



Seasonal distributions and risk assessment of polychlorinated biphenyls (PCBs) in the surficial sediments from the Turag River, Dhaka, Bangladesh

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Abstract

Polychlorinated biphenyls (PCBs) were determined in sediment samples collected from the Turag River, Dhaka city, Bangladesh. This river provides critical ecological services to agriculture, industry, and transportation. However, it is one of the most polluted rivers surrounding the capital city. This study analyzed six PCB congeners (PCB 10, PCB 28, PCB 52, PCB 138, PCB 153, and PCB 180) by GC-ECD at 9 sampling sites in two different seasons. The total concentrations of PCBs in studied samples varied from 344 to 0.217 ng/g dw and 10.6 to 1.68 ng/g dw in Monsoon-season and Dry-season, respectively. The paramount contributor-congener to the total PCBs was PCB 180, and it was found at all the study sites. The ecological risk assessment indicated a high potential risk in the Monsoon-season ($E_r^i = 277$) and low potential risk in the Dry-season ($E_r^i = 25.7$). Sediment quality guideline quotients (SQGQs) showed that PCBs in the Monsoon-season would cause “no” or “moderate” biological effects on organisms at every site except site-5 (S5) (high biological effects), while no adverse ecotoxicological effect was observed in the Dry-season. Considering both probable effect level (PEL) and threshold effect level (TEL), the new sediment quality guideline quotient (NSQGQ) showed that in the Dry-season PCB contamination would cause “moderate” biological effects. At the same time, in the Monsoon-season, the findings remained consistent with the findings of SQGQ. This study looked at the PCB contamination scenario in the Turag River sediments for the first time and allowed for a comparison with other rivers worldwide.

Keywords Occurrence of PCBs · Sediment quality guideline quotients · Ecological risk assessment · GC-ECD · River sediment

Introduction

Polychlorinated biphenyls (PCBs) are manufactured chlorinated compounds consisting of 209 congeners known as persistent organic pollutants (POPs) originally appended in the Stockholm Convention on POPs. In the 1930s–1980s, PCBs widely manufactured worldwide as commercial mixtures

because of their low flammability, thermal and chemical stability, and electric insulating properties (Kampire et al. 2017). For many years, PCBs were extensively used as dielectric fluids in capacitors and transformers, pesticides and wax extenders, printing ink, carbonless copy paper, hydraulic oils, flame retardants, coolants, adhesives, and in various applications (ATSDR 2000; Habibullah-AI-Mamun et al. 2019). Though PCBs were banned in the late 1970s, they are still reported in environmental matrixes, e.g., water, air, and sediments, in various studies worldwide.

Depending on toxicological properties, PCBs have been classified as dioxin-like PCBs (DL-PCBs), which have similar toxicity to dioxins, and non-dioxin-like PCBs (NDL-PCBs) (Squadrone et al. 2015). In this study, all analyzed congeners are NDL-PCBs (PCB 10, PCB 28, PCB 52, PCB 138, PCB 153, and PCB 180). Among them, only PCB 10 is not an indicator PCB congener and it is a degradation

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product of highly chlorinated PCBs. The indicator PCBs (PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180) are known as environmentally persistent and assumed as the suitable representative of all PCB congeners (Afful et al. 2013).

Sediments serve as reservoirs for PCBs as being adsorbed by them (Ranjbar Jafarabadi et al. 2019). When PCBs are transported into the aquatic environment through the diverse paths, they tend to deposit on the surface sediments, and a small portion of PCBs adsorbed on the suspended particulate matter in water (Mechlińska et al. 2010). The adsorbed PCBs on sediments can be resuspended with changes in environmental factors and then released back into the water and begin another cycle of environmental contamination and may end up in the food chain (Cui et al. 2020). In the food chain, they bioaccumulate into the top predators via the consumption of contaminated biota and water (Bjermo et al. 2013). For example, NDL-PCBs are reported to be found in the highest amount in fish and fishery products (Squadrone et al. 2015). Therefore, it is of utmost importance to measure PCB levels in sediments as the surface sediments show the very recent PCB contamination levels in the River (Baqar et al. 2017).

Bangladesh is a signatory to the Stockholm Convention on POPs (UNEP 2001). But environmental quality guidelines on PCBs have barely been set in Bangladesh. However, some studies have been carried out in Bangladesh to quantify the PCB contamination in environmental media and biota in the coastal areas. To the best of our knowledge, no research has been done on PCBs pollution on any river sediment in Bangladesh. Hence, the occurrence and ecotoxicological risks of these environmental chemicals in various river sediments remain unknown.

Turag is one of the most polluted rivers running through the west-north and north of Dhaka City (Islam et al. 2018; Ferdousi et al. 2020). This river is directly affected by various industries ranging from small- to large-scale garments, textile, pharmaceuticals, chemicals, pesticides, jute, metal industries, tobacco, ink, pulp and paper mills, food processing, tanneries, etc. (Sarkar et al. 2016; Aktar and Moonajilin 2017; Islam et al. 2018). The heavy discharge of pollutants by the industries adjacent to the riverbanks causes a dangerous level of water pollution (Begum et al. 2018). The Department of Environment (DoE) (the sole government regulatory authority) declared it as an ecologically critical area (ECA) in September 2009 (Rahman et al. 2018; Majed and Chawdhury 2018).

