BASELINE ASSESSMENT OF HEAVY METAL CONTAMINATION AND ECOLOGICAL RISK OF COASTAL TOP-SOIL IN DAKSHIN BEDKASHI UNION UNDER KOYRA UPAZILA BANGLADESH

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ABSTRACT

Heavy Metals (HMs) released from diverse sources are washed out by the river channels and subsequently deposited on once unpolluted floodplain soil and leads to contamination and ecological risk in coastal areas. This study aims to asses for the first time the HMs (Pb, Cr, Cd, Hg, Zn and Ni) content at the floodplain soil of Dakshin Bedkashi Union under Koyra Upazila, Bangladesh thus, this study will serve as a baseline study of its kind for this area. Since the study area is adjacent to the Sundarbans mangrove forest and minimal industrial and transportation activities that can induce HMs pollution, the primary hypothesis was that the floodplain soil of this area will have less or no contamination of HM. In this regard, top-soil samples were collected from both flood-prone area (frequently flooded by tide action) and non-flood-prone area (not flooded or only flooded during major flood events). The soil samples underwent air-drying before being digested with Aqua regia. Atomic Absorption Spectroscopy (AAS) was employed to measure the concentration of HMs in the digested samples. Critical indices like Pollution Load Index (PLI), Potential Ecological Risk Index (PERI), and Contamination Factor (CF) were utilized to assess the degree of contamination. Moreover, GIS technology aided in pinpointing the region's most susceptible to ecological risks and contamination caused by HMs. Overall, all the studied metals (average concentration) are within the world and Dutch standard for agricultural soil. Surprisingly, a few parts of the area are facing a slight amount of HMs pollution, especially for Pb. The HMs concentration indicates Zn (69.74±13.74mg/kg) has the highest value whereas Hg (0.01±0.02mg/kg) has the lowest concentration. The order of concentration for the other HMs was observed to be Cr > Pb > Ni > Cd. The CF model detects specific areas with elevated level of Pb contamination, whereas Zn, Ni, Cr and Cd levels suggest no contamination by these metals. Hence, the area has naturally occurring Zn, Ni, Cr and Cd content in the floodplain soil but some anthropogenic contribution for Pb contamination in some parts of it has also been suspected. According to the PERI model, the study area is at a low to moderate ecological risk level with an average index value of 128. Besides, the GIS analysis indicates that areas near river sides are more susceptible to HMs pollution. Based on the findings, it appears that most of the parts in this area have not yet been contaminated by HMs and has virgin soil, hence, complying with our hypothesis while only a few parts pose high contamination and ecological risk which can be attributed to the deposition of HMs from non-point sources that are carried out by the river channel.

Keywords: *Heavy Metal, Contamination Factor, Pollution load index, Potential ecological risk index, Baseline study in Coastal area of Bangladesh*

1. INTRODUCTION

Toxic, poisonous, carcinogenic, non-biodegradable and persistent nature of heavy metals (HMs) have become a center of attention in the present global perspective (Fergusson & Prucha, 1990). It is of great concern because the accumulation of HMs in the environment can eventually transfer them into the food chain and hinder the natural balance of both aquatic and terrestrial ecosystem (Alam et al., 2007). HMs also demonstrate toxic and poisonous behavior and may cause serious health effects to the living flora and fauna irrespective of their concentration (Kabata-Pendias, 2010). In addition to that, HMs have the characteristics of biomagnifying and ending up into the higher trophic level in much larger concentration which is a serious health risk for human beings (Morillo et al., 2002).

