršek et al. 2016). Then, the samples were processed in the laboratory of the Interdisciplinary Institute for Food Security (IIFS), Bangladesh Agricultural University, Bangladesh.

Separation of MPs from water samples

Separation of MPs (< 5 mm) from water samples was done according to Masura et al. (2015) with slight modifications. Briefly, water samples were filtered with a sieve (0.3 mm). Sieved samples were taken in 500-mL beakers and dried in an oven (Genlab OV/200/F/DI, England) at 90 °C for 24 h. Then 20 mL of 0.05 M ferrous sulfate ($FeSO_4$) solution was poured into each beaker. Afterward, 20 mL of 30% hydrogen peroxide (H_2O_2) was mixed and kept mixtures at room temperature for about 5 min. Then the mixtures were heated at 75 °C on a hotplate (AM4, Velp Scientifica, Italy) until gas bubbles appeared. Six grams of salt (NaCl) was added per 20 mL of the sample during heating to enhance the density of the wet peroxide oxidation (WPO) solution (~ 5 M). Afterward, the WPO solution was carefully poured into the density separator with 700 mL of filtered $ZnCl_2$ (1.5 g cm^{-3}) solution (Coppock et al. 2017), covered with aluminum foil, and kept overnight to settle down. We use the $ZnCl_2$ solution because $ZnCl_2$ was estimated as an effective and comparatively inexpensive floatation media, enabling the floatation of dense polymers (Coppock et al. 2017). With the help of a vacuum pump, the solution obtained from the density separator was filtered with cellulose nitrate filter paper (47 mm diameter and 5 µm pore size) (Prata et al. 2019). Then the filtrate was examined under the microscope (Olympus CX41 with camera DP22, Japan) to identify potential MPs. The main result of MPs samples is calculated as the number of MPs particles per sample (Kovač Viršek et al. 2016). These data were further normalized as per km^2. The formula for normalization is MPs particles per sample divided by the sampling area, where the sampling area is determined by multiplying the sampling distance (1 km) by the width of the manta net opening (60 cm).

Sediment sample collection and separation of MPs from sediment samples

Sediment samples were collected by an Ekman dredge with three replicates per station during September 2019 (late monsoon in Bangladesh), January 2020 (winter), and March 2020 (early summer) (Table S1) and stored in glass jars. The separation of MPs from sediment samples was performed according to Masura et al. (2015). In brief, wet sediment samples (400 g) were taken in a 1-L beaker and oven-dried (Genlab OV/200/F/DI, England) at 90 °C for 24 h. Afterward, 300 mL of filtered $ZnCl_2$ (1.5 g cm^{-3}) solution (Coppock et al. 2017) was added and stirred for 10 min. Then all the floating particles were filtered with a 0.3-mm sieve and collected into a beaker (500 mL). After that, 20 mL of 0.05 M ferrous sulfate ($FeSO_4$) solution was poured into each beaker. Then 20 mL of 30% H_2O_2 was added and mixed for 5 min. The mixtures were heated at 75 °C on a hotplate (AM4, Velp Scientifica, Italy) until gas bubbles were observed. In this stage, to enhance the density of the WPO solution (~ 5 M), 6 g of salt (NaCl) was added per 20 mL of the sample. Then the WPO solution was carefully poured into the density separator with 700 mL of filtered $ZnCl_2$ (1.5 g cm^{-3}) solution (Coppock et al. 2017), covered with aluminum foil, and left overnight to settle down. With the help of a vacuum pump, the solution from the density separator was filtered with cellulose nitrate filter paper (47 mm diameter and 5 µm pore size) (Prata et al. 2019). Afterward, potential MPs in the filters were categorized under the microscope (Olympus CX41 with camera DP22, Japan).

Identification and categorization of MPs

The definition of a plastic item was based on the criteria put forth by Norén (2007): (i) no cellular or organic structural features should be visible within the plastic particle or fiber; (ii) if the particle is a fiber, it should be similarly thick, not taper toward the ends, and have a three-dimensional bend (not entirely straight fibers which direct a biologically derived particle); (iii) clear and homogeneously colored particles; and (iv) if it is not clear that the particle or fiber is colored, for example, if it is whitish or translucent, it should be carefully inspected under a microscope at high magnification and with fluorescence microscopy to rule out an organic origin. Only particles that met the aforementioned requirements were classified as plastic particles after careful examination of the particles. Other items like algae fragments, animal shells, or other parts found on the filters were ignored throughout the detection period.

A fluorescence microscope (Olympus CX41 with camera DP22, Japan) at 4 × to 100 × magnification was used to identify potential MPs and measured digitally with cellSens imaging software. The MPs were identified visually (Hidalgo-Ruz et al. 2012) and analyzed based on their length, shape, and color (Lusher et al. 2013). Besides, the MPs were characterized into fragments, films, fibers, foams, pellets, and microbeads (Kovač Viršek et al. 2016; Murphy et al. 2016; CLEAR 2017; Calcutt et al. 2018). MPs were also categorized into different colors, such as red, white, blue, black, pink, green, orange, and translucent (Bellas et al. 2016; Murphy et al. 2016; Naji et al. 2019). By merely touching suspected plastic particles with a hot needle, the hot point melting test was made to confirm that the particles were plastic (De Witte et al. 2014; Devriese et al. 2015; Vandermeersch et al. 2015; Bellas et al. 2016).

