

## Article

# Contamination and Ecological Risk Evaluation of Metals in Sediments from a Wetland of International Importance (Ramsar Site)

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**Abstract:** Wetlands are highly productive and diverse ecosystems providing home to thousands of organisms. These ecosystems reduce water pollution, sequester carbon, support livelihoods, and increase food security. However, these ecological functions are being impeded due to increased levels of metals in the environment. Therefore, the primary objective of this study was to evaluate the degree of metal contamination in the surface sediment of a wetland, Tanguar Haor, for the first time. The result demonstrated that the mean concentrations of Fe, Cu, Zn, As, Pb and Hg varied from 13140.39 to 45675, 40.07 to 46.29, 47.60 to 57.15, 18.89 to 35.23, 1.24 to 2.64, and 0.35 to 0.42, respectively. The concentration of As was found to be higher than the average shale value. The concentration of Cu (44.19 µg/g) and Hg (0.38 µg/g) was very close to the shale value (45 µg/g and 0.40 µg/g, respectively), indicating a moderate level of contamination. The contamination level was further evaluated by multi-indices, e.g., the contamination factor (CF), the enrichment factor (EF), and the geo-accumulation index ( $I_{geo}$ ). The average EF values for As (115.41), Cu (57.68), and Hg (55.47) were >50, indicating a high degree of contamination (extremely severe enrichment). However, CF values showed varied levels of pollution; for example, the majority of the area was only somewhat contaminated with As, Cu, and Hg, but less contaminated with Fe, Zn, and Pb. According to  $I_{geo}$ , sampling sites were found to be unpolluted or less polluted by heavy metals. Based on potential ecological risk assessment (PERI), the degree of risk from the six heavy metals decreased in the following sequence: As > Cu > Zn > Pb > Cr > Ni. PERI values indicated the study area has been exposed to moderate risk to As and low risk to other metals. This study provides an opportunity for frequent monitoring of heavy metals in this ecologically critical environment, and thus curbing heavy metal pollution.

**Keywords:** Tanguar Haor; ecologically critical area; Ramsar site; sediment; heavy metal; Bangladesh



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## 1. Introduction

Wetlands are the distinctive ecotones between terrestrial and aquatic systems and are regarded as one of the planet's most productive ecosystems [1,2]. A wetland ecosystem can include a huge diversity of fish, amphibians, birds, mammals, plants, insects, amphibians, and reptiles. These wetlands offer a wide range of ecosystem services to humans, wildlife, and aquatic organisms, including water storage, water quality improvement, fish and wildlife habitats, and the maintenance of surface water flow [3–5]. Wetlands are home

to numerous migrating birds as well as endangered and threatened species [2,6]. Even migratory bird species have a reliance on certain wetlands that would be destroyed if these wetlands were lost [3]. However, due to increasing human activities, at least 33% of global wetlands have been destroyed, including wetlands and 2.64 million km<sup>2</sup> of open water [1].

Tanguar Haor, located in the northern haor basin of Bangladesh, is one of the most significant wetlands in South Asia. It plays a vital role in the complex hydrological and biological ecosystem, supporting a wide variety of rare and vulnerable aquatic flora and fauna including endemic species [7]. Being a natural freshwater wetland of Bangladesh, it has magnificent conservation value for its rich biodiversity and significant number of wildlife and migratory species. Over 60,000 migratory waterfowl harbor in Tanguar Haor seasonally together with the resident birds. Furthermore, it plays a vital role as the last vestige of a swamp forest with over 140 fish species [7]. Unfortunately, the diversified biodiversity of Tanguar Haor is under pressure of extinction due to extensive exploitation of natural resources [7]. Tanguar Haor was, thus, designated as an ecologically critical area by the Government of Bangladesh in 1999, taking into account the fragile state of this ecologically significant wetland [3]. Further, it was declared as the second Ramsar site in Bangladesh on 10 July 2000 for its unique ecosystem of national and international importance [7].

Heavy metals generally have relatively high densities or weights. These metals are broadly classified as essential (Zn, Fe, Se, Cu etc.), probably essential (V, Co) and potentially harmful (Hg, As, Cd, Pb, Ni). Some of them (Hg and As) are extremely poisonous to biota, even at low concentrations in the air or in food [7]. After being introduced by human activities or natural processes to an aquatic ecosystem, these metals are dispersed throughout the water column, deposited in sediments, or stored there. The metals are then devoured by inhabitant biota including fish [8]. These could contaminate water and sediment directly, killing or having a sub-lethal effect on the local fish population. Consuming fish or drinking water from these contaminated areas results in oxidative stress, which damages cells at the molecular level. Such damage can cause the development of several diseases (such as nausea, liver and kidney damage) and other health issues [7,9].

