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Assessment of Physicochemical Properties and Comparative Pollution Status of the Dhaleshwari River in Bangladesh

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Abstract: The Dhaleshwari river which flows near Dhaka, the capital of Bangladesh, is currently under threat due to the recent relocation of the Hazaribagh tannery to the Savar area. This study investigated the physicochemical parameters of water quality along with the heavy metal levels in the Dhaleshwari river and performed a comparative analysis among the peripheral rivers around Dhaka City. Surface water quality parameters such as total dissolved solids (TDS), biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD) obtained for the Dhaleshwari river deviated by as much as 90% from World Health Organization (WHO) standards in certain instances due to direct discharge from untreated point sources. Concentrations of toxic metals such as chromium (Cr), cadmium (Cd), and nickel (Ni) were above the Food and Agriculture Organization (FAO) standards for heavy metals in surface waters. Strong correlations among the heavy metals indicated significant linear dependences. Based on the physicochemical and toxicity-based characterization, the river system in Dhaka city can be termed as severely polluted with respect to organic and solids discharge, while ecological risk indices (E_{RI}) indicated disastrously high risk in the Dhaleshwari and Buriganga rivers. The study outcomes emphasize the necessity of frequent investigation while controlling the point and nonpoint urban pollution sources discharging into the peripheral rivers of Dhaka city.

Keywords: river water; pollution; Dhaleshwari; heavy metals; wastewater; ecological risk

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1. Introduction

Life and health depend on freshwater, which is a vital issue to public health and welfare. Almost all civilizations on Earth are inextricably linked by rivers, which are the places where they originated and evolved from. Once, the rivers of Bangladesh were its lifeblood, but pollution is now a major national problem, mainly owing to the ever-increasing development activities surrounding riverbank areas that lack appropriate environmental protection [1,2]. Such rivers are vast reservoirs for numerous fish and different aquatic species [3]. The river water is utilized inconceivably for maintaining the water system, energy generation, navigation, amusement, and numerous industrial and domestic purposes [4].

Changes in the quality of inland surface water are typically caused by industrial operations and seasonal variations in river flow [5]. Rapid and unplanned urban sprawl, industrial growth, and population pressure have made the city an environmentally polluted area [6,7]. The waterways of Bangladesh have become more polluted due to the excessive usage of pesticides in the surrounding river lands, unrestricted urbanization, lack of well-planned construction along riverbanks, and population expansion. In Bangladesh, surface water is used for drinking purposes, farming, and fishing [8,9]. Mills and industries are dumping chemical and hazardous wastes into numerous rivers posing health risks to people. Since the dawn of society and progress, threats continue to exist side by side with development initiatives. As a young delta, the river channels are constantly shifting.

The peripheral rivers of Dhaka city are vulnerable to natural calamities, climate-change-related problems, transboundary challenges, and, last but not the least, anthropogenic interventions [10]. In recent years, water quality issues have emerged with concerns surrounding water flow and, subsequently, the water bodies' carrying capacity.

In central Dhaka, the Dhaleshwari River is one of the main distributaries on the left bank of the Jamuna River, which has a length of 160 km and has an average depth of around 37 m [11,12]. In its surrounding territories, this river makes a significant contribution to socio-economic development [13]. The Dhaleshwari receives substantial amounts of municipal waste, surface runoff, unregulated industrial waste, and directly or indirectly treated sewage waste from Saver City [14]. These contaminants pollute the river water making it unsuitable for use and harming aquatic lifeforms. Most notably, the physicochemical quality of the river has deteriorated, and most of the water quality parameters do not meet the minimum standard guidelines for safe drinking water by World Health Organization (WHO). Contaminated water intake may be associated with several illnesses such as cancer, congenital abnormalities, central nervous system problems, and endocrine system disturbance and heart disease. Blue baby diseases, gastric cancer, and other disorders are also associated with nitrate and nitrite-contaminated water diseases [15–17]. Biological diversity as well as other aquatic communities, including fish, are declining, putting the rivers of Dhaka, such as Dhaleshwari, at risk of becoming "dead" river in the coming days.

The government of Bangladesh relocated the tannery industries from their previous site in Hazaribagh beside the Buriganga river, to a new location in Savar due to the dangerous impact that the tannery wastes were posing for human and environmental health in Hazaribagh. Modernization of the tanneries and treatment of effluents in a contemporary central effluent treatment plant (CETP) have been the primary goals of this move, which would result in a waste management system for the tannery industry that is more environmentally sound. However, as claimed by tannery industrial park residents, the water quality of the Dhaleshwari river has worsened, and this has been published in several local newspapers. Improper release of waste into the waterway, circumventing the mainline of the CETP, was the subject of several frightening media reports. CETP effluent released from the tannery industrial park has not been characterized in detail for its influence on the water quality of the surrounding river stretch. This warrants thorough investigation and characterization of water quality in the vicinity of the tannery. On another alarming note, heavy metals contamination in the aquatic ecosystem has drawn global attention in recent years because of the persistent nature, abundance, and prevalence of the same [18–20]. The rapid expansion of the world population, household activities, agricultural and industrial output have resulted in the release of large quantities of toxics such as heavy metals into rivers across the world [21–23]. Severe contamination of water, soil, and atmosphere are observed with unprecedented accumulation and dispersion of heavy metals, affecting marine and aquatic species [24–27]. Rivers constitute predominant pathways for the transport of heavy metals [28,29], and several poisonous metals eventually become part of numerous riverine frameworks [30] due to absorption, precipitation, solubility, and complexity processes [30–32], affecting their actions and bioavailability [31,32].

Due to the practice of dumping untreated commercial and residential trash into water bodies, metal concentrations are increasing in river water [33,34]. The nature of metals in natural water is dependent on the composition of the water substrate, suspended sediment, and the quality of the water [35]. The Association of metals in sediments of various geological stages has a significant impact on the cumulative behavior of heavy metals in aquatic environments [36]. In predicting potential pollution, flexibility, and bioavailability, geochemical speciation and metal distribution in the given chemical fractions are generally used [36–39]. River water polluted with heavy metals such as cadmium (Cd), chromium (Cr), zinc (Zn), and nickel (Ni) can damage crops such as vegetables and rice [40–44]. The assessment of the contamination by and transmission of heavy metals in the riverine environment is therefore essential. Heavy metals in the concerned peripheral rivers around Dhaka city may be a result of human activities, such as mining and the disposal of improperly handled or untreated effluent from industries such as tanneries, battery industries, steel plants, and thermal power plants, as well as pesticides used in agricultural fields and compost containing heavy metals [45].