Heavy metals in water can either stay dissolved as ions or attach to solid particles like sediment. When they remain dissolved, chemical interactions may change their state, causing them to form solid compounds. When they attach to solid particles, these particles act as carriers, helping metals move through water. Eventually, these particles settle, continuing to pollute the water or forming sediment on the riverbed (Salomons & Förstner, 1984). Multiple studies on coastal sediment provide evidence on the availability of HMs in a higher concentration and surfaced its effects on environment as well as health risk to human beings with the help of pollution assessment indices (Ahmad et al., 2021; Kinuthia et al., 2020; Mallick et al., 2019; Sadeghi et al., 2022; Tchounwou et al., 2012). In river systems, the amounts of solid particles suspended in the water and pollutants tend to increase as the water flow increases (Müller, 1998). During a flooding event, pollutants that were previously stored in the channel are rapidly mobilized and transported to the floodplain and adjacent coastal areas (Matys Grygar et al., 2014). The process of sediment sorting in a channel, occurring during both high and low discharge events, as well as in a floodplain during flood events, is a significant mechanism that contributes to the swift alterations in heavy-metal concentrations observed in sedimentary sequences(Ciszewski & Grygar, 2016). Countries like Bangladesh is in serious risk of HMs pollution as approximately 80% of the country’s landmass is comprised of floodplain (Brammer, 1990). Studies has shown that the floodplain topsoil of the coastal regions of Bangladesh is facing HMs pollution due to the regular events of inundation (Arafin et al., 2023; Kibria et al., 2016; Siddique et al., 2021; Siddiquee et al., 2012).

Bangladesh is a nation situated in a deltaic area, characterized by low-lying terrain and the convergence of three significant rivers: the Ganges, the Brahmaputra, and the Meghna and south facing funnel shaped Bay of Bengal, making it susceptible to natural disasters, namely instances of flooding (Baten et al., 2018). Coastal flooding and river bank breaching are recurrent phenomena in Bangladesh, with significant consequences for the nation's geographical features and societal framework. Coastal regions that are exposed to the vast expanse of the open ocean are inherently vulnerable to natural calamities and have an increased propensity for soil pollution when compared with their inland equivalents. As per the Program Development Office for Integrated Coastal Zone Management Plan (PDO-ICZMP) report of 2003, coastlines that are exposed to the sea are subject to frequent inundation and have direct impacts on them. The areas that have not been flooded are comparatively less affected by the open sea and therefore have a lower probability of being contaminated. This study will be conducted on the coastal floodplain soil of both areas which are subject to regular inundation event and which are not of Dakshin Bedkashi Union of Koyra Upazila, Bangladesh. Koyra Upazila, according to the ICZMP is categorised as one of the exposed and vulnerable coastal regions of Bangladesh. The geographical location of Koyra Upazila makes it particularly vulnerable to frequent cyclones, tidal surges, inundation, and intense precipitation events. The re-emergence of pollutants, specifically HMs, on the surface soil can have adverse impacts on the livelihood and health of the local population.

The primary objective of this study is to assess the concentration of heavy metals in soil samples collected from both flood-prone and non-flood-prone zones within the Dakshin Bedkashi Union of Koyra Upazila for the very first time. Additionally, the study aims to evaluate the pollution level using different environmental indices to better understand the impact of heavy metal contamination on the local ecosystem.

2. MATERIALS AND METHODS

2.1 Description of the study area

Koyra Upazila, in Khulna district, spans 1775.41 sq km, positioned between 22°12' to 22°31' north latitudes and 89°15' to 89°26' east longitudes. It shares borders with Paikgachha Upazila to the north, the Bay of Bengal and Sundarbans to the south, Dacope Upazila to the east, and Assasuni and Shyamnagar Upazila to the west. Situated downstream in the Ganges Delta, it's linked with Kapotaksha river, Sakbaria river, and the Sundarbans. Notable for its deltaic location, it benefits from the protective role of the Sundarbans against erosion and storms. Economic activities primarily revolve around agriculture, including rice, jute, and fruit cultivation. Fishing thrives due to its proximity to the Bay of Bengal. Like other coastal areas, Koyra faces recurring monsoon floods and cyclonic disturbances, owing to its river network and coastal location.

The research was conducted within the jurisdiction of the Dakshin Bedkashi Union in the Koyra Upazila of Khulna, Bangladesh. The total population residing in Dakshin Bedkashi was recorded as 16,755 individuals, distributed across 3,881 homes (BBS, 2011). The Union is geographically bordered by Shamnagar Upazila to the West and the Sundarban Mangrove Forest to the North, East, and South. The indigenous population mostly engages in agricultural and aquacultural activities, with a focus on cultivating rice during a single growing season (Naus et al., 2019). The summer season, occurring from March to June, was marked by high temperatures. During the conclusion of the summer season, namely in the months of April and May, the tidal river exhibited elevated levels of salinity (Bhuiyan & Dutta, 2012).