The process of urbanization, industrialization, and medium to large scale landfills using industrial sludges, open burning of industrial and municipal waste, e-waste, etc., and many other polluting activities on riverbanks might be the key sources of PCBs in this River. Besides, the tropical climate of Dhaka causes frequent rainfall with

an annual average temperature of 25 °C which might result in the transportation of contaminants to this River. Thus, the contamination status of PCBs and their risks on ecology in terms of seasonal and spatial distribution are very important to evaluate in the River sediments. Hence, the consensus-based sediment quality guideline (SQG) given by Long and MacDonald (1998) has been extensively used to assess PCBs-induced ecotoxicological risks in sediments (Zhang et al. 2016; Barakat et al. 2013; Liber et al. 2019). Therefore, the prime objectives of this study were to assess the seasonal and spatial distribution of PCBs in river sediments and evaluate the ecological and ecotoxicological risk of PCBs in sediment.

Materials and methods

Study area and sample collection

The study area was located at the lower stretch of the Turag River, Dhaka, Bangladesh. The Turag River is one of the most prominent floodplain regions generated from the Bangshi river at Kaliakoir Upazila (Hossain and Chowdhury 2019). This river is active and has a small river flow in the Dry-season. It joins the Buriganga River near Mirpur (Dhaka) (Aktar and Moonajilin 2017; Hossain and Chowdhury 2019). It is navigable by boats throughout the year (Islam et al. 2018).

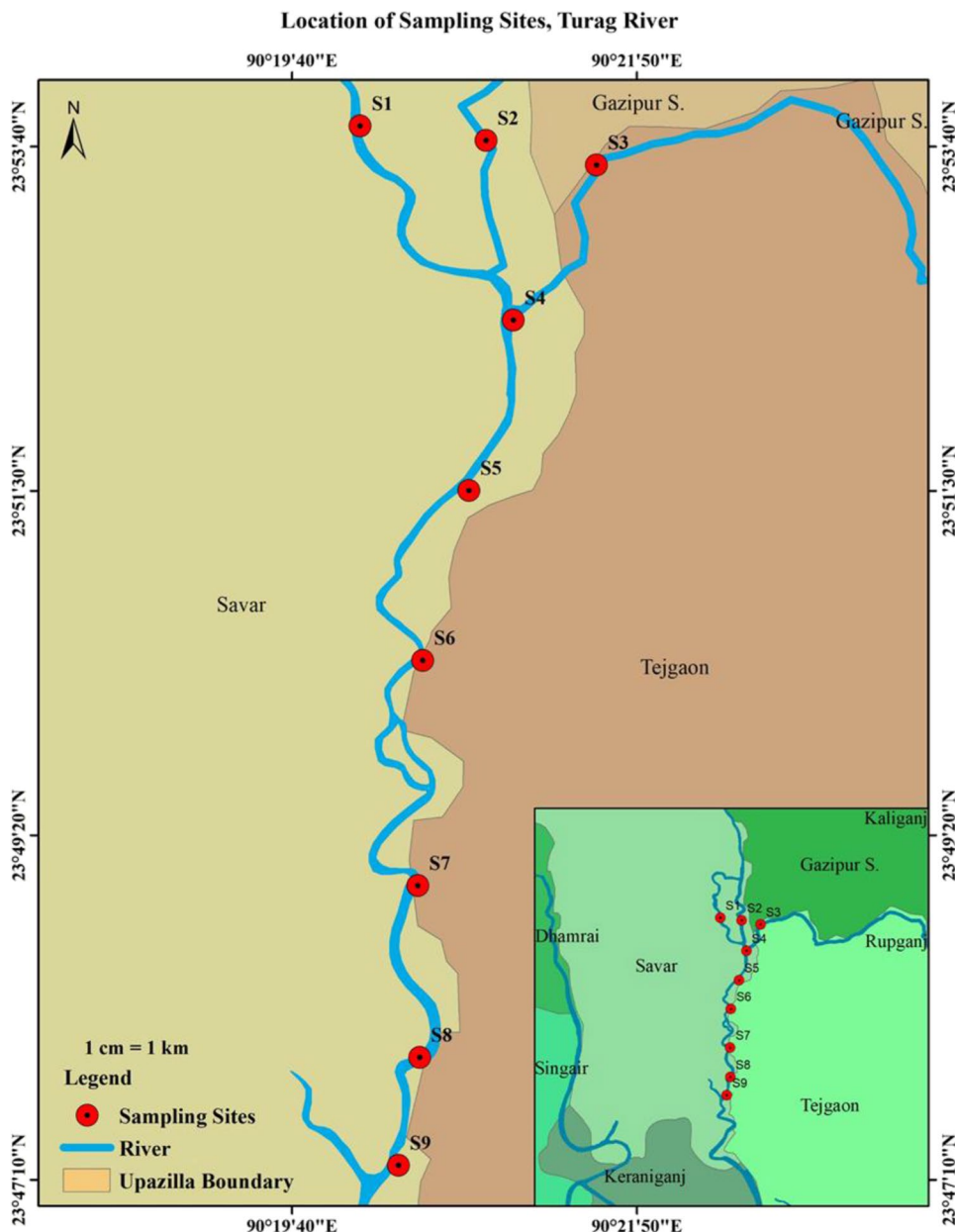
In the Monsoon-season (May–July) 2019 and the Dry-season (November–March) 2020, two sampling trips were conducted to collect surface sediments on the bank of the Turag River (Fig. 1). During low tide, a total of 54 sediment samples ($n = 27$ Monsoon-season; $n = 27$ Dry-season) were collected from nine sampling sites along the river bed. We collected 200 g of sediment samples by a hand trowel from the top surface (0–6 cm) of the riverbank. We had kept the samples in polyethylene (PE) ziplock bags and transferred them to the laboratory in an airtight ice-filled insulating box.

