 DOI: 10.35382/TVUJS.14.2.2024.3768

ASSESSMENT OF CONTAMINATION AND POLLUTION RISKS CAUSED BY HEAVY METALS IN FISH POND SEDIMENTS

Sha Md. Shahan Shahriar[1*], Md. Wahad Uz Zaman[2], Umme Kulsum[3], Md. Sarwar Hossain[4], Sumaiya Dipti[5], Mst. Mahmuda Akhtar[6], Sayed M A Salam[7]

Abstract – *Pollution by heavy metals poses a significant risk to human health and ecology through the food web. Metal contamination in fish pond sediments can be caused by improper waste management and the overuse of artificial feed to increase output and profit. By using an atomic absorption spectrometer to analyse heavy metals such as Cd, Mn, Pb, and Cr, this study aims to assess the contamination levels and pollution risk from bottom sediment samples taken from 12 different fish ponds in the Rajshahi City of Bangladesh. According to this investigation, the concentrations of the metals Pb, Mn, Cr, and Cd were 0.1188 to 1.5139, 0.1899 to 0.8483, 0.0292 to 0.0395, and 0.3017 to 1.6182 mg/kg, respectively. All results show that the metal contents of all the sediments studied around the area do not exceed the standard limit. The risk assessment of the sediments was evaluated based on the geoaccumulation index, enrichment factor, and contamination factor. The analysis indicated that Cd, Pb, and Cr accumulation are within the acceptable limit except for Mn. This study provides essential baseline data on heavy metal contamination, serving as a foundation for future research by focusing on identifying contamination sources, accumulation pathways, and element mobility from feed to fish and sediment to significantly reduce environmental risks and protect both ecosystem integrity and public health.*

Keywords: contamination, heavy metals, pollution risk, pond sediments, public health.

[1,3,4,5,6,7]University of Rajshahi, Bangladesh
[2]South Chungcheong Province, South Korea
*Corresponding author: shahan@ru.ac.bd
Received date: 24th January 2024; Revised date: 05th May 2024; Accepted date: 20th May 2024

I. INTRODUCTION

Since the quality of sediment has been identified as a critical indicator of water contamination, heavy metals (HMs) are mostly absorbed in sediment in aquatic ecosystems [1]. When environmental variables including temperature and pH fluctuate, or when sediments experience other types of physical as well as biological disturbances, HMs may be discharged into the water column [2]. Additionally, the development of reservoirs often results in silt with a high level of HMs due to a prolonged residency time frame. In order to support the management of the environment, it is essential to analyse sediments from reservoirs for the presence of HMs, especially for sediments from reservoirs that hold drinking water [3]. Pollution has accumulated in coastal environments as a result of rapid urbanization, industrialization, as well as land alteration, especially along an aquatic system that extends from estuaries and rivers toward coastal marine zones. However, when environmental circumstances change, these sediments may serve as sources for HMs for a variety of aquatic creatures, allowing HMs to move up into the food chain and ultimately endanger human health. HMs have been identified as major sinks in estuarine and coastal ecosystems' sediments [4]. The presence of HMs in sediments needs to be investigated to see if there is an ecological adverse impact on the aquatic ecosystem. The risk evaluation of the HMs in the sediments was then estimated by contrasting the HMs concentrations with standard quality guidelines [5–6]. HMs' toxicity to people depends on several factors, especially their quantity, duration of exposure, and rate of emission. Due to their frequent exposure, mercury (Hg), lead (Pb), chromium (Cr), cadmium (Cd), manganese (Mn), etc. have received a great deal of attention lately. Kidney damage, effects on cardiovascular abnormalities osteotoxicity, carcinogenesis, and reproductive biology are only a few of the major health issues that exposure to Cd compounds can cause [7–10]. Furthermore, acute Cd exposure can cause inflammation, coughing, dizziness, nose and throat irritation, pulmonary edema, chest pain, dryness, headache, and pneumonitis [9, 10]. Pb exposure can occur through the food chain, water, or when people inhale polluted dust or aerosols. Pb poisoning can harm the liver, kidneys, heart, skeleton brain, and neurological system [11]. Lead can increase blood pressure and damage blood vessels. Lead-clogged blood arteries result in a heart attack and death. Higher blood lead levels were found to be substantially associated with higher cardiovascular morbidity and mortality [9, 10]. The environment being polluted by Cr, specifically hexavalent Cr, has received significant attention in recent years. There are many adverse health effects associated with Cr (VI) exposure, including occupational asthma, irritation of the eyes, perforated eardrums, irritation of the respiratory tract, kidney and liver damage, bronchial obstruction and swelling upper abdominal pain, nasal inflammation or damage, lung cancer, dermal irritation, erosion and discoloration of the teeth [12, 13]. Overexposure to Mn raises the risk of developing potentially hazardous health issues such as liver, neurological, respiratory, cardiovascular, and kidney problems, as well as mellitus, Parkinson's disease, pigmentation changes, hyperkeratosis, Huntington's disease, and diabetes [9, 10, 14].

Rajshahi is a divisional city in Bangladesh. The city is located on the bank of the Padma River. As this is a major city there are some industries as well. The amount of heavy metal pollution in the river's midstream, groundwater, surface water, coal mine area water, sediments, and soil is being investigated by several researchers in different parts of Bangladesh [15–20]. It was predicted that fish pond sediment near Rajshahi City will be contaminated with various metals as a result of industrialization and other human activities. Fish cultivated in this pond are at risk of contamination from heavy metals present in the sediment, potentially leading to contamination of both the pond fish and the wider food web. Some of the industries present in Rajshahi City include automobile repair, battery manufacturing, maintenance and recycling, leather processing and tanneries, pottery and ceramics, manufacturing of paint and coating, metal processing and fabrication, pharmaceutical manufacturing, small-scale metal and craft industries, recycling of electronic waste, and textile and garment manufacturing. These industries could be the major contributors to heavy metal contamination in Rajshahi. Fertilizers, pesticides, and agricultural chemicals used in crop production may contain HMs that leach into the soil and water. Toxic effects of HMs on the human body are both carcinogenic and non-carcinogenic, so determination of the level of heavy metal pollution in pond sediment is critical. Analysing how metal concentrations vary over time in a study region is also crucial.

The location (Figure 1) selected for this study had no prior research on the concentrations of heavy metals in pond sediment that was published in any of the literature. Therefore, the current study would serve to reflect the amount of contamination of certain HMs in pond sediment from the locations under study, and it would facilitate the comparison of results over time and with other studies. Because of this, a thorough investigation is needed to ascertain the degree of pollution in the Rajshahi City region.