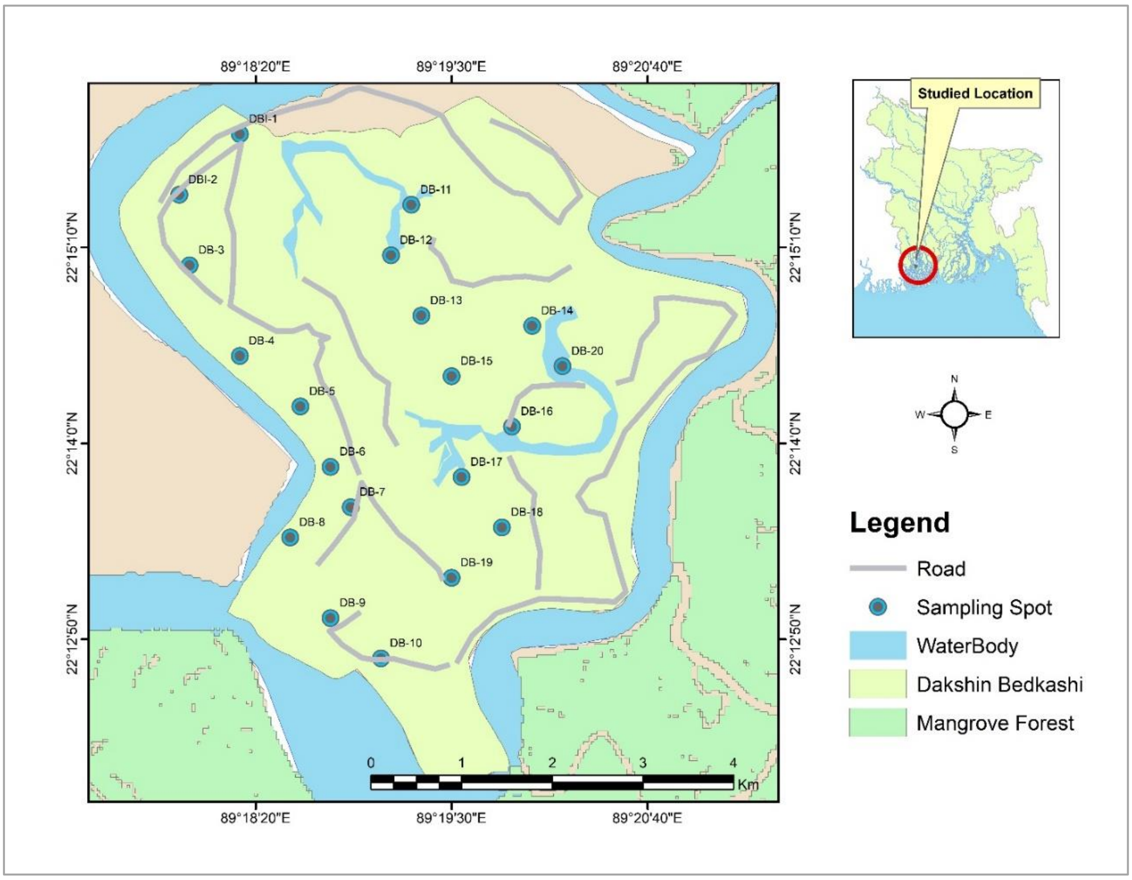

Figure 1: Map of the study area

2.2 Sampling and Sample Preparation

A comprehensive collection of soil data was conducted throughout the Dakshin Bedkashi Union, encompassing both flood-prone and non-flood-prone regions. A systematic methodology was employed to collect a comprehensive set of soil samples, totaling 20 in number, with an equal distribution of ten samples obtained from each designated region. The samples were collected from the subsoil located inside the root zone, namely at a depth of 5-10 cm. The collection process involved obtaining 10 samples from locations prone to flooding and an additional 10 samples from areas not prone to flooding.

