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Research Article

Anthropic Interventions: Imposing Ecological Risk to the Natural Spawning Ground of Major Carps in Bangladesh

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Abstract

Bangladesh Fisheries Research Institute conducted a study to evaluate heavy metal contamination in the sediment of the Halda river. Data were collected from four locations: Khondokia Khal, Katakhali, Madari Khal, and Madarsha. Concentrations of eight heavy metals (Cd, Cr, Ni, Cu, Fe, Mn, Pb, and Zn) were measured, with Cd ranging from 0.04 to 0.96 mg kg^{-1}, Cr from 18.20 to 48.14 mg kg^{-1}, Ni from 0.70 to 9.10 mg kg^{-1}, Cu from 6.70 to 9.10 mg kg^{-1}, Fe from 14501.00 to 20323.00 mg kg^{-1}, Mn from 270.00 to 430.00 mg kg^{-1}, Pb from 1.83 to 8.12 mg kg^{-1}, and Zn from 29.00 to 43.00 mg kg^{-1}, respectively. The geoaccumulation index (I_{geo}) indicated Mn contamination (0.37 ± 0.02), supported by Improved Nemerow Index (I_N) showing moderate contamination of heavy metals in the river Halda. The pollution load index (PLI) (0.31 ± 0.04) indicated no significant pollution, and the contamination factor (CF) also demonstrated low pollution levels. Katakhali Khal exhibited the highest degree of contamination and the modified degree of contamination was (mCd) 4.22 ± 0.45. Enrichment factor (E_F) ranged from 0.43 ± 0.10 to 4.14 ± 3.33, indicating minimal to moderate enrichment. Ecological risk factor (E^i_r) (12.75 ± 0.68 to 49513.56 ± 39.23) and risk index (RI) (467.70 ± 4.53 to 641.92 ± 27.72) demonstrated varying degrees of ecological risk. The modified hazard quotient (mHQ) indicated very low to low contamination severity. Principal Component Analysis (PCA) and Cluster Analysis (CA) revealed correlations among heavy metals, suggesting similar sources. These findings emphasize the need for immediate action to address heavy metal contamination in the Halda river sediment.

Introduction

The continuous discharge of pollutants into aquatic systems from both natural and anthropogenic sources, such as rapid urbanization, industrial development, domestic sewage, mining, agriculture, electronic waste, accidents, navigation traffic, and climate change events like floods, has raised significant concerns regarding the stability of aquatic ecosystems [1-9]. Among these pollutants, heavy metals have become particularly concerning environmental contaminants, especially in developing countries were infrastructure and environmental management lag behind population growth and urbanization [10]. Heavy metals, generally defined as metals with a specific weight greater than 5 g cm^{-3}, encompass approximately 40 different elements [11]. These metals, including cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn), naturally occur in the environment [12,13] and play essential roles in ecosystems and human health [14-19]. For instance, copper (Cu) and zinc (Zn) are vital for enzyme reactions, functioning as cofactors and enzyme activators, forming complexes with enzymes and substrates, and serving as prosthetic groups in metalloproteins [20]. Despite their essential roles, even trace amounts of these metals can be harmful. Additionally, heavy

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metals are non-biodegradable and can bio-accumulate in organisms such as mussels, oysters, shrimp, and fish [21-33]. The accumulation of heavy metals disrupts ecosystems and causes toxic effects, leading to severe health issues or death in most living organisms [34]. These metals enter the human body through inhalation or ingestion, posing significant health risks. The accumulation and adverse effects of heavy metals on human health and aquatic life, including fish and other aquatic organisms, have thus become a global concern [11,23,35-40].

Fluvial natural water bodies play a crucial role in transporting heavy metals derived from terrestrial runoff, atmospheric deposition, sewage discharge, and other pathways [41-43]. Due to their low solubility in water, heavy metals are predominantly sequestered by fine particles, resulting in their accumulation in sediments [44-46]. Consequently, sediments serve as the principal repository for heavy metals and various chemical constituents, making them key indicators of water pollution in lakes and rivers [47-49]. These sediment matrices provide valuable insights into recent environmental perturbation. Environmental variations such as pH, oxidation-reduction potential (Eh), salinity, and organic matter content can influence the retention of heavy metals in sediments, potentially leading to their remobilization and subsequent release into the water column, thus causing secondary contamination [50-52].

Fish and sediments are recognized as primary bio-indicators for assessing heavy metal levels in natural aquatic ecosystems [40,53,54]. This underscores the precision and utility of fish in gauging habitat transformations within these ecosystems. However, Malik, et al. [54] argued that, due to their position at the base of the aquatic food chain, fish may accumulate heavy metals from sediment. Thus, identifying and quantifying heavy metals in both water and sediments are crucial environmental considerations [55-57]. Numerous global studies have examined heavy metal contamination in soils, contributing to a comprehensive understanding of this environmental concern [55-59].

In recent years, Bangladesh has experienced a noticeable increase in exposure to heavy metals and metalloids, supported by a growing body of literature [2,10,34,36,41,42,44,47]. This rise in contamination stems from diverse sources such as industrial activities, domestic waste, and agrochemical use, collectively contributing to the degradation of water quality [34,60-62]. While several studies have investigated heavy metal presence in various rivers across Bangladesh [2,10,34,36,42,44], limited attention has been focused on assessing contamination in the Halda river to date [63-65]. The Halda River holds significant ecological importance in Bangladesh as a natural breeding ground for Indian Major Carps (IMCs) during their breeding season, representing a unique natural heritage of the country. However, the river's water quality is progressively deteriorating due to both natural factors and human activities. This study aims to evaluate the current status of heavy metals, assess their potential ecological risks, and propose mitigation measures to preserve the biodiversity of the Halda river. Initial findings from the first year of research have been previously published [63], with the present study presenting outcomes of subsequent year's investigation.

Materials and methods

Sampling sites

The present study extends the previous year's investigation and was conducted at the same sampling locations along the Halda river, situated between 22° 25′ 13″–22° 48′ 51.37″ N and 91° 45′ 00″–91° 52′ 33″ E [63]. Four specific points along the river-Khondokia Khal, Katakhali Khal, Madari Khal, and Madarsha-were selected for sediment sample collection.

These 'Khals,' local canals, are primary conduits for pollutant transport into the Halda river.

Sampling and data collection were conducted monthly over one year, from July 2021 to June 2022. The Global Positioning System (GPS) coordinates for these sampling sites are detailed in Figures 1,2 and Table 1.

Sample collection, preparations and analysis

Over the course of one year, a total of 48 surface soil samples were collected from specific locations along the Halda river. To minimize potential contamination, these samples

Figure 1: Map of the study area and the location of different sampling sites and glimpse of river Halda.

Figure 2: Outlet of Khal, primary conduit of disposing municipal sewerage and other untreated contaminants in to the river Halda.

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Table 1: GPS location of selected sampling points of the river Halda.

Places	GPS Point (Longitude and Latitude)
Madarsha	22°28'2.80"N 91°51'24.04"E
Madari Khal	22°26'59.04"N 91°51'31.76"E
Khondokia Khal	22°26'7.79"N 91°52'10.99"E
Katakhali Khal	22°25'49.58"N 91°52'30.92"E

were carefully placed in clean polythene covers. Sampling was performed using an Ekman dredge, targeting soil layers between 10 and 50 centimeters deep. The GPS coordinates for each sampling location are detailed in Table 2.

At each site, three individual samples were gathered and combined to form a composite sample. Subsequently, samples from different locations were further combined, resulting in four composite samples representing distinct areas along the river.

The analysis focused on eight common heavy metals: Cadmium (Cd), Chromium (Cr), Nickel (Ni), Copper (Cu), Iron (Fe), Manganese (Mn), Lead (Pb), and Zinc (Zn). Initially, soil samples were air-dried at room temperature. They were then processed to remove plant roots, large stones, debris, organic residues, and visible impurities. Finally, the samples were crushed, ground, and sieved through a 0.85 mm plastic sieve before being stored at 4°C until spectrophotometric analysis was conducted.

Following preliminary preparations, sediment samples were promptly transported to the Soil and Water Analysis Laboratory at the Institute of Water and Flood Management, Bangladesh University of Engineering and Technology (BUET) for analysis. Each 2-gram sample was treated equivalently to a 1-liter sample for Inductively Coupled Plasma (ICP) analysis. Consequently, concentrations were expressed as micrograms per 2 grams of sample (µg/2 g) or milligrams per 2 kilograms of sample (mg/2 kg). These values were converted to milligrams per kilogram (mg/kg) by multiplying by 0.5.

Stringent measures were employed to prevent sample contamination, including the use of clean, powder-free latex gloves and laboratory coats. Glassware was meticulously cleaned with a chromic acid solution and distilled water to eliminate residual impurities. Analyticalgrade chemicals and reagents were utilized to ensure accuracy throughout the analysis. Blank determinations were conducted to correct instrumental readings and account for background interference.

The assessment of heavy metal pollution in the surface sediments of the Halda river involved the application of various indices derived from the concentration data of these metals. These indices played a crucial role in evaluating the extent of heavy metal contamination in the river sediments.

Sediment quality assessment

Index of geo-accumulation: The geo-accumulation index (I_{geo}) serves as a valuable tool for mitigating the influence of human-related factors when evaluating soil contamination. It has been introduced to replace the traditional single-factor Nemerrow index [68]. I_{geo} was originally introduced by Müller [67] and has found extensive application in sediment geochemistry for assessing the extent of heavy metal contamination in sediments. The I_{geo} is defined by the following equation:

$$I_{geo} = \log_2 (Cn/1{:}5 \times Bn) \quad (1)$$

The geo-accumulation index (I_{geo}) is calculated using the above formula, where Cn represents the concentration of elements in the sediment samples, and Bn corresponds to the geochemical background concentration for the same elements (n). The background values used for these elements in the calculation of the index are consistent with those employed in the computation of contamination factors (CFs). A factor of 1.5 is included to account for variations in the background due to lithological differences.

The I_{geo} index is categorized into seven distinct classes, as described in Table 3 [67]. These classes serve as a classification system for assessing the level of heavy metal contamination in sediments based on the calculated I_{geo} values.

I_{geo} is particularly valuable in mitigating the impact of natural factors such as parent rocks and human-induced effects on heavy metal contamination in soil. Consequently, it is wellsuited for assessing heavy metal contamination in areas characterized by industrial and mining activities. However, when evaluating contamination caused by a single heavy metal, I_{geo} alone may not offer a complete representation of the contamination status in a given area. Therefore, it's essential to employ a comprehensive index approach. In this regard, the traditional Nemerow index (I_N) has been enhanced

Table 2: Wave length used in emission measurements and the instrumental detection limit for measurement by using ICP.

Elements	Wavelength (nm)	Instrumental detection limit (µg/l)
Cd	228.8	0.1
Cr	205.5	0.4
Ni	232.0	0.5
Cu	324.7	0.4
Fe	238.2	0.3
Mn	259.3	0.1
Pb	220.3	1.7
Zn	213.8	0.2

Source: Praveen Sarojam [66]. PerkinElmer, Inc. Shelton, CT 06484 USA.

Table 3: Index classification of sediment quality [67,69,70].

I_{geo} Values	Class	Sediment quality
≤ 0	0	Unpolluted
0-1	1	Unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	Moderately to strongly polluted
3-4	4	Strongly polluted
4-5	5	Strongly to extremely polluted
≥6	6	Extremely polluted

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by substituting the single-factor index with I_{geo}, as outlined in Table 4. The following Equation (3) was used in this improved evaluation:

$$I_N = \sqrt{(I_{geomax}{}^2 + I_{geoave}{}^2)/2} \quad (2)$$

I_N = 1.86 (In the present study).

Contamination factor, degree of contamination and modified degree of contamination: The Contamination Factor (CF) and Degree of Contamination (Cd) are employed to evaluate the level of pollution in sediments regarding heavy metal content [59]. The CF is calculated as a ratio, derived by dividing the concentration of each metal in the sediment by a baseline or background value [71]. The CF for each metal is computed using the following formula [72]:

$$CF = \frac{\text{Concentration of measured metal}}{\text{Background concentration of the same metal}} \quad (3)$$

To aid in pollution control efforts, Hakanson [72] introduced a diagnostic tool referred to as the 'degree of contamination' (Cd), which is calculated as the sum of the CF for each individual sample:

$$Cd = \sum_{i=1}^{n} CF \quad (4)$$

The purpose of Cd is to offer an assessment of the overall contamination level in the surface layers of a specific core or sampling site. Hakanson [72] has established four sediment grade classifications based on CF and Cd values (as shown in Table 5).