The Aim of the Study

In the context of the facts discussed above, the present study aims to evaluate the pollution condition of the Dhaleshwari river due to the impact of the newly shifted tannery industrial park as compared to the Buriganga river in general. This study also makes a comparative assessment of the surface water quality among all the peripheral rivers around Dhaka City that has rarely been accomplished with respect to both physicochemical status of water quality and heavy metal contamination. A particular focus of this study consists of evaluating the ecological threat emanating from the presence of heavy metals in the surface water of the Dhaleshwari River which would further pave and necessitate the ways towards mitigating the pollution and rehabilitating the river.

2. Materials and Methods

2.1. Description of the Study Area and River Water Sampling

The peripheral river system of Dhaka city mainly consists of three different systems; Dhaleswari-Kaliganga System, Bangsi-Turag-Buriganga-Dhaleshwari System, and Balu-Lakhya System (Figure 1). The Dhaleswari-Kaliganga and Bangshi-Turag-Buriganga river systems are to the west, and the Balu-Lakhya river system is to the east of Dhaka. The Dhaleshwari River originates from the Jamuna River near the north-western edge of Tangail district and eventually reaches the Shitalakshya river near the district of Narayanganj. This merged flow goes towards the south to combine with the Meghna River [46]. All the samples for the present investigation were collected from selected locations where the river flows through the Savar District industrialized area.

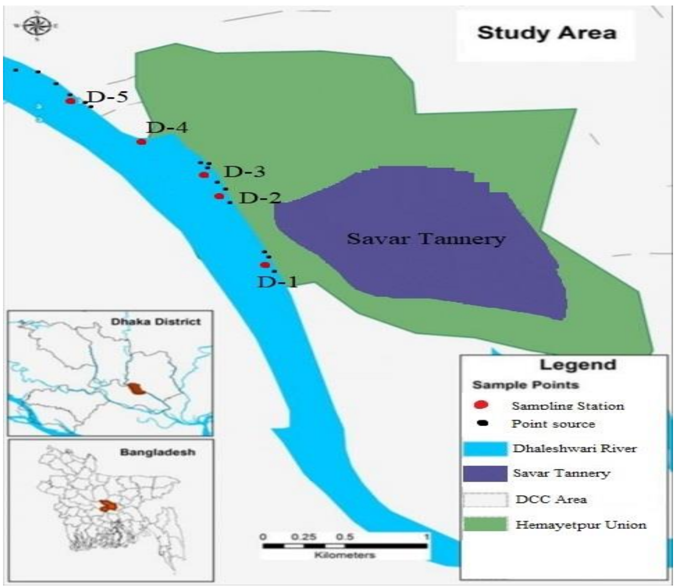

Figure 1. GIS Map of the Sampling Stations along Dhaleshwari River.

Identified sampling stations were selected based on the intensity of industrialized zones and presence of waste disposal points beside the banks of the rivers. In the present study, five of the following places along the river were chosen: Savar Tannery (D-1), Sudkhira (D-2), Dhalla (fish market) (D-3), AKS dying (D-4), and Nama Bazar (D-5) at Savar district in Bangladesh (Figure 1). Global positioning system (GPS) coordinates were used to precisely locate each sampling station. The identification of the sampling stations and distances from the Savar Tannery are provided in Table 1.

Table 1. Identification of sampling stations and distance from D-1 in Dhaleshwari River.

Sampling Stations	Type of Discharge	Distance from Savar Tannery (km)
D-1	Industrial	0
D-2	Municipal	1.7
D-3	Industrial	3.7
D-4	Industrial	4.1
D-5	Industrial	6.2

The peripheral rivers around Dhaka City are depicted in Figure 2, with the red boxes showing the sampling locations. A minimum average of three samples was collected from each of the Turag, Tongi Canal, Balu, Buriganga, and Shitalakhya rivers. The sampling stations were chosen along the zones of concentrated levels of industrial and agricultural activities with numerous point sources and non-point sources of contamination. Different industrial sectors such as leather, textiles, and metal processing constitute the point sources. Other industries considered as point sources include power plants, fertilizer and pharmaceutical plants, and industries that dye fabrics and produce batteries or ink, as well as metal melting plants. In addition, waste disposal points, toxic sewage, terminals, and landing stations also constitute point sources and contribute to pollution. Twenty samples in total were collected from all the rivers for physicochemical analysis, and five additional samples were obtained from Dhaleshwari River for heavy metal analysis. Unfiltered samples of water were obtained from the middle of the river course. The samples were then placed into 100 mL polypropylene bottles, and then the bottles were sealed. In each polypropylene bottle, 1 mL of ultrapure nitric acid was added to achieve a pH of ~1 [47] before transferring to the Department of Soil, Water and Environment Laboratory of the University of Dhaka for heavy metals analysis. The standard sampling procedure was followed to collect all samples at every single sampling station [48–52].

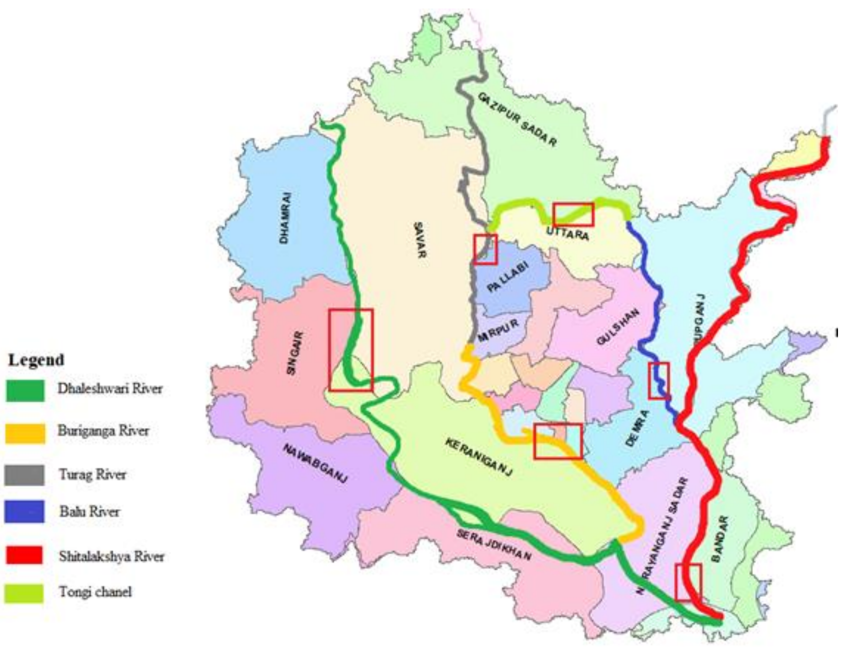

Figure 2. GIS Map Showing Peripheral Rivers around Dhaka city (boxes representing the sampling stretches along the rivers).