The primary objective of this study is to analyse HM contamination in fish pond sediments by quantifying the concentrations of Pb, Cd, Mn, and Cr. HM accumulation in fish, which can be caused by contaminated fish pond sediment. Additionally, the study aims to evaluate various pollution indices, such as contamination factor, modified degree of contamination, enrichment factor, and geology index, to comprehensively understand pollution levels. Through statistical analysis and data interpretation, the study seeks to pinpoint specific areas within the fish pond where heavy metal concentrations exceed regulatory limits. This information will be instrumental in formulating policies and prioritizing clean-up initiatives to mitigate environmental and health risks associated with heavy metal contamination in fish pond ecosystems.

II. LITERATURE REVIEW

The fish pond sediments serve as reservoirs for heavy metals, accumulating pollutants from diverse sources. The ingress of heavy metals into these sediments occurs through industrial discharge, agricultural runoff, atmospheric deposition, and natural weathering processes. Industrial activities, including mining and manufacturing, are prominent contributors to heavy metal contamination in fish pond sediments [21–22]. Agricultural practices, such as using fertilizers and pesticides, also play a significant role [23]. The accumulation of heavy metals in fish pond sediments poses significant risks to aquatic ecosystems. Leaching of heavy metals into the water column can disrupt the health and behaviour of aquatic organisms [24]. Biomagnification of heavy metals along the food chain further exacerbates these effects, posing risks to human health through consuming contaminated fish [25].

Tabari et al. [26] investigated the level of four heavy metals (Cd, Cr, Zn, and Pb) in sediments determined in the Southern Caspian Sea. The concentrations of Cd and Cr in water and sediment samples were recorded by Obire et al. [27]. They added that the level of metals in the water may rise due to sediments being suspended in the body of water [27]. Other studies reveal a range of heavy metal concentrations in fish pond sediments. One study in the northern Bay of Bengal found the following decreasing order of mean concentrations: Mn > Zn > Ni > Cr > Cu > Pb > Cd [28]. Another study in Mymensingh, Bangladesh, detected Cd, Cr, Cu, Pb, and Zn in fish farm water, highlighting their presence in the aquatic environment [29].

Researchers from Ethiopia collected surface sediment samples from various streams in the Awetu watershed in Southwestern Ethiopia. The heavy metal concentrations were analyzed for Pb, Hg, Cd, As, and Cr. The resulting mean concentrations were as follows: Pb: 2005.94, Hg: 4.64, As: 623.32, Cd: 151.09, and Cr: 375.00 mg/kg. The contamination factor (CF) ranged from low to very high, with Pb being the most prominent contaminant [30]. A study in Lake Bafa, Turkey, reported concentrations of Cd ranging from 0.400 to 3.92, Pb from 5.60 to 21.30, Mn from 247.00 to 584.00, and Cr from 18.90 to 120.00 mg/kg [31].

Heavy metals can bioaccumulate in fish, increasing their concentration as they move up the food chain. Fish feeding on organisms that have absorbed metals from the sediment can become unsafe for consumption if concentrations reach high levels [28]. Thus, the level of heavy metals in sediments should be monitored carefully, and necessary mitigation strategies should be taken. Mitigation strategies can help alleviate heavy metal contamination in fish pond sediments. These include sediment dredging, phytoremediation using aquatic plants, and implementing pollution control measures [21].

III. METHODOLOGY

A. *Field of study*

Bangladesh, a country in South Asia, is located between $20^o34'$ to $26^o38'$ N with longitude $88^o01'$ to $92^o41'$ E and occupies a territory in the Northwestern part of the Indian sub-continent above the Bay of Bengal [32]. A prominent divisional city corporation in Bangladesh is the Rajshahi City Corporation. Numerous wards were established within the incorporated area. In Rajshahi City Corporation, numerous fish ponds are utilized for fish cultivation. For this study, a total of 12 fish ponds were selected from four different locations within the Rajshahi City Corporation, chosen based on their prominence in fish cultivation. Sediment samples were collected from these 12 ponds for analysis. The map of the study region indicating the sampling site is shown in Figure 1. The identification number of the sample and the geographic location of the sample collection area are given in Table 1.

Table 1: Sample identification number and sample collection locations

Sample identification number	Geographic location	Name of the locations in Rajshahi City Corporation area
B-1 (n = 3)	24°21'51.4"N, 88°38'56.7"E	
B-2 (n = 3)	24°21'44.9"N, 88°38'35.1"E	Binodpur, Dashmari
B-3 (n = 3)	24°21'56.3"N, 88°38'32.5"E	
M-1 (n = 3)	24°22'52.8"N, 88°38'34.0"E	
M-2 (n = 3)	24°22'49.0"N, 88°38'38.3"E	Meherchondi
M-3 (n = 3)	24°23'04.1"N, 88°38'39.2"E	
R-1 (n = 3)	24°21'55.9"N, 88°36'56.2"E	
R-2 (n = 3)	24°21'56.2"N, 88°36'59.6"E	Ramchandrapur
R-3 (n = 3)	24°21'53.1"N, 88°37'01.5"E	
S-1 (n = 3)	24°22'25.1"N, 88°36'29.2"E	
S-2 (n = 3)	24°22'22.0"N, 88°36'36.5"E	Shiroil
S-3 (n = 3)	24°22'14.6"N, 88°36'45.2"E	

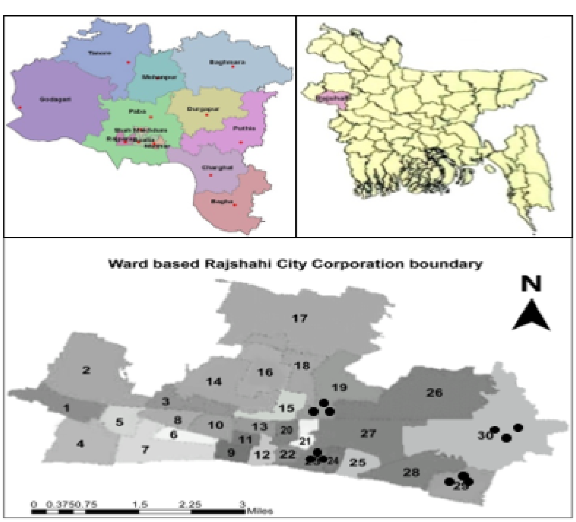

Fig. 1: Location of sample collection region [32]

B. Sample collection

Pond sediment samples from four distinct locations throughout Rajshahi City were gathered using a spade and a metallic hand trowel from 0 to 15 cm depth from the ground level of the pond. Sediment was collected from three places in the same pond (n = 3) to determine the standard deviation. The hand trowel's central port was utilized to sample about 1 kg of sediment, which was then put into pre-cleared polythene bags. The bag was closed tightly with a complete label placed inside, and it was labelled with a permanent marker on the exterior [33].