In order to calculate the degree of contamination, at least five sediment samples are required to provide a mean concentration and to compare with the background value. To avoid this constraint, a generalized index was developed [73]; named modified degree of contamination (mCd) to assess the overall heavy metal contamination of soil (Table 6). The modified degree of contamination (mCd) was estimated using the following equation:

$$mCd = \frac{\sum_{i=1}^{n} CF}{n} \quad (5)$$

Enrichment factor

Enrichment Factor (EF) is a convenient method to evaluate the magnitude of anthropogenic heavy metal contaminants [74] in the environment [75]. The EF was calculated using the following equation:

$$EF = \frac{\left(\frac{CM}{CFe}\right) sample}{\left(\frac{CM}{CFe}\right) Earth' \text{ scrust}} \quad (6)$$

Where, (CM/CFe) sample is the proportion of concentration of heavy metal (CM) and iron (CFe) in the sediment sample, and (CM/CFe) Earth's crust is the proportion of heavy metal and iron in the Earth's crust [76]. Iron (Fe) is used for the geochemical normalization to calculate the enrichment factor. Different values of EF, indicates different degrees of enrichment; where EF<1= indicates no enrichment; EF<3 = minor enrichment; EF 3-5 = moderate enrichment; EF 5-10 = moderately severe enrichment; EF 10-25 = severe enrichment; EF 25-50 = very severe enrichment; and EF>50 = extremely severe enrichment [74,77].

Pollution load index

Pollution Load Index (PLI) determines the communal effects of various pollutants in sampling sites deposited in soils and sediments [78]. The PLI for each site has been estimated by the multiplications of the nth root of the studied heavy metals [79].

$$PLI\ (CF1 \times CF2 \times CF3 \times \ldots\ldots\ldots \times CFn)^{n} \quad (7)$$

where, CF is the contamination factor and n is the number of metals. The PLI of >1 indicates polluted, whereas <1 indicates no pollution [80]. This index provides a quick assessment to unskilled people to compare the pollution status of different places.

Table 4: Improved Nemerow Index [68].

I_N Values	Class	Sediment quality
$0 < I_N \le 0.5$	0	Uncontaminated
$0.5 < I_N \le 1.0$	1	Uncontaminated to moderately contaminated
$1.0 < I_N \le 2.0$	2	Moderately contaminated
$2.0 < I_N \le 3.0$	3	Moderately to heavily contaminated
$3.0 < I_N \le 4.0$	4	Heavily contaminated
$4.0 < I_N \le 5.0$	5	Heavy to extremely contaminated
$I_N > 5.0$	3	Extremely contaminated

Table 5: Sediment classes according to CF and C_d values [72].

CF/C_d Values	Class	Sediment quality
CF>1	0	Low CF
1≤CF<3	1	Moderate CF
3≤CF<6	2	Considerable CF
CF≥6	3	Very high CF
C_d<6		Low degree of contamination
6<C_d<12		Moderate degree of contamination
12<C_d<24		Considerable degree of contamination
C_d> 24		High degree of contamination

Table 6: Sediment classifications according to mCd [73].

mCd Values	Contamination situation
mCd<1.5	Nil to very low degree of contamination
1.5<mCd<2	Low degree of contamination
2≤mCd<4	Moderate degree of contamination
4≤mCd<8	High degree of contamination
8≤mCd<16	Very high degree of contamination
16≤mCd<32	Extremely high degree of contamination
mCd≥32	Ultra-high degree of contamination

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Ecological risk factor and risk index

The E_r^i is widely used to assess the ecological risk of heavy metals in sediments [81]. The index was calculated by the following equations [72]:

$$Er^i = Tr^i \times C^i \quad (8)$$

$$RI^i = \sum Er^i \quad (9)$$

where E_r^i is the potential ecological risk factor for a given contaminant and T_r^i is the toxic response factor of each element, including Cd = 30, Cr = 2, Ni=5, Cu = 5, Fe = 2.82, Mn = 1, Pb = 1 and Zn = 1 [81-87]. Risk index (RI) is the sum of E_r^i and represents potential toxicity response of various heavy metals in sediments. The E_r^i and RI values [84,87,88] are furnished in Table 7.

Probable effects level

Probable Effects Level (PEL) are guidelines widely accepted to evaluate bio-toxic risks of sediments. In view of the fact that heavy metals always occur in sediments as complex mixtures, the mean PEL quotient (m-PEL-Q) method has been proposed and used to determine the possible biological effect of combined toxicant groups by calculating the mean quotients for a range of heavy metals using the following formula:

$$PEL - Q = \frac{\sum_{i=1}^{n}\left(\frac{Ci}{PELi}\right)}{n} \quad (10)$$

where C_i is the content of measured element i, PEL_i is the PEL value of element i and n is the number of elements. Several classes of toxicity probability [89] for biota are presented in (Table 8).

Modified hazard quotient (mHQ)

A novel approach to assessing the risk posed by individual metals to organisms in a specific region is the modified hazard quotient [90] (Table 9). Its validity, reliability, and accuracy have been confirmed by various researchers [91-95]. As mentioned earlier, this innovative method enables the detection of contamination by contrasting metal concentrations in sediment (measured in mg/kg) with the distributions of adverse ecological impacts at slightly different Threshold Effect Levels (TEL), probable effect levels (PEL), and Severe Effect Levels (SEL), as outlined in Tables 10,11.

$$mHQ = 2\sqrt{\left[C_i\left(\frac{1}{TEL_i} + \frac{1}{PEL_i} + \frac{1}{CEL_i}\right)\right]} \quad (11)$$

Equipment used

Ekman dredge (10 cm - 50 cm layer of the soil), handheld GPS, 0.85 mm plastic sieve, spectrophotometer, clean polythene covers.

Table 7: Ecological risk factor (E_r^i) and risk index (RI) for studied metals in the river Halda.

E_r^i Values	Ecological Class
<40	Low ecological risk
40< E_r^i≤80	Moderate ecological risk
80< E_r^i≤160	Appreciable ecological risk
160< E_r^i≤320	High ecological risk
E_r^i>320	Serious ecological risk
RI Values	Ecological Class
<150	Low ecological risk
150≤RI <300	Moderate ecological risk
300≤RI <600	Considerable ecological risk
RI>600	High ecological risk

Table 8: Probable effects level quotient and ecological classification of the river Halda.

PEL-Q Values	Ecological Class
PEL-Q < 0.1	8% probability of toxicity
PEL-Q = 0.11-1.5	21% probability of toxicity
PEL-Q = 1.51-2.3	49% probability of toxicity
PEL-Q > 2.3	73% probability of toxicity

Table 9: Modified hazard quotient (mHQ).

mHQ Values	Ecological Class
mHQ < 0.5	Nil to very low severity of contamination
0.5 ≤ mHQ < 1.0	Very low severity of contamination
1.0 ≤ mHQ < 1.5	Low severity of contamination
1.5 ≤ mHQ < 2.0	Moderate severity of contamination
2.0 ≤ mHQ < 2.5	Considerable severity of contamination
2.5 ≤ mHQ < 3.0	High severity of contamination
3.0 ≤ mHQ < 3.5	Very high severity of contamination
mHQ > 3.5	Extreme severity of contamination

Statistical analysis

Initially, the data were collected and processed using Microsoft Excel. Subsequent analyses were conducted using various statistical software packages. For instance, JMP software version 14 was employed to perform one-way analysis of variance (ANOVA) to determine if any statistically significant ($p < 0.05$) spatial variations existed in the concentrations of heavy metals. To create Pearson's product-moment correlation matrix (Table 10), GraphPad Prism version 6 was utilized. Cluster Analysis (CA) was carried out to identify similarities and variations in relation to the influencing factors on the studied heavy metals [46]. A dendrogram, illustrating the similarities among the heavy metals and helping identify their sources of origin, was prepared using Past software version 4. The findings of the present study, derived from the various software tools, are presented in the form of charts and Tables.

Results and discussion

The concentrations of heavy metals in sediment samples collected from four distinct sampling locations of the river

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Table 10: Sediment quality guidelines.

Sediment Quality Threshold values	Heavy metals concentration (mg/kg)							
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn
TEL	0.596	26	16	16	-	460	31	540
PEL	3.53	160	36	108	-	-	112	315
SEL	10	110	75	110	40000	1100	250	820
References	MacDonald, et al. [129]; Canadian Council of Ministers of Environment [131]	Persuad, et al. [130]; MacDonald, et al. [129]	MacDonald, et al. [129]; Canadian Council of Ministers of Environment [131]	Persuad, et al. [130]; MacDonald, et al. [129]	MacDonald, et al. [129]	Persuad, et al. [130]; MacDonald, et al. [129]	Persuad, et al. [130]; MacDonald, et al. [129]	Zubir, et al. [132]

Table 11: Severity of contamination on the basis of modified hazard quotient (mHQ) of heavy metals.

Sites	Modified hazard quotient (mHQ)							
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn
Khondokia	0.99	1.09	0.89	0.83	0.60	0.92	0.45	0.47
Katakhal	1.31	1.15	0.32	0.74	0.63	1.00	0.30	0.45
Madarikhal	0.79	1.67	0.78	0.77	0.70	1.13	0.35	0.51
Madarshah	0.70	1.27	0.93	0.77	0.71	1.06	0.61	0.48
Overall Mean ± SD	0.95 ± 0.27	1.29 ± 0.26	0.73 ± 0.28	0.77 ± 0.4	0.66 ± 0.05	1.03 ± 0.09	0.43 ± 0.13	0.48 ± 0.03
Class	Very low	Low	Very low	Very low	Very low	Low	Very low	Very low

Halda have been provided in Table 10. To assess variations in the mean concentrations of these different heavy metals, a one-way ANOVA was initially conducted, followed by a Tukey-Kramer test. The results of these analyses revealed statistically significant spatial differences ($p < 0.05$) (Table 12). The present study observed a range of average concentrations for these heavy metals in Halda river sediments: 0.24 - 0.84 mg kg-1 for Cadmium (Cd), 20.20 – 47.27 mg kg-1 for Chromium (Cr), 1.0 - 8.40 mg kg-1 for Nickel (Ni), 6.90 - 8.70 mg kg-1 for Copper (Cu), 14520.0 - 20281.0 mg kg-1 for Iron (Fe), 274.0 - 416.0 mg kg-1 for Manganese (Mn), 1.95 - 7.87 mg kg-1 for Lead (Pb), and 32.40 - 42.10 mg kg-1 for Zinc (Zn). The relative concentrations of heavy metals, in descending order, were: Iron (Fe), Manganese (Mn), Zinc (Zn), Chromium (Cr), Nickel (Ni), Lead (Pb), Copper (Cu), and Cadmium (Cd).

The findings in the present study revealed that the concentrations of all studied heavy metals in the sediment were above the permissible limit as set by WHO [42,46], USEPA [47] and DPHE [48] (Table 13). In addition to comparing the data of the present study with some other global standards, the results were also compared with some previous works on the same river and other important river system of Bangladesh (Table 14). The results demonstrated that all most all heavy metal concentrations were lower than Buriganga, Dhaleshwari and Shitalakhya as these rivers are severely polluted by municipal and industrial effluents, sewerage and other non-treated chemicals [96-98,106]. However, the present status of the river Halda is not peasant as the condition of the river is gradually exacerbating compared to some recent investigations.

In the present study, Katakhali Khal exhibited the highest mean concentration of Cd (0.8 ± 0.1), while Madarshah had the lowest concentration (0.1 ± 0.1). Significant ($p < 0.05$) deviations were observed among the studied sites. The mean Cd levels observed exceeded both global and country-specific permissible limits, as outlined in Tables 13,14. A comparative analysis with prior investigations on sediment samples from various significant rivers in Bangladesh revealed divergent findings. Specifically, the Cd concentration in the Halda River was lower than that reported by Alam, et al. [63] but higher than the findings of Bhuyan, et al. [65]. Moreover, it was lower than the levels detected in the Buriganga [2,10,42], Dhaleshwari [98,99], Turag [102,103], and Shitalakhya rivers [106,117], yet higher than those in the Karnafuly [100,109], Meghna [105], and Brahmaputra River [47] (Table 14). Regional disparities in heavy metal concentrations are common, influenced by the presence or absence of various pollution sources along riverbanks and the discharge of these metals into the rivers. Notably, the current study indicates a 54% reduction in Cd concentration in the Halda River compared to the earlier study by Alam, et al. [63].