Moreover, MPs were further analyzed (about 20% of the candidate MPs were selected randomly) to determine their chemical composition with a Fourier transform infrared (FTIR) spectrophotometer. FTIR spectrophotometer (Shimadzu IR Prestige 21™, Japan) was used to investigate the chemical composition of different particles. The particles were randomly selected and distributed on a KBr crystal (Parvin et al. 2021). The spectral range was set at 4000–400 cm^{-1}, using the IR solution Agent software with a match threshold > 70% (Tanaka and Takada 2016; Blettler et al. 2017). A SpectraBase™ database from John Wiley & Sons, Inc. has been used to detect the absorption bands of polymers. Additionally, the spectra were compared with the existing literature (Noda et al. 2007; Murphy et al. 2016; Jung et al. 2018).

Quality assurance and quality control

Several control measures were employed strictly during the study. Laboratory coats made of natural fibers, nitrile gloves, and face masks were worn to prevent plastic contamination during sample collection and processing. All the glassware, containers, filtration units, and other necessary instruments were rinsed three times with filtered (45 µm) clean water before use. Samples were wrapped with aluminum foil to prevent air-borne contamination. Procedural blank tests with three replicates (per season) were performed at the same time without any dried sediments or water samples to cross-check the air-borne contamination in the research laboratory (Wu et al. 2020). In brief, 20 mL of 0.05 M ferrous sulfate ($FeSO_4$) solution and 20 mL of 30% hydrogen peroxide (H_2O_2) were poured into a 500-mL glass beaker. Then 6 g of salt (NaCl) was added, and the solution was poured into the density separator with 700 mL of filtered $ZnCl_2$ (1.5 g cm^{-3}) solution and kept overnight without any covering/foil paper. Afterward, the solution in the density separator was filtered through a 5-µm cellulose nitrate filter. This filter was examined under the microscope, and any particles identified were tested using FTIR. We did not find any potential candidate MPs in the filter, except for a few fibers. We could fairly exclude laboratory contamination because FTIR confirmed that the detected fibers were rayon fibers from clothing, not fishing gear (Nakano et al. 2021).

Statistical analysis

In this study, a descriptive analysis was performed to get mean ± standard deviation (SD), maximum and minimum values. Two-way ANOVA was executed to determine the mean differences among the tested samples in different sampling time points and sampling locations, followed by Tukey's HSD post hoc comparisons. Before the analyses, research data were further verified for normality and homoscedasticity assumptions employing Shapiro–Wilk's test and Levene's test, respectively, without any transformation. The type, shape, size, and color of MPs throughout the study period were determined in frequency percentage (%). Statistical analyses were performed using the SPSS software (version 22, IBM, USA), and variations between the mean values at $p < 0.05$ were considered significant.

Results

MPs in surface water

The mean concentrations of MPs in surface water of the river Karnaphuli during September 2019, January 2020, and March 2020 were found to be 120,111.11, 152,222.22, and 164,444.44 items/km^2, respectively, and varied significantly ($p < 0.001$) among the three sampling time points (Table 1, Fig. 2a). Besides, the mean MPs concentrations in surface water of S1, S2, S3, S4, and S5 were measured as 65,740.74, 102,222.22, 148,888.89, 182,222.22, and 228,888.88 items/km^2, respectively. The MPs values among the sampling stations varied significantly ($p < 0.001$) (Table 1, Fig. 2b). However, significant differences were not observed in the abundance of MPs in the months and sampling stations (Months*Stations; $p > 0.05$) (Table 1). Throughout the investigation, MPs from surface water varied from 30,000 to 270,000, with a mean value of 145,592.59 ± 63,739.88 items/km^2 (Table S1).

Table 1 Two-way ANOVA test results of analyzed data at different seasons, locations, and interactions in surface water and sediments of the river Karnaphuli

Parameter	Source	df	***F***	***p*** value*
Surface water	Seasons	2	24.18	**< 0.001**
	Stations	4	114.48	**< 0.001**
	Seasons*Stations	8	1.67	0.147
Sediments	Seasons	2	3.94	**< 0.05**
	Stations	4	12.60	**< 0.001**
	Seasons*Stations	8	2.99	**< 0.05**

df, degree of freedom; **p* values in bold indicate significant differences

In the present study, identified MPs were categorized into three sizes, including 0.3 to 0.5 mm, 0.5 to 1 mm, and 1 to 5 mm. The largest proportion of the MPs recorded in surface water was 0.3 to 0.5 mm in size, followed by 0.5 to 1 mm and 1 to 5 mm (Fig. 3). In temporal occurrence, the largest proportion of MPs (52%) was 0.3 to 0.5 mm recorded in March 2020 (Fig. 3a). In the case of spatial occurrence, the largest proportion of MPs (50%) was 0.3 to 0.5 mm observed in S4 (Fig. 3b). Furthermore, six different types of MPs (fibers, fragments, foams, films, pellets, and microbeads) were found in the studied samples. Fibers (55%) were the prevalent type of MPs detected in surface water in March 2020. The least number of microbeads (1%) was noted in March 2020, whereas the least number of pellets (1%) was recorded in both January and March 2020 (Table 2). In spatial occurrence, fibers (54%) were prevalent in S3, where pellets (0%) were not found (Table 3).

In the current study, different colored MPs were recorded from the river Karnaphuli, such as black, purple, white, blue, green, translucent, red, pink, and brown. In the case of temporal occurrence, the predominant color of MPs in surface water was black (32%), as found in September 2019. The least number of pink (3%) colored MPs was detected in January 2020, while the least number of brown (3%) colored MPs was detected in both September 2019 and March 2020 (Table 2). In the case of station-wise distribution, black (30%) colored MPs were prevalent in S5, whereas brown (2%) were the least dominant in S1 (Table 3).