The samples were stored at -8 °C. All the samples were air-dried for 2 days, and foreign objects such as leaves, shells, plastic fragments, and other visible impurities were discarded. Subsequently, a mortar and a pestle were used to ground the dried sediments. Then, these were sieved for homogenization by using a stainless-steel sieve (Testing Sieve, Chung gye, Seoul, Korea) (1 mm) and resulted in fine powder. The powder was then transferred into polyethylene (PE) ziplock bags and kept in a freezer at -20 °C before extraction.

PCBs extraction and clean-up

The APHA 6431B method (American Public Health Association et al. 2012) was followed to extract the target

Fig. 1 Sampling sites along the Turag River



compounds from the sediment samples. Briefly, 50 mL of n-hexane and 50 mL of acetone were introduced into a 250-mL conical flask containing 10.0 g of the sediment sample and sonicate vigorously for 60 min. The sample was filtered into a 250-mL round bottle flask. The procedure was repeated twice. The extracts were later combined to make a whole and concentrated to 1 mL using a rotary evaporator in a water bath at 35 °C. The remains were moved into a 10-mL test tube with 5 mL n-hexane with anhydrous Na_2SO_4 . Here, clean-up was done by adding 1 mL of H_2SO_4 with 10% water, shaken vigorously using a vortex mixer for 1 min, and then centrifuged at 3000 rpm/min to separate the two layers recording the volume collected in GC sample vial for the instrumental analysis.

GC-ECD analysis

The quantification of polychlorinated biphenyls (PCBs) was performed by injecting a 1.0 μL aliquot of final extract into a gas chromatograph (Shimadzu 2010 plus) equipped with a ^{63}Ni electron capture detector (ECD) and a moving needle-type injection system, and injection mode was splitless. The column consisted of SH Rtx-5, 30 m long, 0.32 mm i.d. 0.25 μm film thickness. Here, the column temperature was started from 120 °C (Habibullah-Al-Mamun et al. 2019) (1 min hold) at a rate of 20 °C / min to 210 °C (4 min hold) and then at a rate of 5 °C / min to 290 °C (3 min hold). Detector and injector temperatures were

maintained at 300 °C and 200 °C, respectively. Nitrogen gas was the carrier gas.

Data acquisition and processing were carried out by a chromatogram, GCsolution Postrun, Version 2.41.00 with a workstation (GCsolution), and a computer. PCBs were quantified by examining the individual peak areas between the sample and the standard.

Quality assurance and quality control

For the study of linear range, a diluted PCBs standard mixture solution series of 2.5, 5, 10, 50, 100, and 200 ng/mL were prepared and injected onto the GC-ECD. The results showed that the relationship was linear up to 200 ng/mL, and the coefficients of determination ($R^2 = 0.994$) value showed excellent linearity.

All solvents were of analytical grade for PCBs analysis. Quality assurance (QA) and quality control (QC) measures are baking all glassware at 400 °C and rinsing them with solvent before use, and running method blanks, QC samples, and matrix blanks for every batch of 10 samples, also run three repetitive samples for each sampling site. The limit of detection (LOD) and limit of quantification (LOQ) were determined by using for linear regression method from Shrivastava and Gupta 2011 (Supplementary Table S5). Moisture content was recorded to supplement the dry-weight data of the sample.

Data analysis

IBM SPSS Statistics (Version 22.0) and Microsoft Excel (Version Microsoft Office Professional Plus) were employed for statistical analyses. The Shapiro–Wilk W-test was conducted for the data normality test, and data were normally distributed. Thus, one-way ANOVA was conducted to find the variations of the concentrations of PCBs among sampling sites and seasons of the study. The Arc-GIS software (Version 10.5) was used for site identifications and the spatial variations of PCBs in sediments.

Sediment quality guideline quotient (SQGQ)

SQGQ was carried out to identify the adverse biological effects of PCBs in sediments. Firstly, the probable effects level quotient (PELQ) was calculated by applying the following formula (Long and MacDonald 1998):

$$PELQ_i = \frac{C_i}{PEL} \quad (1)$$

where PEL is the guideline value for the target contaminant (i) and C_i is the measured concentration of the target contaminant. For each site, the SQGQ was calculated as:

$$SQGQ = \frac{\sum_{i=1}^n PELQ_i}{n} \quad (2)$$

where n is the total number of measured contaminants having sediment quality guideline values. Three ranges of SQGQ were categorized based on potential adverse biological effects of sediment contamination. They are no biological effects ($SQGQ < 0.1$), moderate biological effects ($0.1 \leq SQGQ < 1$), and high biological effects ($SQGQ \geq 1$) (Tian et al. 2013; Wang et al. 2019; Lv et al. 2020).

