Available online at www.most.gov.bd
Volume 05, Page: 45-52, 2023
DOI: https://doi.org/10.3329/jscitr.v5i1.74001

Ministry of Science and Technology
Government of the People's of Bangladesh
Bangladesh Secretariat, Dhaka

Pollution of Toxic Heavy Metals and Ecological Risk in Mirzapur Industrialized Zone of Gazipur, Bangladesh

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Received: 30.04.2023
Revised: 05.05.2023
Accepted: 10.05.2023

Abstract

The Mirzapur industrial area in Bangladesh underwent an assessment for soil contamination with toxic heavy metals such as Cr, Cu, Cd, Pb, & Ni. Pollution in the region attributed to the discharge of industrial wastewater into irrigation canals and lakes. The prevalent contaminants were found to be Cr, Cu, and Ni, followed by Pb and Cd. The geo-accumulation index (Igeo) indicated that the area was classified as experiencing mild to moderate contamination, with Ni exhibiting the highest levels, followed by Cd, Cu, Cr, and Pb. Both the pollution load index (PLI) & contamination factor (CF) showed a moderate level of pollution, while the potential ecological risk index (RI) suggested a moderate ecological risk in this area. The study concluded that the Mirzapur industrial area in Bangladesh exhibited moderate heavy metal contamination, posing a moderate environmental risk.

Keywords: Toxic heavy metal, Geo-accumulation index, Pollution load index, Potential ecological risk index

Introduction

The usual low levels of toxic heavy metals and metalloids in the environment contribute to a balanced ecology. However, the escalation of toxic heavy metal pollution in agricultural soil is a major concern in developing nations, primarily due to its high poisonousness (Ağca and Özdel 2014). Human activities, such as mechanisation and expansion, play a pivotal role in this pollution by elevating concentrations of heavy metals in water, land, and crops (Islam *et al.*, 2017). Cultivated soil bears the brunt of heavy metal contamination from various sources like smelting, mining, and the use of manures and insecticides, resulting in the degradation of ecosystems and the deterioration of soil and water quality (Jiang *et al.*, 2017). The entry of toxic heavy metals into the food chain poses a substantial health hazard to both mans and animals (He *et al.*, 2015). In Bangladesh, the concentration of major industrial regions in densely populated areas has led to unregulated waste dumping and significant pollution (Aktaruzzaman *et al.*, 2014).

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This particular study concentrated on the Gazipur District in Bangladesh, covering diverse sectors such as clothing, fabric, colouring, ceramics, drug, dye, and packing businesses. These industries discharge untreated waste and effluents into nearby water bodies, while domestic and urban wastewater from the Mirzapur area further contributes to heavy metal pollution. The increasing urbanization and industrialization in the study area negatively impact water quality and agricultural practices. Farmers in the study site utilize contaminated wastewater for irrigation, which is the primary driver of heavy metal contamination in the agricultural land. Hence, this study aimed to evaluate the ecological risk of the study area using various indices.

Materials and Methods

Study area

Mirzapur, the focal point of the study, is positioned in the Gazipur district, an outskirt industrial zone situated approximately 40 kilometers north of Dhaka, Bangladesh. Encompassing an area of 1,806 square kilometers, the district is home to a population of 3.4 million people (BBS 2011). The topography is characterized by low-lying and flat terrain, with elevations ranging from 4 m to 24 m (Shapla *et al.*, 2015). The soil in the region stays notably scarce in nutrients, organic matter (OM), phosphate, N_2, and lime, as reported by UNDP/FAO in 1988. The climate features an avg. annual precipitation of 2,036 millimetres, with the wet period extending from April to October and the dry period spanning from November to March. The avg. yearly temp. is recorded at 25.8°C (Merkel 2012). Mirzapur functions as a minor industrial hub, covering various industries such as textiles, dyes, batteries, ceramics, plastics, garments, and agrochemicals, as indicated by Ahmed et al. in 2018 and 2019. Throughout the year, these industrial facilities release their effluents into adjoining irrigation channels (Fig. 1).

