

# Seasonal Distributions, and Risk Assessment of Polychlorinated Biphenyls (PCBs) in the Surficial Sediments from the Turag River, Dhaka, Bangladesh

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## Research Article

**Keywords:** Bangladesh, PCBs, Sediments, Risk assessment, Turag River

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**Title**

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) assessment in sediments of Turag River, Dhaka, Bangladesh has been conducted for the first time. This River provides critical ecological services to agriculture, industry, and transportation. However, the Turag River is one of the most industrially polluted rivers surrounding Dhaka in Bangladesh. In this study, six PCB congeners namely PCB 10, PCB 28, PCB 52, PCB 138, PCB 153, and PCB 180, were analyzed in surface sediments by GC-ECD at 9 sampling sites. Pre-monsoon and post-monsoon season sampling were collected in this study. The total concentrations of PCBs varied from 344.49 to 0.22 ng/g dw and 10.6 to 1.68 ng/g dw in pre-monsoon and post-monsoon, respectively. The paramount contributor congener to the total PCBs was PCB 180 and was found at all sites. The ecological risk assessment indicated a high potential risk in pre-monsoon ( $E_r^i = 277.32$ ) and low potential risk in post-monsoon ( $E_r^i = 25.69$ ). Sediment quality guideline quotients (SQGQs) showed that PCBs in pre-monsoon would cause no or moderate biological effects on organisms at most sampling sites except in surface sediments of

24 site S5 (high biological effects), while no adverse ecotoxicological effect was observed in post-  
25 monsoon. Considering both probable effect level (PEL) and threshold effect level (TEL), the new  
26 sediment quality guideline quotient (NSQGQ) showed that in post-monsoon PCBs contamination  
27 would cause moderate biological effects, while in pre-monsoon the findings remained consistent  
28 with the findings of SQGQ. This study gave a quick look at the PCB contamination scenario in the  
29 Turag River sediments and also allowed for a comparison between the investigated River and other  
30 rivers worldwide.

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32 Keywords: Bangladesh; PCBs; Sediments; Risk assessment; Turag River

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## 35 **1. Introduction**

36 Polychlorinated biphenyls (PCBs) are a type of man-made chlorinated compounds consisting of  
37 209 congeners known as persistent organic pollutants (POPs) originally appended in the  
38 Stockholm Convention on POPs. In the 1930s-1980s, PCBs were widely manufactured around the  
39 world as commercial mixtures because of their low flammability, thermal and chemical stability,  
40 and electric insulating properties (Kampire et al. 2017). For many years, PCBs were extensively  
41 used as dielectric fluids in capacitors and transformers, pesticide and wax extenders, printing ink,  
42 carbonless copy paper, hydraulic oils, flame retardants, coolants, adhesives, and in various  
43 applications (ATSDR 2000; Habibullah-Al-Mamun et al. 2019). Though PCBs have been banned  
44 in the late 1970s, worldwide they are still reported in environmental matrixes e.g., water, air,  
45 sediments, etc., in various studies.

46 Sediments serve as reservoirs for PCBs as being absorbed by them (Ranjbar Jafarabadi et al. 2019).  
47 When PCBs are transported into the aquatic environment through the diverse paths, they tend to  
48 deposit on the surface sediments and a small portion of PCBs adsorbed on the suspended  
49 particulate matter in water (Mechlińska et al. 2010). Then, these sediments bound contaminants  
50 are carried away through incorporating with trophic level e.g., consumption of benthic organisms  
51 by fish (Bjermo et al. 2013). Again, sediment can resuspend with changes in environmental  
52 components, and then be released back into the water and begin another cycle of environmental  
53 contamination and may end up in the food chain (Cui et al. 2020). Therefore, the surface sediments  
54 show the current PCBs contamination levels in the river (Baqar et al. 2017).

55 Bangladesh is a signatory country to the Stockholm Convention on POPs, 2001. But environmental  
56 quality guideline on PCBs has barely been set in Bangladesh. However, in Bangladesh, some  
57 studies have been carried out to evaluate the PCBs contamination in environmental media and  
58 biota at the coastal areas. Yet, no researches have been conducted on PCBs pollution on any river  
59 body. Also, the occurrence and ecotoxicological risks of this compound in various river sediments  
60 are remained unknown.

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

69 The process of urbanization, industrialization, and medium to large-scale landfills using industrial  
70 sludges, open burning of industrial and municipal waste, e-waste, etc., and many other polluting  
71 activities on riverbanks might be the key sources of PCBs in this River. Besides, the tropical  
72 climate of Dhaka causes frequent rainfall with an annual average temperature of 25 °C might  
73 attribute to the transportation of contaminants to this River. Thus, the contamination status of PCBs  
74 and its harmful consequences are paramount to evaluate seasonally and spatially in the River  
75 sediments. Very few studies have been carried out regarding organic pollutants on the River, and  
76 ecological risks due to organic pollutants are still unknown. Hence, the consensus-based sediment  
77 quality guideline (SQG) given by Long and MacDonald (1998) has been extensively used to assess  
78 PCBs induced ecotoxicological risks in sediments (Barakat et al. 2013; Zhang et al. 2016; Liber et  
79 al. 2019). Therefore, the prime objectives of this study were to assess the seasonal and spatial  
80 distribution of sedimentary PCBs pollution and to evaluate the ecological and ecotoxicological  
81 risk of PCBs in sediment.