New sediment quality guideline quotient (NSQGQ)

According to Wang et al. (2019), SQGQs might depreciate the risks of PCBs for not considering the TEL (threshold effects level). Below the threshold effects level (TEL), adverse effects are unexpected or rarely occur for the majority of sediment-dwelling organisms and here sediments are considered to be clean to marginally polluted (MacDonald et al. 2000). Thus, considering both PELs and TELs, they introduced a new sediment quality guideline quotient (NSQGQ) (Long and MacDonald 1998; Zhang et al. 2016). At first, NSQGQ for total PCB congeners was derived from the following formula (Wang et al. 2019):

$$NSQGQ_i = \frac{\sqrt{\frac{C_i}{TEL} + \left(\frac{C_i}{PEL}\right)^2}}{2} \quad (3)$$

Finally, the combined risk index of total PCBs and other contaminants could be assessed based on the following equation:

$$NSQGQ = \frac{\sum_{i=1}^n NSQGQ_i}{n} \quad (4)$$

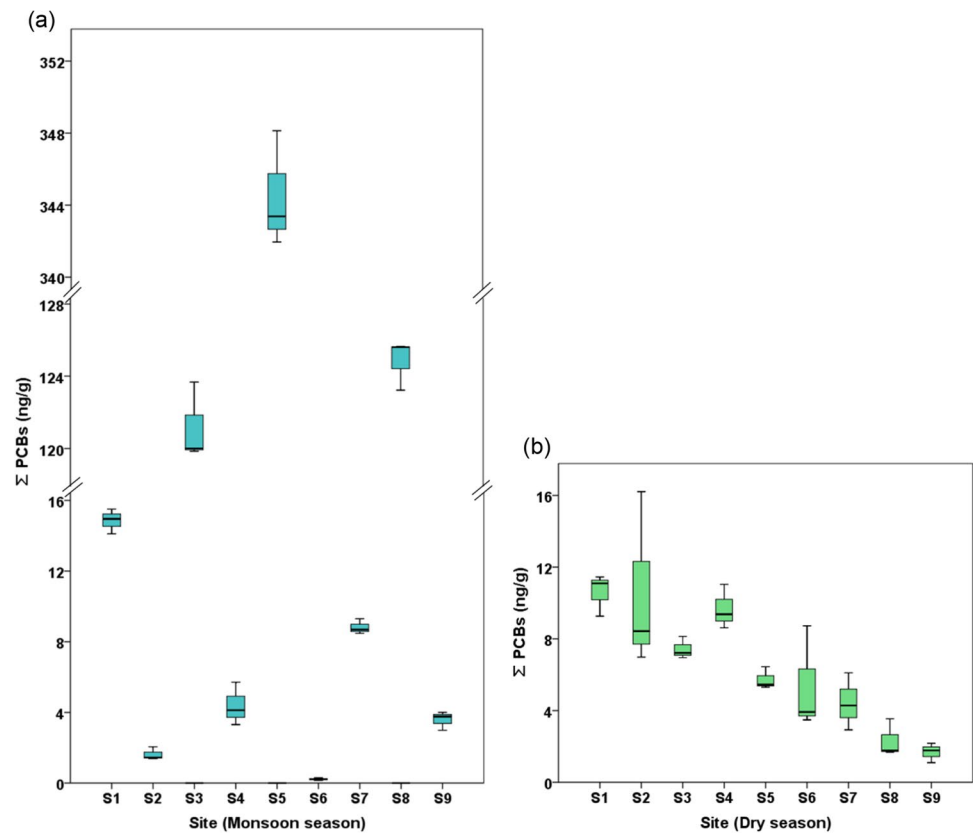
where $NSQGQ_i$ is the new SQGQ of a certain contaminant; C_i denotes the measured concentration of the target contaminant; n denotes the total number of the measured contaminants having sediment quality guideline values and NSQGQ refers to the combined new sediment quality guideline quotient.

Results and discussion

Composition and occurrence of PCBs in sediments

In this study, detectable levels of PCBs were noticed in all the collected sediment samples. The PCB congeners concentrations at each sampling site in surface sediments were illustrated in Fig. 2, and the descriptive data is presented in Table S1. The PCB concentrations ranged from 0.217 to 344

Fig. 2 PCBs concentration in the surface sediments at each sampling site of (a) Monsoon and (b) Dry seasons



and 1.68 to 10.6 ng/g dry weight (dw) in Monsoon-season and Dry-season, respectively, in the river sediments.