Following the collecting process, the samples were subjected to an initial air-drying period lasting around 2-3 weeks in order to decrease their moisture content. Following that, the process of screening using a 5-mm sieve was employed to eliminate foreign particles of greater size and provide a consistent texture. The removal of organic debris was carried out using cleaning procedures in the laboratory, while soil clumps were dispersed by employing mechanical screening techniques using mesh widths ranging from 10.0 to 0.075 mm. Samples with a size above 2.0 mm were appropriately stored in plastic bags that were clearly labelled. The meticulous procedure ensured the preservation of the samples' integrity, hence facilitating precise analysis.

2.3 Heavy Metal Determination

Prepared soil samples were digested with aqua regia method (USEPA, 2007) that involves treating a soil sample with a mixture of hydrochloric (HCl) and nitric (HNO_3) acids in proportions of 3:1. The nitric acid decomposes organic matter and oxidizes sulfide-based substances. Aqua regia is produced by its reaction with concentrated hydrochloric acid: $3HCl+HNO_3 \rightarrow 2\ H_2O+NOCl+Cl_2$ (Gaudino et al., 2007). The analysis of the digested soil sample to quantify the concentration of heavy metals has been conducted using Atomic Absorption Spectrometer (AAS) (Varian AA240 FS). The daily preparation of the working standard solutions involved the required dilution of the corresponding 1000 mg/L stock standard solutions (Spectropure, USA) using 1% (w/w) supra-pure grade nitric acid (Merck, Darmstadt, Germany). The instruments for analyzing samples were used in conjunction with the validated methodologies (using Certified Reference Material in soil-based matrix) and these methodologies were certified on ISO/IEC 17025:2017.

2.4 Pollution Assessment Indices

2.4.1 Contamination Factor (CF)

The contamination factor (CF), is a crucial metric in determining the extent of metal pollution in soil caused by human activity. It is a measure used to assess the extent of contamination of a particular element (e.g., heavy metals) in a specific sample compared to a reference or background value. The following formula can effectively quantify the metal deposits in the soil (Ahmed et al., 2016; Arafin et al., 2023b).

$$\boldsymbol{CF = \frac{E_{concentration}}{E_{background}}}$$

Here, $E_{concentration}$ represents the concentration of heavy metals in the studied region, while $E_{background}$ represents the background concentration of the analyzed metal. The mean geochemical baseline values for metals within the Earth’s crust were used in this study as background values (Rahman et al., 2021; Taylor & McLennan, 1985).

2.4.2 Pollution Load Index (PLI)

Tomlinson's pollution load index (PLI) was used to determine the existing metal pollution levels at each site (Tomlinson et al., 1980). This index is an important tool for evaluating the environmental quality of a particular region.

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times \ldots\ldots..\times CF_n}$$

Here CF is the contamination factor for each HMs. The evaluation of a site's quality can be done through the use of PLI metrics (Arafin et al., 2023). Typically, a PLI value of less than one is considered optimal, while a PLI value of one indicates the presence of contaminants in amounts equivalent to the reference line. If the PLI value exceeds one, it is assumed that the site's quality is deteriorating.

2.4.3 Potential Ecological Risk Index (PERI):

The assessment of the overall potential ecological risk of heavy metals in sediment was conducted using the Potential Ecological Risk Index (PERI), which was first introduced by (Hakanson, 1980). The PERI can be calculated as:

$$E_f^i = CF \times T$$

$$RiskIndex\ (RI) = \sum E_f^i$$

Here, E_f^i represents the potential ecological risk for each metal which is the multiplication product of contamination factor and biological toxic Factor (T). The biological toxic factor for Zn, Cr, Pb, Cu, and Ni are 1, 2, 5, 5, and 30 respectively (Kabir et al., 2020). Table 1 provides the definition of the indexed value.