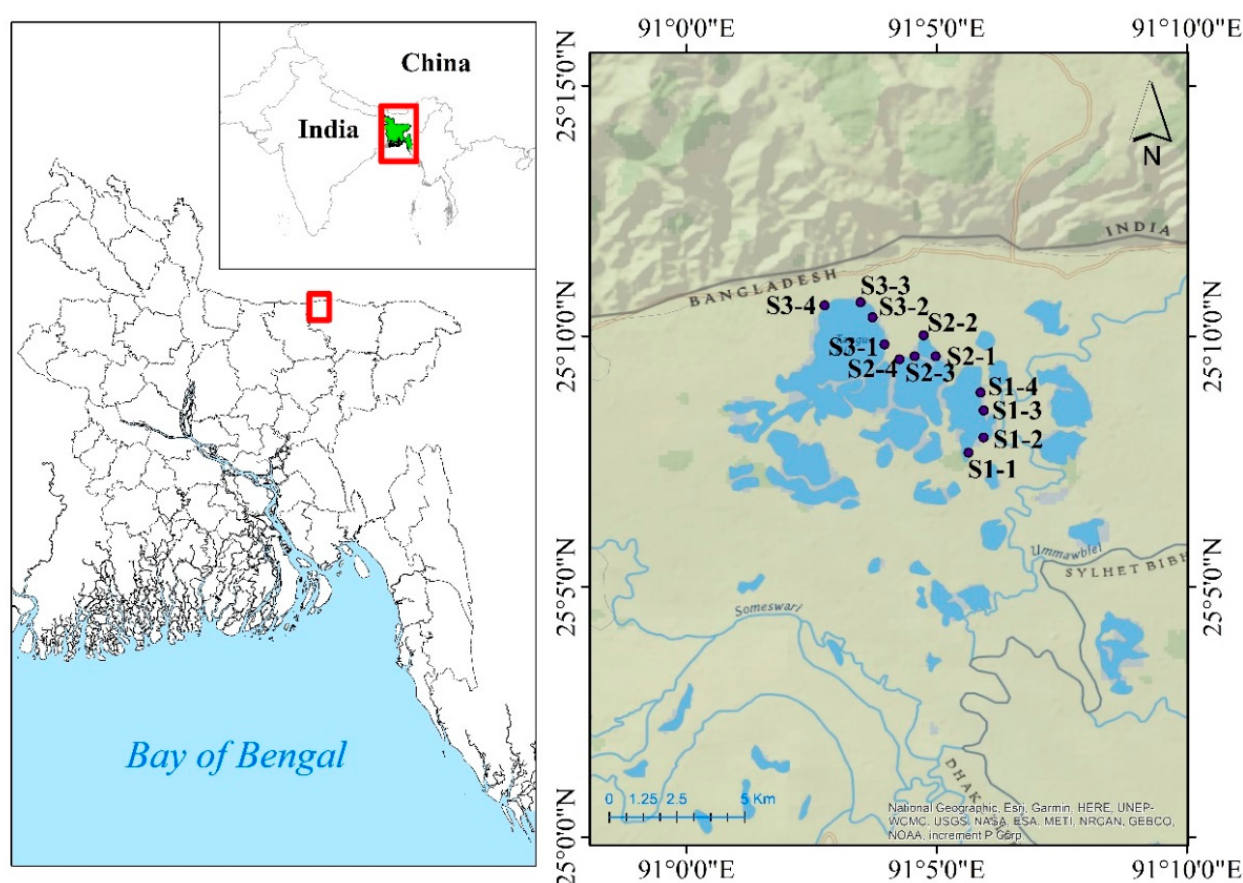
Heavy metal pollution in aquatic environments has drawn a great deal of attention due to its toxicity and persistence in the environment, and consequent build-up in the aquatic ecosystem. Because of the potential for accumulation in microbes, aquatic plants, and fauna, its remnants in aquatic ecosystems could infiltrate the human food chain and cause health issues [5,6]. These metals can enter into an aquatic ecosystem from two main sources, namely natural processes and human activities [7]. Volcanic eruptions, weathering, and erosion are examples of natural sources. On the other hand, human activities include the application of fertilizers and pesticides indiscriminately in agricultural areas, urbanization, and industrial waste as well as the dumping of partially or improperly treated household and municipal waste [8–11]. They are then transported into the aquatic ecosystem and ingested by biota [12]. Therefore, fish and sediment are useful markers for assessing the long-term buildup of heavy metals in aquatic environments [13].

The excessive pollution of Tanguar Haor has recently drawn the attention of scientists from Bangladesh [14,15]. Previously, a number of studies has been conducted in Tanguar Haor regarding biodiversity [7,16–19], birds [20], aquatic plants [21], water quality [17], radioactivity [15], and ecosystem management [22,23]. However, none of them focused on heavy metal contamination or its ecological risk to inhabitants. Sun et al. [9] reported that ecosystem services in terms of rice production and fish supply of Tanguar Haor have significantly reduced due to land use change, population growth and the resultant pollution in the catchment area. These reduced services have had profound effects on the food security of the area. More than 60,000 people in 88 surrounding villages directly depend on Tanguar Haor for their livelihood [7]. Therefore, it is crucial to identify the specific causes and sources of pollution in the study area. The objectives of this study were to quantify and reveal the extent of heavy metal (Cu, Zn, As, Pb, Fe and Hg) contamination, and assess associated ecological risks in the surface sediment from the study area for the first time.