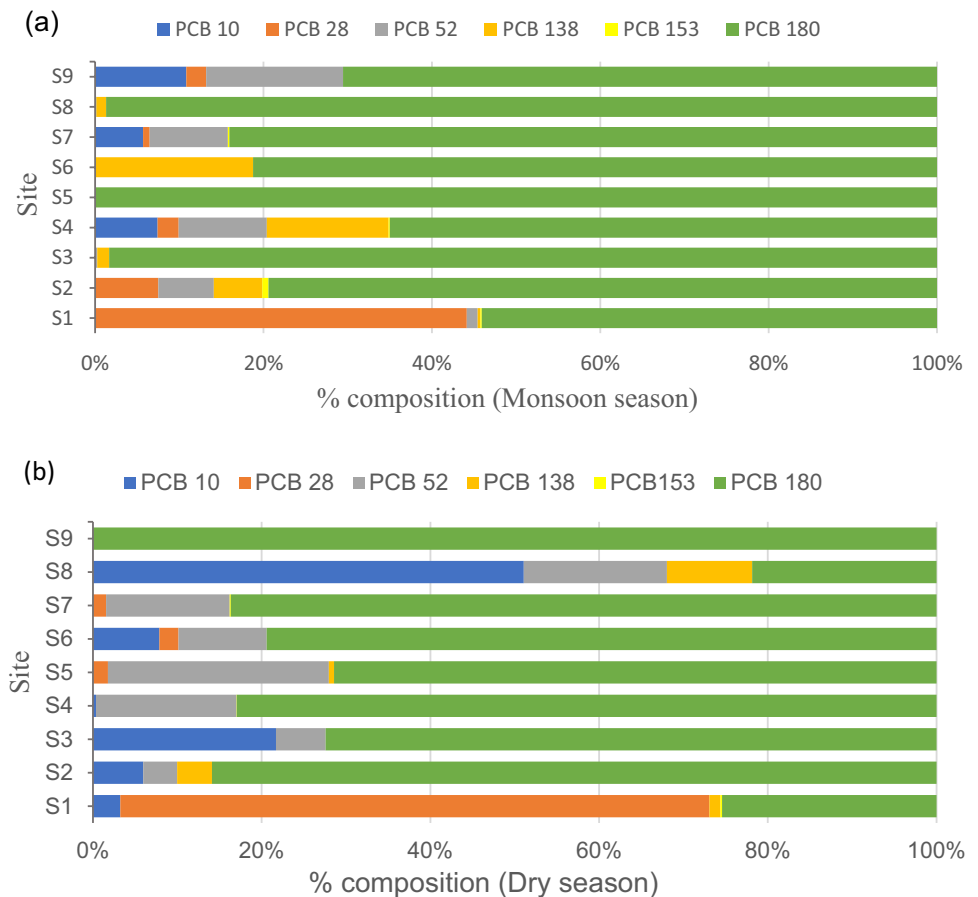
The percentage composition of six PCB congeners is shown in Fig. 3. PCB 180 was the most abundant among the analyzed congeners in the investigated samples in the Monsoon-season, followed by PCB 28 and PCB 138. PCB 180 alone contributed more than 97% to the total PCBs in the analyzed sediments. From Fig. 3(a), PCB 52 was the second dominant congener at Sites 7 and 9. PCB 28 was the second dominant congener at Sites 1 (> 40%) and 2. Also, PCB 138 was the second dominant congener at Sites 4 and 6 (> 15%). On the other hand, PCB 180 was again the most abundant in the investigated samples for the Dry-season, followed by PCB 28 and PCB 52. Here, PCB 180 alone contributed more than 68% to the total PCBs in the sediments analyzed. From Fig. 3(b), PCB 180 showed predominance at all sites except Sites 1 and 8. PCB 10 showed predominance at Site 8 (> 40%), and PCB 28 showed predominance at Site 1 (> 60%). PCB 52 was the second dominant congener at Sites 4, 5, 6, and 7. The least dominant congeners were PCB 153 and PCB 138.

High abundance and dominance of PCB 180 had been observed in both seasons. A similar case of the highest presence of PCB 180 in all sediment samples has been reported in the study of Gakuba et al. (2015). Also, in the study of Malik et al. (2014), this congener is reported to be observed

most frequently. Apart from PCB 180, PCB 52 was the second dominant and also abundant congener in both seasons. The high abundance of these two congeners was consistent with the finding of Lai et al. (2015) and Kanzari et al. (2014). Longer half-lives of these two congeners might be responsible for abundance. Because freshly incorporated PCB 180 exhibited half-life in a range of soils varying from 15.8 to 47.2 years (Ayris and Harrad 1999). This persistent congener lasts longer, very slowly degrades, and accumulates in the aquatic environment over time (Gakuba et al. 2015; Kilunga et al. 2017). On the other hand, PCB 52 was reported to have 11.2 years of half-life (Doick et al. 2005).

Leakage from installations at storage or disposal and operating installations of electrical equipment are considered the most significant potential source of environmental pollution by PCBs in several emission inventories (Kakareka and Kukharchyk 2005). During the site visit, it was observed that top sites were directly in contact with landfills. Landfills are a potential source of PCB emissions, as they contain municipal and industrial wastes. The type of PCB wastes in landfills highly affects PCB emissions (Kakareka and Kukharchyk 2007). Municipal waste burning is another potential source of PCB pollution in this study. Various wastes are burnt into large bonfires such as paper, packaging material, paperboard, polyethylene film, plastic bottles, contaminated wood, waste food, and rags. Street sweep, which contains a significant

Fig. 3 Composition (%) of six PCB congeners in sediment samples of (a) Monsoon and (b) Dry seasons



share of domestic wastes, is burnt down often. Sanitary landfills of solid wastes and in other places of their unofficial accumulation cause unavoidable spontaneous fires.

The incomplete burning of e-waste is a potential source of PCBs in the study area. Other potential sources of PCBs in the study area might contain paint industry, burning of e-waste for metal recovery, vehicular fuels, PVC (polyvinyl chloride) industries (Syed et al. 2014; Baqar et al. 2017), dumping and discharges of oils and waste material (Farooq et al. 2011), industrial waste and coal combustion (Chi et al. 2007), and recycling units and steel production (Biterna and Voutsas 2005).