## 82 **2. Materials and Methods**

### 83 **2.1 Study area and sample collection**

84 The study area consists of the part of the Turag River. The Turag River is one of the most  
85 prominent floodplain regions generates from the Bangshi river at Kaliakoir Upazila (Hossain and  
86 Chowdhury 2018). The Turag River is active and has a small flow only in the dry season. It joins  
87 the Buriganga River near Mirpur (Dhaka) (Aktar and Moonajilin 2017; Hossain and Chowdhury  
88 2018). It is navigable by boats throughout the year (Islam et al. 2018).

89 Two sampling trips were undertaken in pre-monsoon (March-May) 2019 and in post-monsoon  
90 (November-February) 2020 to collect surface sediments on the bank of the Turag River (Fig. 1).

91 During low tide, a total of 18 sediment samples were collected during this time from nine sampling  
92 sites. From the top surface (0 – 6 cm) of the riverbank, around 200g of sediments were collected  
93 from each location by a hand Trowel as a sampler. In polyethylene (PE) ziplock bags the samples  
94 were carried and transferred in an airtight ice-filled insulating box.

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

## 101 **2.2 PCBs Extraction and Clean-up**

102 The APA 6431B method was followed to extract the target compounds from the sediment samples.  
103 Briefly, 50 mL of n-hexane and 50 mL of acetone were introduced into a 250 mL conical flask  
104 containing 10.0 g of the sediment sample and sonicate vigorously for 60 minutes. The sample was  
105 filtered into a 250 mL round bottle flask. The procedure was repeated twice. The extracts were  
106 later combined to make a whole and concentrated to 1 mL using a rotary evaporator in a water  
107 bath at  $35\text{ }^{\circ}\text{C}$ . The remains were moved into a 10 mL test tube with 5 mL n-hexane with anhydrous  
108  $\text{Na}_2\text{SO}_4$ . Here, clean-up was done by adding 1 mL of Sulphuric acid with 10% water; shaken  
109 vigorously using a vortex mixer for 1 min, and then centrifuge at 3000 r/min to separate the two  
110 layers recording the volume collected in GC vial for the run.

## 111 **2.3 GC-ECD Analysis**

112 The quantification of polychlorinated biphenyls (PCBs) was performed by injecting 1.0  $\mu$ l aliquot  
113 of final extract into a gas chromatograph (Simadzu 2010 plus) equipped with a  $^{63}$  Ni electron  
114 capture detector (ECD) and a moving needle-type injection system and injection mode was  
115 splitless. The column consisted of SH Rtx-5, 30 m long, 0.32 mm i.d.0.25  $\mu$ m film thickness. Here,  
116 the column temperature was started from 120  $^{\circ}$ C (1 min hold) at a rate of 20  $^{\circ}$ C / min to 210  $^{\circ}$ C (4  
117 min hold) and then at a rate of 5  $^{\circ}$ C / min to 290  $^{\circ}$ C (3 min hold). Detector and injector temperatures  
118 were maintained at 300  $^{\circ}$ C and 200  $^{\circ}$ C respectively. Nitrogen gas was the carrier gas  
119 Data acquisition and processing were carried out by a chromatogram, named GCsolution Postrun,  
120 Version 2.41.00 with a workstation (GCsolution), and a computer. PCBs were quantified by  
121 comparing the individual peak areas between the sample and the standard.

#### 122 **2.4 Quality assurance and quality control**

123 For the study of linear range, a diluted PCBs standard mixture solution series of 2.5, 5, 10, 50, 100,  
124 and 200 ng/mL were prepared and injected onto the GC-ECD. The results show that the relation  
125 is linear up to 200 ng/mL and the coefficients of determination ( $R^2$ ) values showed good linearity  
126 ranging between 0.9844 and 0.9971.

127 All solvents were of analytical grade for PCBs analysis. Quality assurance (QA) and quality  
128 control (QC) measures are baking all glassware at 400  $^{\circ}$ C and rinsing them with solvent before  
129 use, running method blanks, and matrix blanks for every batch of 10 samples. An S/N (signal-to-  
130 noise) ratio equivalent to 10 was applied to set the limit of detection (LOD) for each analyte. The  
131 limit of detection (LOD) was ranged from 0.01 ng/mL (dw) to 200 ng/mL (dw). <0.001ng/g levels  
132 were taken as not detected in the PCB calculations. Moisture content was assessed to present data  
133 on a dry weight basis.

134 **2.5 Data analysis**

135 For statistical analyses, IBM SPSS Statistics (Version 22.0) and Microsoft XL (Version Microsoft  
136 Office Professional Plus) were employed. The Shapiro-Wilk W test was conducted for data  
137 normality test. One-way ANOVA test was conducted to find the variations among the  
138 concentrations of PCBs and seasonal differences. The Arc-GIS software (Version 10.5) was used  
139 for site identifications and the spatial variations of PCBs in sediments.