2.2. Analysis of Physicochemical Parameters and Heavy Metals for Water Samples

Water samples collected from all the rivers were analyzed for the physicochemical parameters in the Environmental Engineering Laboratory, Department of Civil Engineering, University of Asia Pacific. Standard instruments were used to test the conductivity, total dissolved solids (TDS), pH, and dissolved oxygen (DO). Electrical conductivity (EC) and total suspended solids (TSS) were assessed by a model 'CTS-406′ meter manufactured by EZDO (Taipei City, Taiwan); pH was determined by a B-221 pH meter (Twin, Santee, USA), and DO was assessed by a model 'YK-22DO' dissolved oxygen meter (EZDO, Taipei City, Taiwan). Chemical oxygen demand (COD) was determined by using condensation and oxidation with potassium dichromate. All the heavy metals such as cadmium (Cd), chromium (Cr), nickel (Ni), and zinc (Zn) were analyzed in the Department of Soil, Water, and Environment at the University of Dhaka. The toxic metal concentrations were calculated by an "AA-7000' atomic absorption spectrometer manufactured by Shimadzu (South San Francisco, USA). For all measurements an accurate 'ABS 220-4' precision electrical balance manufactured by KERN (Ziegelei, Balingen, Germany) was used. Preconcentrated samples were filtered using a nylon membrane filter (47 mm diameter, Whatman, Washington, DC, USA) to determine hazardous metals concentration [53]. For heavy metal analysis, 100 mL of each sample was collected and placed in a Pyrex volumetric flask. 1 M HCl (9 mL) and 1 M HNO_3 (3 mL) were added next. The volumetric flask was carefully heated in a sand bath placed in a fume hood to reduce the moisture level. Deionized water was added to the sample after the flask was cooled to room temperature. The filtrate was collected in a 250 mL high density polyethylene screw-cap (HDPE) plastic container tube with a polypropylene/low density polyethylene (LDPE)-lined cap; Thermo Scientific, Washington, DC, USA). Finally samples were retained for the calculation of the concentration of the metals. The atomic absorption spectrometer (AAS) was calibrated for all the metals by running different standard concentrations. Three observations of each data point were averaged. In this case, the detection limit was set at 0.001 mg/L. An oven (GAF-7000, ESCO, Changi South Street, Singapore) was used to test the amounts of the metals present.

2.3. Multivariate Statistical Analysis

Pearson's correlation and linear regression analysis was performed to evaluate the relationship between the metals to validate the multivariate analysis (SPSS v.25, Armonk, NY, USA). The map showing the locations of the Dhaleshwari River sampling stations was generated using ArcGIS 10.3 (Esri Bangladesh, Dhaka, Bangladesh).

2.4. Assessment of Ecological Risk

Hakanson [54] suggested the possible ecological risk index approach from a sedimentology aspect first to determine the natural and environmental behavior of heavy metal pollutants. A single coefficient of pollution, an indicator of a heavy metal toxic reaction, an exact measure of pollution, and a possible ecological risk index are included in the process. Ecological risk index (E_{RI}) was obtained by following equations [54]:

$$E^i{}_r = T^i{}_r \, (C^i/C^i{}_o)$$

$$E_{RI} = \sum E^i{}_r$$

where C^i and $C^i{}_o$ are the concentrations of particular heavy metals and their permitted reference value, respectively, and $E^i{}_r$ represents an ecological risk factor. $T^i{}_r$ is the toxicity factor for each metal (Cd = 30, Cr = 2, Ni = 5, and Zn = 1) [53]. E_{RI} represents the ecological risk that determines how sensitive biological populations to particular metals are in the area being considered. Table 2 shows the ranges of the indices of $E^i{}_r$ and E_{RI} based on which the categorization of risk was evaluated for the rivers. Higher values of $E^i{}_r$ and E_{RI} indicate higher risks for the ecosystem. Wastewater does not have a standard value for assessing ecological risks. Thus, classification of ecological risk exposed to toxic metals was consulted, which is provided below:

Table 2. Classification of ecological risk index (E_{RI}) of heavy metal pollution [55,56].

E^i_r	E_{RI}	Classification
$E^i_r < 30$	$E_{RI} < 100$	Low risk
$30 \leq E^i_r < 50$,	$100 \leq E_{RI} < 150$	Moderate risk
$50 \leq E^i_r < 100$	$150 \leq E_{RI} < 200$	Considerable risk
$100 \leq E^i_r < 150$	$200 \leq E_{RI} < 300$	Very high risk
$E^i_r \geq 150$	$E_{RI} \geq 300$	Disastrous risk

3. Results and Discussion

3.1. Assessment of Physicochemical Parameters of Surface Water

Surface water sampled from all the rivers in Dhaka City were analyzed for various water quality indicators. Table 3 summarizes the results on the assessment of physicochemical characterization of the peripheral rivers around Dhaka City along with the water quality guidelines established by the WHO and Environmental Conservation Rule (ECR). Average values of all the parameters that were obtained from sampling at multiple locations have been presented in Table 3 that provides a comparative scenario in a snapshot. The Dhaleshwari River water was dark in color and had an acrid odor during the period of the study. The pH value varied from 6.9 to 11.2, along with the sampling locations of the river. The maximum pH value was observed at Sampling station D-1 (Savar Tannery), and the minimum pH value was recorded at Sampling station D-3 (Dhalla, fish market).

Table 3. Results of Physicochemical properties of the peripheral rivers around Dhaka City.

Parameter	Unit	[a] ECR'97	[b] WHO (2011)	Average ± Standard Error of Mean					
				Dhaleshwar River	Turag River	Tongi Canal	Buriganga River	Balu River	Shitalakshya River
pH		6.5–8.5	6.5–8.5	8.04 ± 0.14	6.7 ± 0.17	6.66 ± 0.15	7.23 ± 0.14	6.9 ± 0.06	7.1 ± 0.06
TSS			-	619.6 ± 107.19	385 ± 61.44	556.33 ± 92.59	605 ± 131.43	278.33 ± 58.9	368.33 ± 80.84
TDS	mg/L		1000	1364.6 ± 321.35	235 ± 2.88	475 ± 2.88	46.66 ± 2.33	241.66 ± 6	930 ± 138. 68
BOD_5	mg/L	>6	5	26.44 ± 7.61	41.33 ± 4.97	33.33 ± 3.48	41.33 ± 4.63	24.66 ± 6.88	34.5 ± 3.67
COD	mg/L		10	461.74 ± 110.36	675.33 ± 371.62	247.86 ± 35.14	602.76 ± 145.92	250.56 ± 40.78	351.4 ± 28.87
DO	mg/L	>5	4–6	2.052 ± 0.97	0.9 ± 0.17	3.96 ± 0.29	2.56 ± 0.37	2.2 ± 0.51	2.13 ± 0.52
EC	µS/cm		1000	1709.34 ± 204.07	987.33 ± 68.71	1283.33 ± 92.79	655 ± 400	620.67 ± 342.13	710 ± 355.01

[a] The Environment Conservation Rules, 1997; [b] World Health Organization, 2011.