## 2. Materials and Methods

### 2.1. Study Area Description

Tangur Haor is located in the Sunamganj district of Bangladesh between  $25^{\circ}12'2.57''$  to  $25^{\circ}5'47.98''$  N and  $90^{\circ}58'49.43''$  to  $91^{\circ}10'0.02''$  E, covering an area of 160 km<sup>2</sup> (Figure 1). The Haor is a part of the Surma–Kushiyara rivers basin wetland [24] and known as the “mother fishery” of Bangladesh for its significant contribution to fish production [25,26]. Administratively, 67% of Tangur Haor lies in the Dharmapasha Upazila whereas the rest is in Tahirpur Upazila. Over 50% of this wetland is covered with water, and 31% of the land is used for agricultural activities [27,28]. The soil texture of Tangur Haor varies from clay and clay loam to loam. The climatic conditions of Tangur Haor are of a subtropical monsoon nature with three dominant seasons, namely summer, monsoon, and winter. The summertime temperature ranges from 30.9 to 33.4 °C, and the wintertime low temperature ranges from 8.5 to 16.6 °C [7]. Average annual rainfall is 8000 mm in the Haor area and flash floods in the area may occur due to high rainfall during the pre-monsoon period [29,30].



**Figure 1.** Map showing sampling sites in Tangur Haor, Sunamganj, Bangladesh.

### 2.2. Selection of Study Site and Period

Study sites were selected based on a discussion with the Fisheries Extension Officer of the Department of Fisheries, Tahirpur Upazila. Three sites named Hatirgatha (S1), Naindar Beel (S2), and Lechuamara (S3) were selected as sampling sites where there was no break in the riverbank and settlement of sediment. The people in these areas were directly engaged in crop cultivation and fishing activities. However, the distance between each site was approximately 3 km.

### 2.3. Sample Collection and Preparation

A total of 36 sediment samples was collected from 12 stations in 3 sites (Figure 1). The samples were then transported to the Atmospheric and Environmental Chemistry Laboratory of the Atomic Energy Centre, Dhaka, Bangladesh. Details of the sample preparation and laboratory analysis were described in Rahman et al. [31]. Briefly, after collection, the sediment samples were allowed to settle so that extra water could be removed. After that, each sample was placed into a separate porcelain dish. Every dish containing the specific sample was put into an oven set at about 70°C until a steady weight was achieved. Dried samples were then pulverized into fine powder using a pestle and mortar and stored within desiccators in a plastic vial with an identification mark. Finally, a pellet maker (Specac Ltd, Orpington, UK) was employed to form pellets under 10 tons of pressure. The elemental analyses in sediment samples were measured by energy dispersive X-ray fluorescence (EDXRF) spectrometry [31]. The pelleted samples were then placed into a sampling tube in the EDXRF system. In an X-ray tube, samples were blasted for about 18 min at a voltage of 25 V and a current of 50 µA. The X-ray properties of the samples were discovered using a solid-state Si-Li detector system. For quality assurance and control (QA/QC), the standard reference materials (Marine sediment, IAEA 433) were prepared and analyzed.

### 2.4. Contamination Indices for Sediment

In this study, a number of indicators, namely the enrichment factor (EF), the contamination factor (CF), and the geo-accumulation index ( $I_{geo}$ ), was calculated using the following equations to assess the current status of sediment:

$$\text{Enrichment factor (EF)} = \frac{[M_x / Fe_x]_{\text{sample}}}{[M_{ref} / Fe_{ref}]_{\text{background}}} \quad (1)$$

where  $[M_x / Fe_x]$  is the load of metals in the soil samples and  $[M_{ref} / Fe_{ref}]$  indicates the background value of the metals and iron [31]. EF values of 2–5: deficiency to moderate enrichment, 5–10: moderately severe enrichment, 10–25: severe enrichment, 25–50: very severe enrichment, >50: extremely high enrichment [31].

$$\text{Contamination factor (CF)} = \frac{(C_{\text{metal}})}{(C_{\text{background}})} \quad (2)$$

where,  $C_{\text{metal}}$  = the metal concentration in the sediment and  $C_{\text{background}}$  = the metals' background value. CF values were grouped into four groups to assess the contamination level [32]. CF values of <1: low contamination,  $1 < CF < 3$ : moderate contamination,  $3 < CF < 6$ : considerable contamination,  $CF > 6$ : very high pollution.

$$\text{Geo-accumulation index } (I_{geo}) = \log_2 \frac{C_n}{1.5B_n} \quad (3)$$

where,  $C_n$  = the metal load in samples and  $B_n$  = the background value.  $I_{geo}$  values are classified into seven classes following Muller [33].  $I_{geo}$  value of <0: practically unpolluted, 0–1: unpolluted to moderately polluted, 1–2: moderately polluted, 2–3: moderately to heavily polluted, 3–4: heavily polluted, 4–5: heavily to extremely polluted, >5: extremely polluted.