MPs in sediments

Mean MPs concentrations in sediments of the river Karnaphuli were recorded to be 103.83, 137.50, and 103.67 items/kg in September 2019, January 2020, and March 2020, respectively, and varied significantly ($p < 0.05$) (Table 1, Fig. 2c). Mean MPs concentrations in sediments at S1, S2, S3, S4, and S5 were 59.44, 75.83, 135.28, 140.28, and 164.17 items/kg, respectively, and differed significantly among the sampling stations ($p < 0.001$) (Table 1, Fig. 2d). In addition, significant variations were also found in MPs abundance at different months and sampling stations (Months*Stations; $p < 0.05$) (Table 1). The range of MPs recorded from sediments throughout the investigation was 10 to 255 items/kg, with a mean value of 115.00 ± 60.68 items/kg (Table S1).

In the current investigation, smaller sizes of MPs (0.3 to 0.5 mm) were found in large numbers in sediments as compared to the other size categories. The highest proportion of a small-sized category (47%) was found in January 2020 (Fig. 3a). In spatial occurrence, the highest proportion of a small-sized category (48%) was reported for S1 (Fig. 3b). Furthermore, fibers (86%) were the dominant type of MPs detected in sediments in March 2020. However, foams (0%)

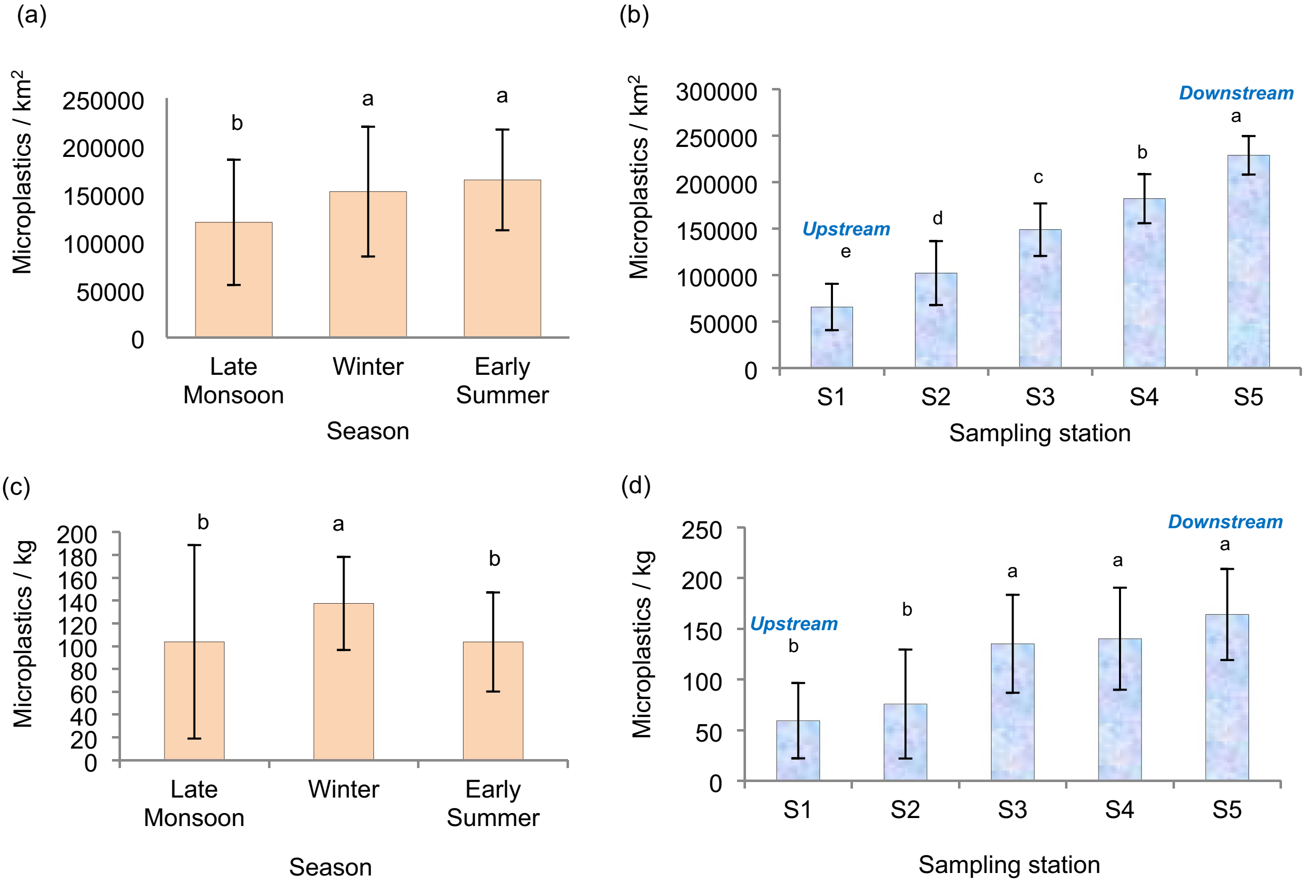

Fig. 2 Abundance of MPs in surface water and sediments of the river Karnaphuli: **a** temporal and **b** spatial distribution of MPs in surface water; **c** temporal and **d** spatial distribution of MPs in sediments; values accompanied by different letters indicate statistically significant differences ($p < 0.05$)

were not found in January 2020, whereas pellets (0%) were not reported in September 2019 and March 2020 (Table 2). In spatial occurrence, fibers were dominant in S5 (78%) (Table 3). In the case of temporal events, the prevalent color of MPs in surface water was black (32%), found in January 2020, while the least dominant color, brown (2%), was also recorded in January 2020 (Table 2). In the case of station-wise distribution, black (44%) was dominant in S1, whereas green (0%) was not found (Table 3). The types of MPs detected in the river Karnaphuli have been shown in Fig. 4.