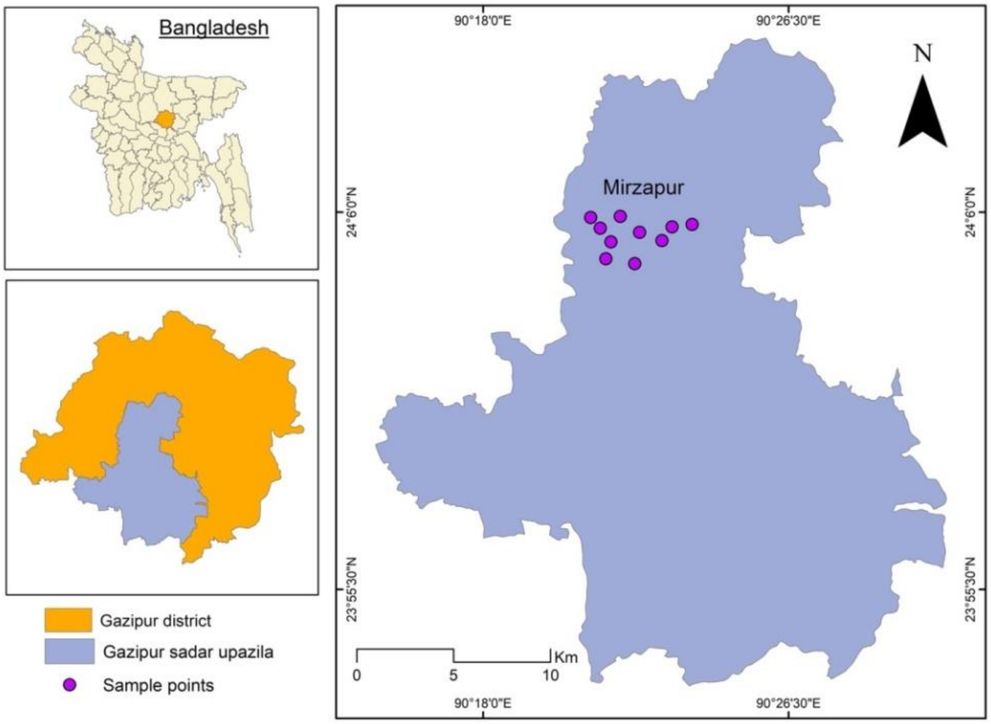

Figure 1. Sampling sites of the Mirzapur, Gazipur District, Bangladesh.

Soil Sampling and analysis

To assess the presence of toxic metal contamination in the farming land of the Mirzapur area in the Gazipur District, samples were collected from the surface soil at each designated sampling area. The sampling depth of 0-15 cm was selected considering the most active root concentration zone & susceptibility to destruction and air deposition, as recommended by Malan *et al.* in 2015 and Neagoe *et al.* in 2005. To generate a representative soil sample for each sampling area, five individual soil samples were amalgamated and thoroughly mixed. Subsequently, these composite soil samples underwent air-drying for a minimum of seven days, followed by crushing into a fine powder and sieving through a 2 millimetres sieve. The processed soil samples were then kept in Ziploc plastic bags within a desiccator till the analysis. The digestion of the soil was carried out using the US EPA 3050B method (USEPA 1996), and the resulting digested solution was filtered through a 4µm paper filter (Whatman 42) before being adjusted to a volume of 100 millilitres with double deionized water.

Instrumental analysis

To evaluate soil quality in the Mirzapur site of Gazipur District, concentrations of heavy metals (Chromium, Copper, Cadmium, Lead, & Nickel) were quantified in digested soils liquids using an Atomic Absorption Spectrophotometer (AAS), specifically the PinAAcleTM 900H model from Perkin Elmer, USA. This analysis was conducted at the Dept. of Agroforestry and Environment, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh. The AAS serves as a dependable and user-friendly tool for heavy metal analysis, operating on the principle of detecting element presence and concentration by examining the spectrum of element vaporization and light absorption at specific frequencies. In this technique, light wavelength absorbed by an element is utilized. The selected wavelengths for the elements in the study are as follows: Chromium at 357 nanometres, Copper at 324.75 nanometres, Cadmium at 228.8 nanometres, Lead at 217 nanometres, and Nickel at 232 nanometres. For standard preparation and following sample dilution, the high purity Milli-Q Millipore water (18.2 MΩ/centimetre; Thermo Scientific, USA) was employed, and a 1000 mg/Litre stock solution served as the basis for making the calibration standard solution in a 50 mililitres volumetric flask.

To evaluate soil quality in this study region, the subsequent contamination indices are employed.

Geo-accumulation index of soil

The geo-accumulation index, as proposed by Müller in 1981 and further developed by Ruiz in 2001, is commonly employed for assessing the toxicity condition of soil.

This index was determined using the provided formula.

$$I_{geo} = \log_2 \frac{\text{CM (sample)}}{1.5 \text{ x CM (Background)}}$$

Where, $CM_{(Sample)}$ is the measured concentration of heavy metal in soil, $CM_{(Background)}$ is the background value (Kabata-Pendias 2011) for same element and 1.5 is a multiplying factor.

The classification system of geo-accumulation index includes seven classes (Ruiz 2001)

$I_{geo} \leq$ zero uncontaminated, zero $< I_{geo} <$ one uncontaminated to moderately contaminated, one $< I_{geo} <$ two moderately contaminated, two $< I_{geo} <$ three moderately to heavily contaminated, three $< I_{geo} <$ four heavily contaminated, four $< I_{geo} <$ five heavily to extremely contaminated, five $\leq I_{geo}$ extremely contaminated.