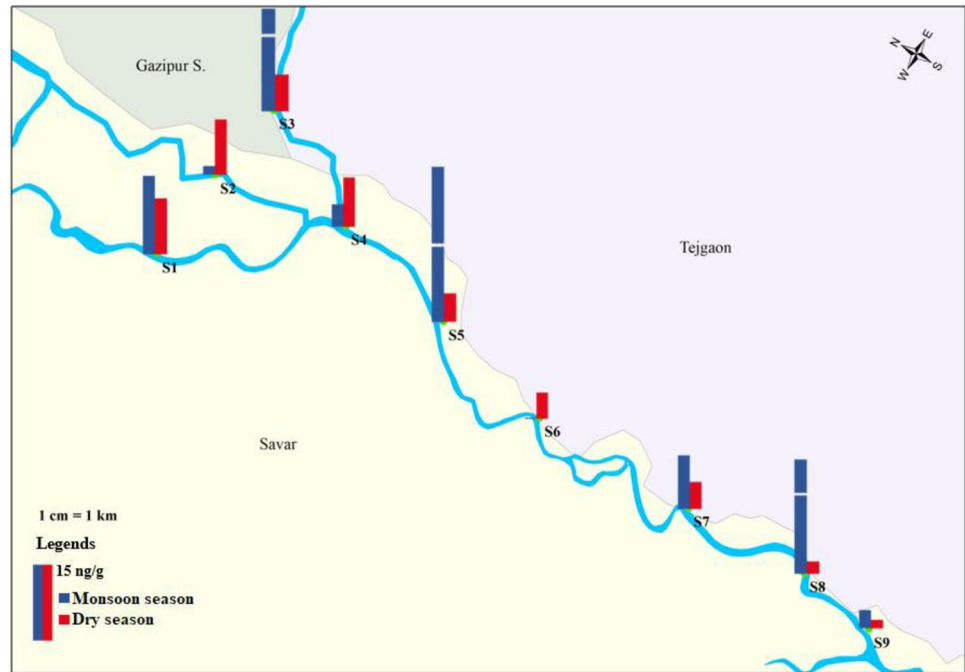
Seasonal and spatial differences of PCBs in sediments

In the study area, the seasonal and spatial dissemination of PCBs in sediments are shown in Fig. 4. Sediments are heterogeneous in constituents, and the different elements of sediments show different interactions with the pollutants (Kampire et al. 2017). It may highly affect the composition of PCBs concentration spatially and seasonally. One-way ANOVA test results showed that seasonally neither the

levels of total PCBs nor the identified congeners distribution patterns differ significantly ($p > 0.05$).

In the Monsoon-season, the total concentration of PCBs ranged from 0.217 to 344 ng/g dw. The highest concentration was observed in sediments collected from Site 5, followed by Sites 3 and 8. All these sites are highly contaminated with PCB 180. In the past, increased concentrations of PCBs 170 and 180 have been reported to be evidence of the presence of Aroclor 1260 (Ormerod et al. 2000). Aroclor 1260 was a usual constituent of capacitor oils and transformers (Erickson and Kaley 2011). This would be consistent with the release from the disassembling of transformers and other types of electrical equipment located within the vicinity of Sites 3, 5, and 8 in the Monsoon season. Especially at Site 5, which is adjacent to a number of small-to-medium scale industrial units, and had several transformers along the roadsides. Leakage from these transformers may be concentrated due to heavy rainfall accompanied by the Cyclone Fani in the same month and lead to the high contamination of PCB 180. Site 3 and 5 were in the surrounding of several small-to-medium scale municipal wastewater outlets from adjacent localities, landfills, cement factory or sand cultivation, and local markets. Site 8 is also exposed to small-to-medium scale motor vehicle repair workshops at the riverbank that

Fig. 4 Distribution of total PCBs in surface sediment along the Turag River in Monsoon and Dry seasons



might release contaminants such as paints and oils into the river system. Also, all those sites are very proximate to a busy highway.

Again, the elevated PCB levels in Monsoon-season samples, especially at Sites 3, 5, and 8 might be caused by heavy rainfall and floods that triggered surface runoff from highly contaminated sites. This reason is suspected because heavy rainfalls took place due to Cyclone Fani before sampling from these sites. This tropical cyclone caused medium to heavy rainfall over the country, and Dhaka experienced 10 to 70 mm of rainfall accompanied by the tropical cyclone (The Daily Star 2019; OCHA 2019). Large water bodies show higher contamination during and immediately after rainstorms (Awwa Research Foundation 2008). An increase in precipitation intensity triggers inputs of pollutants, especially severe nutrients, pathogens, hazardous substances, organic material, and other dissolved contaminants (e.g., pesticides) (Ching et al. 2015). On the day of sample collection in the Monsoon-season, at Mirpur station (SW302), the water level was 2.86 m with regular water flow.

In the Dry-season, the total concentration of PCBs ranged from 1.68 ng/g dw and 10.6 ng/g dw. The highest contamination was observed at Site 1, followed by Site 2 and Site 4. These sites are close to small-to-medium scale industrial units such as tannery, dyeing industries, metal processing industries, battery manufacturing industries, etc. From Figs. 2 and 4, it is observed that the total PCBs concentration showed a somewhat descending pattern in this stretch of the River. The PCBs concentration might be diluted over the course by freshwater supply from the catchment areas of Turag. Co-evaporation of PCBs with water might be one

of the reasons (Dodoo et al. 2012). Another reason might be excessive sedimentation from low mixing effects in the Dry-season because of relatively weaker wave action and decreased upstream rivers inflow (Habibullah-Al-Mamun et al. 2019). It is important to note that the Dry-season flow decreased the water height to such an extent that some of the samples were stored from the river bed and the water level was 1.52 m with low water flow at the Mirpur station (SW302).

A distinct seasonal variation was observed for PCBs in the sediment samples, where concentrations were highest during the Monsoon-season and lowest during the Dry-season. The p -value ($0.121 > 0.05$) from the one-way ANOVA test indicates PCBs were not statistically different between the two seasons. This finding was compatible with earlier studies conducted by Lai et al. (2015) at the Pearl River, China, and Hellar-Kihampa et al. (2013) at the Pangani river basin, Tanzania reporting that the wet or rainy season has a higher mean concentration of \sum PCBs than the dry season, and which was not significant ($P > 0.05$). In the study of Lai et al. (2015), they mentioned that such seasonal fluctuation was steered by precipitation and pollution sources. And, in the Hellar-Kihampa et al. 2013, they indicated contamination patterns could be affected by different factors for sediment samples.