Polymer composition of separated MPs

There were 4010 items and 2070 items found for the MPs in the collected surface water and sediment samples, respectively, of which 802 items of surface water and 414 items of sediment samples (> 300 µm) were analyzed with FTIR. Polyethylene terephthalate was the predominant polymer in both sediments (19%) and surface water (22%) samples (Fig. 5). Polyamide (15%), alkyd resin (13%), polystyrene (13%), polyethylene (12%), urethane alkyd (10%), cellophane (5%), polyvinylidene fluoride (3%), and polyether urethane (3%) were also observed in water samples. However, 2% were non-plastics in water samples, and the remaining 2% belonged to unidentified material (Fig. 5a). In the case of sediment samples, polyethylene (18%), polyamide (13%), polystyrene (11%), alkyd resin (10%), urethane alkyd (9%), polyvinylidene fluoride (8%), polyether urethane (5%), and cellophane (4%) were also found. Around 2% were non-plastics, and the remaining 1% belonged to unidentified material in sediment samples (Fig. 5b).

Correlation of MPs abundance between surface water and sediments

There was a moderate positive correlation of MPs abundance between surface water and sediments of the Karnaphuli river (r: 0.639, $p < 0.001$) (Fig. 6). The linear regression equation was $y = 0.0006x + 26.469$ and the coefficient of determination (R^2) value was 0.408, according to the regression analysis. Therefore, the number of MPs was high in sediments, while MPs were prevalent in surface water.

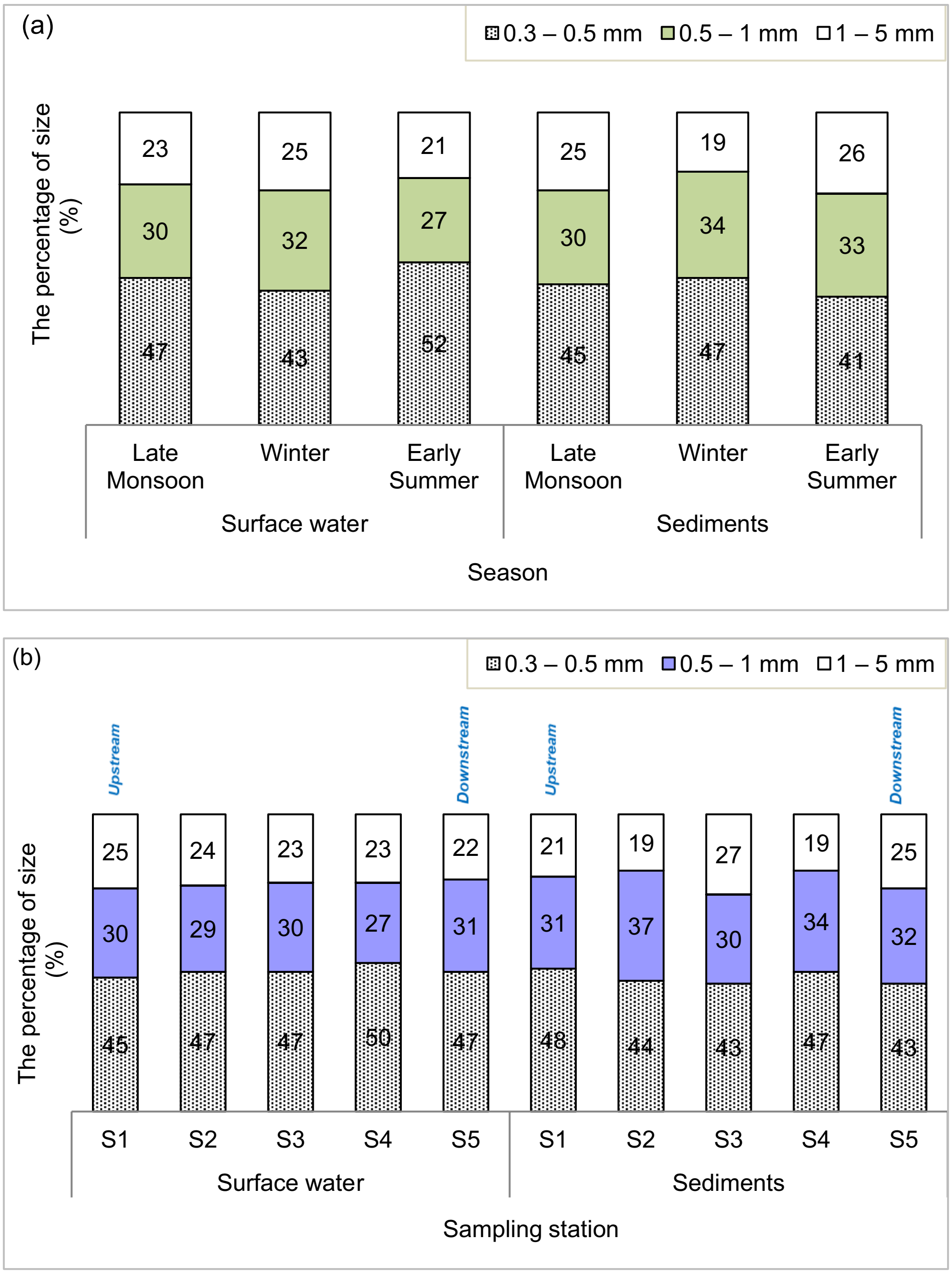

Fig. 3 **a** Temporal and **b** spatial occurrence (%) of MPs size range found in surface water and sediments of the river Karnaphuli

Discussion

Because there is no established standard for measuring MPs, the concentration unit has not been defined in published literature (Jiang et al. 2019). Some researchers used items/kg for sediments and items/km^2 for waterways, while others used items/m^2 for both sediments and waters. In addition, some researchers employed items/L or items/m^3 for water. As concentration levels in different units cannot be compared (Jiang et al. 2019), we found it difficult to compare the research results to other published data. However, the amounts of MPs contamination in the current investigation were compared to studies mentioning similar concentration units. In the present study, MPs recorded from the surface water of the river Karnaphuli were 30,000 to 270,000 items/km^2, with an average value of 145,592.59 items/km^2, comparable to other reported studies.