C. Sample preparation

Waste items were initially removed from sediment samples after they had dried out in the air for ten days. A mortar pestle was used to make a powder from the sediment samples, and sieving was then done to create a uniform mass [34, 35]. Each powder sediment sample weighed 2 g and was digested by the previously described method [36]. Two grams of sediment sample was digested in a 50 ml crucible by adding 10 milliliters of pure HNO_3, which was then heated on a hot plate for 30 to 45 minutes to break down the digested matter. After a few times when the mixture was cooled, 2.5 ml of concentrated $HCLO_4$ (70%) acid was added. The mixture was then heated again on a hot plate until it became transparent and somewhat dried. After cooling, Whatman number 42 filter paper was used to filter the samples [37].

D. Analysis of elements

An atomic absorption spectrophotometer (AAS) (Model No. AA-6650, Shimadzu) was used to evaluate the concentrations of Cd, Pb, Cr, and Mn in the sediment samples that had been filtrated. The instrument had a particular lamp made of a particular metal installed. Utilizing manually crafted standard solutions of the appropriate HMs as well as drift blanks, the instrument was calibrated. Standardized stock solutions with a concentration of 1,000 ppm for every one of the metals were provided by a Tokyo, Japan-based company Kanto Chemical Co. Inc. For the instrument's calibration, the concentrations found in the resulting solutions were diluted to achieve the required levels [37]. The working conditions and Limit of Detection (LOD) of AAS are displayed in Table 2.

Table 2: Shimadzu AA-6650 AAS working conditions and LOD

Element	Wavelength (nm)	Slit width (nm)	Lamp current (mA)	Atomizer	LOD (mg/L)
Cd	228.8	0.5	08	Flame	0.01
Pb	283.3	0.7	10	Flame	0.052
Cr	357.9	0.5	10	Flame	0.078
Mn	285.2	0.5	08	Flame	0.02

E. Pollution assessment

Pb, Cd, Mn, and Cr concentrations in sediment were measured to comprehend metal contamination due to the accumulation of HMs both within and around the Rajshahi City Corporation area. The contamination of the sediment has been determined based on the geoaccumulation index (I_{geo}), enrichment factor (EF), degree of contamination (MDC), and contamination factor (CF) [38].

Geoaccumulation index (I_{geo})

Muller [39] first proposed the following Equation (1), which was then used to determine the I_{geo}. The amounts of heavy metal pollution stated in the literature have been evaluated using such an index on a large scale [40]. The I_{geo} is widely used to assess pollution levels in bottom sediments. It has also been applied to evaluate soil pollution [41].

$$I_{geo} = log_2 \frac{C_n}{1.5B_n} \qquad (1)$$

In this case, B_n represents the associated metal's geochemical baseline concentration in the typical regional shale which was used as a reference value and C_n is the concentration that was determined of metal. As there is no study on background values of metals in sediment in Rajshahi City, we took the values from the earth's crust shale as background values [42]. According to Muller [39], a factor of 1.5 is employed to adjust for potential changes in baseline values brought on by lithogenic influences, as well as he suggested that the geo-accumulation index following seven classes or types: (a) $I_{geo} > 5$ indicating highly contaminated, (b) $I_{geo} = 4 – 5$ indicating strongly to hight contaminated, (c) $I_{geo} = 3$ indicating strongly contaminated, (d) $I_{geo} = 2$ indicating slightly to extremely contaminated, (e) $I_{geo} = 1 – 2$ indicating moderately contaminated, (f) $I_{geo} = 0 – 1$ indicating free of contaminated to slightly contaminated, and (g) $I_{geo} < 0$ indicating practically uncontaminated.

Enrichment factor (EF)

The standardization of an evaluated component over a reference one forms the foundation of the EF. The element with little variation in occurrence is referred to as a reference element. According to Buat-Menard et al. [43], the EF Equation (2) is provided.

$$EF = \frac{\frac{C_n(sample)}{C_{ref}(sample)}}{\frac{C_n(background)}{C_{ref}(background)}} \qquad (2)$$

Here target element's concentration is denoted by C_n and is the reference element's concentration denoted by C_{ref}. When calculating the EFs of metals that are toxic in environmental samples, elements such as Fe [44], Al, and Mn are frequently used as references [45]. Here Mn is chosen as the reference element. Turekian and Wedepohl's world average concentration of metals shale value was used as the background value [42, 46]. According to the EF scale, no enrichment is considered when the EF value is less than 1, minor enrichment is between 1 and 3, moderate enrichment is between 3 and 5, severe enrichment is between 10 and 25, moderate to severe enrichment is between 25 and 50, and extremely severe enrichment is above 50 [42].

Contamination factor (CF)

Hakanson [47] was the first to propose the CF, and it has since been frequently utilized to determine the degree of heavy metal contamination in samples [40]. Based on the study of Hakanson [47], the following Equation (3) was used for estimating CF.

$$CF = \frac{C_{metal}}{C_{background}} \qquad (3)$$

Where metal concentration in the studied sample was denoted by C_metal and the geochemical background value of that metal in the shale is denoted by $C_background$ [42, 46]. For the purpose of analysing the pollution of a particular metal over time, CF is divided into four grades such as (a) zero degree (CF <1), (b) considerable degree ($1 \leq$ CF < 3), (c) significant degree ($3 \leq$ CF < 6), as well as (d) extremely high degree (CF ≥ 6). As a result, throughout time, the CF values may indicate the concentration of a particular metal in sediments [42].

Modified degree of contamination (MDC)

The MDC is additionally utilized to assess the level of heavy metal contamination in environmental samples. The MDC was calculated using Equation (4) [48].

$$MDC = \frac{\sum_{i=1}^{n} CF}{n} \qquad (4)$$

Where n represents total number of studied elements, MDC represents the modified degree of contamination, while i is the i_{th} element. MDC is divided into six classes such as (a) MDC < 1.5 = zero to low contamination, (b) $1.5 \leq$ MDC < 2 = minimal contamination, (c) $1.5 \leq$ MDC < 2 = moderate-contamination, (d) $4 \leq$ MDC < 8 = high contamination, (e) $8 \leq$ MDC < 16 = quite high contamination, (f) $16 \leq$ MDC < 32 = fairly-severe contamination, and (g) MDC > 32 = extremely-high degree of contamination [48].

F. Statistical analysis

The statistical analysis was carried out using version 18 of the SPSS statistics program. For all values, the standard deviation (SD) was utilized. The p-value levels of * ≤ 0.05, ** ≤ 0.01, and *** ≤ 0.001 were employed to denote statistically significant differences between the samples (n=3).

IV. RESULTS AND DISCUSSION

A. Heavy metal concentration

The mean values, standard deviations, and percentage relative standard deviations (%RSD) for each sample were computed, and the results are shown in Table 3. The total metal concentrations were calculated in milligrams per kilogram of sediment samples.