Figures 3 and 4 represent Max^m Vs Min^m concentrations of pH and TDS, respectively for the peripheral rivers of Dhaka, along with the WHO standards in dotted lines. The pH value was within the standard limit in the study, as assessed for the other peripheral rivers in Dhaka City. Total dissolved solids (TDS) primarily represents the different types of minerals, alkalis, some colloidal and dissolved solids in water, some acids, sulfates, metallic ions, etc., [52]. TDS in the water of the Dhaleshwari River ranged from 412 to 3278 mg/L with the maximum level of TDS obtained at sampling station D-1 (Savar Tannery) and the minimum level at sampling station D-5 (Nama Bazar) (Figure 4). Except for Savar tannery (D-1) and Sudkhira (D-2), all sampling stations exhibited values below the permitted level of WHO guidelines (1000 mg/L) for Dhaleshwari River. The water becomes more turbid and saltier when the TDS level exceeds the allowable limit of 1000 mg/L, which has a negative impact on aquatic life [57,58]. Consequently, it has an ultimate effect on the human, crop, and livestock. During the monsoon season, runoff water flow may cause some variance, but this volatility has impacted the irrigation system. Effluents from dyeing units might potentially be a contributing factor to the elevated TDS levels reported in other areas with dyeing facilities [59]. For the other peripheral rivers, TDS concentration was obtained within the permissible limit except for the Shitalakshya River (1200 mg/L) (Figure 4).

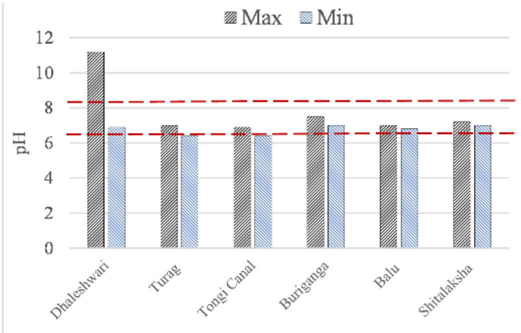

Figure 3. Max^m vs. Min^m Concentrations of pH for the peripheral rivers of Dhaka with WHO standards in dotted lines (6.5–8.5).

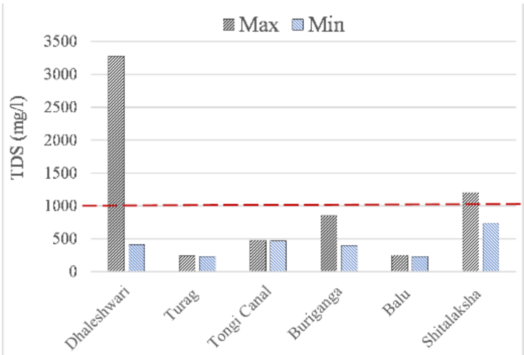

Figure 4. Max^m vs. Min^m Concentration of TDS for the peripheral rivers of Dhaka with WHO standards in dotted lines (1000 mg/L).

Figures 5 and 6 represent Max^m vs. Min^m Concentrations of BOD_5 and DO for all the peripheral rivers of Dhaka, respectively, with WHO standards in dotted lines. Testing of BOD_5 is the best single test for evaluating organic contamination and has significant relevance in water quality evaluation [60]. The BOD_5 ranged from 11 to 45 mg/L for the Dhaleshwari River samples, showing that the water is extremely contaminated (Figure 5). The observed BOD_5 levels in the water samples indicated organic waste in the Dhaleshwari river [61]. Among the sampling stations, the highest BOD_5 was found at Sampling station D-1 (Savar Tannery) (45 mg/L), while the lowest value was observed at Sampling station D-2 (Sudkhira) and D-4 (AKS dying) (11 mg/L) (Figure 5). BOD_5 limits are 0.2 mg/L for drinking water, 3 mg/L for recreation, 6 mg/L for fish, and 10 mg/L for irrigation [62]. Since the sampling stations run through the most heavily populated and industrialized region along the riverbank, the BOD_5 was greater along the selected stretch in Dhaleshwari than it was along the other stretches.

Organic materials are also discharged along with the effluent as a result of poor-functioning of the sewage treatment plants, storm discharges, agricultural slurries, domestic waste (waste from humans and food) and industrial waste (food industries, tannery, and dyeing) and silage liquor, thereby the Dhaleshwari River can accumulate various organic and chemical pollutants. BOD_5 levels varied within 33–49 mg/L for the Buriganga River, 30–39 mg/L for the Shitalakshya River, 32–49 mg/L for the Turag River, 27–39 mg/L for the Tongi Canal, and 15–38 mg/L for the Balu River (Figure 5). This reveals that the discharge of organic substances and subsequent pollution is commonly happening in general for all the peripheral rivers at comparable rates.

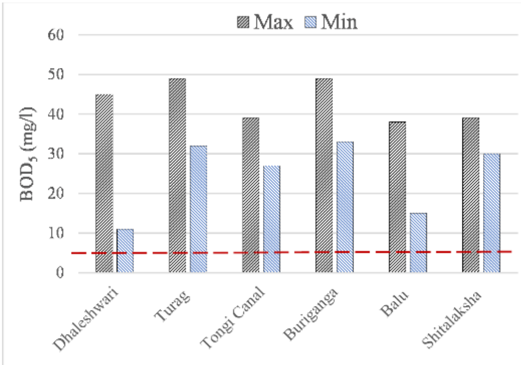

Figure 5. Max^{m} vs. Min^{m} Concentration of BOD_5 in the peripheral rivers of Dhaka with WHO standards (5 mg/L).

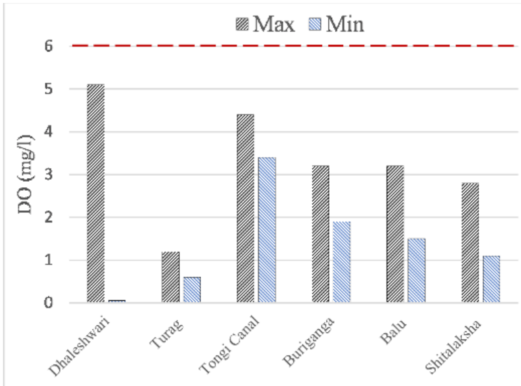

Figure 6. Max^{m} vs. Min^{m} Concentration DO of peripheral rivers of Dhaka with WHO standards (6 mg/L).