Table 1: The range of different pollution level indicated PERI

Sel No	Range	Pollution Degree
1	1<RI<150	No/ Low level of pollution
2	150≤RI<300	Moderate level of pollution
3	300≤RI<600	Considerable level of pollution
4	600≤RI	High level of pollution

3. RESULT AND DISCUSSION

3.1 Heavy Metals Concentration and Spatial Distribution:

This study reveals interesting findings on HMs content and distribution at the Dakshin Bedkashi union. The results showing in Figure 2, has marked Zn (69.74±13.67mg/kg) as the highest occurring HM while Cd (0.26±0.21 mg/kg), Ni (4.77±1.19 mg/kg) and Hg (0.01±0.02 mg/kg) are the lowest occurring HMs. The concentration of Pb (22.46±3.98 mg/kg) and Cr (26.34±4.62 mg/kg) are also relatively higher. However, the concentration of all the HMs was within the limits of both world and Dutch standards (Table 2) for topsoil. These finding is consistent with the findings of other studies conducted in different parts of Bangladesh (Ahsan et al., 2009; Moslehuddin et al., 1999).

According to the spatial distribution analysis shown in Figure 3, both Zn and Ni are widely distributed throughout the studied regions. The analysis also reveals that the southeastern region is particularly susceptible to Pb pollution, while the north and western regions are susceptible to Cd. This high concentration of Pb, Cr, and Cd can be attributed to the polluted river water as the studied region is bounded by the Kapatakkhya river on both the west and east, and the Sundarbans, the world's largest mangrove forest, on the south (Sadik. S., et al., 2017). However, only a few places indicate a high concentration of Hg. which suggests that most of the region still has virgin soil and is free from industrial pollution.

Table 2: Comparison of HMs concentration with different standards

Heavy Metals	Present Study (average concentration mg/kg)	World Limit (mg/kg) (Ahsan et al., 2009; EEA, 1999; Lacatusu, 1998)	Dutch Standard (mg/kg) (Ahsan et al., 2009; Coşkun et al., 2006)
Pb	22.46	35	85
Cr	26.34	70	100
Cd	0.26	0.35	0.8
Hg	0.01	-	0.3
Ni	4.77	50	35
Zn	69.74	90	140

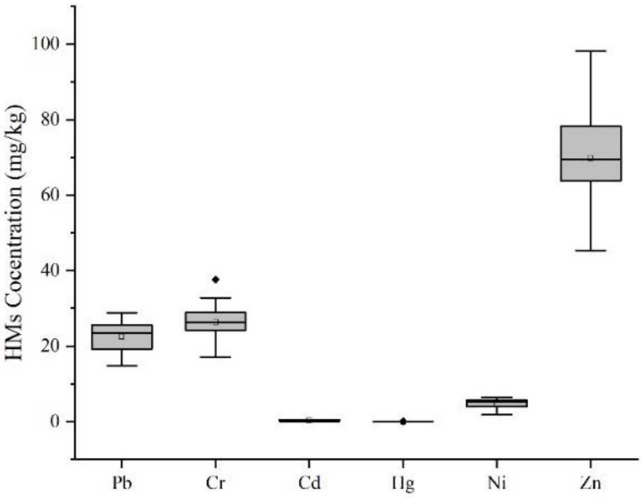

Figure 2: Concentration of heavy metals at the studied region

Figure 3 shows a uniform distribution of Zn and Ni at the studied regions indicates anthropogenic activity is not responsible for the occurrence of these metals. As reported by Islam et al., (2022), the anthropogenic distribution of HMs has an uneven distribution pattern. Furthermore, the study shows that the concentration of Zn is prevalent overall. These findings contradict with similar studies conducted in nearby mangrove areas of Bangladesh where Ni has the highest concentration (Akter et al., 2023; Arafin et al., 2023; Rakib et al., 2022). However, it is worth noting that other studies conducted in the Indian part of the mangrove forest align with the findings of this study (Banerjee et al., 2012; Kumar & Ramanathan, 2015; Rakib et al., 2022). Based on the findings of Banerjee et al. (2012), a high concentration of Zn near mangrove areas is a strong indicator of the natural weathering of soil materials and rapid industrial development in urban areas. This is due to the deposition of sediments near the mangrove forest, which reinforces the link between environmental factors and human activities.