In this study, the seasonal difference in the PCBs concentration might be caused by the variations of the precipitation amount in these two seasons (Li et al. 2012). The subtropical Monsoon-season in the study area is characterized by frequent rainfall, high humidity, and moderately warm temperature. Again, strong tidal influence, high precipitation, and

changes in river dynamics might affect the spatial distribution of pollution. Besides, agricultural and surface runoffs, dumping of industrial wastes, intense dredging operations, intense shipping, and atmospheric depositions might speed up the extent of PCB contamination in this season. Whereas, in the Dry-season, weak tidal influence, low-water flow, low or no precipitation, static river dynamics might affect the spatial distribution of pollution in this season. During the Monsoon-season, the surface sediments generally are worn out, and new sediments are settled down after that. It takes time to accumulate organic pollutants in new sediments. Consequently, relatively low concentrations of PCBs were observed in the Dry-season.

Ecological risk assessment

It is imperative to assess the sediment-bound PCBs inducing the potential risk of the Turag River. As there is still no uniform standard available, the risk assessment of PCBs in the riverine environment was carried out based on the ecological risk index (ERI) of Hakanson (1980) and implemented in previous studies (Baqar et al. 2017; Cui et al. 2016). Here, the risk assessment has been done by the following equations:

$$ERI = \sum E_r^i \tag{5}$$

$$E_r^i = T_r^i \times C_f^i \tag{6}$$

$$C_f^i = \frac{C_0^i}{C_n^i} \tag{7}$$

where ERI is the summation of ecological risk factors of seven heavy metals and PCBs. As this study is about PCBs,

Table 2 SQGQ and NSQGQ of PCBs in sediments of Monsoon and Dry seasons

Site	SQGQ _{Monsoon}	SQGQ _{Dry}	NSQGQ _{Monsoon}	NSQGQ _{Dry}
S1	0.0786	0.0561	0.669	0.589
S2	0.00861	0.0558	0.239	0.551
S3	0.641	0.0393	1.60	0.458
S4	0.0232	0.0512	0.446	0.468
S5	1.82	0.0303	3.69	0.404
S6	0.00115	0.0284	0.0668	0.411
S7	0.0467	0.0235	0.509	0.330
S8	0.660	0.0123	1.58	0.314
S9	0.0190	0.00890	0.352	0.140

so heavy metals were not considered. So, in this calculation, ERI is equivalent to E_r^i (monomial potential ecological risk factor). T_r^i is the toxic-response potential for PCBs. C_f^i is the contamination factor, and C_n^i denotes reference value for \sum PCBs, and it is 10 ng/g.

The potential ecological risk factor (E_r^i) had been graded into the following five categories (Hakanson, 1980): $E_r^i < 40$, low risk; $40-79 E_r^i$, moderate risk; $80-159 E_r^i$, considerable risk; $160-319 E_r^i$, high risk; and $E_r^i > 320$, very high risk.

The ERI was calculated using Eqs. (6) and (7). The ERI value indicated high potential ecological risk during Monsoon-season ($E_r^i = 277$) and low potential ecological risk during Dry-season ($E_r^i = 25.7$). The ecological risk factor of the Turag River is shown in Table 1.

Ecotoxicological risk assessment

Sediment quality guideline quotients (SQGQs)

The average values of SQGQ for both seasons are shown in Table 2. Six sampling sites of the Monsoon-season are

Table 1 Ecological risk index of Turag River in Monsoon and Dry seasons

Site	Monsoon season			Dry season		
	\sum PCBs	Potential ecological risk factor (E_r^i)	Grade Hakanson (1980)	\sum PCBs	Potential ecological risk factor (E_r^i)	Grade Hakanson (1980)
S1	14.9	59.4	Moderate	10.6	42.4	Moderate
S2	1.63	6.51	Low	10.5	42.2	Moderate
S3	121	484	Very high	7.43	29.8	Low
S4	4.39	17.5	Low	9.67	38.7	Low
S5	344	1377	Very high	5.73	22.9	Low
S6	0.217	0.867	Low	5.38	21.5	Low
S7	8.82	35.3	Low	4.44	17.8	Low
S8	124	499	Very high	2.33	9.30	Low
S9	3.59	14.3	Low	1.68	6.73	Low

below 0.1. Besides, the SQGQs in two sampling sites, namely, Site 3 and Site 8, indicate that benthic organisms might suffer from moderate adverse biological effects due to sediment-bound PCBs. The SQGQ of PCBs at Site 5 is above 1, suggesting that this surface sediment of the sampling site was suffering from high adverse biological effects (Table 2). Whereas the SQGQs of the Dry-season show that PCBs would not cause any effects on benthic organisms (Table 2).

New sediment quality guideline quotient (NSQGQ)

Wang et al. (2019) showed in their study that there was a significant linear correlation ($R^2 = 0.987$, $p < 0.01$) between SQGQs and NSQGQs while specifying that NSQGQs was perhaps a valid parameter to evaluate the ecotoxicological risks of PCBs. They recommend NSQGQs can better estimate the ecotoxicological risks for PCBs. Here, the effect levels were divided into the following categories: $NSQGQ < 0.2$, no or low effects; $0.1 \leq NSQGQ < 2$, moderate effects; and $NSQGQ \geq 2$, high adverse effects.