Cadmium

The range of cadmium content in sediment samples was 0.3017 to 1.6182 mg/kg. The maximum permissible limit (MPL) of cadmium in sediment is 4.9 mg/kg as set by NOAA [49]. Under the USEPA guidelines, the concentration of Cd in heavily polluted sediment is less than 6 mg/kg [50, 51]. According to Onianwa et al. [53], the industrial region of Ibadan city (Nigeria) observed an average sediment Cd level of 7.2–7.7 mg/kg, which was around fifty times greater than the level in the rural region. As stated by Soylak et al. [54], the value was greater than the 0.05 mg/kg mean Cd content in Polish sediments. The measured content is identical to the levels of Cd found in sediments from metropolitan areas in Vietnam that are in the 0–20 cm layer [40]. Vietnam's rural soils only have 0.2 mg/kg of Cd, a far lower concentration. The current findings show that samples of sediment are safe for humans and within safe Cd limits.

Lead

The concentration of lead was varied from 0.1188 mg/kg to 1.5139 mg/kg for sediment samples. The MPL of lead in sediment is 35.8 mg/kg as set by NOAA [49]. According to USEPA guidelines, the permissible level of Cd in highly contaminated sediment is below 60 mg/kg [50, 51]. In this study, the Pb level was found within the MPL. Because Pb is used so extensively, its content in all environmental media is higher than any other metal. A study found that sediment

Table 3: The concentration of HMs (mean ± SD) present in sediment (mg/kg)

Sample Id. No.	Cd	Pb	Cr	Mn
B-1	0.5436 ± 0.052**	0.5901 ± 0.064***	0.3348 ± 0.058*	0.8392 ± 0.065*
B-2	0.4790 ± 0.073*	2.2234 ± 0.121**	0.5292 ± 0.084**	0.6608 ± 0.047**
B-3	0.9131 ± 0.048***	0.7948 ± 0.017**	0.6395 ± 0.087*	0.7858 ± 0.058*
M-1	0.7727 ± 0.052*	0.4188 ± 0.022***	2.1030 ± 0.115*	1.4539 ± 0.095*
M-2	1.1045 ± 0.103**	0.9526 ± 0.039*	1.3311 ± 0.095**	2.5686 ± 0.104*
M-3	0.8431 ± 0.064*	0.7378 ± 0.043*	1.4432 ± 0.083***	1.3962 ± 0.086*
R-1	0.4490 ± 0.074***	1.5139 ± 0.075*	0.9405 ± 0.086**	2.8483 ± 0.115**
R-2	0.3017 ± 0.032**	1.2234 ± 0.049**	0.7339 ± 0.098***	0.9610 ± 0.083**
R-3	0.5015 ± 0.048*	0.8139 ± 0.062*	0.8358 ± 0.087**	0.7348 ± 0.092*
S-1	0.5130 ± 0.065**	2.5948 ± 0.097*	0.6395 ± 0.082*	0.9308 ± 0.084**
S-2	1.6182 ± 0.106**	1.1663 ± 0.082***	0.5348 ± 0.075**	0.6899 ± 0.073**
S-3	1.2017 ± 0.088*	1.4044 ± 0.096**	0.7395 ± 0.087*	1.3835 ± 0.094*
MPL	4.9 [49]; > 6 [50, 51]	35.8 [49]; > 60 [50, 1]	26 [49]	300 [52]
Minimum	0.3017	0.4188	0.3348	0.6608
Maximum	1.6182	2.5948	2.1030	2.8483
Average	0.77009	1.20285	0.9004	1.27106
SD	0.386	0.654	0.497	0.730
%RSD	50.139	54.372	55.159	57.446

Note: SD = Standard deviation, %RSD = percentage relative standard deviations, MPL = maximum permissible limit. Results are shown as mean ± SD, where the sample size is 3 (n = 3). The p-value at * $\leq$ 0.05, ** $\leq$ 0.01, and * $\leq$ 0.001 were used to indicate significant differences.*

samples from Tejgaon Khal consist of greater amounts of Pb, which are numerous times greater than the allowed level [51]. Lee et al. [55] studied Pb in sediment in Santubong Estuary, Malaysia, and found the mean concentration in Buntal is 22.86 mg/kg, Penambir is 31.25 mg/kg, and Demak is 49.43 mg/kg. A critical assessment states that the levels of lead pollution in Bangladeshi sediments range from 4.9 to 69.75 mg/kg [56]. According to Adeyemo [57], Pb levels in fish ponds in the southwest Nigerian city of Ibadan were 1.09–2.9 mg/L (mean 1.88 mg/L). Numerous researchers have extensively examined the matter of sediment contamination stemming from Pb, emphasizing its significant implications for the environment [58–59].

Chromium

Another essential micronutrient for life is chromium, which is involved in the metabolism of fat and carbohydrates. A higher concentration of chromium has been connected to cancer. The concentration of chromium is varied from 0.0292 mg/kg to 0.0395 mg/kg for sediments. According to NOAA, the maximum permissible level of lead in sediment is 26 mg/kg [49]. Malami et al. [49] found the mean Cr concentration in sediment is 9.57 mg/kg from Challawa Gorge Dam, Kano, Nigeria. Jurujuba Sound in Southeast Brazil shows high Cr enrichment due to untreated sewage waste and urban surface runoff, influenced by rapid urbanization [60]. A study found high contamination of Cr in river sediment caused by tanneries in the State of Minas Gerais, Brazil [61]. The mean Cr concentration was found 186 mg/kg in a newly established tannery industrial Estate in Bangladesh which is higher than the MPL [62]. According to Bhuyan et al. [63], the Cr concentrations were determined to be within the permissible limits and significantly lower than those reported in a number of national and worldwide situations. The study of Buriganga River sediments in Bangladesh revealed a mean total Cr concentration of 173.4 mg/kg, indicating a severe pollution threat to both city residents and the river's aquatic ecosystem [64].

Manganese

The data shows that the average Mn concentration in sediment is 0.5191 mg/kg, with ranges of 0.1899 to 0.8483 mg/kg. The EPA guideline for manganese in sediments recommends keeping levels under 300 mg/kg [52], while the WHO sets the maximum permissible level for manganese in the soil at 2,000 mg/kg [65]. Chakravarty et al. [66] suggested that an appropriate manganese concentration in uncontaminated soil is 1,000 mg/kg. One study discovered an average manganese content of 269.5 mg/kg in beach sediments of Eastern St. Martin's Island, Bangladesh [63]. In contrast, another investigation revealed a notably elevated mean concentration of manganese in sediments, reaching 4036 mg/kg, along the Buriganga River in Bangladesh [64]. Rahman et al. [62] found a mean of 3.12 mg/kg of Mn in sediment at the newly established tannery industrial Estate in Bangladesh. Malami et al. [49] determined that the average manganese concentration in sediment from Challawa Gorge Dam, Kano, Nigeria, is 6.13 mg/kg. Onjefu et al. [65] found Mn ranged from 22.0–86.0 mg/kg in Shore Sediment Samples along the Coastline of Erongo Region, Western Namibia. Another study found a mean of 328 mg/kg Mn in sediments from sewage-fed fish ponds from Kolkata Wetlands, India [67]. Similarly, the highest 52.9 mg/kg of Mn was recorded in coastal sediments in southern Kuwait [68]. When comparing to the reference values, the average Mn concentration in sediments is low, according to the current results. Manganese compounds find applications in fertilizers, varnishes, and fungicides, as well as serving as supplements in livestock feed.