Additionally, the study highlights that some areas near mangroves have the highest concentration of Pb which also consist with the findings of similar studies (Adimalla et al., 2020; Harvey et al., 2017). Research shows that human activities, particularly urban wastes, traffic, and vehicle emissions, are leading causes of increased Pb concentrations in soil (Adimalla et al., 2019; Gao & Wang, 2018). However, the study area does not exhibit high levels of urban and industrial activity, thus the excess Pb can be carried out by the river water and deposited on the floodplain top-soil. Yet, further investigation is necessary to understand the causes of the elevated Pb concentration in the soil. The lower concentration of chromium (Cr) observed in all the studied locations suggest that the element is not being actively released from nearby anthropogenic sources (Rakib et al., 2022), perhaps naturally deposited with the sedimentation process.

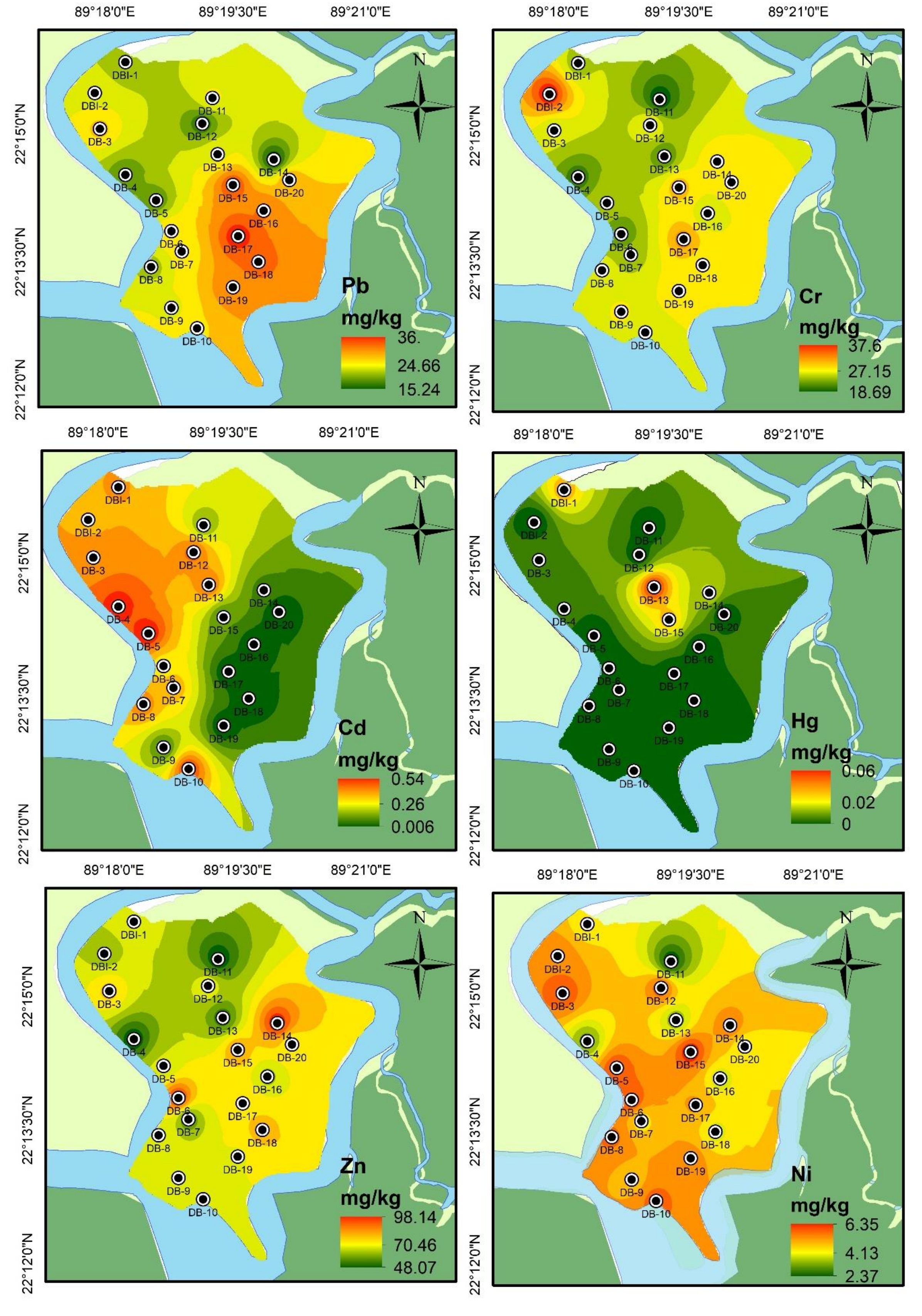

Figure 3: Spatial Distribution of HMs at Dakshin Bedkashi Union

3.2 Pollution Assessment Indices

3.2.1 Contamination factors (CF) and Pollution load Index (PLI):

As numerous studies have shown, the CF value is a key indicator to distinguish between contamination resulting from human activities and that originating from natural sources (Kabata-Pendias & Pendias, 2000; Rahmanian & Safari, 2022). Higher CF values imply a greater anthropogenic contribution, and higher degree of contamination. Conversely, lower values indicate that soil components are naturally occurring. To provide a detailed overview of the analysed heavy metals, Table 2 presents the quantitative description of both CF and PLI values, as determined in this study. The findings indicate the natural occurrence of Cr, Cd, Hg, Ni and Zn while the result for Pb is particularly concerning. The studied regions have been found to have varying concentrations of Pb, at some points it reaches to an alarming level that resulted in a higher CF value for Pb and eventually a higher PLI value. Previous studies have also reported higher Pb values near mangrove (Adimalla et al., 2020; Harvey et al., 2017). Despite of this, it