### 2.5. Potential Ecological Risk Assessment

When one or more stressors (e.g., heavy metals) are present, the process of assessing the potentially harmful ecological impacts that may follow exposure to such stressors is known as ecological risk assessment. According to the toxicity of heavy metals and the

response of the environment, the potential ecological risk index (RI) was introduced to measure the level of heavy metal contamination in sediments [34].

$$E_r^i = T_r^i C_f^i$$

$$C_f^i = C_n^i / C_o^i$$

$$RI = \sum E_r^i \quad (4)$$

where  $RI$  = the sum of all risk factors for heavy metals,  $E_r^i$  = the monomial potential ecological risk factor,  $T_r^i$  = the toxic response factor for a given substance,  $C_f^i$  = the monomial contamination factor,  $C_n^i$  = the metal content in the sediments and  $C_o^i$  = a background value (reference value of metals). PERI or RI value of <150: low pollution, 150–300: considerable pollution, 300–600: high pollution,  $\geq 600$ : very high pollution [34].

## 2.6. Statistical Analysis

The statistical analysis of collected data was performed by using the Statistical Package for the Social Sciences (IBM SPSS, version 20.0). The significant differences in the mean levels of metals among sites were analyzed using one way ANOVA with the software Paleontological Statistics or PAST (Hammer et al., 2001). The degree of connection between the metals was calculated using Spearman's rank correlation coefficient ( $r$ ). The relationship between metals and research sites was visualized using principal component analysis (PCA) and cluster analyses. The study map was generated using ArcGIS (Esri).

## 3. Results and Discussion

### 3.1. Metal Concentrations in Sediment of Tanguar Haor

The results of heavy metal concentration in the surface sediments of Tanguar Haor are shown in Table 1. The mean concentrations of Fe, Cu, Zn, As, Pb and Hg ranged from 13,140.39 to 45,675, 40.07 to 46.29, 47.60 to 57.15, 18.89 to 35.23, 1.24 to 2.64, and 0.35 to 0.42, respectively. The maximum concentration of Fe ( $45,675 \pm 3390.22 \mu\text{g/g}$ ) was recorded in site S1, whereas the highest load of Zn ( $57.15 \pm 6.51 \mu\text{g/g}$ ), Pb ( $2.64 \pm 1.86 \mu\text{g/g}$ ), and Hg ( $0.42 \pm 0.04 \mu\text{g/g}$ ) was in site S2. On the other hand, the highest concentration of Cu ( $46.29 \pm 6.74 \mu\text{g/g}$ ) and As ( $35.23 \pm 8.40 \mu\text{g/g}$ ) was documented in site S3 (Table 1). The one-way ANOVA revealed significant differences between locations in the mean metal values ( $F = 10.73$ ;  $p = 0.0001$ ). Tukey's pairwise comparisons of stations for each metal showed substantially different results ( $p = 0.001$  for each). Studies have reported that the high load of Zn, Cu, As, and Pb may be attributed to anthropogenic activities, e.g., agricultural activities, releasing untreated sewage waste and dumping electronic waste [33–37]. Further, the concentration of these metals could differ from station to station due to the river discharge, surface runoff from the land, population density, and proximity to the urbanized and industrial areas [38,39].

**Table 1.** The mean values of metal concentration in the sediment ( $\mu\text{g/g}$ ) on dry weight basis.

| Metals | S1                   | S2                        | S3                        |
|--------|----------------------|---------------------------|---------------------------|
| Fe     | $45,675 \pm 3390.22$ | $13,140.39 \pm 17,777.27$ | $36,216.13 \pm 22,170.19$ |
| Cu     | $40.07 \pm 4.93$     | $45.96 \pm 8.58$          | $46.29 \pm 6.74$          |
| Zn     | $52.81 \pm 3.11$     | $57.15 \pm 6.51$          | $47.60 \pm 1.87$          |
| As     | $18.89 \pm 1.64$     | $22.93 \pm 2.28$          | $35.23 \pm 8.40$          |
| Pb     | $2.38 \pm 0.62$      | $2.64 \pm 1.86$           | $1.24 \pm 1.03$           |
| Hg     | $0.35 \pm 0.05$      | $0.42 \pm 0.04$           | $0.37 \pm 0.03$           |