The concentration of Cr ranged from 20.20 to 47.30 mg/kg, with the highest level (47.3 ± 1.3 mg/kg) observed at Madari Khal and the lowest (20.2 ± 2.3 mg/kg) at Khondokia Khal. No significant variations were noted among the studied sites for this metal. The mean concentration surpassed the limits established by the World Health Organization (WHO) [42,43] (Table 13). In comparison to prior studies, Mohiuddin, et al. [2] and Islam, et al. [107] reported higher concentrations of Cr in the Buriganga and Shitalakhya rivers, respectively. Conversely, Ahmed, et al. [98] in Dhaleshwari, Islam, et al. [100] in Karnafuly, Banu, et al. [102] in Turag, Hassan, et al. [104] in Meghna, Bhuyan, et al. [47] in Brahmaputra, and Bhuyan, et al. [65] in Halda rivers found lower concentrations of Cr than the present study. However, it is noteworthy that the concentration of Cr in the current study was 32% lower than that was reported by Alam, et al. [63].

In the investigated regions, the concentrations of nickel (Ni), copper (Cu), and lead (Pb) ranged from 1.0 to 8.4, 7.0 to 8.7, and 2.0 to 7.9 mg/kg, respectively. Katakhali Khal exhibited the lowest concentrations (8.4 ± 1.0 and 2.0 ± 0.1 mg/kg for Ni and Cu, respectively), while Madarshah displayed the highest concentrations for Ni (8.4 ± 1.0 mg/kg) and Pb (7.9 ± 0.2 mg/kg), and Khondokia Khal showed the highest concentration for Cu (8.7 ± 0.4 mg/kg). Statistical analysis revealed significant variations ($p < 0.05$) in the concentrations of Ni, Cu, and Pb

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Table 12: Heavy metal concentration in the sediments of the river Halda.

Sites	Metal Concentrations (mg/kg) (Mean ± SD)							
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn
Khondokia Khal	0.5 ± 0.1^{b}	20.2 ± 2.3^{b}	7.7 ± 0.6^{a}	8.7 ± 0.4^{a}	14520.0 ± 19.5^{d}	275.0 ± 4.0^{d}	4.3 ± 0.4^{b}	34.7 ± 2.1^{b}
Katakhali Khal	0.8 ± 0.1^{a}	22.4 ± 1.90^{b}	1.0 ± 0.3^{c}	7.0 ± 0.2^{b}	15911.0 ± 34.7^{c}	324.0 ± 10.2^{c}	2.0 ± 0.1^{c}	32.4 ± 3.1^{b}
Madari Khal	0.3 ± 0.1^{bc}	47.3 ± 1.3^{b}	5.8 ± 0.6^{b}	7.6 ± 0.7^{ab}	19520.0 ± 11.0^{b}	416.0 ± 16.4^{a}	2.7 ± 0.5^{c}	42.1 ± 1.0^{a}
Madarshah	0.1 ± 0.1^{c}	27.7 ± 5.0^{b}	8.4 ± 1.0^{a}	7.5 ± 0.6^{ab}	20281.0 ± 41.5^{a}	366.0 ± 19.0^{b}	7.9 ± 0.2^{a}	37.3 ± 1.^{0a}b

*Levels not connected by same letters are significantly different.

among the surveyed sites. The mean concentrations of these heavy metals exceeded the drinking water standards set by the World Health Organization (WHO) [42-44], USEPA [47], and DPHE [48], but remained within safe limits according to WHO [45,46] (Table 13). Furthermore, Ni concentrations were comparatively lower than those reported in previous studies of various rivers in Bangladesh, including Buriganga [97], Dhaleshwari [99], Karnofuly [101], Turag [103], Meghna [105], Shitalakhya [107], Halda [65], and Brahmaputra [47]. Cu concentrations were lower than those in Buriganga [2,10,42], Dhaleshwari [98,99], and Shitalakhya [106], but higher than Karnofuly [101], Turag [103], Meghna [105], Halda [63,65], and Brahmaputra [47]. Conversely, Pb concentration was lower than that in Buriganga [96], Dhaleshwari [99], Karnofuly [100,101], Meghna [105], Shitalakhya [107], and Halda [65] rivers but higher than Turag [103], Brahmaputra [47], and our previous studies of Halda [63] rivers.

The highest concentration of Fe (20281.0 ± 41.5) was found at Madarshah, whereas the maximum levels Mn and Zn (416.0 ± 16.4 and 42.1 ± 1.0 mg/kg) were found at Madari Khal point. Based upon statistical analysis, significant ($p < 0.05$) deviations were observed for these metals among the studied sites. The concentration of Mn found in the present study (345.07 mg/kg) was substantially lower than the Buriganga (4036 mg/kg) river but it was apparently higher than the level found in some other important rivers in Bangladesh by Ahmed, et al. [96,97], Islam, et al. [100], Bhuyan, et al. [47]. On the contrary, the concentration of Zn found in the present study (max 42.1 ± 1.0 mg/kg) was lower than Buriganga [2,10,42] and Shitalakhya [107] but higher than Karnafuly [100], Turag [103] and Brahmaputra [47] rivers, respectively.

A higher concentration of these metals might be outcomes of discharges of textile and paint industries and domestic sewage waste [10,42,47,103,107,108,112]. Bhuyan and Baker [65] also reported the seasonal fluctuations in the level of the heavy metals in the river Halda.

The Igeo values have been presented in Table 14. In all sampling sites, the Igeo values of all studied heavy metals except Mn configured negative values after calculation, indicating that these sites were not polluted by the heavy metals but Mn (Table 15).

The overall I_{geo} values of all studied heavy metals ranged from -5.08 to 1.16. Muller [83] classification of sediment quality disclosed that all sites were moderately polluted due contamination with Mn and the orderly arrangement of the sites on the basis of the concentration of this metal stand Mad arikhal>Madarshah>Katakhali>Khondokia.

Table 13: Global standards of different heavy metals compared to the present study.

Global Standards	Heavy Metals (mg/l) in drinking water						
	Cd	Cr	Ni	Cu	Mn	Pb	Zn
WHO [42]	0.003	0.05		2.00	0.50	0.01	3.00
WHO [43]	-	0.05		2.00		-	-
WHO [44]	0.003		0.07		0.40	0.01	
USEPA [47]	0.005	0.10		-	0.05	-	5.00
DPHE [48] surface water standard	0.005	0.05	0.1	1.0	30 - 35	0.05	5.00
Global Standards	Heavy Metals (mg/kg) in sediment						
WHO [45,46]	0.1	0.03 - 0.3		0.0 - 0.15	0.2	5.0	≤1.0
Present Study (Mean)	0.46	29.39	5.73	7.68	345.1	4.2	36.6

Mohiuddin, et al. [2] studied the I_{geo} values for Mn for 11 locations of Buriganga river and found the values >1.0, indicating moderately polluted sediment quality. Islam, et al. [108] found higher I_{geo} values for Cd and extremely contaminated sediment quality in Buriganga and Shitalakhya. Hasan, et al. [104] studied the sediment quality of the Meghna River and found positive values for Cd, Pb, Ni and Zn indicating unpolluted to moderately polluted sediment. In the Karnafuly river in Bangladesh, I_{geo} values of for As, Cr exposed unpolluted to extremely polluted status [109]. In the Bortala river in China, the I_{geo} values of Ni, Zn, Cr, As, and Cu indicated no pollution [110]. On the contrary, Malvandi [111] found higher I_{geo} values for As and Se and sediment class ranged from unpolluted to extremely polluted in the Zarrin-Gol River, Iran. Rahman, et al. [112] and Hassan, et al. [113] have opined that higher concentration Al and Mn originates lithogenically and associated with spinning mills and paint industries wastes. The higher I_{geo} values as a result of the increased concentration of Mn found in the river Halda might be the result of similar lithogenic and anthropogenic effects.

To evaluate soil heavy metal contamination in the study area, the improved Nemerow index (IN) was utilized, representing the cumulative effects of all heavy metals. The IN values ranged from 1.29 to 1.74 across the four sampling sites, indicating moderate contamination.

These findings are consistent with the results from the geo-accumulation index (Igeo). Akbor, et al. [105] reported severe contamination in certain sites along the Buriganga River in Bangladesh, as indicated by the IN. Similarly, Guan, et al. [68] observed extreme contamination at all sampling sites in a mining area in Tianjin, China. The elevated values in their studies are attributable to the higher levels of industrialization and anthropogenic activity in those regions compared to the current study area. Table 16 presents the Contamination Factors (CF), Pollution Load Index (PLI), degree of contamination, and modified degree of contamination (mCd) for heavy metals in sediment samples from the Halda River. The overall CF

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Table 14: Concentration of heavy metals in some others rivers in Bangladesh (mg/kg).

Rivers	Heavy Metals								References
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn	
Buriganga	3.33	177.50	200.45	344.20	12989	4036	79.80	502.30	[2,10,42, 97]
Dhaleshwari	2.08	27.39	181.06	37.45	305.2	19.9	15.79	7.3	[98,99]
Karnofuly	0.24	0.76	41.27	1.22		15.30	4.96	16.30	[100,101]
Turag	1.40	0.44	155.4	1.57		5501.6	1.64	1.08	[102,103]
Meghna	0.23	31.74	20.8	4.9		442.60	9.47	79.02	[104,105]
Shitalakhya	5.01	74.82	37.27	143.70		583.90	28.36	200.60	[106,107]
Brahmaputra	0.001	0.01	13.0	0.12		1.44	0.11	0.01	[47]
Halda	1.00	43.22	-	3.77		759.0	4.05	79.10	[63,64]
Present study	0.46	29.39	5.73	7.68		345.07	4.20	36.63	

Table 15: Geo-accumulation indices (I_{geo}) of heavy metals for sediments of all studied sites in the river Halda.

Stations	Geo-accumulation indices (I_{geo})								Improved Nemerow Index (I_N)
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn	
Khondokia	0.07 ± 0.32	-2.90 ± 0.16	-2.10 ± 0.12	-3.11 ± 0.06	-2.29 ± 0.00	0.06 ± 0.02	-1.83 ± 1.59	-2.64 ± 0.09	1.30
Katakhali	0.25 ± 0.03	-2.75 ± 0.12	-5.08 ± 0.42	-3.44 ± 0.04	-2.15 ± 0.00	0.29 ± 0.05	-3.95 ± 0.08	-2.74 ± 0.14	1.74
Madarikhal	-0.62 ± 0.40	1.16 ± 0.04	-2.51 ± 0.14	-3.31 ± 0.13	-1.86 ± 0.00	0.66 ± 0.06	-3.51 ± 0.25	-2.36 ± 0.03	1.36
Madarshah	-2.72 ± 1.07	-2.45 ± 0.28	-1.98 ± 0.19	-3.33 ± 0.11	-1.80 ± 0.00	0.47 ± 0.07	-1.93 ± 0.04	-2.53 ± 0.04	1.29
Mean ± SD	-0.76 ± 0.44	-1.74 ± 0.10	-2.92 ± 0.14	-3.30 ± 0.04	-2.03 ± 0.00	0.37 ± 0.02	-2.80 ± 0.74	-2.57 ± 0.05	1.42 ± 0.21

value for Cadmium (Cd) exceeded 1.54, indicating moderate contamination, whereas the CF values for other heavy metals indicated "low contamination." The CF values observed in the Halda River were lower compared to those found in the Meghna River [105] and Buriganga River [10,42,96,97]. The Buriganga River is heavily polluted due to numerous industrial and sewage discharges that introduce large volumes of toxic wastes daily [114]. Similarly, the Meghna River is polluted at various sites by industries located on or near its banks, including shipyards, cement, paper, jute, super board, oil, sugar, food processing, salt, and chemical industries, which discharge wastewater and contribute domestic and agro-chemical wastes [97]. Higher CF values have been reported in other studies globally. For instance, CF values ranged from 1.3 to 5.5 in the Balok River [82], 0.14 to 6.08 in the Dikrong River [115], and 1.1 to 14.6 in the Tamaki Estuary [116].

The PLI represents the number of times by which the metal content in the sediment exceeds the background concentration and gives a summative indication of the overall level of heavy metal toxicity in a particular sample [45]. The PLI of all sampling sites presented in Table 16 was calculated according to Tomlinson, et al. [79] and the values ranged from 0.29 to 0.51 with the overall value for all four sampling sites (0.37 ± 0.10) considered to be unpolluted. Individual PLI of all sites were also <1 that must be classified as unpolluted.