is especially worrying as scientific studies have demonstrated that the high lead content in soil can result in severe contamination in the bloodstream of young children, who are more likely to put their hands in their mouths (Carrizales et al., 2006; Lake et al., 2021; Mielke et al., 2019). It is shocking to learn that lead poisoning (Pb) is responsible for over a million deaths and 24.4 million disability-adjusted life years worldwide every year (Egendorf et al., 2021). These statistics are a stark reminder that immediate action is needed to address this critical issue.

Table 2: Quantitative description of CF and PLI for studied HMs

Pb	Cr	Cd	Hg	Ni	Zn	PLI
44.92	0.75	0.00	0.58	0.24	0.94	6.86

3.2.2 Potential Ecological Risk Index (PERI):

The PERI study results provide compelling evidence that the concentration of heavy metals (HMs) in the studied regions poses no significant threat to the ecology. As shown in Figure 4, the indexed value ranges from low to moderate levels of risk, indicating a safe environment. Interestingly, the analysis suggests that areas adjacent to the river body have higher indexed values compared to other areas, which further underscores the importance of maintaining vigilance in those regions.

The findings of this study are significant. They reveal that this region remains free from high levels of contamination, unlike other areas near the mangrove forest (Arafin et al., 2023). This is due to the lower levels of anthropogenic and industrial activity in the area, which have helped preserve the virgin soil. As a result, the concentration of harmful metals (HMs) is lower in this region. This study's HMs concentration measurements are crucial to establish a baseline for future studies, as there are currently no standards for soil HMs concentration in Bangladesh. While the HMs concentration in this study does not pose a significant threat to ecology, it is still essential to conduct continuous monitoring. This area is located next to the mangrove forest, which is a crucial ecosystem that requires protection. Therefore, the authority must be vigilant, as high levels of pollution can be harmful to the mangrove ecosystem.