The concentration of dissolved oxygen (DO) is a vital issue for aquatic organisms in surface waters [8,63]. Low DO levels are indicative of the presence of oxygen-consuming pollutants in the water body. The concentration of dissolved oxygen influences several aspects of the water body (bacteria and photosynthesis), the availability and concentration of nutrients [64]. The DO concentration among sampling stations along Dhaleshwari River ranged from 0.06 to 5.1 mg/L (Figure 6). The DO concentrations of all sampling stations were deficient in the Dhaleshwari River. Sampling station D-1 exhibited the lowest value of DO (0.06 mg/L) beside the Savar tannery area. According to the Environmental Quality Standard (EQS), the accompanying DO requirements are acceptable: fish and domesticated animals require 4 to 6 milligrams per liter and 6 mg/L for drinking, 4 to 5 milligrams per liter, whereas industrial applications require up to 5 milligrams per liter [50].

The low levels of dissolved oxygen could be attributed to the release of organic substances with high organic content, such as sewage treatment plants, storm flooding, slurry cultivation, alcohol silage, etc. These low values of DO eventually impact the aquatic species. By encouraging the growth of microorganisms in the water body, biodegradable waste from industrial and residential sources causes a fast drop in DO value. All aquatic species with aerobic respiratory biochemistry require oxygen to function [65]. When BOD_5 levels are high, the amount of dissolved oxygen (DO) reduces because the bacteria absorb the oxygen obtained in the water [65]. Consequently, fish and other aquatic species cannot survive in oxygen-depleted conditions. Including the Dhaleshwari River as stated above, all the peripheral rivers of Dhaka were witnessed to have very low levels of dissolved oxygen, ranging from 1.9–3.2 mg/L for the Buriganga River, 1.1–2.8 mg/L for the Shitalakshya River, 0.6–1.2 mg/L for the Turag River, 3.4–4.4 mg/L for the Tongi Canal and 1.5–3.2 mg/L for the Balu River (Figure 6). Almost all these ranges fall outside the required DO levels based on the WHO guidelines (4–6 mg/L) (Figure 6). Figures 7 and 8 represent Max^{m} vs. Min^{m} Concentrations of TSS and COD respectively, for the peripheral rivers of Dhaka.

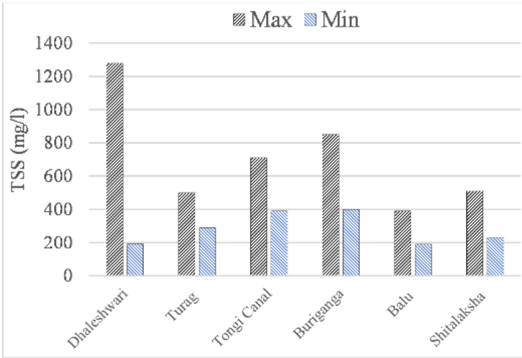

Figure 7. Max^{m} vs. Min^{m} Concentration of TSS for the peripheral rivers of Dhaka for TSS.

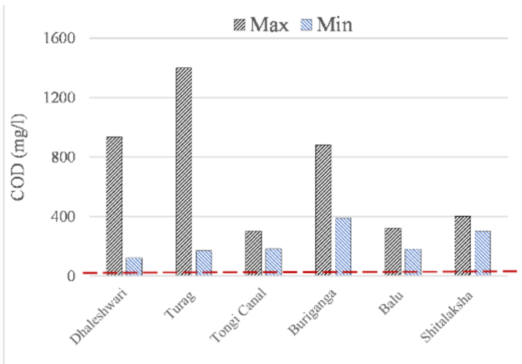

Figure 8. Max^{m} vs. Min^{m} Concentration of COD for the peripheral rivers of Dhaka for with WHO standards (10 mg/L).

Total suspended solids (TSS) values in the Dhaleshwari River varied from 191 to 1278 mg/L (Figure 7). In studies involving sewage and other wastewater, the determination of suspended solids is especially useful and is as critical as the determination of BOD_5 [61]. The presence of suspended solids in the canal is undesirable for causing putrefaction, and suspended particles can also contain many organic materials. The concentration levels of TSS were observed at high levels in all the peripheral rivers of Dhaka under assessment (Figure 7). Chemical oxygen demand (COD) is very useful in assessing the resistance of industrial waste and sewage to contamination and the quantity of oxygen required to oxidize organic and inorganic materials in a sample [66]. The COD levels in Dhaleshwari varied between 121.2 and 935 mg/L (Figure 8). In sampling station D-1, the highest COD value was correlated with the flow of effluent from the dyeing unit that is released into the river. The higher levels of COD in the samples suggest an increased concentration of industrial contaminants containing inorganic and organic compounds, thereby indicating a higher degree of toxicity [67,68]. COD values ranged from 170–1400 mg/L for the Turag River, 182.2–302.4 mg/L for the Tongi Canal, 390.1–882.2 mg/L for the Buriganga River, 180.2–321.49 mg/L for the Balu River, and 302.1–402.1 mg/L for the Shitalakshya River, suggesting a high level of contamination in these rivers based on the WHO guideline (10 mg/L) (Figure 8).

Figure 9 represents Max^{m} vs. Min^{m} Concentrations of EC for the peripheral rivers of Dhaka while WHO standards are shown in dotted lines. Electrical conductivity (EC) varied from 286.1 to 5309.6 µS/cm in the Dhaleshwari River (Figure 9). According to the WHO standards, a water body with an EC of more than 1000 mg/L is not suitable for the agricultural sector, domestic, bathing, industrial, or drinking purposes. Among the five sampling stations, the highest EC was found at Sampling station D-1 (Savar tannery) (5309.6 μS/cm), while the lowest value was found at Sampling station D-2 (Sudkhira) (286.1 μS/cm). Sampling stations D-1 (Savar Tannery) and D-3 (Dhalla, fish market) exceed WHO guidelines (1000 μS/cm) for the permissible limit of EC. Emissions from tanneries and metal plating industries might be responsible for the increase in electrical conductivity. Industries like textile and dyeing generate heavy metals as well. There may be some physiological effects of high EC levels on plants and some of the environmental species. However, these concentrations suggest that wastewater (industrial and sewage effluent) containing high ionic concentrations get discharged into the rivers, ultimately causing detrimental effects to the aquatic biodiversity. With respect to the other peripheral rivers, EC varied from 890 to 1120 μS/cm for the Turag River, 1100 to 1400 μS/cm for the Tongi Canal, 10 to 1390 μS/cm for the Buriganga River, 220 to 1400 μS/cm for the Shitalakhya River, and 210 to 1300 μS/cm for the Balu River. Based on WHO criteria, these rivers have significant levels of ionic pollution (Figure 9).