Table 2 represents the comparison of this study with the previous studies conducted worldwide together with different international standards. It was found that the mean

concentration of Fe (31,677.18  $\mu\text{g/g}$ ) recorded in this study was lower than in the ship-breaking yard in Chittagong (68,260  $\mu\text{g/g}$ ) [31] but higher than in the Karnaphuli River (3297.38  $\mu\text{g/g}$ ) [40]. The average Cu load in this study (44.19  $\mu\text{g/g}$ ) was lower than the Karnaphuli River (45.79  $\mu\text{g/g}$ ) [40] and Ulsan Bay (95.6  $\mu\text{g/g}$ ) [41]. Again, the concentration of Zn (52.52  $\mu\text{g/g}$ ) and Pb (2.07  $\mu\text{g/g}$ ) in Tanguar Haor was found to be higher than in the Karnaphuli River [40], the shipbreaking area [31], Ulsan Bay [41], and the Fenghe River [42]. In contrast, the As (25.69  $\mu\text{g/g}$ ) and Hg (0.38  $\mu\text{g/g}$ ) load in this experiment was found to be lower than in the shipbreaking area [31] and Ulsan Bay [41]. The hydrogeological flow and some soil properties, inhabiting plants in the system, may be responsible for the variation in the metal loads in Tanguar Haor. For instance, flooding and changes in the water level lead to transitions in the soil's oxidation-reduction potential, which is thought of as a key factor in the destiny of metals [31]. Freshwater wetlands have redox interfaces that are ideal for microaerophilic iron (II) oxidizing bacteria because they have circumneutral pH, steep  $\text{O}_2$  gradients, and a steady source of Fe (II). High Fe-rich sediment accumulations and artificial redox gradients are created when lowland marshes are extensively drained. This oxidation reduction process may have increased the level of Fe in the study area. However, the mean value of Fe in this study was lower than the natural shale value. The absorption by the roots and stems of existing plants may be responsible for the variable amount of Cu, Zn and Pb in Tanguar Haor because plants remove metals through cation exchange, filtering, absorption, and chemical changes via the process of root aggregation [31]. Many of these aquatic plants have the capacity to store large amounts of metal in their tissues. Heavy metals usually accumulate in the roots of halophytes and diffuse in minute amounts to the stems and leaves as well. Direct and untreated waste discharge from local industries in the ecosystem may be attributed to the high concentration of Zn and Pb [43,44]. Furthermore, extensive use of fertilizers and pesticides in crop cultivation may also lead to a high As load in the environment [45]. However, the values of Cu and As in Tanguar Haor exceeded some well-established standard values (Table 2). Arsenic is naturally abundant in the South Asian region, where it has been determined to originate from eroded Himalayan sediments. It is thought to reach a solution following reductive release from solid phases under anaerobic conditions. Though all the values of metal concentration in this study did not exceed the shale value, except for As, some of these (e.g., Cu, As, and Hg) crossed the TEL values.

**Table 2.** Comparison of metals in sediment ( $\mu\text{g/g dw}$ ) with different international guidelines and other studies in the world.

| Country         | Name of Sampling Area             | Fe                  | Cu              | Zn              | As              | Pb              | Hg               | References    |
|-----------------|-----------------------------------|---------------------|-----------------|-----------------|-----------------|-----------------|------------------|---------------|
| Bangladesh      | Tanguar Haor                      | 31,677.18           | 44.19           | 52.52           | 25.69           | 2.07            | 0.38             | Present Study |
|                 | Karnaphuli River, Chittagong      | 3297.38             | 45.79           | 105.0           | NA              | 26.7            | NA               | [40]          |
|                 | Sitakunda, Chittagong             | 68,260              | 18.7            | 151.5           | 10.55           | 90              | NA               | [31]          |
|                 | Feni River Estuary                | NA                  | NA              | NA              | 0.85            | 6.47            | 0.71             | [39]          |
|                 | Tamil Nādu                        | NA                  | NA              | 39.49           | NA              | NA              | NA               | [46]          |
| India           | Thirumalairajan River             | 1736.3–3144         | 13.65–28.17     | 23.4–56.32      | NA              | 1.73–6.74       | NA               | [47]          |
|                 | Point Calimere Wildlife Sanctuary | NA                  | 0.4             | 0.3             | NA              | 2.5             | 26.0             | [48]          |
| South Korea     | Ulsan Bay                         | NA                  | 95.6            | 361.9           | 15.8            | 90.7            | 0.16             | [41]          |
| China           | Fenghe River Basin                | NA                  | 28.73           | 90.39           | 250.32          | 30.20           | NA               | [42]          |
| TEL             |                                   | -                   | 20.6            | 68.4            | 14.5            | 44              | 0.11             | [49]          |
| PEL             |                                   | -                   | 64.4            | 157             | 75.5            | 119             | 0.62             | [49]          |
| Shale value     |                                   | 47,200              | 45              | 95              | 13              | 20              | 0.4              | [50]          |
| Standard values |                                   | 41,000 <sup>a</sup> | 33 <sup>a</sup> | 95 <sup>b</sup> | 13 <sup>c</sup> | 19 <sup>b</sup> | 0.5 <sup>d</sup> |               |

TEL: threshold effects level. PEL: probable effects level. <sup>a</sup> [51], <sup>b</sup> [52], <sup>c</sup> [53], <sup>d</sup> [54].