The order of PLI of four sampling sites from higher to lower was Khondokia>Katakhali>Madarikhal>Madarshah. The PLI values found in the present study in the river Halda were lower than some previous studies, for instance; Ali, et al. [109] found higher PLI values in the Karnafuly river. Mohiuddin, et al. [103] reported PLI values 4.924.2 and 5.2 - 27.4 in summer and winter samples of the Buriganga river which was manifold higher than the present study. Ahmed, et al. [97] stated that 100% sampling points of Buriganga river had PLI>1, which indicated a polluted condition. In another study, Islam, et al. [108] also reported similar results. Furthermore, Abdullah, et al. [82] and Varol [71] found higher PLI values than the present study in the Balok and Tigris rivers, respectively. The reasons of this higher PLI values might be associated with the direct disposal of untreated effluents to the river from different industrial and agro-chemical sources.

In this study, Katakhali exhibited the highest level of contamination (3.79 ± 2.07), followed by three other sites. The overall contamination across the four sampling sites was measured at 2.68 ± 1.84, indicating a low degree of contamination. The mCd values for the eight analyzed elements were consistently found to be <1.5, suggesting minimal to low levels of contamination. These findings contrast with earlier studies by Sikder, et al. [96] and Akbor, et al. [105], who reported higher contamination levels in the Buriganga river. Similarly, studies by Sivakumar, et al. [73] in Tamil Nadu, India, and Abrahim and Parker [116] in New Zealand documented higher mCd values compared to this study. These variations may be attributed to differences in geographical location, with coastal areas typically experiencing higher sediment deposition rates due to river discharge. Despite variations, the average mCd values in our study indicate localized enrichment relative to geochemical background levels, potentially linked to the use of phosphate fertilizers in agricultural soils. Soil and lake acidification processes may also contribute to increased mobilization of cadmium from sediments and soils [117].

Table 17 presents the Enrichment Factor (EF) values for heavy metals analyzed in the sediments of the river Halda. The results indicate that the mean EF value for cadmium (Cd) was >4, indicating moderate enrichment in the river. Conversely, the EF values for other metals studied at all sites indicated "minor enrichment" (Table 17). Previous studies, such as those on the Luanhe river (for Cr, Ni, and Zn) and the Bortala river (for As, Ni, and Cu) [110,118], reported mean EF values >1.5. Abdullah, et al. [82] and Varol [71] suggested that these elevated EF values predominantly originate from natural processes or crustal materials. This factor may also influence the EF values observed in the current study.

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To evaluate the ecological risk of elements in the Halda River, potential ecological risk indices (E^r_i and RI) were measured and are detailed in Table 18. The ranking of potential ecological risk factor (E^r_i) for heavy metals in the river Halda sediments was Fe > Mn > Cr >> Zn > Cu > Ni > Pb > Cd. The average concentrations of Fe and Mn across the four sites indicate a serious ecological risk, while Cr poses a moderate ecological risk. The mean potential ecological risk coefficients for Cd, Ni, Cu, Pb, and Zn were all below 40, classifying them as low ecological risk. Additionally, the RI values at all sites were greater than 400, indicating a considerable ecological risk. Overall, the E^r_i and RI indices for the studied elements in the Halda River surface sediment suggest a potential ecological risk.

Rahman, et al. [112] reported lower E^r_i and RI indices in an adjacent area of the Dhaka Export Processing Zones compared to this study, likely due to their study being conducted in a floodplain area and a river in Savar upazila, which receives less municipal effluent than Dhaka. In contrast, Islam, et al. [119] found significantly higher E_{ri} and RI indices in the Buriganga River compared to the Halda River. Malvandi, et al. [111] observed lower indices in the Zarrin-Gol River in Iran, while Soliman, et al. [84] found higher E^r_i for Cd in Egypt, with other metals showing lower values than in this study. Sivakumar, et al. [73] reported lower RI values than those observed in this study. These discrepancies in E^r_i and RI indices with local and international studies may be due to different types of contaminants from various anthropogenic sources, resulting in variations in metallic element concentrations.

The mean Probable Effects Level (PEL) for the four sampling sites was calculated for metals including Cd, Cr, Ni, Cu, Fe, Mn, Pb, and Zn to assess potential risks to aquatic life. The PEL values ranged from 0.04 to 0.44, while the mean Probable Effects Level Quotient (PEL-Q) ranged from 0.16 to 0.20, with an overall value of 0.18 ± 0.00 (Table 19). These results suggest that the combined presence of heavy metals has a 21% probability of being toxic (Table 8). No literature reports on the PEL and PEL-Q of heavy metals in any native river, making it difficult to compare the current study's results with previous ones. However, Li, et al. [120] reported a similar probability of toxicity on the Weihai coast in China, and Soliman, et al. [84] found a 30% probability of toxicity on the Mediterranean coast in Egypt.

The concentrations of heavy metals in sediment samples (mg/kg) were compared with sediment quality guidelines (SQGs): Threshold Effect Level (TEL), Probable Effect Level (PEL), and Severe Effect Level (SEL). Cd concentrations in Katakhali Khal exceeded the TEL (0.596 ppm), while other sites had lower TELs. No heavy metals exceeded PEL or SEL values. Islam, et al. [121] reported higher Cd and Ni levels than TEL, PEL, and SEL in the Old Brahmaputra River, Bangladesh. Agah [122] found TEL, PEL, and SEL values for heavy metals in Chabahar Bay, Makoran, Iran. Factors such as manufacturing releases, land use practices, urban discharges, and urbanization may contribute to elevated metal levels. [94,123]. Apart from that, the production facility is likely to be a significant generator of Cd [124]. Production facilities, particularly those manufacturing phosphate fertilizers and pesticides, are significant Cd sources.

Table 16: Metal contamination factors (CF) and pollution load index (PLI), degree of contamination and modified degree of contamination (mC_d) in the sediment of the river Halda.

Stations	Contamination Factor								PLI	Degree of Contamination	mCd
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn			
Khondokia	1.60 ± 0.35	0.20 ± 0.02	0.35 ± 0.03	0.17 ± 0.01	0.31 ± 0.00	0.31 ± 0.00	0.22 ± 0.02	0.24 ± 0.01	0.33	3.40 ± 0.33	0.42 ± 0.06
Katakhali	2.79 ± 0.39	0.22 ± 0.02	0.05 ± 0.01	0.14 ± 0.00	0.34 ± 0.00	0.36 ± 0.01	0.10 ± 0.01	0.23 ± 0.02	0.25	4.22 ± 0.45	0.53 ± 0.06
Madarikhal	1.00 ± 0.27	0.47 ± 0.01	0.26 ± 0.03	0.15 ± 0.01	0.41 ± 0.00	0.46 ± 0.02	0.13 ± 0.02	0.29 ± 0.01	0.34	3.19 ± 0.31	0.40 ± 0.05
Madarshah	0.79 ± 1.11	0.28 ± 0.05	0.38 ± 0.05	0.15 ± 0.01	0.43 ± 0.00	0.41 ± 0.02	0.39 ± 0.01	0.26 ± 0.01	0.31	3.09 ± 1.10	0.39 ± 0.16
Overall (Mean ± SD)	1.54 ± 0.39	0.29 ± 0.02	0.26 ± 0.01	0.15 ± 0.00	0.37 ± 0.00	0.38 ± 0.01	0.21 ± 0.01	0.25 ± 0.01	0.31 ± 0.04	3.47 ± 0.37	0.43 ± 0.05

Table 17: The values of enrichment factor (EF) of studied heavy metals for sediments in the river Halda.

Stations	Enrichment Factors (EF)							
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn
Khondokia	5.20 ± 1.14	0.66 ± 0.07	1.14 ± 0.10	0.57 ± 0.02	1.00 ± 0.00	0.99 ± 0.01	0.70 ± 0.07	0.78 ± 0.05
Katakhali	8.27 ± 1.16	0.66 ± 0.06	0.13 ± 0.04	0.41 ± 0.01	1.00 ± 0.00	1.07 ± 0.04	0.29 ± 0.02	0.67 ± 0.06
Madarikhal	2.42 ± 0.65	1.14 ± 0.03	0.64 ± 0.06	0.37 ± 0.03	1.00 ± 0.00	1.12 ± 0.04	0.32 ± 0.06	0.71 ± 0.01
Madarshah	0.65 ± 0.51	0.64 ± 0.12	0.39 ± 0.05	0.35 ± 0.03	1.00 ± 0.00	0.95 ± 0.05	0.92 ± 0.03	0.60 ± 0.01
Mean ± SD	4.14 ± 3.33	0.78 ± 0.24	0.58 ± 0.43	0.43 ± 0.10	1.00 ± 0.00	1.03 ± 0.08	0.56 ± 0.31	0.69 ± 0.08

Table 18: Potential ecological risk factors (E_r^i) and risk index (RI) for studied heavy metals in the river Halda.

Stations	Eri								RI	Risk grade
	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn		
Khondokia	14.40 ± 3.16	40.40 ± 4.58	38.50 ± 3.28	43.50 ± 1.80	40946.40 ± 55.04	274.60 ± 3.97	21.60 ± 2.22	34.70 ± 2.05	467.70 ± 4.53	Considerable
Katakhali	25.10 ± 3.48	44.80 ± 3.82	5.00 ± 1.32	34.50 ± 1.00	44869.02 ± 97.73	323.67 ± 10.21	9.73 ± 0.53	32.40 ± 3.08	475.20 ± 22.80	Considerable
Madarikhal	9.00 ± 2.40	94.53 ± 2.54	29.00 ± 2.78	38.00 ± 3.28	55046.40 ± 31.02	416.00 ± 16.37	13.28 ± 2.36	42.10 ± 0.90	641.92 ± 27.72	Considerable
Madarshah	2.50 ± 2.00	55.40 ± 10.05	42.00 ± 5.22	37.50 ± 3.04	57192.42 ± 117.06	366.00 ± 19.00	39.35 ± 1.23	37.30 ± 0.92	580.05 ± 31.00	Considerable
Overall Mean ± SD	12.75 ± 0.68	58.78 ± 3.31	28.63 ± 1.61	38.38 ± 1.07	49513.56 ± 39.23	345.07 ± 6.71	20.99 ± 0.87	36.63 ± 1.04	541.22 ± 11.81	Considerable
Eri grade	Low	Moderate	Low	Low	Serious	Serious	Low	Low	Considerable Ecological Risk	

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Table 19: Probable effects level and effects level quotient of heavy metals in the river Halda.

	PEL								PEL-Q
Stations	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn	
Khondokia	0.11 ± 0.03	0.13 ± 0.01	0.18 ± 0.02	0.08 ± 0.00	0.36 ± 0.00	0.25 ± 0.00	0.04 ± 0.00	0.13 ± 0.01	0.16 ± 0.00
Katakhali	0.20 ± 0.03	0.14 ± 0.01	0.02 ± 0.01	0.06 ± 0.00	0.40 ± 0.00	0.29 ± 0.01	0.02 ± 0.00	0.12 ± 0.01	0.16 ± 0.01
Madarikhal	0.07 ± 0.02	0.30 ± 0.01	0.14 ± 0.01	0.07 ± 0.01	0.49 ± 0.00	0.38 ± 0.01	0.02 ± 0.00	0.16 ± 0.00	0.20 ± 0.01
Madarshah	0.02 ± 0.02	0.17 ± 0.03	0.20 ± 0.02	0.07 ± 0.01	0.51 ± 0.00	0.33 ± 0.02	0.07 ± 0.00	0.14 ± 0.00	0.19 ± 0.01
Overall Mean ± SD	0.10 ± 0.01	0.18 ± 0.01	0.13 ± 0.01	0.07 ± 0.00	0.44 ± 0.00	0.31 ± 0.01	0.04 ± 0.00	0.14 ± 0.00	0.18 ± 0.00

The elevated Cd in Katakhali Khal is likely due to these factors [125]. The higher amount of Cd in the Katakhali Khal might be associated with the above reasons.