140 **2.6 Sediment quality guideline quotient (SQGQ)**

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

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

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

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

148 where n is the total number of measured contaminants having sediment quality guideline values.  
149 Three ranges of SQGQ were categorized based on potential adverse biological effects of sediment  
150 contamination. They are: no biological effects ( $SQGQ < 0.1$ ), moderate biological effects ( $0.1 \leq$   
151  $SQGQ < 1$ ), and high biological effects ( $SQGQ \geq 1$ ) (Tian et al. 2013; Wang et al. 2019; Lv et al.  
152 2020).

153 **2.7 New sediment quality guideline quotient (NSQGQ)**



154 According to Wang *et al.*, 2019, SQGQs might depreciate the risks of PCBs for not taking into  
 155 consideration the TEL effects. Thus, considering both PELs and TELs, they introduced a new  
 156 sediment quality guideline quotient (NSQGQ) (Long and MacDonald 1998; Zhang et al. 2016).  
 157 At first, NSQGQ for total PCB congeners was derived from the following formula (Wang et al.  
 158 2019):

$$159 \quad NSQGQ_i = \frac{\sqrt{\frac{C_i}{TEL} + (\frac{C_i}{PEL})^2}}{2} \dots\dots\dots(3)$$

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

$$162 \quad NSQGQ = \frac{\sum_{i=1}^n NSQGQ_i}{n} \dots\dots\dots(4)$$

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

### 167 **3. Results and discussion**

#### 168 **3.1 Composition and occurrence of PCBs in sediments**

169 In the present study, detectable levels of PCBs were noticed in all sedimentary samples. The PCB  
 170 congeners concentration in sediments from Turag are presented in Table 1. The PCB  
 171 concentrations ranged from 0.217 to 344.49 ng/g and 1.68 to 10.6 ng/g dry weight (dw) in pre-  
 172 monsoon and post-monsoon, respectively in the surface sediments.

173 In pre-monsoon, the highest concentration (344.49 ng/g) was observed in sediments collected from  
174 Site 5 with the only presence of PCB 180 (344.412 ng/g dw) and PCB 52 (0.074 ng/g dw) (Table  
175 4.1). Followed by Site 5, both Site 3 and 8 were higher in PCB concentrations. For Site 8 and 3,  
176 the concentrations were 124.82 ng/g and 121.18 ng/g, respectively.

177 The percentage composition of six PCB congeners is shown in Fig. 2. In pre-monsoon, PCB 180  
178 was the most abundant among the analyzed congeners with an average concentration of  
179  $67.67 \pm 115.6$  ng/g in the investigated samples, followed by PCB 28 ( $0.786 \pm 2.17$ ng/g) and PCB  
180 138 ( $0.441 \pm 0.68$  ng/g). PCB 180 alone contributed more than 97% to the total PCBs in the  
181 analyzed sediments. PCB 180 showed predominance at all sites. From Fig. 2(a), PCB 52 was the  
182 second dominant congener at Sites 7 and 9. PCB 28 was the second dominant congener at Sites 1  
183 (> 40%) and 2. Also, PCB 138 was the second dominant congener at Sites 4 and 6 (> 15%).

184 Whereas, in post-monsoon (Fig. 2(b)), PCB 180 was the most abundant congener with an average  
185 concentration of  $4.38 \pm 2.78$  ng/g, followed by PCB 28 ( $.86 \pm 2.48$  ng/g) and PCB 52. Here, PCB  
186 180 alone contributed more than 68% to the total PCBs in the analyzed sediments. From Fig.  
187 4.1(b), PCB 180 showed predominance at all sites except Sites 1 and 8. PCB 10 showed  
188 predominance at Site 8 (> 40%), and PCB 28 showed predominance at Site 1 (> 60%). PCB 52  
189 was the second dominant congener at Sites 4, 5, 6, and 7.

190 High abundance and dominance of PCB 180 had been observed in both seasons. In the past,  
191 increased concentrations of PCBs 170 and 180 have been reported to be evidence of the presence  
192 of Aroclor 1260 (Ormerod et al. 2000). Aroclor 1260 was a usual constituent of capacitor oils and  
193 transformer (Erickson and Kaley 2011). This would be consistent with the release from the  
194 disassembling of transformers and other types of electrical equipment at Sites 3, 5, and 8 in the

195 pre-monsoon season. Both Sites 5 and 8 were in the vicinity of landfills. Especially at Site 5,  
196 several transformers were observed along the roadsides. Leakage from these transformers may be  
197 concentrated due to heavy rainfall accompanied by Cyclone Fani in the same month and lead to  
198 the high contamination of PCB 180.

199 PCBs are conclusively a significant source of environmental pollution because of leakage from  
200 installations at storage or disposal, operating installations, and considered a great source of  
201 environmental pollution by PCBs in several emission inventories (Kakareka and Kukharchyk  
202 2005). During the site visit, it was observed that maximum sites direct in contact with landfills.  
203 Landfills are a potential source of PCBs emission, as they contain municipal and industrial wastes.  
204 The type of PCB wastes in the landfills highly affects the levels of PCBs emissions (Kakareka and  
205 Kukharchyk 2007). Municipal waste burning is another potential source of PCBs pollution in this  
206 study. A variety of wastes are burnt into large bonfires such as paper, packaging material,  
207 paperboard, polyethylene film, plastic bottles, contaminated wood, waste food, rags, etc. Street  
208 sweep which contains a significant share of domestic wastes is burnt down often. Sanitary landfills  
209 of solid wastes and in other places of their unofficial accumulation cause unavoidable spontaneous  
210 fires.