B. *Pollution risk assessment*

The study region's sediment samples were tested for contamination using the indices EF, I_{geo}, CF, and MDC. Table 4 lists the calculated EF and I_{geo} values in sediment samples taken from different locations of Rajshahi, while Table 6 lists the derived CF and MDC values.

A more objective approach to evaluating pollution appears to be the indicator of geo-accumulation [58]. The I_{geo} values have been used in order to clarify the quality of sediment. The I_{geo} values for Pb, Mn, Cr were below one for all the samples using the Muller [39] scale, indicating that the sampling sites were uncontaminated and Cd values varied -0.576 (T-2) to 1.846 (S-2), indicated that the sediment samples were uncontaminated or moderately contaminated. According to Lee et al. [55], the Igeo values for Cd and Pb were less than one, indicating the presence of heavy metal pollution in the study area. Rahman et al. [62] found the Igeo values for Pb, Mn, and Cr were -2.18, -8.80, and -0.44, respectively. The values of Cr for some sampling stations were found to be higher. Bhuyan et al. [63] discovered no significant adverse impact on the quality of sediment but a moderate risk to the aquatic ecosystem based on the Igeo. Similarly, the Igeo for Mn in five locations was higher than 3.0, indicating strongly polluted sediment quality [64]. Cd absorption and saturation are influenced greatly by anthropogenic activities and household activities like our daily used products such as batteries, and cigarette smoke. According to the findings of this study, the results indicate that Rajshahi City exhibits a moderate level of cadmium pollution.

According to Table 4, the greatest EF values for the Pb and Cd were 143.00 mg/kg, and 6645.746 mg/kg respectively, while the lowest value for Cr was 13.660 mg/kg. Among the examined HMs, the EF values were measured in the following order: Cd > Pb > Cr. In all the investigated sites, Cd enrichment was unfortunately found to be exceedingly severe as EF > 50. In the case of Pb S-1, S-2, B-2, and T-2 sites were very extremely severely enriched as EF > 50, and sites B-1, B-3, T-3, S-3 were severely enriched as EF > 25, other sites were in the range of moderate to moderately severe. The Cr enrichment in the sediments was found in the range of moderate to severe enriched. Lee et al. [55] observed EF values ranging between 5 and 20 for Pb and Cd, indicating pollution with heavy metals in the study area. According to the study, the average EF for Mn and Cd indicates an exceptionally high level of pollution, suggesting that these metals likely originated from specific point sources of pollution and are significantly enriched in river sediments [64]. Nour et al. [68] found that all studied sites are extremely severely

Table 4: The EF and I_{geo} in sediment samples

Sample Id no.	EF			I_{geo}			
	Pb	Cr	Cd	Pb	Cr	Mn	Cd
B-1	29.884	3.767	1835.319	-5.667	-8.807	-10.569	0.272
B-2	143.000	7.563	2053.824	-3.754	-8.146	-10.913	0.090
B-3	42.986	7.686	3292.335	-5.238	-7.874	-10.664	1.020
M-1	12.242	13.660	1505.823	-6.162	-6.156	-9.776	0.779
M-2	15.761	4.894	1218.336	-4.976	-6.816	-8.955	1.295
M-3	22.458	9.762	1710.918	-5.345	-6.699	-9.834	0.905
T-1	22.589	3.118	446.640	-4.308	-7.317	-8.806	-0.003
T-2	54.104	7.212	889.507	-4.615	-7.675	-10.373	-0.576
T-3	47.075	10.742	1933.746	-5.203	-7.488	-10.760	0.156
S-1	118.477	6.488	1561.56	-3.531	-7.874	-10.419	0.189
S-2	71.847	7.321	6645.746	-4.684	-8.132	-10.851	1.846
S-3	43.142	5.048	2461.017	-4.416	-7.664	-9.847	1.417
Min	12.242	3.118	446.6407	-6.162	-8.807	-10.913	-0.576
Max	143.000	13.660	6645.746	-3.754	-6.156	-8.806	1.846
Average	51.96419	7.27224	2129.56435	-4.824	-4.182	-10.147	0.615

enriched with Cd. The present study revealed that all examined sites exhibited enrichment in heavy metals, indicating that Rajshahi City is likely enriched in heavy metals due to anthropogenic activities.

CF values of studied HMs were found to be less than one for Mn, Pb, and Cr, whereas Cd exhibited higher CF values (Table 5). Among the examined HMs, the EF values were measured in the following order: Cd > Pb > Cr > Mn. Among all the studied sites considerable contamination was found by Cd as B-3(3.043), M-2(3.681), S-2(5.394), S-3(4.005) > 3. Low contamination was found by Pb, Mn, and Cr as CF < 1. According to Bhuyan et al. [63], the contamination factors (CFs) for Pb, Mn, and Cr suggest a moderate risk to the aquatic ecosystem that does not signalling a significant detrimental impact on sediment quality. Another study, confirmed by the results of the CF analysis on coastal sediments, concluded that Southern Kuwait was highly contaminated with cadmium [68]. The levels of the heavy metals studied in this study were found to be substantial according to CF guidelines.

The MDC was used to show the degree of contamination for a metal pollutant [59]. All of the sediment samples had MDC values for Pd, Mn, Cr, and Cd that indicated minimal to zero contamination as MDC < 1.5. This study indicates that the studied HMs values for MDC were within acceptable limits.

Table 5: The CF and MDC in sediment samples

Sample Id No.	CF				MDC
	Pd	Cr	Mn	Cd	
B-1	0.029	0.003	0.0009	1.812	0.461
B-2	0.111	0.005	0.0007	1.596	0.428
B-3	0.039	0.007	0.0009	3.043	0.772
M-1	0.021	0.023	0.0017	2.575	0.655
M-2	0.047	0.014	0.0030	3.681	0.936
M-3	0.036	0.016	0.001	2.810	0.716
T-1	0.075	0.010	0.0033	1.496	0.396
T-2	0.061	0.008	0.0011	1.005	0.269
T-3	0.040	0.009	0.0008	1.671	0.430
S-1	0.129	0.007	0.0010	1.71	0.461
S-2	0.058	0.00	0.0008	5.394	1.364
S-3	0.070	0.008	0.0016	4.005	1.021
Min	0.021	0.003	0.001	1.005	0.269
Max	0.129	0.023	0.003	5.394	1.364
Average	0.060	0.010	0.001	2.566	0.659