A pollution index pertaining to contamination levels, termed the modified hazard quotient (mHQ), was recently introduced by Benson, et al. [91]. The mHQ assesses pollution levels by comparing each metal(oid) concentration in sediments with thresholds for adverse environmental effects, such as TEL, PEL, and SEL. Evaluating the mHQ is critically important as it gauges the threat posed by individual metal(oid)s to biota and the aquatic environment [126]. The mHQ was computed using equation 11, and the specific contributions of each metal are presented in Tables 10,11. Among the analyzed heavy metals, only Cr and Mn showed a Low Severity of Pollution (1.5>mHQ≥1), while other heavy metals exhibited Very Low Severity of Pollution (1>mHQ≥0.5) (Table 10). The elevated levels of Cr and Mn may originate from chemical industry activities along the riverbank [127].

Heavy metals in sediments typically originate from various natural and anthropogenic sources [132]. Organic matter and grain size are key factors influencing heavy metal distribution in sediments [133]. The correlation among metals in sediments provides critical information on their sources and pathways in aquatic environments. Correlation analyses, supported by PCA and CA, revealed strong relationships among certain metals, indicating similar origins, particularly from industrial effluents, municipal wastes, and agricultural inputs. A correlation matrix was applied to identify relationships among elements and potential common metal sources in the Halda River. The Pearson correlation matrix (95% confidence level, $p = 0.05$) showed significant correlations among several metals (Table 20). Cd correlated closely with Ni and Fe; Cr with Fe, Mn, and Zn; Ni with Cu and Pb; Fe with Mn and Zn; and Mn with Zn, suggesting common sources, likely anthropogenic [134]. In contrast, other metal pairs showed no significant correlation, indicating distinct pollution sources. Similar associations were found by Alam, et al. [63], Bhuyan and Bakar [47], and Hossain, et al. [135] in the Halda River, and by Hassan, et al. [104] and Akbor, et al. [105] in the Buriganga River, where most metals showed positive correlations except a few.

The Principal Component Analysis (PCA) revealed three components (Eigen values > 1) explaining 94% of the total variance (Table 21). The first component (PC1) accounted for 50% of the variance with high loadings for Fe, Zn, Mn, Cr, Ni, and Pb. The second component (PC2) explained 30% of the variance with high loadings for Ni, Cu, and Pb. The third component (PC3) accounted for 14% of the variance with high loadings for Cu and Cr. Pearson's Correlation Matrix indicated

Table 20: Pearson's Correlation Matrix of heavy metals of Halda river.

Heavy metals	Cd	Cr	Ni	Cu	Fe	Mn	Pb	Zn
Cd								
Cr	-0.382							
Ni	-0.784*	0.092						
Cu	-0.319	-0.109	0.611*					
Fe	-0.594*	0.664*	0.324	-0.335				
Mn	-0.414	0.904*	0.054	-0.318	0.867*			
Pb	-0.522	-0.194	0.752*	0.208	0.464	0.019		
Zn	-0.526	0.857*	0.394	0.182	0.666*	0.789*	0.119	

Table 21: Factor loadings on elements in sediments from the river Halda (n = 24).

Element	PC1	PC2	PC3
Cd	-0.38838	-0.28545	0.01525
Cr	0.39577	-0.31766	0.30701
Ni	0.28573	0.51340	0.02797
Cu	0.03190	0.47321	0.61129
Fe	0.44402	-0.7668	-0.38573
Mn	0.42108	-0.33311	-0.02705
Pb	0.20558	0.44081	-0.52002
Zn	0.43949	-0.09235	0.33334
Eigen value	4.0	2.40	1.11
% variance explained	50	30	14
Cumulative % variance	50	80	94

significant positive correlations among these elements, suggesting lithogenic (natural) origins for elements in PC1 (Fe, Zn, Mn, Cr, Ni, and Pb) [136,137]. Potential sources include industrial discharges, municipal waste, household garbage, and urban runoff [105]. Elements in PC2 (Ni, Cu, and Pb) and PC3 (Cu and Cr) indicate natural or anthropogenic origins. Previous studies by Alam, et al. [63], Bhuyan and Bakar [47], Bhuyan, et al. [64], and Akbor, et al. [105] found similar results in the Halda and Buriganga rivers. Soliman, et al. [84] and Li, et al. [120] observed similar patterns on the Mediterranean coast, Egypt, and Weihai coast, China, respectively. Variations in the number of components and element loadings are likely due to spatial differences and analytical procedures (Figures 3,4).

Conclusion and recommendations

The investigation reveals critical information regarding metal contamination in the sediments of the Halda River. The heavy metals are distributed in the following order: Fe > Mn > Zn > Cr > Ni > Pb > Cu > Cd (mg/kg). These levels exceed the certified reference values set by WHO and USEPA.

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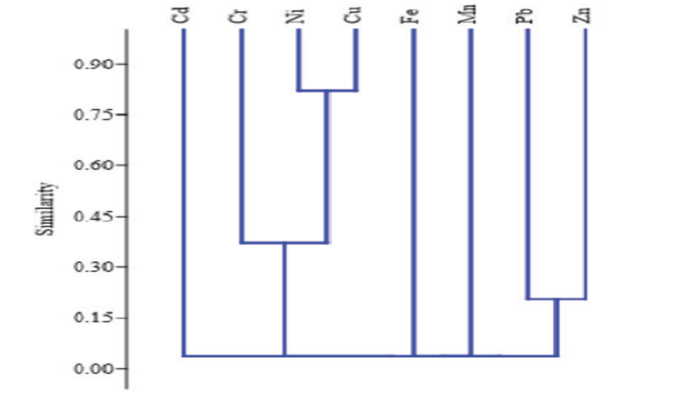

Figure 3: Bray-Curti's similarity index of heavy metals found in the sediments of the river Halda.

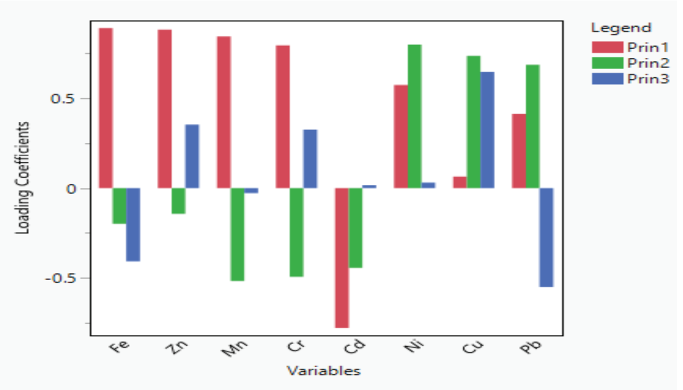

Figure 4: Plot of loading matrix for the measured heavy metals in the river Halda.

Although the eight elements displayed different distribution characteristics, lithogenic and anthropogenic sources were the primary contributors. The impact on aquatic biota was evaluated using various indices. The average I_{geo} values indicated pollution from Mn (0.37 ± 0.02). The average PLI (0.37 ± 0.10) showed no significant pollution across the sites, while the average mCd values indicated a nil to very low degree of contamination. The average EF (0.43 ± 0.10 to 4.14 ± 3.33) suggested none to moderate enrichment. However, average Eri (12.75 ± 0.68 to 49513.56 ± 39.23) and RI (467.70 ± 4.53 to 641.92 ± 27.72) revealed low to serious ecological risk. The PEL-Q indicated a 21% probability of sediment toxicity. The modified hazard quotient (mHQ) showed very low to low levels of contamination.

Multivariate statistical analysis revealed significant correlations among the studied heavy metals, indicating similar sources and/or lithogenic/anthropogenic processes regulating their occurrence. The study of the Halda River in Bangladesh provides crucial insights into the current state of metal pollution in the river. This research is a valuable resource for academics, researchers, and government authorities in Bangladesh. It will aid in developing future management strategies aimed at conserving and restoring the Halda River, which is recognized as the only natural breeding ground for Indian major carps and has been designated as the Bangabandhu Fisheries Heritage.

References

1. Silambarasan K, Senthilkumaar P, Velmurugan K. Studies on the distribution of heavy metal concentrations in River Adyar, Chennai, Tamil Nadu. Eur J Exp Biol. 2012;2(6):2192-2198. Available from: https://www.researchgate.net/profile/Krishnan-Silambarasan/publication/273135794_Studies_on_the_distribution_of_heavy_metal_concentrations_in_River_Adyar_Chennai_Tamil_Nadu/links/54f944f70cf2ccffe9e081ea/Studies-on-the-distribution-of-heavy-metal-concentrations-in-River-Adyar-Chennai-Tamil-Nadu.pdf

2. Mohiuddin KM, Alam MM, Ahmed I, Chowdhury AK. Heavy metal pollution load in sediment samples of the Buriganga river in Bangladesh. J Bangladesh Agril Univ. 2015;13(2):229-238. Available from: https://ageconsearch.umn.edu/record/235285

3. Dabaradaran S, Naddafi K, Nazmara S, Ghaedi H. Heavy metals (Cd, Cu, Ni and Pb) content in two fish species of Persian Gulf in Bushehr Port Iran. Afr J Biotechnol. 2010;37:6191-6193. Available from: https://www.ajol.info/index.php/ajb/article/view/92227

4. Wilson B, Pyatt FB. Heavy metal dispersion, persistence, and bioaccumulation around an ancient copper mine situated in Anglesey, UK. Ecotoxicol Environ Saf. 2007;66:224-231. Available from: https://doi.org/10.1016/j.ecoenv.2006.02.015

5. Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ Pollut. 2008;152:686-692. Available from: https://doi.org/10.1016/j.envpol.2007.06.056

6. Sekabira K, Oryem Origa H, Basamba TA, Mutumba G, Kakudidi E. Assessment of heavy metal pollution in the urban stream sediments and its tributaries. Int J Environ Sci Technol. 2010;7:435-446. Available from: https://link.springer.com/article/10.1007/BF03326153

7. Zhang C, Qiao Q, Piper JDA, Huang B. Assessment of heavy metal pollution from a Fe-smelting plant in urban river sediments using environmental magnetic and geochemical methods. Environ Pollut. 2011;159:3057-3070. Available from: https://doi.org/10.1016/j.envpol.2011.04.006

8. Grigoratos T, Samara C, Voutsa D, Manoli E, Kouras A. Chemical composition and mass closure of ambient coarse particles at traffic and urban background sites in Thessaloniki, Greece. Environ Sci Pollut Res. 2014;21:7708-7722. Available from: https://doi.org/10.1007/s11356-014-2732-z

9. Martin JAR, Arana CD, Ramos-Miras JJ, Gil C, Boluda R. Impact of 70 years urban growth associated with heavy metal pollution. Environ Pollut. 2015;196:156-163. Available from: http://dx.doi.org/10.1016/j.envpol.2014.10.014

10. Ahmad MK, Islam S, Rahman S, Haque MR, Islam MM. Heavy metals in water, sediment and some fishes of Buriganga River, Bangladesh. Int J Environ Res. 2010;4:321-332. Available from: https://www.bioline.org.br/request?er10035

11. Sharma RK, Agrawal M. Biological effects of heavy metals: An overview. J Environ Biol. 2005;26(2 Suppl):301-313. Available from: https://pubmed.ncbi.nlm.nih.gov/16334259/

12. Alexander DE, Fairbridge WR. Encyclopedia of environmental science. Dordrecht: Kluwer Academic Publishers; 1999.

13. USEPA. Risk-based Concentration Table. Philadelphia, PA: United States Environmental Protection Agency; 2000.

14. Giaccio L, Cicchella D, De V B, Lombardi G, De RM. Does heavy metals pollution affect semen quality in men? A case study in the metropolitan area of Naples (Italy). J Geochem Explor. 2012;112:218-225. Available from: https://doi.org/10.1016/j.gexplo.2011.08.009

15. Morton-Bermea O, Hernandez E, Martinez-Pichardo E, Soler-Arechalde AM, Lozano Santa-Cruz R, Gonzalez-Hernandez G, et al. Mexico City topsoil:

Citation: Alam MA, Flura, Rahman MH, Haidar MI, Ali A, Amin Chowdhury AI, et al. Anthropic Interventions: Imposing Ecological Risk to the Natural Spawning Ground of Major Carps in Bangladesh. Int J Aquac Fish Sci. 2024;10(4):050-065. Available from: https://dx.doi.org/10.17352/2455-8400.000095

Heavy metals vs. magnetic susceptibility. Geoderma. 2009;151:121-125. Available from: http://dx.doi.org/10.1016/j.geoderma.2009.03.019

16. Mielke HW, Wang G, Gonzales CR, Powell ET, Le B, Quach VN. PAHs and metals in the soils of inner-city and suburban New Orleans, Louisiana, USA. Environ Toxicol Pharmacol. 2005;18:243-2477. Available from: https://doi.org/10.1016/j.etap.2003.11.011