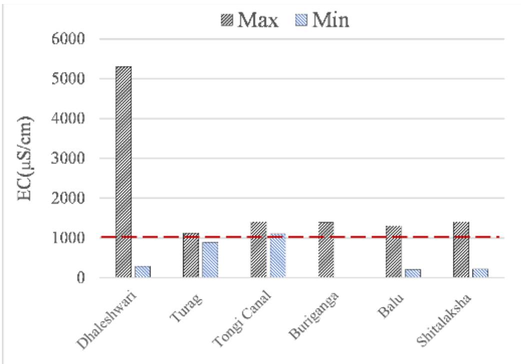

Figure 9. Max^{m} vs. Min^{m} Concentration of EC for the peripheral rivers of Dhaka for with WHO standard in dotted line (1000 μS/cm).

3.2. Correlation among the Physicochemical Parameters of Dhaleshwari River

The correlation coefficient represents the relations among the variables and the assessment of whether a specific variable depends on the other variables or not. Correlations among the physicochemical parameters of analyzed water samples from the Dhaleshwari River were obtained using Pearson's correlation and linear regression analysis in order to determine their interrelationships [61]. The correlation matrix among different water quality parameters of the Dhaleshwari River is presented in Table 4. The correlation coefficient ranges between −1 and +1. Between 0.5 and 0.8, the relationship could be considered moderate, and above 0.8, the association could be considered substantial [69].

Table 4. Pearson's correlation coefficients among the physicochemical parameters in the Dhaleshwari River (significance of correlation was measured both at 0.01 and 05 levels).

Parameters	pH	TSS	TDS	BOD_5	COD	DO	EC
pH	1						
TSS	0.888 *	1					
TDS	0.821	0.773 *	1				
BOD_5	0.550	0.590	0.547	1			
COD	0.726	0.735	0.756	0.960 **	1		
DO	−0.517	−0.796	−0.452	−0.783	−0.766	1	
EC	0.541	0.695	0.879 *	0.570	0.718	−0.613	1

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

This investigation demonstrated that pH has significant strong positive correlations ($p < 0.01$) with TSS and TDS (r = 0.888 and 0.821). It was also observed that DO has strong negative correlations with pH, TSS, TDS, BOD_5, COD and EC (r = −0.517, −0.796, −0.452, −0.783, −0.766 and −0.613, respectively). The photosynthetic activity of algae, water temperature, aquatic respiration, oxidative degradation of organic materials, etc., impact pH and DO fluctuations [69]. It is also clear from the results that the TDS was moderately correlated with TSS, BOD_5, COD, and EC (r = 0.773, 0.547, 0.756, 0.879 respectively) (Table 4). In water, this implies the presence of dissolved materials (organic matter and salts) [70]. DO was shown to be negatively associated with all factors and not substantially connected with any of the examined parameters by Usharani et al. [61]. COD was found to have strong positive correlations ($p < 0.01$) with BOD_5 (r = 0.960). EC was observed to possess significant positive correlation ($p < 0.01$) with pH, TSS, TDS, BOD_5, and COD respectively (r = 0.541, 0.695, 0.879, 0.570 and 0.718, respectively) and negatively correlated with DO (r = −0.613). It is also evident from these observations that the aquatic body is severely contaminated due to the different forms of industrial waste that are dumped directly into the water body.

3.3. Comparative Assessment of Heavy Metal Contamination

Table 5 shows the concentrations of heavy metals in the Dhaleshwari River analyzed in the present study. This table also lists the heavy metal levels in the other peripheral rivers of Dhaka city that were reported by previous studies. Surface water standards by WHO and FAO are provided in the table as well. The average concentration levels of the analyzed heavy metals followed a decreasing order of Cr > Ni > Cd > Zn in the river water. The concentration of chromium in water varied from 0.08 to 0.92 mg/L in Dhaleshwari River, which might be due to the extensive disposal of domestic sewage and runoff from agricultural zone [22,24].

Table 5. Heavy Metals Concentration (mg/L) levels of the water samples of the Dhaleshwari River and the other peripheral rivers in Dhaka city.

	Average ± Standard Error of Mean				References
	Cd	**Cr**	**Ni**	**Zn**	
Dhaleshwari River	0.19 ± 0.01	0.71 ± 0.16	0.62 ± 0.1	0.18 ± 0.03	Present Study
Buriganga River	0.015 ± 0.003	2.04 ± 1.53	0.19 ± 0.03	0.21 ± 0.04	[70]
Shitalakshya River	0.011 ± 0.003	-	-	0.0263 ± 0.003	[71]
Turag River	-	0.32 ± 0.02	0.018 ± 0.003	0.10 ± 0.01	[55]
Tongi Canal	-	0.01	0.005	0.156	[72]
Balu River	0.01 ± 0.001	-	-	0.03 ± 0.002	[71]
WHO [a]	0.003	0.05	0.05	3	[73]
FAO [b]	0.01	0.1	0.2	2	[74]

[a] WHO = World Health Organization; [b] FAO = Food and Agriculture Organization.

Figures 10 and 11 represent the Max^{m} vs Min^{m} Concentrations of the heavy metals Cd and Cr, respectively for all the peripheral rivers of Dhaka. The figures also show the WHO standards in dotted lines. The highest contamination of Cd was recorded at sampling location D-1 (0.25 mg/L), resulting from the Savar tannery industries zone, and the lowest amount was recorded at sampling location D-2 (Sudkhira) (0.15 mg/L) in the Dhaleshwari River (Figure 11). The results exceeded the allowable limits specified by World Health Organization (0.003 mg/L, Food and Agriculture Organization (0.01 mg/L), and The Environmental Conservation Rules (0.005 mg/L) [72–75]. Table 5 shows that Arefin et al. [55] recorded Cr at 0.32 mg/L in the Turag River, and Biswas et al. [72] found Cr at 0.01 mg/L in the Tongi Canal. The present study observed the highest chromium concentration at 7.76 mg/L in the Buriganga River [70] among the peripheral rivers (Figure 11), which may result from the operation and maintenance of various cooling towers at different industries beside Buriganga. Chromium-containing compounds from cooling towers might have been discharged into the Buriganga River. Although the selected section of the Dhaleswari river is located near the Savar tannery effluent discharge region, the concentration of Cr at this site is lower than that in Buriganga, however, exceeding the permissible level. Since water cotyledons (*E. crassipes*) were growing surrounding the sample site throughout the sampling period, these water cotyledons are believed to accumulate Cr and are termed chrome-sorbent plants [76,77].