V. CONCLUSION

Studying HMs in pond sediment is crucial for environmental impact, human health concerns, regulatory compliance, pollution source identification, and ecosystem health assessment. Contaminated sediment can lead to HM accumulation in fish, contaminating the food chain and posing risks to human health. Monitoring levels helps identify pollution sources and assess ecosystem health. In addition to evaluating the level of pollution, the purpose of this research was to determine the HM concentrations of Pb, Mn, Cr, and Cd in sediment samples taken from several locations inside the Rajshahi City Corporation of Bangladesh. Almost all sediment tests had harmful metal levels that were within the safe, allowable limits set by the European Union and the World Health Organization. The order of HMs accumulation in sediment (mg/kg as dry weight basis) was shown by the average data analysis to be Mn (1.27106) > Pb (1.20285) > Cr (0.9004) > Cd (0.7709) respectively. The data showed that Mn was in high concentration in the sediments, while Cd concentration was minimal. The information demonstrated that where Cd accumulated very little, Mn was extremely concentrated within the sediment samples. These pollution assessment indices suggested that, given the studied HMs, the study area currently had a low level of pollution. But the sampling sites were extremely severe enriched by Cd as EF > 50. In the case of Pb few sites were extremely severe enriched. This study may indicate that additional investigation is required to identify possible causes of contamination with HMs as well as determine the concentrations necessary to take appropriate action. Future research on certain HMs will benefit from this study.

ACKNOWLEDGMENTS

The authors are grateful for the laboratory facilities provided by the Department of Applied Chemistry and Chemical Engineering, Faculty of Engineering, and Central Laboratory of University of Rajshahi, Bangladesh.

REFERENCES

[1] Singh KP, Mohan D, Singh VK, Malik A. Studies on distribution and fractionation of heavy metals in Gomti river sediments—a tributary of the Ganges, India. *Journal of Hydrology*. 2005;312(1–4): 14–27. http//doi.org/10.1016/j.jhydrol.2005.01.021.

[2] Ágarwal AK, Singh RK, Mishra S, Bhunya PK. ANN-based sediment yield models for Vamsadhara river basin (India). *Water SA*. 2005;31(1): 85–100. https://doi.org/10.4314/wsa.v31i1.5125.

[3] Loska K, Wiechuła D. Application of principal component analysis for the estimation of source of heavy metal contamination in surface sediments from the Rybnik Reservoir. *Chemosphere*. 2003;51: 723–733. https://doi.org/10.1016/s0045-6535(03)00187-5.

[4] Chapman PM, Wang F, Janssen C, Persoone G, Allen HE. Ecotoxicology of metals in aquatic sediments: binding and release, bioavailability, risk assessment, and remediation. *Canadian Journal of Fisheries and Aquatic Sciences*. 1998;55(10): 2221–43. https://doi.org/10.1139/cjfas-55-10-2221.

[5] Costa-Böddeker S, Thuyên LX, Hoelzmann P, de Stigter HC, van Gaever P, Huy HDC, et al. The hidden threat of heavy metal pollution in high sedimentation and highly dynamic environment: Assessment of metal accumulation rates in the Thi Vai Estuary, Southern Vietnam. *Environmental Pollution*. 2018;242: 348–56. https://doi.org/10.1016/j.envpol.2018.05.096.

[6] Fakhradini SS, Moore F, Keshavarzi B, Lahijanzadeh A. Polycyclic aromatic hydrocarbons (PAHs) in water and sediment of Hoor Al-Azim wetland, Iran: a focus on source apportionment, environmental risk assessment, and sediment-water partitioning. *Environmental Monitoring and Assessment*. 2019;191(4): 233. https//doi.org/ 10.1007/s10661-019-7360-0.

[7] Hernández-Cruz EY, Amador-Martínez I, Aranda-Rivera AK, Cruz-Gregorio A, Pedraza Chaverri J. Renal damage induced by cadmium and its possible therapy by mitochondrial transplantation. *Chemico-Biological Interactions*. 2022;361: 109–961. https://doi.org/10.1016/j.cbi.2022.109961.

[8] Qing Y, Yang J, Chen Y, Shi C, Zhang Q, Ning Z, et al. Urinary cadmium in relation to bone damage: cadmium exposure threshold dose and health-based guidance value estimation. *Ecotoxicologyand Environmental Safety*. 2021;226: 112824. https://doi.org/10.1016/j.ecoenv.2021.112824.

[9] Shahriar SMS, Munshi M, Hossain MS, Zakir HM, Salam SMA. Risk assessment of selected heavy metals contamination in rice grains in the Rajshahi City of Bangladesh. *Journal of Engineering Science*. 2023a;14(1): 29–41. https://doi.org/10.3329/jes.v14i1.67633.

[10] Shahriar SMS, Munshi M, Zakir HM, Islam MJ, Mollah MMA, Salam SMA. Assessment of heavy metal pollution in irrigation water of Rajshahi City, Bangladesh. *Environmental and Earth Sciences Research Journal*. 2023b;10(3): 100–110. https://doi.org/10.18280/eesrj.100303.

[11] Kinuthia GK, Ngure V, Beti D, Lugalia R, Wangila A, Kamau L. Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. *Scientific Reports*. 2020;10(1): 8434. https://doi.org/10.1038/s41598-020-65359-5.

[12] Rojas-Avelizapa NG. *Biotechnology for treatment of residual wastes containing metals*. Denmark: River Publishers; 2022.

[13] Shahriar SMS, Islam MJ, Hanif MA, Salam SMA. Level of chromium and zinc in groundwater and cows' raw milk in Rajshahi, Bangladesh. *International Journal of All Research Education and Scientific Methods*. 2022;10(2): 2153–2158.

[14] Rahman MA, Hashem MA, Rana MS, Islam MR. Manganese in potable water of nine districts, Bangladesh: human health risk. *Environmental Science and Pollution Research*. 2021;28: 45663–45675. https://doi.org/10.1007/s11356-021-14016-z.

[15] Ahmed MJ, Matsumoto M, Kurosawa K. Heavy metal contamination of irrigation water, soil, and vegetables in a multi-industry district of Bangladesh. *International Journal of Environmental Research*. 2018;12: 531–542. https://doi.org/10.1007/s41742-018-0113-z.

[16] Bhuiyan MAH, Islam MA, Dampare SB, Parvez L, Suzuki S. Evaluation of hazardous metal pollution in irrigation and drinking water systems in the vicinity of a coal mine area of northwestern Bangladesh. *Journal of Hazardous Materials*. 2010;(1-3): 1065–1077. https://doi.org/10.1016/j.jhazmat.2010.03.114.

[17] Jewel SA, Haque A, Amin R, Hasan J, Alam L, Mondal S, et al. Heavy metal contamination and human health risk associated with sediment of Ganges River (Northwestern Bangladesh). *An International Quarterly Scientific Journal*. 2020;19: 783–790. http//-doi.org/10.46488/NEPT. 2020.v19i02.035.