17. García Sánchez A, Contreras F, Adams M, Santos Francés F. Mercury contamination of surface water and fish in a gold mining region (Cuyuni river basin, Venezuela). Int J Environ Pollut. 2008;33:260-274. Available from: http://dx.doi.org/10.1504/IJEP.2008.019398

18. Santos Francés F, García Sánchez A, Alonso Rojo P, Contreras F, Adams M. Distribution and mobility of mercury in soils of a gold mining region, Cuyuni river basin, Venezuela. J Environ Manag. 2011;92:1268-1276. Available from: https://doi.org/10.1016/j.jenvman.2010.12.003

19. Martínez-Graña AM, Goy JL, De Bustamante I, Zazo C. Characterization of environmental impact on resources, using strategic assessment of environmental impact and management of natural spaces of "Las Batuecas-Sierra de Francia" and "Quilamas" (Salamanca, Spain). Environ Earth Sci. 2014;71:39-51. Available from: https://dx.doi.org/10.1007/s12665-013-2692-5

20. Mildvan AS. Metals in enzyme catalysis. In: Boyer DD, editor. The enzymes, Vol. 1. London: Academic Press. 1970; 445-536. Available from: https://doi.org/10.1016/S1874-6047(08)60188-2

21. Abdullah EJ. Quality assessment for Shatt Al-Arab River using heavy metal pollution index and metal index. J Environ Earth Sci. 2013;3:114-120. Available from: https://www.iiste.org/Journals/index.php/JEES/article/view/5722

22. Zhou QX, Kong FX, Zhu L. Ecotoxicology: Principles and Methods. Beijing: Science Press; 2004;161-217.

23. Sankar TV, Zynudheen AA, Anandan R. Distribution of organochlorine pesticides and heavy metal residues in fish and shellfish from Calicut region, Kerala, India. Chemosphere. 2006;65:583-90. Available from: https://doi.org/10.1016/j.chemosphere.2006.02.038

24. Sharma RK, Agrawal M, Marshall FM. Heavy metals contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicol Environ Saf. 2007;66:258-266. Available from: https://doi.org/10.1016/j.ecoenv.2005.11.007

25. Yi Y, Yang Z, Zhang S. Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. Environ Pollut. 2011;159:2575-2585. Available from: https://doi.org/10.1016/j.envpol.2011.06.011

26. Vieira C, Morais S, Ramos S. Mercury, cadmium, lead and arsenic levels in three pelagic fish species from the Atlantic Ocean: intra- and inter-specific variability and human health risks for consumption. Food Chem Toxicol. 2011;49:923-32. Available from: https://doi.org/10.1016/j.fct.2010.12.016

27. Forti E, Salovaara S, Cetin Y, Bulgheroni A, Tessadri R, Jennings P, et al. In vitro evaluation of the toxicity induced by nickel soluble and particulate forms in human airway epithelial cells. Toxicol In Vitro. 2011;25:454-461. Available from: https://doi.org/10.1016/j.tiv.2010.11.013

28. Banerjee N, Nandy S, Kearns JK. Polymorphisms in the TNF-α and IL10 gene promoters and risk of arsenic-induced skin lesions and other non-dermatological health effects. Toxicol Sci. 2011;121:132-139. Available from: https://doi.org/10.1093/toxsci/kfr046

29. Alhashemi AH, Sekhavatjou MS, Kiabi BH. Bioaccumulation of trace elements in water, sediment, and six fish species from a freshwater wetland, Iran. Microchem J. 2012;104:1-6. Available from: http://dx.doi.org/10.1016/j.microc.2012.03.002

30. Pan K, Wang WX. Trace metal contamination in estuarine and coastal environments in China. Sci Total Environ. 2012;421-422:3-16. Available from: https://doi.org/10.1016/j.scitotenv.2011.03.013

31. Rahman MM, Asaduzzaman M, Naidu R. Consumption of arsenic and other elements from vegetables and drinking water from an arsenic-contaminated area of Bangladesh. J Hazard Mater. 2013;262:1056-1063. Available from: https://doi.org/10.1016/j.jhazmat.2012.06.045

32. Fang Y, Sun X, Yang W. Concentrations and health risks of lead, cadmium, arsenic, and mercury in rice and edible mushrooms in China. Food Chem. 2014;147:147-151. Available from: https://doi.org/10.1016/j.foodchem.2013.09.116

33. Islam MS, Ahmed MK, Habibullah-Al-Mamun M, Hoque MF. Preliminary assessment of heavy metal contamination in surface sediments from a river in Bangladesh. Environ Earth Sci. 2015;73:1837-1848. Available from: http://dx.doi.org/10.1007/s12665-014-3538-5

34. He ZL, Yang XE, Stoffella PJ. Trace elements in agroecosystems and impacts on the environment. J Trace Elem Med Biol. 2005;19:125-140. Available from: https://doi.org/10.1016/j.jtemb.2005.02.010

35. Ahmed MK, Baki MA, Islam MS, Kundu GK, Sarkar SK, Hossain MM. Human health risk assessment of heavy metals in tropical fish and shellfish collected from the river Buriganga, Bangladesh. Environ Sci Pollut Res. 2015;22:15880-15890. Available from: https://doi.org/10.1007/s11356-015-4813-z

36. Rainbow PS, Amiard-Triquet C, Amiard JC, Smith BD, Langston WJ. Observations on the interaction of zinc and cadmium uptake rates in crustaceans (amphipods and crabs) from coastal sites in the UK and France differentially enriched with trace metals. Aquat Toxicol. 2000;50:189-204. Available from: https://doi.org/10.1016/s0166-445x(99)00103-4

37. Shuhaimi-Othman M, Pascoe D. Bioconcentration and depuration of copper, cadmium, and zinc mixtures by the freshwater amphipod Hyalella azteca. Ecotoxicol Environ Saf. 2007;66:29-35. Available from: https://doi.org/10.1016/j.ecoenv.2006.03.003

38. Islam MS, Ahmed MK, Habibullah-Al-Mamun M, Islam KN, Ibrahim M, Masunaga S. Arsenic and lead in foods: a potential threat to human health in Bangladesh. Food Addit Contam Part A. 2014;31:1982-1992. Available from: http://dx.doi.org/10.1080/19440049.2014.974686

39. Ahmed MK, Shaheen N, Islam MS, Al-Mamun MH, Islam S, Mohiduzzaman M, et al. Dietary intake of trace elements from highly consumed cultured fish (Labeo rohita, Pangasius pangasius, and Oreochromis mossambicus) and human health risk implications in Bangladesh. Chemosphere. 2015;128:284-292. Available from: https://doi.org/10.1016/j.chemosphere.2015.02.016

40. Islam MS, Ahmed MK, Raknuzzaman M, Habibullah-Al-Mamun M, Islam MK. Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. Ecol Indic. 2015;48:182-191. Available from: http://dx.doi.org/10.1016/j.ecolind.2014.08.016

41. Islam MS, Ahmed MK, Raknuzzaman M, Habibullah-Al-Mamun M, Masunaga S. Assessment of trace metals in fish species of urban rivers in Bangladesh and health implications. Environ Toxicol Pharmacol. 2015;39:347-357. Available from: http://dx.doi.org/10.1016/j.etap.2014.12.009

42. Saha PK, Hossain MD. Assessment of heavy metal contamination and sediment quality in the Buriganga river, Bangladesh. In: Proceedings of the 2nd International Conference on Environmental Science and Technology (EST' 11), IACSIT Press; 2011;384-8. Available from: https://www.researchgate.net/publication/266527192_Assessment_of_Heavy_Metal_Contamination_and_Sediment_Quality_in_the_Buriganga_River_Bangladesh

43. Miller CV, Foster GD, Majedi BF. Baseflow and stormflow metal fluxes from two small agricultural catchments in the coastal plain of Chesapeake Bay Basin, United States. Appl Geochem. 2003;18(4):483-501. Available from: https://doi.org/10.1016/S0883-2927(02)00103-8

Citation: Alam MA, Flura, Rahman MH, Haidar MI, Ali A, Amin Chowdhury AI, et al. Anthropic Interventions: Imposing Ecological Risk to the Natural Spawning Ground of Major Carps in Bangladesh. Int J Aquac Fish Sci. 2024;10(4):050-065. Available from: https://dx.doi.org/10.17352/2455-8400.000095

44. Mohiuddin KM, Zakir HM, Otomo K, Sharmin S, Shikazono N. Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. Int J Environ Sci Technol. 2010;7:17-28. Available from: http://dx.doi.org/10.1007/BF03326113

45. Barakat A, Baghdadi ME, Rais J, Nadem S. Assessment of heavy metal in surface sediments of Day river at Beni-Mellal Region, Morocco. Res J Environ Earth Sci. 2012;4:797-806. Available from: https://www.researchgate.net/publication/268006243_Assessment_of_Heavy_Metal_in_Surface_Sediments_of_Day_River_at_Beni-Mellal_Region_Morocco

46. Gao X, Chen CTA, Wang G, Xue Q, Tang C, Chen S. Environmental status of day a bay surface sediment inferred from a sequential extraction technique. Estuar Coast Shelf Sci. 2009;86:369-378. Available from: http://dx.doi.org/10.1016/j.ecss.2009.10.012

47. Bhuyan MS, Bakar MA, Nabi MRU, Senapathi V, Chung SY, Islam MS. Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra River, Bangladesh. Appl Water Sci. 2019;9:125. Available from: https://ui.adsabs.harvard.edu/link_gateway/2019ApWS....9..125B/doi:10.1007/s13201-019-1004-y

48. Guo Y, Yang S. Heavy metal enrichments in the Changjiang (Yangtze River) catchment and on the inner shelf of the East China Sea over the last 150 years. Sci Total Environ. 2016;543:105-115. Available from: https://doi.org/10.1016/j.scitotenv.2015.11.012

49. Forstner U, Wittman GTW. Metal Pollution in the Aquatic Environment. 2nd ed. Berlin: Springer; 1981. Available from: https://doi.org/10.1007/978-3-642-69385-4

50. Salomons W, Forstner U. Metals in the Hydrocycle. Berlin: Springer; 1984;169. Available from: https://doi.org/10.1007/978-3-642-69325-0

51. Rybicka H. Phase-specific bonding of heavy metals in sediments of the Vistula River, Poland. Appl Geochem. 1993;45-48. Available from: https://doi.org/10.1016/S0883-2927(09)80008-5

52. Vardi V, Chenji V. Bioaccumulation of heavy metals in edible marine fish from coastal areas of Nellore, Andhra Pradesh, India. GSC Biol Pharma Sci. 2020;10(01):18-24. Available from: https://doi.org/10.30574/gscbps.2020.10.1.0244

53. Authman MMN. Oreochromis niloticus as a biomonitor of heavy metal pollution with emphasis on potential risk and relation to some biological aspects. Global Vet. 2008;2(3):104-109. Available from: https://www.scirp.org/reference/referencespapers?referenceid=1565435

54. Malik DS, Maurya P, Hemant K. Alteration in haematological indices of Heteropneustis fossilis under stress of heavy metals pollution in the Kali river, Uttar Pradesh, India. Int J Curr Res. 2015;7(5):15567-15567. Available from: https://www.journalcra.com/article/alteration-haematological-indices-heteropneustis-fossilis-under-stress-heavy-metals

55. Selvaraj K, Ram Mohan V, Szefer P. Evaluation of metal contamination in coastal sediments of the Bay of Bengal, India: geochemical and statistical approaches. Mar Pollut Bull. 2004;49:174-185. Available from: https://doi.org/10.1016/j.marpolbul.2004.02.006

56. Esslemont G. Heavy metals in seawater, marine sediments and corals from the Townsville Section, Great Barrier Reef Marine Park, Queensland. Mar Chem. 2000;71:215-231. Available from: http://dx.doi.org/10.1016/S0304-4203(00)00050-5

57. Xu J, Wang H, Liu Y, Ma M, Zhang T, Zheng X. Ecological risk assessment of heavy metals in soils surrounding oil waste disposal areas. Environ Monit Assess. 2016;188(125). Available from: https://doi.org/10.1007/s10661-016-5093-x

58. Ogbeibu AE, Omoigberale MO, Ezenwa I, Eziza JO, Igwe JO. Using Pollution Load Index and Geoaccumulation Index for the assessment of heavy metal pollution and sediment quality of the Benin River, Nigeria. Nat Env. 2014;2:1-9. Available from: http://dx.doi.org/10.12966/ne.05.01.2014