### 3.2. Contamination Levels Assesemnt of Metals in Sediments

The values of the contamination factor (CF) and enrichment factor (EF) for studied metals are presented in Table 3. The average CF values of Fe, Cu, Zn, As, Pb, and Hg ranged

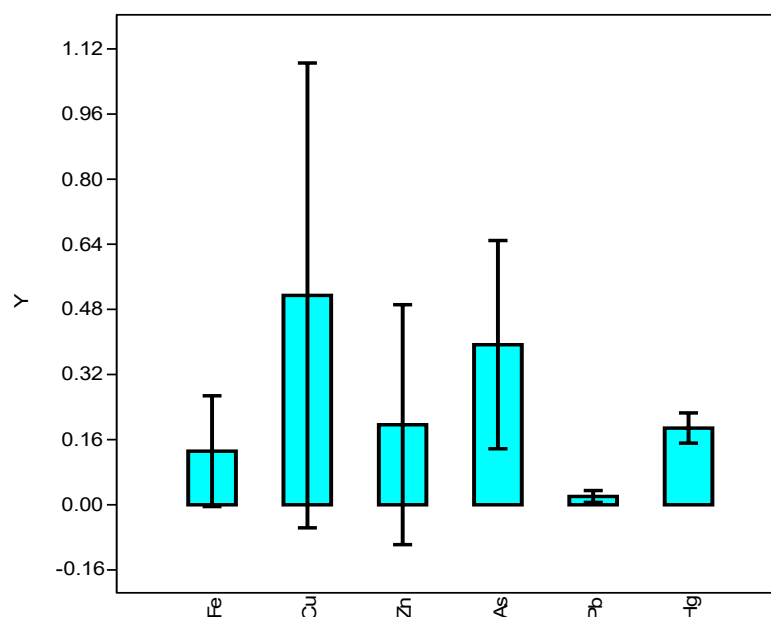
from 0.28 to 0.97, 0.89 to 1.03, 0.50 to 0.60, 1.45 to 2.71, 0.1 to 0.2 and 0.88 to 1.05, respectively in Tanguar Haor. In this study, it was found that the CF value for Fe, Zn, and Pb in all sampling sites was below 1, indicating a low contamination level. In contrast, As (arsenic) showed a moderate contamination level ( $1 < CF < 3$ ) in all sampling sites. In the case of Cu, the CF values specified a moderate contamination rate in sampling sites S2 and S3 but a low contamination rate in site S1. On the other hand, Hg showed a moderate contamination level in S2 and a low contamination level in S1 and S3 (Table 3).

**Table 3.** Contamination factor (CF) and enrichment factor (EF) of heavy metals for sediments of all sites studied in Tanguar Haor.

| Stations | Fe    |       | Cu    |       | Zn   |       | As   |        | Pb    |      | Hg    |       |
|----------|-------|-------|-------|-------|------|-------|------|--------|-------|------|-------|-------|
|          | CF    | EF    | CF    | EF    | CF   | EF    | CF   | EF     | CF    | EF   | CF    | EF    |
| S1       | 0.970 | 56.60 | 0.89  | 52.81 | 0.55 | 32.46 | 1.45 | 84.85  | 0.183 | 6.94 | 0.875 | 51.09 |
| S2       | 0.278 | 16.25 | 1.02  | 59.63 | 0.60 | 35.12 | 1.76 | 102.99 | 0.20  | 7.70 | 1.05  | 61.31 |
| S3       | 0.767 | 44.80 | 1.028 | 60.6  | 0.50 | 29.25 | 2.71 | 158.4  | 0.095 | 3.62 | 0.925 | 54.0  |

The average EF values of Fe, Cu, Zn, As, Pb, and Hg ranged from 16.25 to 56.60, 52.81 to 60.6, 29.25 to 35.12, 84.85 to 158.4, 3.62 to 6.94, and 51.09 to 61.31, respectively. The EF values in this study clearly indicated that the metals in the sediment of Tanguar Haor were severely enriched. However, an EF value of more than 1.5 indicates that the metals originated from anthropogenic activities [55]. Principal sources of these metals could be associated with urban and industrial waste, as well as domestic waste, fossil fuel incineration and agricultural runoff [36,37,43,44]. Hence, further investigations are recommended to identify the exact sources of heavy metals in this Ramsar site to protect its ecology from pollution.

The  $I_{geo}$  values in this study for six metals were below 1 (Figure 2) in the sediments of Tanguar Haor, indicating an unpolluted to low pollution level ( $0 \leq I_{geo} < 1$ ).  $I_{geo}$  values have been used to explain the sediment quality [56]. However, among the metals, Cu and As showed the highest accumulation of metals in the sediment.