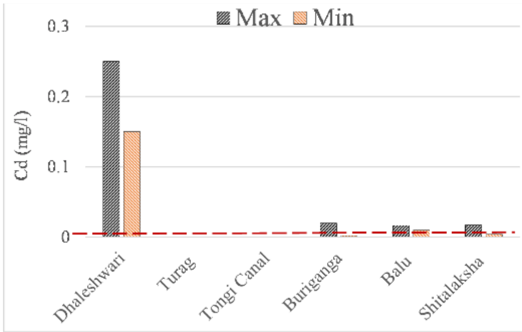

Figure 10. Concentrations for Cd in the peripheral rivers of Dhaka with WHO standard in dotted line (0.003 mg/L).

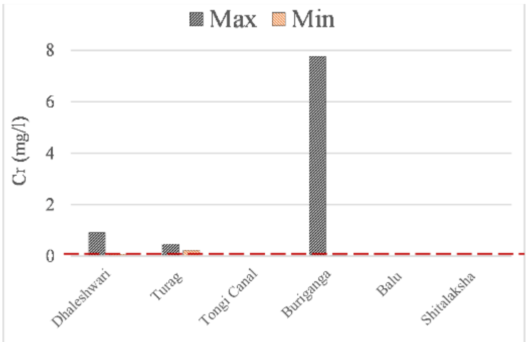

Figure 11. Concentrations for Cr in the peripheral rivers of Dhaka with WHO standard in dotted line (0.05 mg/L).

In the Dhaleshwari River, Cd (cadmium) values varied from 0.15 to 0.25 mg/L along the five sampling locations. Figure 10 shows that the concentration of Cd is above the tolerable limit specified by World Health Organization (WHO) and Food and Agriculture Organization (FAO) (0.003 mg/L and 0.01 mg/L, respectively) [73,74]. Potential sources of cadmium in the Dhaleshwari River include batteries, pigments, and plating businesses [37,70]. The highest Cr concentration observed at D-1 (0.92 mg/L), which may be caused by effluents from the Savar tannery industries, is higher than WHO allowable limit (0.05 mg/L). Apart from this, every sampling station around the industrial sector of Savar city has a Cr content over the permissible limit. Cadmium exposure for a prolonged period over the permissible limit could cause allergic dermatitis [78]. El-Ebiary et al. [79] reported that red tilapia mortality was caused in Alexandria, Egypt, through exposure to very high levels of cadmium.

Table 5 shows that average (arithmetic means) of Ni was found at 0.011 mg/L for water samples for the Shitalakshya River by Mokaddes et al. [71] and 0.015 mg/L for the Buriganga River by Sarkar et al. [70]. However, the concentration of cadmium in the current study was obtained at a much lower concentration than the water quality standard limit [80]. Figures 12 and 13 represent Max^{m} vs. Min^{m} concentrations of peripheral rivers of Dhaka for Ni and Zn, respectively, while the WHO standards are shown in dotted lines. The concentration of nickel (Ni) in the water of the Dhaleshwari River varied from 0.33 to 0.87 mg/L (Figure 12). Every sample location exceeded Ni concentrations according to WHO permitted limit (0.1 mg/L). Nickel is a carcinogenic metal that leads to severe damage to the liver and heart, reduced body weight, and skin irritation due to long-term exposure [81].

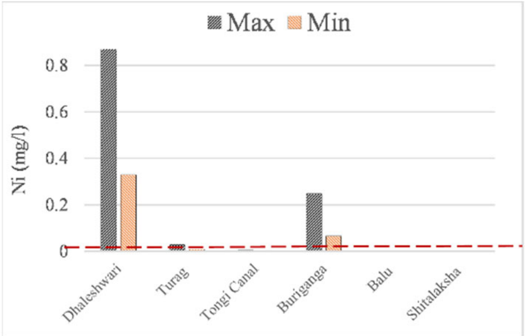

Figure 12. Concentrations for Ni in the peripheral rivers of Dhaka with WHO standard in dotted line (0.003 mg/L).

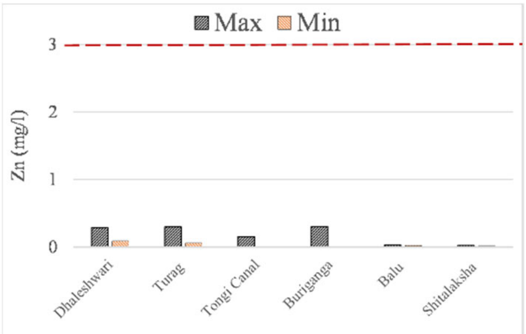

Figure 13. Concentrations for Zn in the peripheral rivers of Dhaka with WHO standard in dotted line (3 mg/L).

Table 5 shows that average (arithmetic mean) level of Ni was found at 0.19 mg/L in the Buriganga River by Sarkar et al. [70], 0.018 mg/L was recorded upstream of the Turag River by Islam et al. [82], and 0.005 mg/L of Ni was recorded in Tongi Canal by Biswas et al. [72]. Several dockyards were established beside the Buriganga Riverbank, and a few launch stations are located near the station [70]. Nickel concentrations in the Buriganga River might result from several factors relating to discharge from specific manufacturing industries. Ni has been associated with cancer, lung damage, and dermatitis, among other health problems [83]. Zinc contamination at various sampling stations in the Dhaleshwari River water varied from 0.09 to 0.29 mg/L (Figure 13). Zn could be precipitated as $ZnCO_3$, which might explain why surface water has a lower percentage of Zn than deep water does, according to previous researchers [84]. The contamination of Zn was within the acceptable limit by WHO (3 mg/L) in all the peripheral rivers.

3.4. Correlation among the Heavy Metals in Dhaleshwari River

The Pearson's correlation matrix among the different trace metals for Dhaleshwari River is presented in Table 6. The majority of heavy metals showing a significantly linear dependence among them. A strong correlation emerged between Cr and Cd (r = 0.639), Ni and Cd (r = 0.627), Ni and Cr (r = 0.663), Zn and Cd (r = 0.919) and Zn and Cr (r = 0.719). This is because runoff from agricultural land, leather industries, and tanneries located in Savar city are constantly contributing untreated sewage and solid waste in the Dhaleshwari River, leading to an increased concentration of each of the metals. Tannery wastewater, including residues from the tanning, re-tanning, and basification phases of leather manufacturing, as well as municipal sewerage, are included in this category. It is utilized to allow the chromium or aldehyde to attach to the skin protein during the tanning process [84].