### 211 **3.2 Seasonal and spatial differences of PCBs in sediments**

212 In the study area, the seasonal and spatial dissemination of PCBs in sediments are shown in Fig.  
213 3. Seasonally, neither the levels of total PCBs nor the identified congeners distribution patterns  
214 differ significantly ( $p > 0.05$ ).

215 Sediments are heterogeneous in constituents, and the different elements of sediments show  
216 different interactions with the pollutants (Kampire et al. 2017). It may highly affect the

217 composition of PCBs concentration spatially and seasonally. Only Site 1 exhibited a little bit  
218 consistent during two seasons (14.86 ng/g and 10.6 ng/g in pre-monsoon and post-monsoon,  
219 respectively). It indicates the sources of PCBs might be similar in both seasons (Dodoo et al. 2012;  
220 Habibullah-Al-Mamun et al. 2019).

221 The seasonal difference in the PCBs concentration might be caused by the variations of the  
222 precipitation amount in these two seasons (Li et al. 2012). The elevated levels of PCBs in pre-  
223 monsoon samples, especially at Sites 3, 5, and 8 might be caused by heavy rainfall and floods  
224 which triggered surface runoff from highly contaminated sites. This reason is suspected because  
225 heavy rainfalls took place due to Cyclone Fani before sampling from these sites. This tropical  
226 cyclone caused medium to heavy rainfall over the country, and Dhaka experienced 10 to 70 mm  
227 rainfall accompanied by the tropical cyclone (The Daily Star 2019; OCHA 2019). Large water  
228 bodies show higher contamination during and immediately after rainstorms (Awwa Research  
229 Foundation 2008). An increase in precipitation intensity triggers inputs of pollutants, especially  
230 severe nutrients, pathogens, hazardous substances, organic material, and other dissolved  
231 contaminants (e.g., pesticides) (Ching et al. 2015). On the day of sample collection in the pre-  
232 monsoon season, at Mirpur station (SW302) the water level was 2.86 m with regular water flow.  
233 Intense shipping and fishing activities during the pre-monsoon season might be another reason for  
234 PCBs contamination.

235 In premonsoon, higher levels of PCBs were observed at Site 2 (10.54 ng/g), Site 4 (9.67 ng/g), and  
236 Site 6 (5.38 ng/g). Co-evaporation of PCBs with water might be one of the reasons (Dodoo et al.  
237 2012). Another reason might be excessive sedimentation from low mixing effects in the dry season  
238 because of relatively weaker wave action and decreased upstream rivers inflow (Habibullah-Al-  
239 Mamun et al. 2019). It is important to note that the dry flow during post-monsoon decreased the

240 water height to such extent that some of the samples were stored from the river bed and the water  
241 level was 1.52 m with low water flow at the Mirpur station (SW302).

242 Despite sampling sites in the study area, the mean concentration of  $\sum$ PCBs in pre-monsoon (69.33  
243 ng/g dw) was much higher than in post-monsoon (6.42 ng/g dw). The findings were compatible  
244 with earlier research conducted by Lai *et al.*, in 2015 at Pearl River, China which reported that the  
245 wet season has a higher mean concentration of  $\sum$ PCBs than the dry season, and which was not  
246 significant ( $P > 0.05$ ). In several studies, PCBs concentration remains the same or slightly changes  
247 over seasons (Baqar et al. 2017; Habibullah-Al-Mamun et al. 2019).

248 The spatial distribution of  $\sum$ PCBs deviated highly from the mean concentration of  $\sum$ PCBs in pre-  
249 monsoon (SD = 115.12 ng/g). High tidal influence, high precipitation, changes in river dynamics  
250 might affect the spatial distribution of pollution in pre-monsoon. Besides, agricultural and surface  
251 runoffs, dumping of industrial wastes, intense dredging operations, and atmospheric depositions  
252 might speed up the extent of PCB contamination in this season. Whereas, in post-monsoon, the  
253 spatial distribution of  $\sum$ PCBs did not deviate highly from the mean concentration of  $\sum$ PCBs (SD  
254 = 3.37 ng/g). Weak tidal influence, low water flow, low or no precipitation, static river dynamics  
255 might affect the spatial distribution of pollution in this season. During the monsoon season (June  
256 to Mid-October), the surface sediments generally are worn out and new sediments are settled down  
257 thereafter. It takes time to accumulate organic pollutants in new sediments. Consequently,  
258 relatively very lower concentrations of PCBs were observed in the post-monsoon season.

259 The incomplete burning of e-wastes is a potential source of PCBs in the study area. Other potential  
260 sources of PCBs in the study area might contain paint industry, burning of e-waste for metal  
261 recovery, vehicular fuels, PVC (polyvinyl chloride) industries (Syed et al. 2014; Baqar et al. 2017),

262 dumping and discharges of oils and waste material (Farooq et al. 2011), coal combustion and  
 263 industrial waste (Chi et al. 2007), and recycling units and steel production (Biterna and Voutsas  
 264 2005),.