59. Manoj K, Kumar B, Padhy PK. Characterization of metals in water and sediments of Subarnarekha River along the project's sites in Lower Basin, India. Universal J Environ Res Technol. 2012;2:402-410. Available from: https://www.environmentaljournal.org/2-5/ujert-2-5-5.pdf

60. Arnason JG, Fletcher B. A 40+ year record of Cd, Hg, Pb, and U deposition in sediments of Patroon Reservoir, Albany County, NY, USA. Environ Pollut. 2003;123:383-391. Available from: https://doi.org/10.1016/s0269-7491(03)00015-0

61. Li M, Yang W, Sun T, Jin Y. Potential ecological risk of heavy metal contamination in sediments and macrobenthos in coastal wetlands induced by freshwater releases: A case study in the Yellow River Delta, China. Mar Pollut Bull. 2016;103:227-239. Available from: https://doi.org/10.1016/j.marpolbul.2015.12.014

62. Alshahri F, Taher AE. Assessment of heavy and trace metals in surface soil nearby an oil refinery, Saudi Arabia, using geo-accumulation and pollution indices. Arch Environ Contam Toxicol. 2018;75:390-401. Available from: https://doi.org/10.1007/s00244-018-0531-0

63. Alam MA, Flura Rahman MA, Ali A, Chowdhury AIA, Rahman MH, Moniruzzaman M, et al. Ecological risk of the River Halda: A perspective from heavy metal assessment. Int J Aquacul Fish Sci. 2022;8(3):66-79. Available from: http://dx.doi.org/10.17352/2455-8400.000080

64. Bhuyan MS, Bakar MA. Assessment of water quality in Halda River (the major carp breeding ground) of Bangladesh. Pollution. 2017;3(3):429-441. Available from: http://dx.doi.org/10.7508/pj.2017.03

65. Bhuyan MS, Bakar MA. Seasonal variation of heavy metals in water and sediments in the Halda River, Chittagong, Bangladesh. Environ Sci Pollut Res Int. 2017;24(35):27587-27600. Available from: https://doi.org/10.1007/s11356-017-0204-y

66. Praveen S. Analysis of wastewater for metals using ICP-OES. PerkinElmer, Inc. Shelton, CT 06484 USA. Available from: https://resources.perkinelmer.com/corporate/pdfs/downloads/app_metalsinwastewater.pdf

67. Müller G. Index of geo-accumulation in sediments of the Rhine River. Geol J. 1969;2:108-118. Available from: https://www.scirp.org/reference/ReferencesPapers?ReferenceID=1803049

68. Guan Y, Shao C, Ju M. Heavy metal contamination assessment and partition for industrial and mining gathering areas. Int J Environ Res Public Health. 2014;11:7286-7303. Available from: https://doi.org/10.3390/ijerph110707286

69. Al-Haidarey MJS, Hassan FM, Al-Kubaisey ARA, Douabul AAZ. The geoaccumulation index of some heavy metals in Al-Hawizeh Marsh, Iraq. J Chem. 2010;7(S1):157-162. Available from: http://dx.doi.org/10.1155/2010/839178

70. Nowrouzi M, Pourkhabbaz A. Application of geoaccumulation index and enrichment factor for assessing metal contamination in the sediments of Hara Biosphere Reserve, Iran. Chem Spe Bioavail. 2014;26(2):99-105. Available from: http://dx.doi.org/10.3184/095422914X13951584546986

71. Varol M. Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. J Hazard Mater. 2011;195:355-364. Available from: https://doi.org/10.1016/j.jhazmat.2011.08.051

72. Hakanson L. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res. 1980;14:975-1001. Available from: http://dx.doi.org/10.1016/0043-1354(80)90143-8

73. Abrahim GM, Parker RJ. Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environ Monit Assess. 2007;136(1-3):227-238. Available from: https://doi.org/10.1007/s10661-007-9678-2

Citation: Alam MA, Flura, Rahman MH, Haidar MI, Ali A, Amin Chowdhury AI, et al. Anthropic Interventions: Imposing Ecological Risk to the Natural Spawning Ground of Major Carps in Bangladesh. Int J Aquac Fish Sci. 2024;10(4):050-065. Available from: https://dx.doi.org/10.17352/2455-8400.000095

74. Sakan SM, Dordević DS, Manojlović DD, Predrag PS. Assessment of heavy metal pollutants accumulation in the Tisza river sediments. J Env Manage. 2009;90(11):3382-3390. Available from: https://doi.org/10.1016/j.jenvman.2009.05.013

75. Franco-Uría A, López-Mateo C, Roca E, Fernández-Marcos ML. Source identification of heavy metals in pasture land by multivariate analysis in NW Spain. J Hazard Mater. 2009;165(1-3):1008-1015. Available from: https://doi.org/10.1016/j.jhazmat.2008.10.118

76. Turekian KK, Wedepohl KH. Distribution of the elements in some major units of the earth's crust. Geol Soci Am Bull. 1961;72:175-192. Available from: http://dx.doi.org/10.1130/0016-7606(1961)72[175:DOTEIS]2.0.CO;2

77. Rashdi SA, Arabi AA, Howari FM, Siad A. Distribution of heavy metals in the coastal area of Abu Dhabi in the United Arab Emirates. Mar Pollut Bull. 2015;97(1-2):494-498. Available from: https://doi.org/10.1016/j.marpolbul.2015.05.052

78. El-Sammak AA, Aboul-Kassim TA. Metal pollution in the sediments of Alexandria region, southeastern Mediterranean, Egypt. Bull Environ Contam Toxicol. 1999;63(2):263-270. Available from: http://dx.doi.org/10.1007/s001289900975

79. Tomlinson DC, Wilson JG, Harris CR, Jeffrey DW. Problems in the assessment of heavy metal levels in estuaries and the formation of a pollution index. Helgoland Mar Res. 1980;33:566-575. Available from: https://hmr.biomedcentral.com/articles/10.1007/BF02414780

80. Harikumar PS, Nasir UP, Mujeebu RMP. Distribution of heavy metals in the core sediments of a tropical wetland system. Int J Env Sci Tech. 2009;6:225-232. Available from: https://link.springer.com/article/10.1007/BF03327626

81. Lin Y, Han P, Huang Y, Yuan GL, Guo JX, Li J. Source identification of potentially hazardous elements and their relationships with soil properties in agricultural soil of the Pinggu district of Beijing, China: multivariate statistical analysis and redundancy analysis. J Geochem Explor. 2017;173:110-118. Available from: https://www.researchgate.net/publication/311692753_Source_identification_of_potentially_hazardous_elements_and_their_relationships_with_soil_properties_in_agricultural_soil_of_the_Pinggu_district_of_Beijing_China_Multivariate_statistical_analysis_and_

82. Abdullah MZ, Louis VC, Abas MT. Metal pollution and ecological risk assessment of Balok River Sediment, Pahang Malaysia. Am J Env Eng. 2015;5:1-7. Available from: https://www.researchgate.net/profile/Mohd-Zahari-Abdullah-Rafie/publication/281289895_Metal_Pollution_and_Ecological_Risk_Assessment_of_Balok_River_Sediment_Pahang_Malaysia/links/55e0293408ae2fac47196323/Metal-Pollution-and-Ecological-Risk-Assessment-of-Balok-River-Sediment-Pahang-Malaysia.pdf

83. Maanan MM, Saddik M, Chaibi M, Assobhei O, Zourarah B. Environmental and ecological risk assessment of heavy metals in sediments of Nador lagoon, Morocco. Ecol Indic. 2015;48:616-626. Available from: https://doi.org/10.1016/j.ecolind.2014.09.034

84. Soliman NF, Nasr SM, Okbah MA. Potential ecological risk of heavy metals in sediments from the Mediterranean coast, Egypt. J Env Health Sci Eng. 2015;13:70. Available from: https://link.springer.com/article/10.1186/s40201-015-0223-x

85. Tang Z, Zhang L, Huang Q, Yang Y, Nie Z, Cheng J, et al. Contamination and risk of heavy metals in soils and sediments from a typical plastic waste recycling area in North China. Ecotox Environ Saf. 2015;122:343-351. Available from: https://doi.org/10.1016/j.ecoenv.2015.08.006

86. Zhuang W, Gao X. Distributions, sources and ecological risk assessment of arsenic and mercury in the surface sediments of the southwestern coastal Laizhou Bay, Bohai Sea. Mar Pollut Bull. 2015;99(1-2):320-327. Available from: https://doi.org/10.1016/j.marpolbul.2015.07.037

87. Krishna AK, Mohan KR. Distribution, correlation, ecological and health risk assessment of heavy metal contamination in surface soils around an industrial area, Hyderabad, India. Env Earth Sci. 2016;75:1-17. Available from: https://link.springer.com/article/10.1007/s12665-015-5151-7

88. Sun G, Chen Y, Bi X, Yang W, Chen X, Zhang B, et al. Geochemical assessment of agricultural soil: a case study in Songnen-Plain (Northeastern China). Catena. 2013;111:56-63. Available from: http://dx.doi.org/10.1016/j.catena.2013.06.026

89. Long ER, Field LJ, MacDonald DD. Predicting toxicity in marine sediments with numerical sediment quality guidelines. Env Toxi Chem. 1998;17:714-727. Available from: https://doi.org/10.1002/etc.5620170428

90. Barjoee SS, Abadi SZM, Elmi MR, Varaoon VT, Nikbakht M. Evaluation of trace elements pollution in deposited dust on residential areas and agricultural lands around Pb/Zn mineral areas using modified pollution indices. J Env Health Sci Eng. 2021;1-17. Available from: https://doi.org/10.1007/s40201-021-00643-8

91. Benson NU, Adedapo AE, Fred-Ahmadu OH, Williams AB, Udosen ED, Ayejuyo OO, et al. A new method for assessment of sediment-associated contamination risks using multivariate statistical approach. MethodsX. 2018;5:268-276. Available from: https://doi.org/10.1016/j.mex.2018.03.005

92. Eker ÇS. Distinct contamination indices for evaluating potentially toxic element levels in stream sediments: a case study of the Harşit stream (NE Turkey). Arab J Geosci. 2020;13:1-18. Available from: http://dx.doi.org/10.1007/s12517-020-06178-w

93. Ustaoğlu F, Islam MS. Potential toxic elements in sediment of some rivers at Giresun, Northeast Turkey: a preliminary assessment for ecotoxicological status and health risk. Ecol Indic. 2020;113:106237. Available from: http://dx.doi.org/10.1016/j.ecolind.2020.106237

94. Yuan Q, Wang P, Wang C, Chen J, Wang X, Liu S, et al. Metals and metalloids distribution, source identification, and ecological risks in riverbed sediments of the Jinsha River, China. J Geochem Explor. 2019;205:106334. Available from: http://dx.doi.org/10.1016/j.gexplo.2019.106334

95. Wang YB, Liu CW, Liao PY, Lee JJ. Spatial pattern assessment of river water quality: implications of reducing the number of monitoring stations and chemical parameters. Env Monit Assess. 2014;186(3):1781-1792. Available from: https://doi.org/10.1007/s10661-013-3492-9

96. Department of Public Health Engineering (DPHE). Water Quality Parameters (Water Quality Parameters Bangladesh Standards & WHO Guide Lines). Department of Public Health Engineering, Bangladesh; 2019. Available from: https://dphe.gov.bd/site/page/15fa0d7b-11f1-45c0-a68410a543376873

97. Sikder D, Islam MS. Heavy metal contamination assessment of the Buriganga River bed sediment. In: Proceedings of the 3rd International Conference on Advances in Civil Engineering; 21-23 December 2016; CUET, Chittagong, Bangladesh. Available from: https://www.cuet.ac.bd/icace/papers/environment/66.pdf

98. Ahmed G, Uddin MK, Khan GM, Rahman MS, Chowdhury DA. Distribution of trace metal pollutants in surface water system connected to effluent disposal points of Dhaka Export Processing Zone (DEPZ), Bangladesh: a statistical approach. J Nat Sci Sustain Tech. 2009;3:293-304.

99. Ahmed MK, Shahad A, Rahman MS, Haque MR, Islam MM. Heavy metals concentration in water, sediments and their bioaccumulations in some freshwater fishes and mussel in Dhaleshwari River, Bangladesh. Terres Aquat Env Toxicol. 2009;3:33-41.