Table 6. Pearson's Correlation matrix among the Heavy Metals in the Dhaleshwari River (significance of correlation was measured both at 0.05 levels).

Parameters	Cd	Cr	Ni	Zn
Cd	1			
Cr	0.639 *	1		
Ni	0.627 *	0.663 *	1	
Zn	0.919 *	0.719 *	0.446	1

* Correlation is significant at the 0.05 level (2-tailed).

3.5. Ecological Risk Assessment

A technique for assessing ecological hazards with relation to water pollution reduction was devised by Hakanson [54]. The ecological risk indices of individual metals for all the peripheral rivers have been estimated, which are presented in Table 7. The measured values of the ecological risk index (E_{RI}) for heavy metals show a descending trend along with the locations of Dhaleshwari River as follows: D-1 > D-4 > D-5> D-3> D-2. The calculated E_{RI} values ranged from 469.71 to 830.32, with an average of 623.47 in Dhaleshwari River. The lower value was observed at D-2, representing the Sudkhira area while the highest value was observed in the D-1 location (Savar tannery area). This may be due to the tannery activities, which also indicate a high degree of ecological risk. Every sampling station was contributed by leather and dying industries. According to Table 7, sampling stations D-1 (Savar tannery), D-2 (Sudkhira), D-3 (Dhalla, fish market), D-4 (AKS dying), and D-5 (Nama Bazar) showed E_{RI} values greater than 300, all of which are indicating a disastrous degree of ecological risk. The ecological risk index was very low (E_{RI} < 100), indicating low risk in the Shitalakshya River, Turag River, and Tongi Canal.

Table 7. Ecological risk characterization of the Peripheral Rivers in Dhaka city.

Sampling Station	$^a E^i_r$				$^b E_{RI}$	Risk Grade
	Cd	Cr	Ni	Zn		
D-1	750	36.8	43.5	0.02	830.32	Disastrous risk
D-2	450	3.2	16.5	0.006	469.71	Disastrous risk
D-3	510	31.2	36.5	0.007	577.71	Disastrous risk
D-4	570	35.6	19.5	0.015	625.11	Disastrous risk
D-5	540	36	38.5	0.012	614.51	Disastrous risk
Buriganga River	59.4	310.62	10.35	0.02	380.39	Disastrous risk
Shitalakshya River	36	-	-	0.002	36.002	Low risk
Turag River	-	10	1.4	0.013	11.413	Low risk
Tongi Canal	-	0.4	0.25	0.01	0. 66	Low risk

^{a} E^i_r = Ecological risk factor; ^{b} E_{RI} = Ecological risk index.

It is worth mentioning that these higher values of E_{RI} might be attributed to the presence of greater degrees of Cd at each sampling station. Phosphate fertilizers, non-ferrous metal mining or refining, and waste disposal are among the anthropogenic (result of human activity) sources of cadmium in the environment [85]. A vast amount of agricultural land and metal processing industries exist around the Dhaleshwari River. Extra cadmium accumulates in the aquatic organism and crops. Untreated waste from tanneries, unplanned urbanization, raw effluent from several dying industries, leather waste throughout the selected stretch are the plausible causes of the disastrous ecological risk. The Ecological risk indices for the other peripheral rivers were also evaluated with the information gathered from different studies [71–73,86,87] and presented in Table 7. Authors obtained an ecological risk at a level of 380.39 in the surface water of the Buriganga River according to the concentration levels reported by Sarkar et al. (2015), which also indicates disastrous level of risk in the Buriganga. However, based on the characterization by Ecological Risk Index, all the other rivers (Turag, Tongi Canal and Shitalakshya) exhibited low level of risks. Thus ecosystems are severely under threat in the Dhaleshwari and Buriganga rivers while the other rivers could maintain ecosystem without significant threat.

4. Conclusions

The present study dealt with evaluating the current water quality of the Dhaleshwari river in terms of physicochemical parameters and heavy metals while the study also attempted to make a comparative assessment on pollution status among all the peripheral rivers around Dhaka City. Significant contamination was observed at every peripheral river concerning identified parameters such as dissolved oxygen (DO), total dissolved solids (TDS), 5-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD). This study also performed investigation on the status of relevant heavy metals (chromium-Cr, cadmium-Cd, nickel-Ni, zinc-Zn) pollution in different rivers of Dhaka City. The concentration levels of the toxic metals such as Cr, Cd, and Ni in the Savar tannery (D-1), Sudkhira (D-2), AKS dying (D-4), and Nama Bazar (D-5) areas of Dhaleshwari River and Buriganga river in general seemed to be of significant and of high concern warranting regular and detailed investigation and monitoring.

Heavy metals pollution was further characterized in this study by ecological risk index (E_{RI}). Except for the Burganga and Dhaleshwari rivers, the ecological risk index values showed very low levels ($E_{RI} < 100$) for the Shitalakshya River, Turag River, and Tongi Canal, indicating lower level of risk. However, the ecological risk index measured contamination intensity of heavy metals that revealed disastrous risk ($E_{RI} \geq 300$) at sampling stations D-1 (Savar tannery), D-2 (Sudkhira), D-3 (Dhalla, fish market), D-4 (AKS dying), and D-5 (Nama Bazar) in the Dhaleshwari River and disastrous level of ecological risk was also obtained in the Buriganga River. Based on all the physicochemical and toxicity-based risk characterization, the river system in Dhaka city can be termed as severely polluted based on organic and solids discharge whilst not all the rivers could be considered as significant threats to maintain ecosystems in general, except for the Dhaleshwari and Burganga rivers. A wider level and continuous comprehensive investigation will be required to confirm on the ecological characterization of the rivers. Although, it was observed that the deviation of physicochemical parameters for certain peripheral rivers of Dhaka were not significant enough from the standards, however, satisfactory conditions are yet to be expected. Furthermore, after the relocation of Hazaribagh tannery to Savar, the water quality of the Dhaleshwari river started to deteriorate and quite possibly could pose a severe threat to the ecosystem. If appropriate measures are not adopted soon enough, this will impact both the ecological and public health around the river. On the context of ever-increasing industrial growth and urbanization concerns in Dhaka city, present findings lay down additional foundation for frequent monitoring of the river systems and their tributaries. As part of the steps to abate the water pollution for river system of Dhaka City, a continual assessment of waste discharge and pollutant loadings is warranted on a regular basis.

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