265 **4.4 Ecological risk assessment**

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

271  $ERI = \sum E_r^i \dots\dots\dots(5)$

272  $E_r^i = T_r^i \times C_f^i \dots\dots\dots(6)$

273  $C_f^i = \frac{C_o^i}{C_n^i} \dots\dots\dots(7)$

274 Where ERI is the summation of ecological risk factors of seven heavy metals and PCBs. As this  
 275 study is about PCBs, so heavy metals were disregarded. So, in this calculation, ERI is equivalent  
 276 to  $E_r^i$  (monomial potential ecological risk factor).  $T_r^i$  is the toxic-response factor for PCBs.  $C_f^i$  is  
 277 the contamination factor, and  $C_n^i$  denotes reference value for  $\sum$ PCBs, and it is 0.01 ppm or 10  
 278 ng/g.

279 The potential ecological risk factor ( $E_r^i$ ) had been graded into following five categories  
 280 (Hakanson, 1980):  $E_r^i < 40$ , low risk; 40–79  $E_r^i$ , moderate risk; 80–159  $E_r^i$ , considerable risk;  
 281 160–319  $E_r^i$ , high risk; and  $E_r^i > 320$ , very high risk.

282 The ERI was calculated using Eqs. (3) and (4). The ERI value indicated high potential ecological  
283 risk during pre-monsoon ( $E_r^i = 277.32$ ) and low potential ecological risk during post-monsoon  
284 ( $E_r^i = 25.69$ ). The ecological risk factor of the Turag River is shown in Table 2.

## 285 **4.5 Ecotoxicological risk assessment**

### 286 **4.5.1 Sediment Quality Guideline Quotients (SQGQs)**

287 The average values of SQGQ for both seasons are shown in Fig. 4.5. Six sampling sites of pre-  
288 monsoon are below 0.1. Besides, the SQGQs in two sampling sites, namely, Site 3 and Site 8  
289 indicate the benthic organisms might suffer from moderate adverse biological effects due to  
290 sediment-bound PCBs. The SQGQ of PCBs at Site 5 is above 1, suggesting that this surface  
291 sediment of the sampling site was suffering from high adverse biological effects (Table 3).  
292 Whereas, the SQGQs of post-monsoon show that PCBs would not cause any effects on benthic  
293 organisms (Table 3).

### 294 **4.5.2 New sediment quality guideline quotient (NSQGQ)**

295 Wang *et al.*, 2019 showed in their study that there was a significant linear correlation ( $R^2 = 0.9869$ ,  
296  $p < 0.01$ ) between SQGQs and NSQGQs while specifying that NSQGQs perhaps a valid method  
297 to evaluate the ecotoxicological risks of PCBs. They recommend NSQGQs can better estimate the  
298 ecotoxicological risks for PCBs. Here, the effect levels were divided into the following categories:  
299  $NSQGQ < 0.2$ , no or low effects;  $0.1 \leq NSQGQ < 2$ , moderate effects; and  $NSQGQ \geq 2$ , high  
300 adverse effects.

301 In pre-monsoon, the NSQGQs reflect that the PCBs contamination would cause low to moderate  
302 biological effects on the Turag River except Site 5 indicating a high adverse effect on biological  
303 organisms (Table 3). Whereas, in post-monsoon, the NSQGQs denote that PCBs contamination

304 caused moderate biological effects during the post-monsoon, while according to SQGQ, this  
305 season had no effects on aquatic species of the Turag River (Table 3).

#### 306 **4.6 Comparison with previous studies worldwide**

307 A comparison of mean sedimentary  $\Sigma$ PCBs concentration of the Turag River with those recorded  
308 from other rivers around the world is presented in Table 4.

309 No data on PCB contamination in the Turag River is accessible to compare with the findings of  
310 other studies in sedimentary PCBs. In Bangladesh, the literature indicates no research on riverine  
311 sedimentary PCBs.

312 The comparison of mean PCBs concentration in sediments of Pre-monsoon with other studies  
313 (Table 4) presented that the  $\Sigma$ PCBs concentration of this study was comparable or lower than those  
314 reported from Huveane River, France (Kanzari et al. 2014); Umgeni River, South Africa (Gakuba  
315 et al. 2015); Pearl River Delta, China (Wang et al. 2019); and Pangani River and its tributaries,  
316 Tanzania (Hellar-Kihampa et al. 2013).

317 Whereas, the comparison of the mean PCBs concentration in sediments of Post-monsoon with  
318 other studies showed that the  $\Sigma$ PCBs concentration of this study was significantly lower than those  
319 reported from Makelele, Kalamu, and Nsanga, Congo (Kilunga et al. 2017); River Ravi, Pakistan  
320 (Baqar et al. 2017); Liaohe River, China (Lv et al. 2020); CauBay River, Vietnam (Toan and Quy  
321 2015); Sarno River, Italy (Montuori et al. 2014); Soan River, Pakistan (Malik et al. 2014); and  
322 River Chenab, Pakistan (Eqani et al. 2012). However, the  $\Sigma$ PCBs concentration was slightly lower  
323 or somewhat comparable to those studies recorded from River Thames, England (Lu et al. 2017);  
324 Yamuna River, India (Kumar et al. 2013); Songhua River, China (Cui et al. 2016) and Bahlui  
325 River, Romania (Neamtu et al. 2009).