100. Hoque MMM, Sarker A, Sarker ME, Kabir MH, Ahmed FT, Yeasmin M, et al. Heavy metals in sediments of an urban river at the vicinity of tannery industries in Bangladesh: a preliminary study for ecological and human health risk. Int J Env Anal Chem. 2023;103(19):7909-7927. Available from: https://research.manchester.ac.uk/en/publications/heavy-metals-in-sediments-of-an-urban-river-at-the-vicinity-of-ta

101. Islam F, Rahman M, Khan SSA, Ahmed B, Bakar A, Halder M. Heavy metals in water, sediment and some fishes of Karnofuly River, Bangladesh. Pollut Res. 2013;32:715-721. Available from: https://www.researchgate.net/publication/261365082_Heavy_metals_in_water_sediment_and_some_fishes_of_Karnofuly_river_Bangladesh

102. Wang A, Kawser A, Xu Y, Ye X, Rani S, Chen K. Heavy metal accumulation during the last 30 years in the Karnaphuli River estuary, Chittagong, Bangladesh. Springerplus. 2016;5:2079. Available from: https://doi.org/10.1186/s40064-016-3749-1

103. Banu Z, Chowdhury MSA, Hossain MD, Nakagami K. Contamination and ecological risk assessment of heavy metal in the sediment of Turag River, Bangladesh: an index analysis approach. J Water Res Prot. 2013;5:239-248. Available from: https://www.scirp.org/journal/paperinformation?paperid=28446

104. Mohiuddin K, Islam M, Basak S, Abdullah H, Ahmed IT. Status of heavy metal in sediments of the Turag river in Bangladesh. Progress Agril. 2016;27:78-85. Available from: http://dx.doi.org/10.3329/pa.v27i2.29315

105. Hassan M, Mirza AT, Rahman T, Saha B, Kamal AKI. Status of heavy metals in water and sediment of the Meghna River, Bangladesh. Am J Env Sci. 2015;11:427-439. Available from: http://dx.doi.org/10.3844/ajessp.2015.427.439

106. Islam MS, Hassan MK, Bhuiyan MD, Sajeeb MI. Heavy metal contamination in surface water and sediment of the Meghna River ecosystem. Int J Adv Res Biol Sci. 2023;10(4):22-45. Available from: http://dx.doi.org/10.22192/ijarbs.2023.10.04.003

107. Islam SMD, Bhuiyan MAH, Rume T, Mohinuzzaman M. Assessing heavy metal contamination in the bottom sediments of Shitalakhya River, Bangladesh; using pollution evaluation indices and geo-spatial analysis. Pollution. 2016;2:299-312. Available from: https://jpoll.ut.ac.ir/article_57874_1c9b89bdb8c36e5fe8b463400487e057.pdf

108. Jolly YN, Rakib MRJ, Kumar R, Islam ARM, Rabby A, Mamun KM, et al. Deciphering the source of heavy metals in industrially affected river sediment of Shitalakshya river, Bangladesh, and potential ecological and health implications. J Hazard Mat Adv. 2023;10:2772-4166. Available from: http://dx.doi.org/10.1016/j.hazadv.2023.100268

109. Islam MM, Rahman SL, Ahmed SU, Haque MKI. Biochemical characteristics and accumulation of heavy metals in fishes, water and sediments of the river Buriganga and Shitalakhya of Bangladesh. J Asian Sci Res. 2014;4:270-279. Available from: https://archive.aessweb.com/index.php/5003/article/view/3640

110. Ali MM, Ali ML, Islam MS, Rahman MZ. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. Env Nanotech Monit Manag. 2016;5:27-35. Available from: https://doi.org/10.1016/j.enmm.2016.01.002

111. Zhang Z, Juying L, Mamat Z. Sources identification and pollution evaluation of heavy metals in the surface sediments of Bortala River, Northwest China. Ecotox Env Saf. 2016;126:94-101. Available from: http://dx.doi.org/10.1016/j.ecoenv.2015.12.025

112. Malvandi H. Preliminary evaluation of heavy metal contamination in the Zarrin-Gol River sediments, Iran. Mar Pollut Bull. 2017;117:547-553. Available from: https://doi.org/10.1016/j.marpolbul.2017.02.035

113. Rahman MS, Saha N, Molla AH. Potential ecological risk assessment of heavy metal contamination in sediment and water body around Dhaka export processing zone, Bangladesh. Env Earth Sci. 2014;71:2293-2308. Available from: http://dx.doi.org/10.1007/s12665-013-2631-5

114. Akbor MA, Rahman MM, Bodrud-Doza M, Haque MM, Siddique MAB, Ahsan MA, et al. Metal pollution in water and sediment of the Buriganga River, Bangladesh: an ecological risk perspective. Desal Wat Treat. 2020;193:284-301. Available from: https://www.deswater.com/DWT_articles/vol_193_papers/193_2020_284.pdf

115. Islam MM, Akhtar MK, Masud MS. Prediction of environmental flow to improve the water quality in the river Buriganga. Proceedings of the 17th IASTED International Conference on Modelling and Simulation, Montreal, QC, Canada. 2006. Available from: https://www.researchgate.net/publication/262276497_Prediction_of_environmental_flow_to_improve_the_water_quality_in_the_river_Buriganga

116. Chakravarty M, Patgiri AD. Metal pollution assessment in sediments of the Dikrong River, N.E. India. J Hum Ecol. 2017;27(1):63-67. Available from: https://krepublishers.com/02-Journals/JHE/JHE-27-0-000-09-Web/JHE-27-1-000-09-Abst-PDF/JHE-27-01-063-09-1769-Chakravarty-M/JHE-27-01-063-09-1769-Chakravarty-M-Tt.pdf

117. Sivakumar S, Chandrasekaran A, Balaji G, Ravisankar R. Assessment of heavy metal enrichment and the degree of contamination in coastal sediment from South East Coast of Tamilnadu, India. J Heavy Met Tox Dis. 2016;1(2):2473-6457. Available from: http://heavy-metal-toxicity-diseases.imedpub.com/archive.php

118. Samlafo BV. Levels of cadmium in soil, sediment, and water samples from Tarkwa and its environs. Afri J Edu Stud Math Sci. 2006;4. Available from: https://doi.org/10.4314/ajesms.v4i1.46281

119. Liu J, Yin P, Chen B, Gao F, Song H, Li M. Distribution and contamination assessment of heavy metals in surface sediments of the Luanhe River Estuary, northwest of the Bohai Sea. Mar Pollut Bull. 2016;109(1):633-639 Available from: https://doi.org/10.1016/j.marpolbul.2016.05.020

120. Islam MS, Proshad R, Ahmed S. Ecological risk of heavy metals in sediment of an urban river in Bangladesh. Hum Ecol Risk Assess. 2018;24(3):699-720. Available from: http://dx.doi.org/10.1080/10807039.2017.1397499

121. Li H, Kang X, Li X, Li Q, Song J, Jiao N, et al. Heavy metals in surface sediments along the Weihai coast, China: Distribution, sources, and contamination assessment. Mar Pollut Bull. 2017;115:551-558. Available from: http://dx.doi.org/10.1016/j.marpolbul.2016.12.039

122. Islam MS, Shammi RS, Jannat R, Kabir MH. Spatial distribution and ecological risk of heavy metal in surface sediment of Old Brahmaputra River, Bangladesh. Chem Ecol. 2022;39:173-201. Available from: https://doi.org/10.1080/02757540.2022.2152015

123. Agah H. Ecological risk assessment of heavy metals in sediment, fish, and human hair from Chabahar Bay, Makoran, Iran. Mar Pollut Bull. 2021;169:112345. Available from: https://doi.org/10.1016/j.marpolbul.2021.112345

124. Proshad R, Kormoker T, Mamun AA, Islam MS, Khadka S, Idris AM. Receptor model-based source apportionment and ecological risk of metals in sediments of an urban river in Bangladesh. J Hazard Mater. 2021;423:127030. Available from: https://doi.org/10.1016/j.jhazmat.2021.127030

125. Pan L, Ma J, Hu Y, Su B, Fang G, Wang Y, et al. Assessments of levels, potential ecological risk, and human health risk of heavy metals in the soils from a typical county in Shanxi Province, China. Environ Sci Pollut Res. 2016;23:19330-19340. Available from: https://doi.org/10.1007/s11356-016-7044-z

126. Sun C, Liu J, Wang Y, Sun L, Yu H. Multivariate and geostatistical analyses of the spatial distribution and sources of heavy metals in agricultural soil in Dehui, Northeast China. Chemosphere. 2013;92:517-523. Available from: https://doi.org/10.1016/j.chemosphere.2013.02.063

127. Emenike PC, Tenebe IT, Neris JB, Omole DO, Afolayan O, Okeke CU, et al. An integrated assessment of land-use change impact, seasonal variation of pollution indices and human health risk of selected toxic elements in sediments of river Atuwara, Nigeria. Environ Pollut. 2020;265:114795. Available from: https://doi.org/10.1016/j.envpol.2020.114795

Citation: Alam MA, Flura, Rahman MH, Haidar MI, Ali A, Amin Chowdhury AI, et al. Anthropic Interventions: Imposing Ecological Risk to the Natural Spawning Ground of Major Carps in Bangladesh. Int J Aquac Fish Sci. 2024;10(4):050-065. Available from: https://dx.doi.org/10.17352/2455-8400.000095

128. Rahman MS, Ahmed Z, Seefat SM, Alam R, Islam ARM, Choudhurye TR, et al. Assessment of heavy metal contamination in sediment at the newly established tannery industrial Estate in Bangladesh: A case study. Environ Chem Ecotox. 2022;4:1-12. Available from: https://doi.org/10.1016/j.enceco.2021.10.001

129. MacDonald DD, Ingersoll CG, Berger TA. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch Environ Contam Toxicol. 2000;39(1):20-31. Available from: https://link.springer.com/article/10.1007/s002440010075

130. Persuad D, Jaagumagi R, Hayton A. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment, Canada; 1993. Available from: https://atrium.lib.uoguelph.ca/server/api/core/bitstreams/d662f9f3-49b4-403e-95ce-8c481224cd1a/content

131. Canadian Environmental Quality Guidelines. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. CCME (Canadian Council of Ministers of Environment); 2002. Available from: https://ccme.ca/en/current-activities/canadian-environmental-quality-guidelines

132. Zubir AAA, Saad FNM, Dahalan FA. The Study of Heavy Metals on Sediment Quality of Kuala Perlis Coastal Area. E3S Web Conf. 2018;34:02018. Available from: https://doi.org/10.1051/e3sconf/20183402018

133. Xia P, Meng XW, Yin P, Cao ZM, Wang XQ. Eighty-year sedimentary record of heavy metal inputs in the intertidal sediments from the Nanliu River estuary, Beibu Gulf of South China Sea. Environ Pollut. 2011;159:92-99. Available from: https://doi.org/10.1016/j.envpol.2010.09.014

134. Bilali LE, Rasmussen PE, Hall GEM, Fortin D. Role of sediment composition in trace metal distribution in lake sediments. Appl Geochem. 2002;17:1171-1181. Available from: http://dx.doi.org/10.1016/S0883-2927(01)00132-9

135. Armah FA, Obiri S, Yawson DO, Onumah EE, Yengoh GT. Anthropogenic sources and environmentally relevant concentrations of heavy metals in surface water of a mining district in Ghana: A multivariate statistical approach. J Environ Sci Health. 2010;45:1804-1813. Available from: https://doi.org/10.1080/10934529.2010.513296

136. Hossain MB, Semme SA, Ahmed ASS, Hossain MK, Porag GS, Parvin A, et al. Contamination levels and ecological risk of heavy metals in sediments from the tidal river Halda, Bangladesh. Arab J Geosci. 2021;14:158. Available from: http://dx.doi.org/10.1007/s12517-021-06477-w

137. Dou Y, Li J, Zhao J, Hu B, Yang S. Distribution, enrichment and source of heavy metals in surface sediments of the Eastern Beibu Bay, South China Sea. Mar Pollut Bull. 2013;67(1-2):137-145. Available from: https://doi.org/10.1016/j.marpolbul.2012.11.022

Citation: Alam MA, Flura, Rahman MH, Haidar MI, Ali A, Amin Chowdhury AI, et al. Anthropic Interventions: Imposing Ecological Risk to the Natural Spawning Ground of Major Carps in Bangladesh. Int J Aquac Fish Sci. 2024;10(4):050-065. Available from: https://dx.doi.org/10.17352/2455-8400.000095