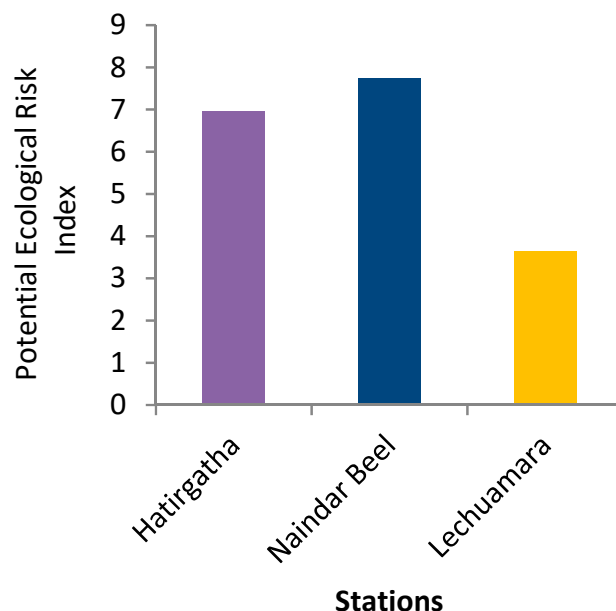


**Figure 2.** Geo-accumulation index ( $I_{geo}$ ) of metals in the sediments of Tanguar Haor.

### 3.3. Potential Ecological Risk Assessment (PERI)

The calculated results for the potential ecological risk index of heavy metals in the surface sediment of Tanguar Haor are illustrated in Figure 3. Heavy metal pollution by

a single element was obtained, and the degree of pollution from the six heavy metals decreased in the following sequence: As > Cu > Zn > Pb > Cr > Ni. In comparison with the other elements, the PERI for As was higher. However, the  $E_{ri}$  values of Ni and Cr indicated low pollution in the sediment samples of Tanguar Haor.



**Figure 3.** Potential ecological risk (PER) value of heavy metals in sediments.

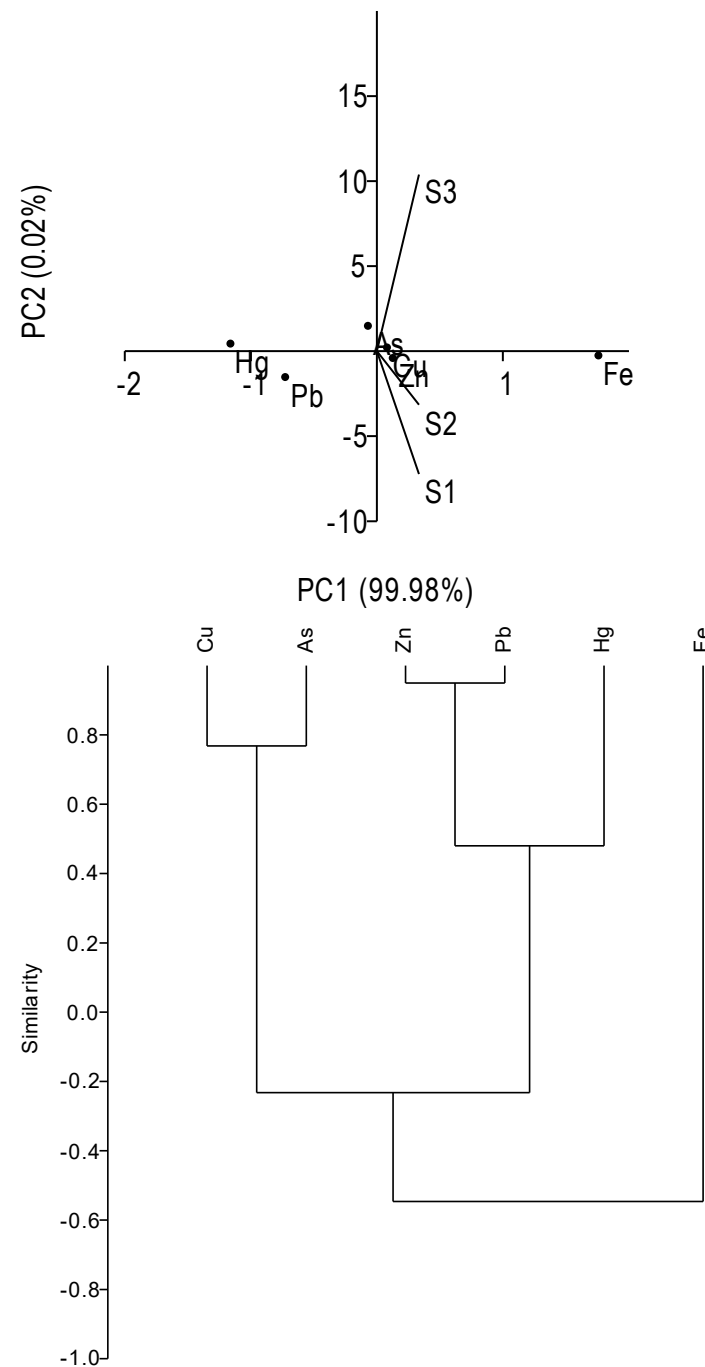
#### 3.4. Source Identification of Heavy Metals Using Univariate and Multivariate Analyses