[18] Rampley CPN, Whitehead PG, Softley L, Hossain MA, Jin L, David J, et al. River toxicity assessment using molecular biosensors: heavy metal contamination in the Turag-Balu-Buriganga River systems, Dhaka, Bangladesh. *Science of the Total Environment*. 2020;703: 134760. https://doi.org/10.1016/j.scitotenv.2019.134760.

[19] Saha N, Zaman MR. Concentration of selected toxic metals in groundwater and some cereals grown in Shibganj area of Chapai Nawabganj, Rajshahi, Bangladesh. *Current Science*. 2011;101(3): 427–431. http://www.jstor.org/stable/24078523 [Accessed 16^{th} January 2024].

[20] Zakir H, Rahman MM, Rahman A, Ahmed I, Hossain M. Heavy metals and major ionic pollution assessment in waters of midstream of the river Karatoa in Bangladesh. *Journal of Environmental Science and Natural Resources*. 2013;5(2): 149–160. https://doi.org/10.3329/jesnr.v5i2.14806.

[21] Rai RK. Heavy metal pollution in aquatic ecosystems and its phytoremediation using wetland plants: an ecosustainable approach. *International Journal of Phytoremediation*. 2008;10(2): 131–58. https://doi.org/10.1080/15226510801913918.

[22] MHe Z, Li F, Dominech S, Wen X, Yang S. Heavy metals of surface sediments in the Changjiang (Yangtze River) Estuary: Distribution, speciation and environmental risks. *Journal of Hazardous Materials*. 2019;198: 18–28. https://doi.org/10.1016/j.gexplo.2018.12.015.

[23] Hu Y, Cheng H, Tao S. The challenges and solutions for cadmium-contaminated rice in China: A critical review. *Environment International*. 2016;92–93: 515–532. https://doi.org/10.1016/j.envint.2016.04.042.

[24] Chan WS, Routh J, Luo C, Dario M, Miao Y, Luo D, et al. Metal accumulations in aquatic organisms and health risks in an acid mine-affected site in South China. *Environmental Geochemistry and Health*. 2021;43: 4415–4440. https://doi.org/10.1007/s10653-021-00923-0.

[25] Ahmed MK, Baki MA, Kundu GK, Islam MS, Islam MM, Hossain MM. Human health risks from heavy metals in fish of Buriganga River, Bangladesh. *SpringerPlus*. 2016;5(1): 1697. https://doi.org/10.1186/s40064-016-3357-0.

[26] Tabari S, Saravi SSS, Bandany GA, Dehghan A, Shokrzadeh M. Heavy metals (Zn, Pb, Cd, and Cr) in fish, water, and sediments sampled form Southern Caspian Sea, Iran. *Toxicology and Industrial Health*. 2010;26(10): 649–656. https://doi.org/10.1177/0748233710377777.

[27] Obire O, Tamuno DC, Wemedo SA. Physico-chemical quality of Elechi Creek in Port Harcourt, Nigeria. *Journal of Applied Science and Environmental Management*. 2003;7(1): 43–49.

[28] Hossain MB, Sultana J, Pingki FH, Nur AAU, Mia MS, Bakar MA, et al. Accumulation and contamination assessment of heavy metals in sediments of commercial aquaculture farms from a coastal area along the northern Bay of Bengal. *Frontiers in Environmental Science*. 2023;11. https://doi.org/10.3389/fenvs.2023.1148360.

[29] Sultana N, Sarker MJ, Palash MAU. A study on the determination of heavy metals in freshwater aquaculture ponds of Mymensingh. *Bangladesh Maritime Journal*. 2019;3(1): 143–149.

[30] Astatkie H, Ambelu A, Mengistie E. Contamination of stream sediment with heavy metals in the Awetu watershed of Southwestern Ethiopia. *Frontiers*. 2021;9. https://doi.org/10.3389/feart.2021.658737.

[31] Algül F, Beyhan M. Concentrations and sources of heavy metals in shallow sediments in Lake Bafa, Turkey. *Scientific Reports*. 2020;10: 11782. https://doi.org/10.1038/s41598-020-68833-2.

[32] Banglapedia. *Bangladesh*. https://en.banglapedia.org/index.php/Bangladesh [Accessed 23^{rd} November 2023].

[33] Awal R, Saptoka P, Chitrakar S, Thapa BS, Neopane HP, Thapa B. A general review on methods of sampling and mineral content analysis. *Journal of Physics: Conference Series*. 2019;1266(1): 12005. https://doi.org/10.1088/1742-6596/1266/1/012005.

[34] Rahman MS, Khan MDH, Jolly YN, Kabir J, Akter S, Salam A. Assessing risk to human health for heavy metal contamination through street dust in the southeast Asian megacity: Dhaka, Bangladesh.

Science Total Environment. 2019;660: 1610–1622. https//doi.org/10.1016/j.scitotenv.2018.12.425.

[35] Eaton AD, Franson MAH, Clesceri LS, Rice EW, Greenberg AE (eds.). *Standard methods for the examination of water and wastewater*. 21st ed. Washington, DC: American Public Health Association; 2005.

[36] Hossain MS, Ahmed MK, Sarker S, Rahman MS. Seasonal variations of trace metals from water and sediment samples in the northern bay of Bengal. *Ecotoxicology and Environmental Safety*. 2020;193: 110347. https://doi.org/10.1016/j.ecoenv.2020.110347.

[37] 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. *Environmental Earth Sciences*. 2014;71: 2293–2308. https://doi.org/10.1007/s12665-013-2631-5.

[38] Looi LJ, Aris AZ, Yusoff FM, Isa NM, Haris H. Application of enrichment factor, geoaccumulation index, and ecological risk index in assessing the elemental pollution status of surface sediments. *Environmental Geochemistry Health*. 2019;41: 27–42. https://doi.org/10.1007/s10653-018-0149-1.

[39] Muller G. Index of geoaccumulation in sediments of the Rhine River. *Geojournal*. 1969;2: 108–118. https://ci.nii.ac.jp/naid/10030367619/.

[40] Dat ND, Nguyen VT, Vo TDH, Bui XT, Bui MH, Nguyen LSP, et al. Contamination, source attribution, and potential health risks of heavy metals in street dust of a metropolitan area in Southern Vietnam. *Environmental Science and Pollution Research*. 2021;28: 50405–19. https://doi.org/10.1007/s11356-021-14246-1.

[41] Nguyen GT. Initial survey of heavy metal concentrations in paddy soil and rice plants (*oryza sativa* l.) near and far from open landfill in Southern Vietnam. *Tra Vinh University Journal of Science*. 2020;10(38): 48–59. https://doi.org/10.35382/18594816.1.38.2020.554.

[42] Salam MA, Alam MA, Paul SI, Islam F, Shaha DC, Rahman MM, et al. Assessment of heavy metals in the sediments of Chalan Beel Wetland area in Bangladesh. *Processes*. 2021;9(3): 410. https://doi.org/10.3390/pr9030410.