In the Monsoon-season, the NSQGQs reflect that the PCB contamination would cause low to moderate biological effects on the Turag River except Site 5, indicating a high adverse effect on biological organisms (Table 2). Whereas, in Dry-season, the NSQGQs denote that PCB contamination caused moderate biological effects during the Dry-season, while according to SQGQ, this season had no effects on aquatic species of the Turag River (Table 2).

Comparison with previous studies worldwide

A comparison of mean sedimentary Σ PCBs concentration of the Turag River with those recorded from other rivers around the world is presented in Table 3.

No data on PCB contamination in the Turag River is accessible to compare with the findings from this study. In Bangladesh, the literature indicates no research on riverine sedimentary PCBs.

The comparison of mean PCBs concentration in sediments of the Monsoon-season with other studies (Table 3) presented that the Σ PCBs concentration of this study was comparable or lower than those reported from Pearl River Delta, China (Wang et al. 2019); Umgeni River, South Africa (Gakuba et al. 2015); and Pangani River and its tributaries, Tanzania (Hellar-Kihampa et al. 2013).

Whereas, the comparison of the mean PCBs concentration in sediments of the Dry-season with other studies showed that the Σ PCBs concentration of this study was significantly lower than those reported from River Nile, Egypt (Omar and Mahmoud 2017); Liaohe River, China (Lv et al. 2015); and Soan River, Pakistan (Malik et al. 2014). On the contrary, it was relatively higher than the Colorado River, Mexico (Lugo-Ibarra et al. 2011). However, the Σ PCBs concentration was slightly lower or somewhat comparable to those studies recorded from River Thames, England (Lu et al. 2017); Songhua River, China (Cui et al. 2016); CauBay River, Vietnam (Toan and Quy 2015); and Bahlui River, Romania (Neamtu et al. 2009).

Table 3 Comparison of total PCBs (ng/g dw) in sediments of Rivers worldwide

Location	Country	N ^a	Σ PCBs	References
Turag River	Bangladesh	6	0.03–344.5 (Mon) ^b 1.68–10.6 (Dry) ^b	Present Study
River Thames	England	7	0.12–27.4	Lu et al. 2017
River Nile	Egypt	11	1.677–2.464	Omar and Mahmoud 2017
Umgeni River	South Africa	8	102.60–427.80	Gakuba et al. 2015
Pearl River Delta	China	7	19.8–111	Lai et al. 2015
Pearl River Delta	China	16	16.15–477.85	Wang et al. 2019
Songhua River	China	48	0.59–12.38	Cui et al. 2016
Bahlui River	Romania	11	3–26	Neamtu et al. 2009
Liaohe River	China	33	4.92–179.61	Lv et al. 2015
CauBay River	Vietnam	6 [†]	5.58–36.18	Toan and Quy 2015
Pangani River and its tributaries	Tanzania	28	357–11,000	Hellar-Kihampa et al. 2013
Colorado River	Mexico	30	0.07–4.14	Lugo-Ibarra et al. 2011
Soan River	Pakistan	34	37.4–187	Malik et al. 2014

^aNumber of PCB congeners

^bMon and Dry represent Monsoon and Dry seasons, respectively

[†]indicator PCBs

N.B. PCB 28, PCB 52, PCB 138, PCB 153 and PCB 180 are analyzed in all studies except at the studies of Omar and Mahmoud 2017 & Lugo-Ibarra et al. 2011, PCB 153 is absent

The total sedimentary PCB levels reported from developed countries (China, England, France, Italy, and South Africa) were generally comparable to or higher than the total PCB levels in the present study. This suggests that the industrial activities and various waste discharges in the environmental compartments of developed countries were very high (Kampire et al. 2017). Whereas the levels of total PCBs on the river sediments from developing countries (Egypt, Vietnam, Romania, and Mexico) were generally comparable or lower than the total PCB levels in the present study. The history of PCBs is prevalent and more extensive in developed nations than in developing countries, and the contamination seems to be more profound in developed countries (Mochungong and Zhu 2015).

Conclusion

The present study was the first to focus on organic pollutant PCBs in the surficial sediments of the Turag River, Dhaka, Bangladesh. Due to the urban river surrounding different types of industry, a considerable amount of PCBs was present in different samples. PCB 180 was the most conspicuous one in sediments during both seasons. Considering seasonal variation, the mean concentration of \sum PCBs in the Monsoon-season (69.3 ng/g dw) was higher than the Dry-season (6.42 ng/g dw). In Monsoon-season, sites 3, 5, and 8 were subjected to moderate to high adverse biological effects on benthic organisms. Ecological risk assessment reflected high potential ecological risk in the Monsoon-season ($E_r^i = 277$) and low potential ecological risk in the Dry-season ($E_r^i = 25.7$). The sedimentary PCB concentrations of the investigated area were comparable with rivers around the world.

The possible sources of PCBs are from dyeing, chemicals, paper mills, domestic industrial and wastewater discharge from factories (e.g., paper, paint, iron, and textile factories) of industrial clusters. The sources also include landfills, e-wastes, transformers, constructions and demolition wastes, municipal waste open burning, etc., into the Turag River. In the lack of any data on PCBs in the study area, the present study would yield baseline data for subsequent ecological studies in the future. Again, this study would stress the efforts of Bangladesh's national implementation plan (NIP) to the exclusion of PCBs as a party of the Stockholm Convention (UNEP 2001).

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Author contribution NJC, MS, and MKU designed and planned the study. NJC collected and prepared the samples for analysis. MAA and NJC carried out all lab analyses. NJC prepared the draft manuscript. MS and MMR did the revision and proof reading.

Data availability All data are available within the manuscript.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All the authors approved the manuscript for publication.

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