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

#### 335 **4. Conclusion**

336 The present study was the first to focus on the levels of PCB organic pollutants in the surficial  
337 sediments of the Turag River, Dhaka, Bangladesh. PCB 180 was the most conspicuous one in  
338 sediments during both seasons. Considering seasonal variation, the mean concentration of  $\sum$ PCBs  
339 in pre-monsoon (69.33 ng/g dw) was higher than in post-monsoon (6.42 ng/g dw). Sites 3, 5, and  
340 8 in pre-monsoon were subjected to moderate to high adverse biological effects on benthic  
341 organisms. Ecological risk assessment reflected high potential ecological risk in pre-monsoon ( $E_r^i$   
342 = 277.32) and low potential ecological risk in post-monsoon ( $E_r^i = 25.69$ ). The sedimentary PCB  
343 concentrations of the investigated area were comparable with rivers around the world.

344 The possible sources of PCBs are from dyeing, chemicals, paper mills, domestic industrial and  
345 wastewater discharge from factories, (e.g., paper, paint, iron, and textile factories) of industrial  
346 clusters. The sources also include landfills, e-wastes, transformers, constructions and demolition  
347 wastes, municipal waste open burning, etc. into the Turag River. In the lack of any data on PCBs  
348 in the study area, the present study will yield baseline data for subsequent ecological studies in the

349 future. Again, this study will put stress on the assays of Bangladesh's national implementation  
350 plan (NIP) to the exclusion of PCBs as being a party of the Stockholm Convention, 2001.

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356 during sample analysis.

### 357 **Author's Contribution**

358 NJC, MS, and MKU designed and planned the study. NJC collected and analyzed the samples.  
359 MAA supported all lab analyses. NJC prepared the draft manuscript. MS and MMR did proof  
360 reading.

### 361 **Declarations**

362 **Availability of Data and Materials** The authors confirm that the data supporting the findings of  
363 this study are available within the article.

364 **Ethics approval and consent to participate** Not applicable.

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

366 **Competing interests** The authors declare that they have no competing interests.