Correlations among heavy metals may reflect the origin and migration of these elements [57]. If no correlation exists among the elements, then the metals are not controlled by a single factor [58]. However, in this study, a very high positive correlation was observed in the case of Zn–Pb ( $r = 0.967$ ), and a high positive correlation was found in Cu–As ( $r = 0.726$ ). In contrast, a high negative correlation was documented between Zn–As ( $r = -0.758$ ) and As–Pb ( $r = -0.898$ ) (Table 4). Hence, the positive relationship between the identified metals specified that these originated from a common source, either natural or anthropogenic [59]. The Z score technique and log-transformed data were used to perform PCA. The original dataset dimension was decreased through PCA. Based on the PCA results, it was possible to separate the variables with eigenvalues >1 into two components. These two components, PC1 and PC2, contributed 99.98% and 0.019%, respectively, to the change (Figure 4). Fe is associated with the first component that accounts for the majority of the variation. Given that this metal was typically present in the soil's parent material, lithogenic origins can be assumed for this component. The wetland's soils were silted; hence, this region is referred to as an alluvial one. In addition, redox interfaces with circumneutral pH and a constant supply of Fe (II) from Fe-oxidizing bacteria (FeOB) raised Fe levels in freshwater wetlands. The concentration of this heavy metal in the soil as determined by this investigation is consistent with the ranges of concentration found in the parent material [6,15,60–62]. This finding suggests that the lithogenic component predominates the distribution of the majority of the studied elements. Hg and Pb, which may be linked to human activity, are included in the second component. Enrichment factor values also indicated their high levels, and it has been noted that Pb and Hg are easily accumulated in the topsoil [6]. Cu, Zn, and As are found at the base of the two axes, which shows that their origins are both lithogenic and anthropogenic. The results of CA, which divided the data into three groups to represent various areas, were nearly identical to those of PCA. The single metal (Fe) was in Group 1, followed by Groups 2 (Pb, Hg, and Zn), Group 3 (Cu, and As). Group 1 contained the most anthropogenic metal by volume.

**Table 4.** Correlation matrix of the analyzed heavy metals in sediment samples.

|    | Fe     | Cu     | Zn       | As       | Pb    | Hg |
|----|--------|--------|----------|----------|-------|----|
| Fe | 1      |        |          |          |       |    |
| Cu | −0.689 | 1      |          |          |       |    |
| Zn | −0.651 | −0.102 | 1        |          |       |    |
| As | −0.002 | 0.726  | −0.758   | 1        |       |    |
| Pb | −0.437 | −0.350 | 0.967 ** | −0.898 * | 1     |    |
| Hg | −0.367 | −0.201 | 0.58     | 0.311    | 0.451 | 1  |

\* indicates significant relation ( $p < 0.05$ ). \*\* indicates highly significant relation ( $p < 0.01$ ).

**Figure 4.** Principal component and cluster analyses of the metals in the sediment of Tanguar Haor.

### 3.5. Limitations of the Study

Although this is the first study to report heavy metal data from Tanguar Haor, it does have some drawbacks. Because of the project's financial and time constraints, the sample size and the duration were limited, and the results should be considered preliminary. Other sediment characteristics, such as texture, organic matter, pH, and vegetation cover, which may affect the variation in metal concentrations at various sampling sites, were not feasible to include in this analysis because high levels of organic matter and clay allow plants to directly absorb or uptake metals from sediments. Due to these restrictions, longer investigations with a higher sample size are recommended. In addition, the contamination level of heavy metals in the water and organisms is still unknown.

### 3.6. Current Challenges and Future Perspectives

Few studies have documented the fact that the ecosystem services of the studied wetland have been reduced due to changes in land use, population growth and resultant anthropogenic pollution. However, the specific reasons for the reduced services are yet to be known. Pollution from various sources may be the reason. Therefore, future studies should focus on measuring the holistic ecological quality of the study area using water, sediment and biota, and identifying the specific sources of pollution.

## 4. Conclusions

This study assessed the trace element concentrations (Fe, Zn, Cu, Pb, As, and Hg) in the sediment of Tanguar Haor, the second Ramsar site in Bangladesh, for the first time. The results showed that the study area was in a low-to-moderate-pollution state. Arsenic concentrations were higher than the amounts found in natural shale. The concentration of Cu and Hg was very close to the shale value, indicating moderate levels of contamination. Land erosion, the use of agrochemicals and the disposal of untreated sewage may be attributed to this increased level. The findings suggest monitoring As, Cu, and Hg on a regular basis. Future studies should pay attention to identifying the specific sources of these metals. Different levels of contamination were evaluated by the use of several contamination assessment techniques. According to CF values, the area was moderately contaminated by As, Cu, and Hg. Additionally, the average EF values for As, Cu, and Hg were >50, indicating exceptionally severe enrichment. Arsenic levels are associated with a considerable risk, according to possible ecological risk assessment values. The results suggest that some areas could be impacted by anthropogenic sources that are highly contaminated with Cu, Fe, Zn, and As. Data on heavy metals and their possible risks at this Ramsar site of national and international importance are scant. As a result, our findings will be useful information for regulatory bodies, environmentalists, conservationists, and public health authorities to protect this area from further pollution. Furthermore, future researchers can use this data as a reference value for the evaluation of any further pollution status of this ecologically critical area.

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