MPs in the backwater area of Xiangxi river, China (55,000 to 34,200,000 items/km^2), and the surface water of the Yangtze river (162,000 to 4,250,000 items/km^2, with an average abundance of 2,800,000 items/km^2) were observed to be higher, as reported by Zhang et al. (2017) and He et al. (2021), respectively, than the current measured abundance. Furthermore, Eriksen et al. (2013) recorded 43,000 to 466,000

Table 2 Temporal occurrence (%) of different types and colors of MPs in surface water and sediments of the river Karnaphuli

Category of micro-plastics		Surface water			Sediments		
		Late monsoon	Winter	Early summer	Late monsoon	Winter	Early summer
Type (%)	Fiber	49	50	55	56	76	86
	Fragment	25	28	28	27	17	9
	Foam	9	8	4	2	0	1
	Film	12	11	11	12	1	2
	Pellet	2	1	1	0	1	0
	Microbead	3	2	1	3	5	2
Color (%)	Black	32	27	26	23	32	26
	Purple	14	18	17	15	16	15
	White	12	12	13	10	11	9
	Blue	11	14	14	14	12	11
	Green	7	6	6	8	6	7
	Translucent	11	11	12	11	10	14
	Red	6	5	5	9	6	8
	Pink	4	3	4	6	5	5
	Brown	3	4	3	4	2	5

Table 3 Spatial occurrence (%) of different types and colors of MPs in surface water and sediments of the river Karnaphuli

Category of microplastics		Surface water					Sediments				
		S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Type (%)	Fiber	49	46	54	50	51	73	74	65	74	78
	Fragment	24	28	27	28	28	16	14	22	16	19
	Foam	9	7	8	8	6	3	3	0	1	0
	Film	12	13	10	11	14	4	2	9	5	1
	Pellet	2	2	0	1	0	0	1	1	0	0
	Microbead	4	4	1	2	1	4	6	3	4	2
Color (%)	Black	28	25	28	27	30	44	43	24	24	20
	Purple	22	20	19	16	13	25	15	13	12	16
	White	12	11	12	14	13	9	2	15	11	9
	Blue	14	12	13	12	14	3	15	14	12	13
	Green	7	8	5	6	5	0	6	6	8	10
	Translucent	6	9	10	12	15	7	9	11	14	13
	Red	5	7	5	6	4	6	3	8	9	8
	Pink	4	5	4	4	3	3	4	5	6	7
	Brown	2	3	4	3	3	3	3	4	4	4

particles/km^2 with an average of 43,000 particles/km^2 in the surface water samples from the Laurentian Great Lakes, which is also greater than the current study. According to published reports, the abundance of MPs is related to geographical location, population density, and urbanization (Wang et al. 2017a, b; Wen et al. 2018; Nakano et al. 2021). A higher abundance of MPs was observed in downstream surface water (station 5) of the Karnaphuli river. This may be due to waste materials coming from upstream, adjacent channels (Boalkhali and Murai Channels), power stations, and other industries mixed with the river. Besides, a larger number of MPs in surface water were found in early summer (March 2020) than in late monsoon and winter. Reasons for these variations in the abundance of MPs include loadings from the sources such as household waste, garments washing, agricultural and industrial waste, tourist activity, fishing, navigation, and transportation at bridges on the river Karnaphuli; geographic features including Bangladesh is a low lying country, and monsoon brings heavy rainfall here; and hydrodynamic circumstances including the velocities of the emitted particles due to water level rise and fall (Peng et al. 2017; Gray et al. 2018; Bordós et al. 2019; Kataoka et al. 2019).

In the current investigation, MPs recorded in the sediments of the river Karnaphuli were 10 to 255 items/kg, with an average value of 115.00 items/kg. According to Jiang et al. (2019), MPs recorded from the Tibet Plateau