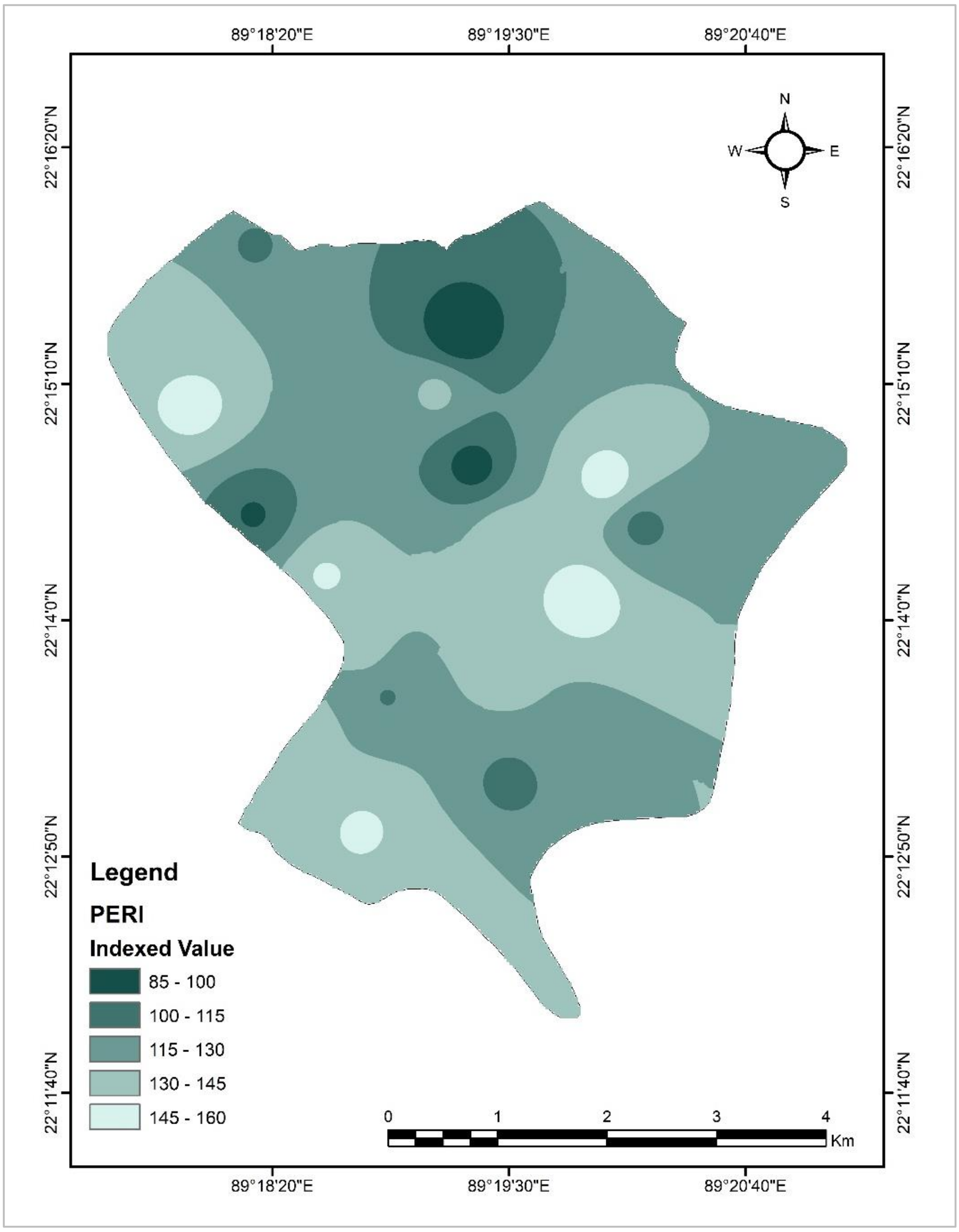

Figure 4: The Potential Ecological Risk analysis at Dakshin Bedkashi Union

4. CONCLUSIONS

The harmful effects of heavy metal pollution on the environment and human health cannot be overstated. This study indicates that while the dakshin bedkashi union area is currently free from industrial activity, the high concentration of pb suggests an increase in industrial growth in upstream which is currently deposited in this area or vehicle activity. The amount of metal present in soil can vary depending on the type of pollutants and their accumulation or deposition. The specific metals found in an area can indicate the source and extent of environmental contamination, underscoring the urgent need for action. The area's proximity to a mangrove forest, a vital ecological hotspot for biodiversity, makes it all the more crucial to address this issue promptly. Any further increase in pb concentration could have devastating consequences. It is imperative that the authorities act now to safeguard the environment and protect human health.

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