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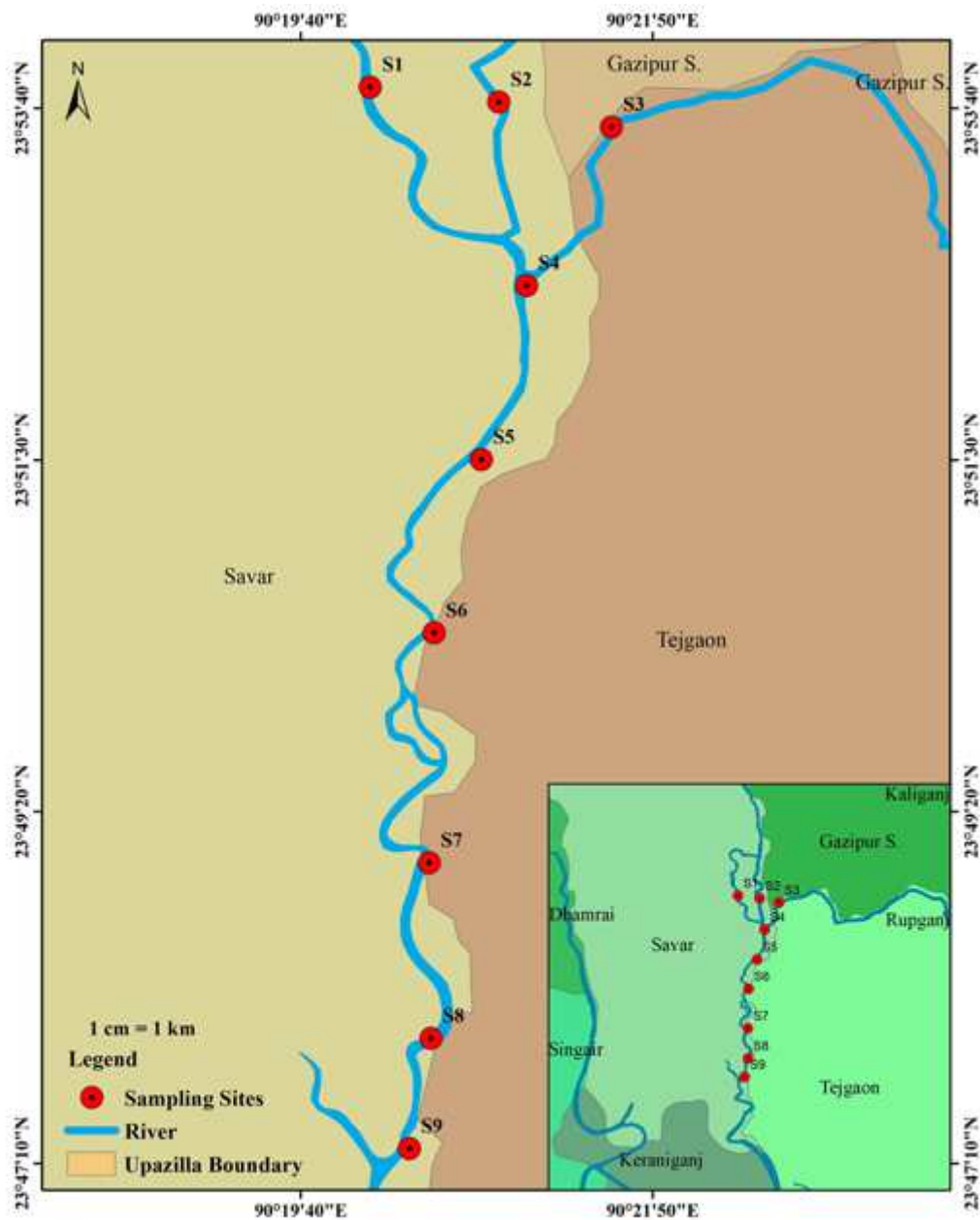
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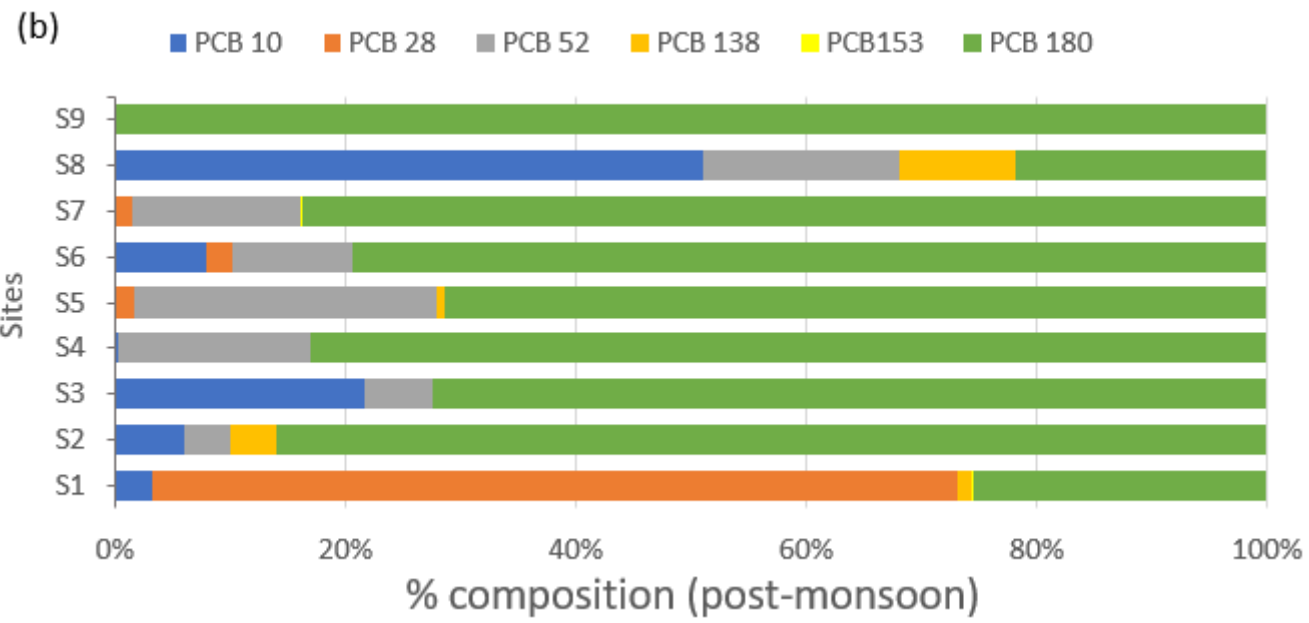
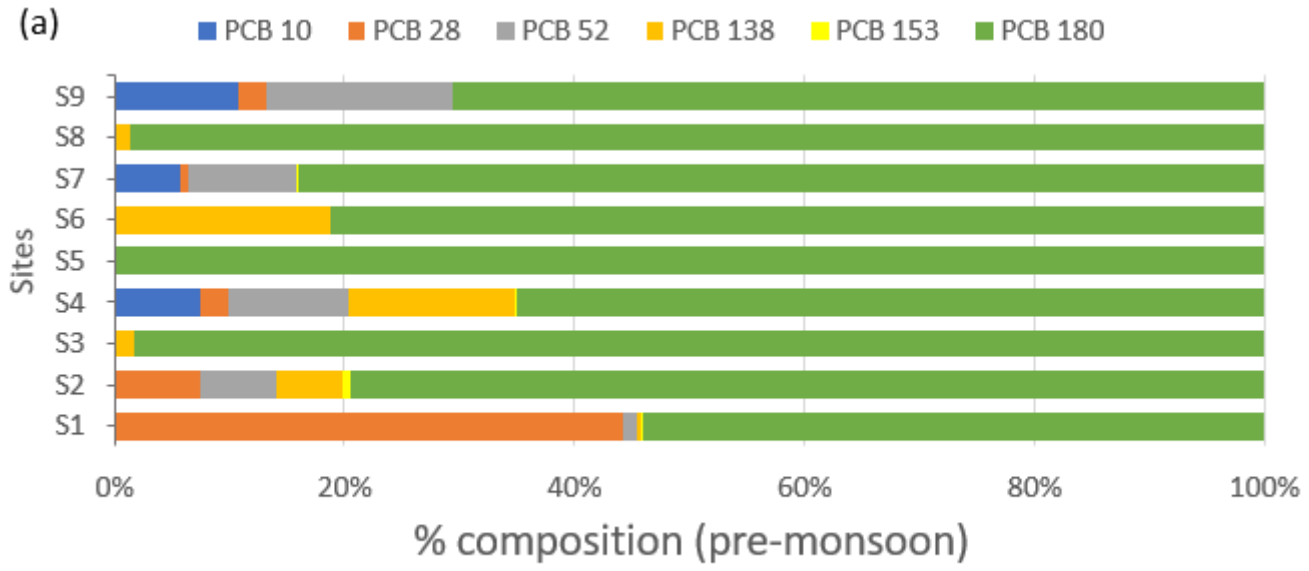
529