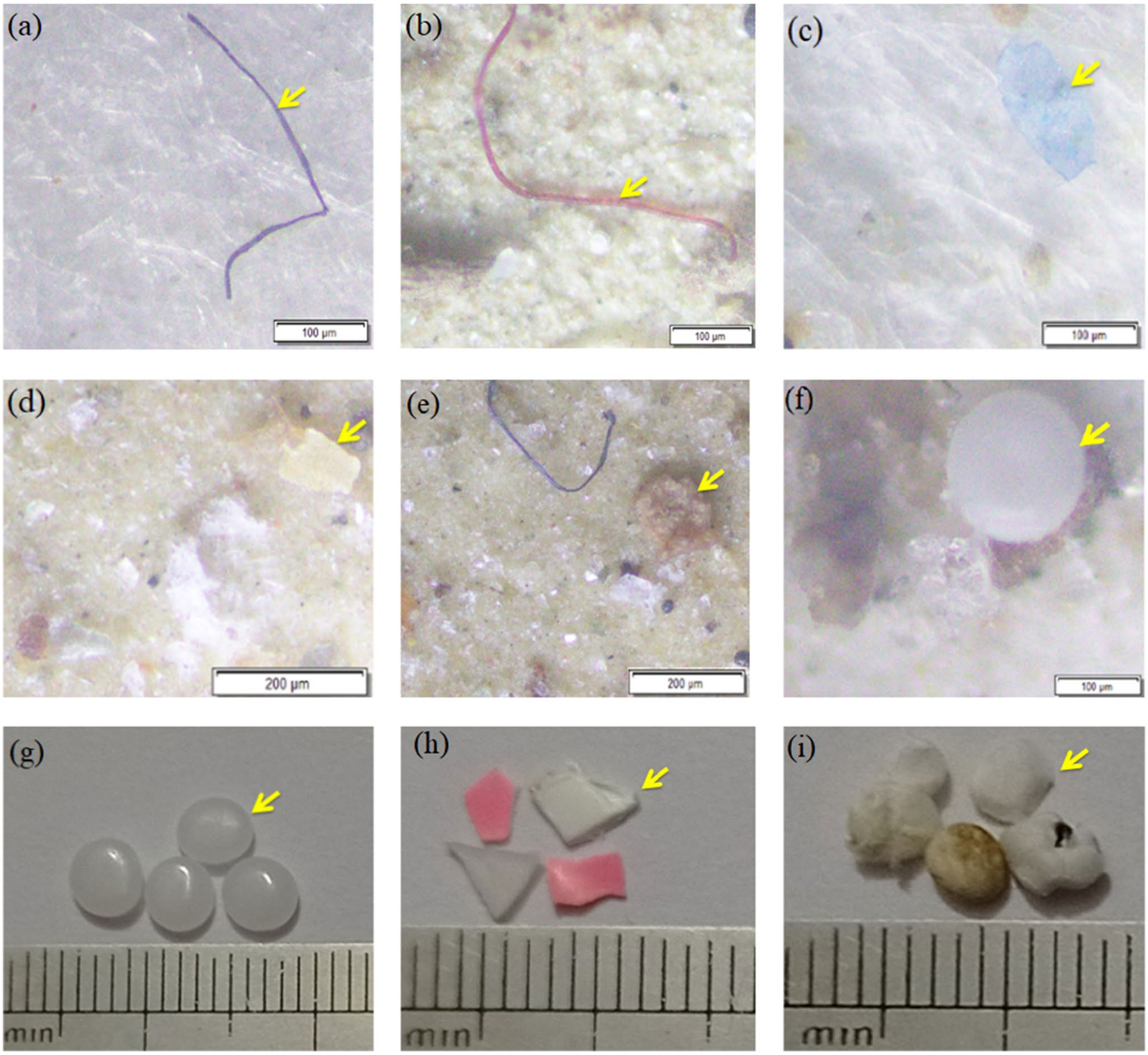

Fig. 4 Examples of some MPs observed in the river Karnaphuli: fiber (**a**, **b**); film (**c**); fragment (**d**, **h**); foam (**e**, **i**); microbead (**f**); and pellet (**g**)

sediments fluctuated from 50 to 195 items/kg, which is more or less similar to the current study. Moreover, MPs were recorded as 0.9 to 298.1 items/kg in sediment samples in a coastal metropolis of Australia (Su et al. 2020), supporting the present findings. MPs in the sediments of the Chao Phraya river, Bangkok (2290 items/kg), and Beijiang river, China (178 to 544 items/kg), were found to be higher than the current measured concentrations, as documented by Ta et al. (2020) and Wang et al. (2017a), respectively. Heavy rainfall during the monsoon might increase the river flow (Zhao et al. 2019) and dilute the MPs concentration in the waters (Yan et al. 2019). So, the amount of rainfall, currents, and anthropogenic events (release of industrial waste, fishing, etc.) in the research area may have caused temporal fluctuations in MPs abundance in surface water and sediments. However, at station 5 (near the Shah Amanat Bridge), all the waste materials from adjacent channels and industries are mixed with the river. So, it was obvious that it showed high MPs flux in that particular station's surface water and sediments. Moreover, several aspects may promote the huge spatial variability of MPs contamination in the samples of this study, such as upstream input, fisheries, navigation, and agricultural and industrial activities in the river (Peng et al. 2018; Kiessling et al. 2019).

In comparison to the other groups, smaller sizes of MPs (0.3 to 0.5 mm) were predominant in sediments and surface water