[43] Buat-Menard P, Chesselet R. Variable influence of atmospheric flux on the trace metal chemistry of oceanic suspended matter. *Earth and Planetary Science Letters*. 1979;42(3): 398–411. http://dx.doi.org/10.1016/0012-821X(79)90049-9.

[44] Khademi H, Gabarrón M, Abbaspour A, Martínez-Martínez S, Faz A, Acosta JA. Distribution of metal(loid)s in particle size fraction in urban soil and street dust: influence of population density. *Environmental Geochemistry and Health*. 2020;42: 4341–54. https://doi.org/10.1007/s10653-020-00515-4.

[45] Zhou L, Liu G, Shen M, Hu R, Sun M, Liu Y. Characteristics and health risk assessment of heavy metals in indoor dust from different functional areas in Hefei, China. *Environmental Pollution*. 2019;251: 839–849. https://doi.org/10.1016/j.envpol.2019.05.058.

[46] Turekian KK, Wedepohl KH. Distribution of the elements in some major units of the earth's crust. *Geological Society of America Bulletin*. 1961;72(2): 175–192. https://doi.org/10.1130/0016-7606(1961)72[175:DOTEIS]2.0.CO;2.

[47] Hakanson L. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research*. 1980;14(8): 975–1001. https://doi.org/10.1016/0043-1354(80)90143-8.

[48] Hossain MdS, Ahmed MdK, Liyana E, Hossain MdS, Jolly YN, Kabir MJ, et al. Case study on metal contamination in water and sediment near a coal thermal power plant on the Eastern coast of Bangladesh. *Environments*. 2021;8(10): 108. https://doi.org/10.3390/environments8100108.

[49] Malami DI, Zakaria ZI, Mohammed MI, Audu AA. Comparison of levels of some metals in the water and sediment from Challawa Gorge Dam, Kano, Nigeria. *Bayero Journal of Pure and Applied Sciences*. 2014;7(1): 80–84. https://doi.org/10.4314/bajopas.v7i1.15.

[50] USEPA (United States Environment Protection Agency). *Guidelines for water reuse*. Washington, USA: U.S. EPA, Offices of Water and Waste Water Compliance; 1992. p.200–247.

[51] Uddin MJ, Parveen Z, Hossain MF. Status of heavy metals in water and sediments of canals and rivers around the Dhaka city of Bangladesh and their subsequent transfer to crops. *Advances in Plants & Agriculture Research*. 2016;5(4): 593–601. https://doi.org/10.15406/apar.2016.05.00189.

[52] Ogbeibu AE, Omoigberale OM, Ezenwa IM, 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. *Natural Environment*. 2014;2(1); 1–9.

[53] Onianwa P, Fakayode SO. Lead contamination of topsoil and vegetation in the vicinity of a battery factory in Nigeria. *Environmental Science*. 2000;22: 211–218. https//doi.org/10.1023/A:1026539531757.

[54] Soylak M, Divrikli U, Saracoglu S, Elci L. Monitoring trace metal levels in Yozgat-Turkey: Copper, iron, nickel, cobalt, lead, cadmium, manganese, and chromium levels in stream sediments. *Polish Journal of Environmental Studies*. 2002;11(1): 47–52.

[55] Lee AC, Idrus FA, Aziz F. Cadmium and lead concentrations in water, sediment, fish, and prawn as indicators of ecological and human health risk in Santubong Estuary, Malaysia. *Jordan Journal of Biological Sciences*. 2021;14(2): 317–325. https://doi.org/10.54319/jjbs/140218.

[56] Majumder AK, Al Nayeem A, Islam M, Akter MM, Carter WS. Critical review of lead pollution in Bangladesh. *Journal of Health & Pollution*. 2021;11(31): 210902. https://doi.org/10.5696/2156-9614-11.31.210902.

[57] Adeyemo OK. Lead levels in rivers, sediments and fish ponds in the Ibadan metropolitan area, south-west Nigeria. *African Journal of Aquatic Science*. 2007;32(2): 153–157. https://doi.org/10.2989/AJAS.2007.32.2.6.203.

[58] Mishra R, Dubey S. Fresh water availability and its global challenge. *International Journal of Engineering Science Invention Research & Development*. 2005; 2(6): 351–407.

[59] Zair W. *Conservation of crop wild relatives' diversity in the Fertile Crescent*. Doctoral dissertation. England: University of Birmingham; 2019.

[60] Baptista Neto JA, Smith BJ, McAllister JJ. Heavy metal concentrations in surface sediments in a nearshore environment, Jurujuba Sound, Southeast Brazil. *Environmental Pollution*. 2000;109(1): 1–9. https//doi.org/ 10.1016/s0269-7491(99)00233-x.

[61] Jordao CP, Pereira JL, Jham GN. Chromium contamination in sediment, vegetation and fish caused by tanneries in the State of Minas Gerais, Brazil. *Science of the Total Environment*. 1997;207(1): 1–11. https://doi.org/10.1016/S0048-9697(97)00232-5.

[62] Rahman MS, Ahmed Z, Seefat SM, Alam R, Islam ARMT, Choudhury TR, et al. Assessment of heavy metal contamination in sediment at the newly established tannery industrial Estate in Bangladesh: A case study. *Environmental Chemistry and Ecotoxicology*. 2022;4: 1–12. https://doi.org/10.1016/j.enceco.2021.10.001.

[63] Bhuyan MS, Haider SMB, Meraj G, Bakar MA, Islam MT, Kunda M, et al. Assessment of heavy metal contamination in beach sediments of Eastern St. Martin's Island, Bangladesh: implications for environmental and human health risks. *Water*. 2023;15: 2494. https://doi.org/10.3390/w15132494.

[64] Mohiuddin KM, Alam MM, Ahmed I, Chowdhury AK. Heavy metal pollution load in sediment samples of the Buriganga river in Bangladesh. *Journal of the Bangladesh Agricultural University*. 2015;13(2): 229–238.

[65] Onjefu, SA, Kgabi NA, Taole SH. Heavy metal seasonal distribution in shore sediment samples along the coastline of Erongo region, Western Namibia. *European Journal of Scientific Research*. 2016;39(1): 49–63.

[66] Chakravarty M, Patgiri AD. Metal pollution assessments of Dikrong River, NE India. *Journal of Human Ecology*. 2009;27(1): 63–67.

[67] Kumar B, Shah R, Mukherjee D. Geochemical distribution of heavy metals in sediments from sewage fed fish ponds from Kolkata Wetlands, India. *Chemical Speciation & Bioavailability*. 2011;23(1): 24–32. https//doi.org/10.3184/095422911X12966667026105.

[68] Nour HE, Ramadan F, Shammari NE, Tawfik M. Status and contamination assessment of heavy metals pollution in coastal sediments, southern Kuwait. *AIMS Environment Sciences*. 2022;9(4): 538–552. https://doi.org/10.3934/environsci.2022032.