# Figures



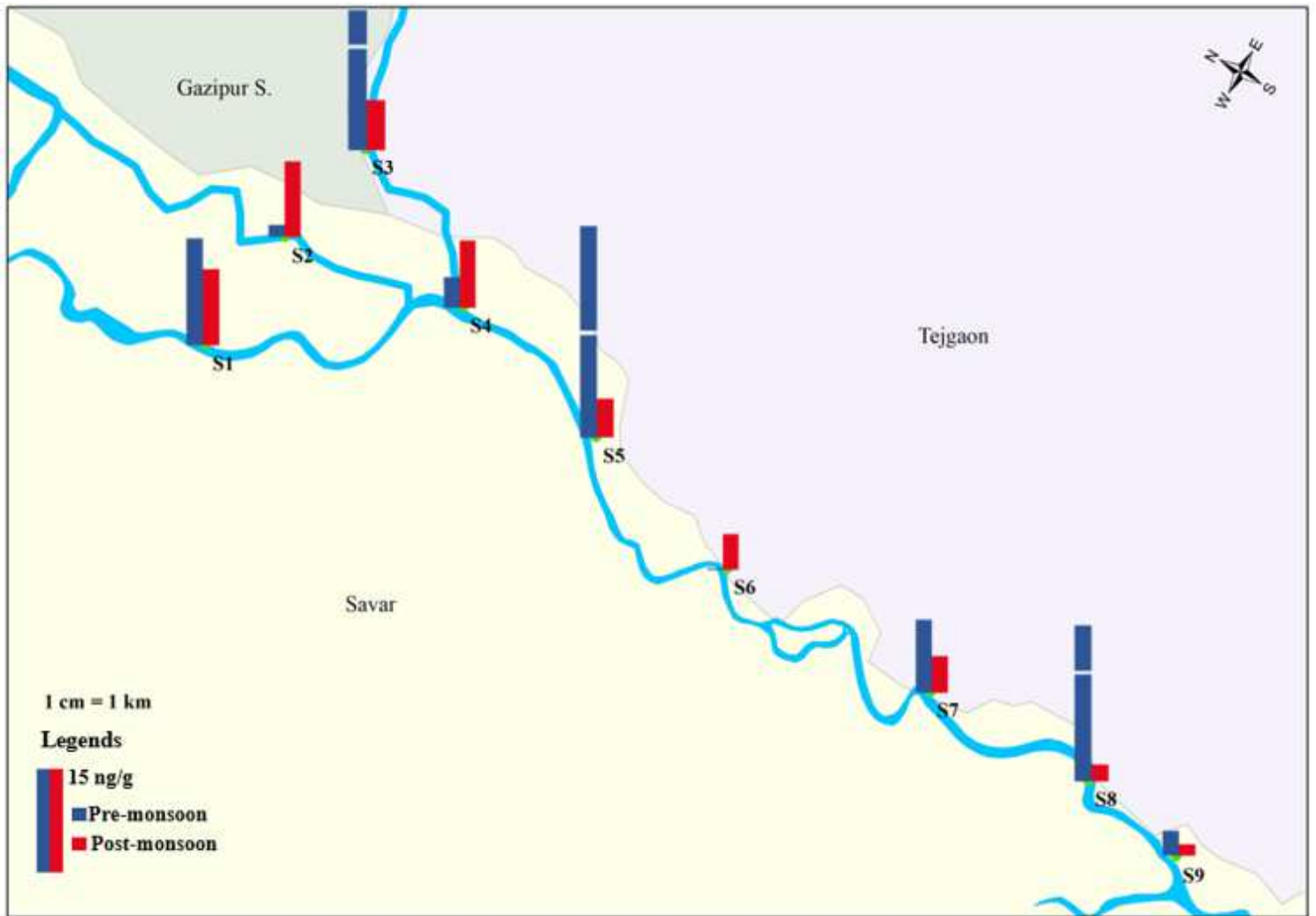
**Figure 1**

Sampling sites along the Turag River Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



**Figure 2**

Composition (%) of six PCB congeners in sediment samples of (a) pre-monsoon and (b) post-monsoon



**Figure 3**

Distribution of total PCBs in surface sediment along the Turag River collected in post-monsoon and pre-monsoon. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.