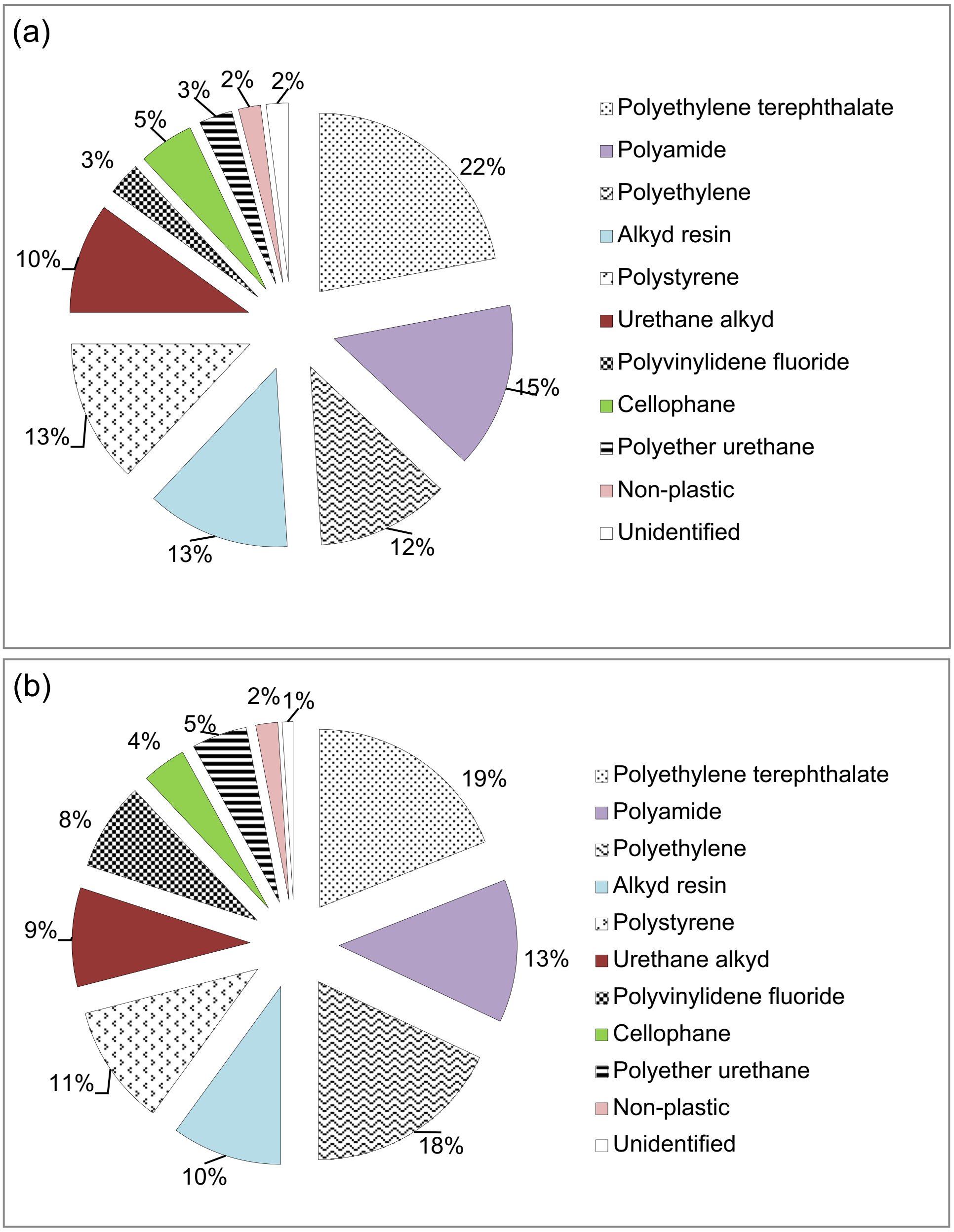

Fig. 5 Percentage (%) of the composition of MPs in the river Karnaphuli: **a** surface water and **b** sediments

in the current investigation. Wu et al. (2020) also found a large quantity of 0.1 to 1 mm-sized MPs in the Maozhou river's sediments and surface water. The most common size of MPs reported in the Saigon river was less than 50–250 µm (Lahens et al. 2018), whereas Baldwin et al. (2016) recorded 72% of 0.35 to 0.99 mm-sized MPs in 29 lakes globally. Furthermore, MPs of small sizes (< 1 mm) were found in both trawling and filtering water samples taken from the Yangtze river (He et al. 2021). However, MPs of a smaller size can readily penetrate the various food chains of an aquatic environment and, therefore, potentially influence it (Jeong et al. 2016). As we detected, MPs from surface water and sediments, pelagic and benthic fish, bivalves, crustaceans, etc., may be affected by MPs pollution. MPs may affect aquatic organisms by causing physiological injury, obstructing the digestive tract, disrupting eating and reproductive behavior, decreasing the offspring's survival rate, and impairing immunological function (Jabeen et al. 2018; Prokić et al. 2019; Strungaru et al. 2019).

Fibers/threads were the most common MPs in the river Karnaphuli's sediments and surface water, followed by fragments, films, foams, microbeads, and pellets. These types of MPs are suspected of having come from daily-used plastic items such as water bottles, containers, toys, food packaging, and cosmetic scrubbers. In addition, thread MPs were also found in significant quantities in the inland freshwaters of Wuhan, China (Wang et al. 2017b) and two typical estuaries in Bohai Bay, China (Wu et al. 2019). Furthermore, Chauhan et al. (2021) discovered fibers/threads as prevalent MPs in both the sediments

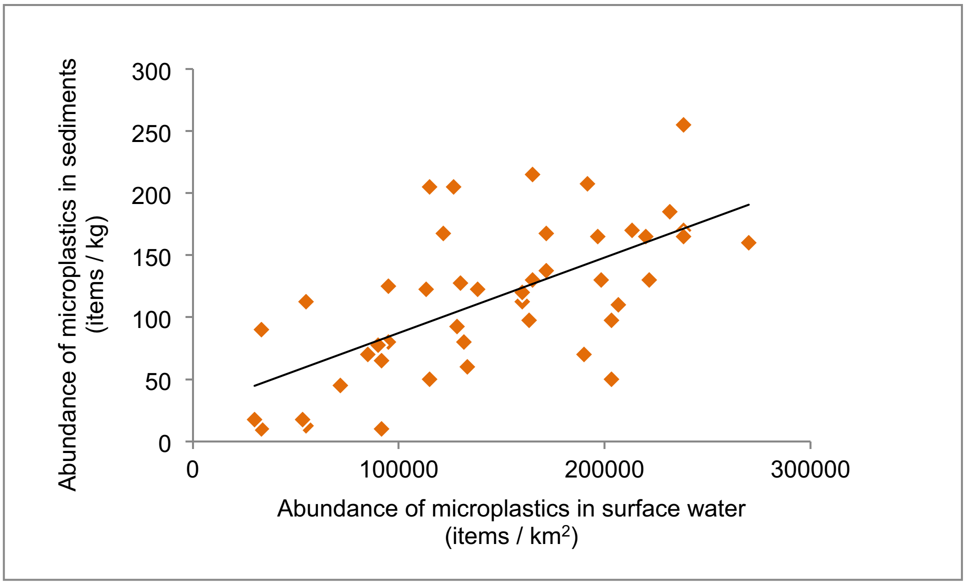

Fig. 6 Significant correlation of MPs abundance between surface water and sediments of the river Karnaphuli

and surface water of the Alaknanda river, whereas Napper et al. (2021) found fibers/threads to be the most common kind in the surface water of the Ganga. On the other hand, Wu et al. (2020) found fragment type to be prominent in both water and sediments from the river Maozhou and reported packing industry might be the critical source of this type of MPs. Domestic trash is a significant source of MPs fibers/threads, which are regularly discharged during garment and other home items cleaning (Browne et al. 2011; Kalčíková et al. 2017). Discarding damaged or unusable fishing nets and ropes were found along the Karnaphuli river, which might be another reason for the higher amount of fibers/threads. Furthermore, microbeads from cosmetic items such as facial cleansers (Fendall and Sewell 2009) and pellets from personal care products and medications may be other sources of MPs in the riverine ecosystem (Kalčíková et al. 2017).

Color is often thought to be one of the significant crucial factors influencing MPs ingestion by aquatic organisms, as specific colors may attract predators whenever they resemble the color of their prey (Kühn et al. 2015; Abayomi et al. 2017). In this study, black and purple were the most abundant colors in sediments and surface water of the river Karnaphuli. Moreover, Hossain et al. (2021) speculated that colored MPs might be generated by synthetic and organic compounds, necessitating more extensive research. Colors might differ between regions due to their sources, such as discharge from the residents, industries, and adjacent channels.

Polyethylene terephthalate, polyamide, polyethylene, polystyrene, and alkyd resin were the major polymers in sediments and surface water of the river Karnaphuli, which is more or less similar to other reported findings (Jiang et al. 2019; Ta et al. 2020). Besides, polyethylene and polypropylene were the significant polymers in the identified MPs from the Yangtze river water (He et al. 2021), which does not support the present findings. Furthermore, polyamide and polyethylene terephthalate were revealed in the fish gut documented by Hossain et al. (2019) for the northern Bay of Bengal. However, polyethylene terephthalate is the main component for garments, drinking water bottles, maximum colored fibers, as well as several transparent fragments (Wang et al. 2017a, b). A variety of disposable products, including disposable bags, kitchen utensils, and cutlery, are found in the study area; the majority of them are composed of inexpensive and low-weight polyethylene. Moreover, paint particles (mainly alkyd resin) were estimated as a significant contributor to MPs particles in the surface water of the Incheon/Kyeonggi coastal region (Chae et al. 2015). The boats, ships, and trawlers may release paint particles in the river Karnaphuli. In addition, the discarding of damaged fishing gears, nets, ropes, floats, and fish baskets/bags may increase polyamide particles in the study area (Pruter 1987; Hossain et al. 2019).

In the current study, surface water and sediments had a moderately positive correlation in terms of MPs abundance. As a result, MPs were numerous in sediments, whereas they were common in surface water. According to Browne et al. (2007), high-density plastics typically sink, deposit in the sediments, and may be consumed by deposit feeders. In contrast, low-density plastics float at the surface and may be uptaken by filter feeders/planktivores. However, vertical transport may occur due to biofouling (the development of a biofilm on the MPs), turbulence, and freshwater inflow (Kooi et al. 2017; Melkebeke et al. 2020).

Conclusions

This research presented a preliminary investigation of MPs contamination in the river Karnaphuli of Bangladesh in Asia. MPs were identified in all the surface water and sediment samples at five sampling stations during late monsoon, winter, and early summer. Throughout the investigation, MPs from surface water varied from 30,000 to 270,000 items/km^2, with a mean value of 145,592.59 items/km^2. In the case of sediment samples, the range of MPs was 10 to 255 items/kg with a mean value of 115.00 items/kg. Smaller sizes (0.3 to 0.5 mm) of MPs were predominant; fibers or threads were the frequent types, and black was the most common color in the river Karnaphuli. Besides, there was a moderate positive correlation between MPs abundance in surface water and sediments of the Karnaphuli river. Polyethylene terephthalate (surface water: 22%; sediments: 19%), polyamide (surface water: 15%; sediments: 13%), polyethylene (surface water: 12%; sediments: 18%), polystyrene (surface water: 13%; sediments: 11%), and alkyd resin (surface water: 13%; sediments: 10%) were the major types of polymers. In conclusion, it is essential to implement an effective management strategy for reducing, reusing, and recycling plastic materials in this region. Long-term research with a broad temporal and spatial distribution is necessary to determine the flux of MPs from the river Karnaphuli to the Bay of Bengal.

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Author contribution Kaniz Fatema analyzed data and drafted the manuscript. Turabur Rahman and Md. Helal Uddin collected and analyzed the sample. Md Jakiul Islam, Kizar Ahmed Sumon, Shanur Jahedul Hasan, Md. Mahfuzul Haque, and Hisayuki Arakawa provided technical and editorial assistance. S. M. Abe Kawsar performed chemical analysis (FTIR). Harunur Rashid conceived and supervised the study and edited the manuscript.

Data availability The data that support the findings of this study are available from the corresponding author upon request.

Declarations

Ethical approval Not applicable.

Consent to participate All names in the author list have been involved throughout the study and writing.

Consent for publication This manuscript was approved by all authors. Moreover, this work has original research that has not been published previously and is not under consideration for publication elsewhere, in whole or in part.

Conflict of interest The authors declare no competing interests.

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