Pollution load index of soil (PLI)

To measure soil quality, a comprehensive method involving the calculation of pollution load indexes (PLI) for heavy metals is employed. This approach facilitates the identification of pollution, enabling similarities of pollution levels across different areas and over various time periods. The PLI is the n^{th} root multiplication of the pollution factor of several toxic heavy metals (Islam *et al.*, 2015).

$$PLI = (CF_1 \text{ X } CF_2 \text{ X } CF_3 \text{ X} \ldots\ldots \text{X } CFn)^{1/n}$$

Where CF in contamination factor or single pollution index

Potential ecological risk index (RI)

Taking into account the toxicity of heavy metals & their impact on the environment, the potential ecological risk index (RI) assesses the extent of toxic heavy metal pollution in the soil.

The calculation of the RI involves the following computations (Guo *et al.,* 2010).

$C^i_f = C^i / C^i_n$

$E^i_r = T^i_r X C^i_f$

$RI = \sum_{i=1}^{n} E^i_r$

Where C^i_f is the contamination factor; C^i is the concentration of heavy metal in the soil; C^i_n is the reference value for the heavy metal (Kabata-Pendias 2011); E^i_r is the monomial potential ecological risk factor; T^i_r is the heavy metal toxic response factor. The toxic response factors for Nickel, Chromium, Copper, Zinc, Arsenic, Cadmium and Lead were five, two, five, one, ten, thirty, & five, respectively (Guo *et al.*, 2010; Islam *et al.*, 2017). Table 1 provides indices and grades for the potential ecological risk of toxic heavy metals.

Table 1. Indices and grades of potential ecological risk of toxic heavy metal contamination (Luo *et al.,* 2007)

Potential ecological risk factor (E^i_r)	Grade of ecological risk	Potential ecological risk index (RI)	Pollution degree
$E^i_r < 40$	Low risk	RI < 65	Low risk
$40 \leq E^i_r < 80$	Moderate risk	65 ≤ RI < 130	Moderate risk
$80 \leq E^i_r < 160$	Considerable risk	130 ≤ RI < 260	Considerable risk
$160 \leq E^i_r < 320$	High risk	RI ≥ 260	Very high risk
$E^i_r \geq 320$	Very high risk		

Data Analysis

Data calculations, analysis, and the creation of graphical representations were carried out using Excel version 16.71, Numbers version 11.1, & Origin Pro 8 software. ArcMap 10.3 was employed for representing the map of study sites.

Results and Discussion

Toxic heavy metals are inherent components of soil, and their levels are contingent on the parent materials, as outlined by Barbieri in 2016. The concentration of these metals is subject to influences from both natural and human-induced factors. Human activities, notably the disposal of industrial waste, have led to an escalation in heavy metal levels within the Mirzapur study area, adversely affecting soil health. In the study's heavy metal analysis, chromium (Cr) exhibited the highest mean concentration at 62.79 μg/g, followed by nickel (Ni) at 52.55 μg/g, copper (Cu) at 43.01 μg/g, and lead (Pb) at 27.84 μg/g, with cadmium (Cd) registering the lowest concentration at 0.60 μg/g (Table 2). Uneven distribution across the study site was observed for copper, nickel, and lead, indicated by their elevated standard errors. However, with the exception of nickel, which slightly crossed the allowable limit, the concentrations of the remaining toxic heavy metals in the soil adhered to the standards set by the Ministry of Environment in Finland. Fluctuations in toxic heavy metal concentrations in the soil may be linked to variations in the distribution of irrigation water from discharge points to adjacent areas, as proposed by Ahmed and Goni in 2010. In Bangladesh, agricultural soil is frequently compromised by the recurrent use of effluent from diverse industries and other human-related sources, mirroring the situation in the Mirzapur study region. Overall, the hierarchy of toxic heavy metal concentrations in the soil was as follows: Chromium > Copper > Nickel > Lead > Cadmium.

Table 2. Toxic heavy metal concentrations in soil (µg/g) of Mirzapur industrial site, Gazipur (*n* =10)

Heavy metal	Mean	S.E.	Range	Permissible Limit [a]
Cr	62.79	1.96	52.76 -70.59	100
Cu	43.01	4.46	23.58- 74.98	100
Cd	0.60	0.01	0.53- 0.64	1
Pb	27.84	2.45	17.76- 46.77	60
Ni	52.55	3.77	28.28- 71.67	50

[a] Ministry of Environment Finland (2007)

Relying solely on the assessment of toxic heavy metal concentrations in the top soil layer may not offer a comprehensive understanding of soil contamination, as it fails to differentiate between natural background values and enrichment caused by human activities, as emphasized by Barbieri in 2016. To address this limitation, researchers, including Islam et al. in 2017 and 2015, as well as Aktaruzzaman et al. in 2014, employ various indices to evaluate soil pollution. These indices, such as the geo-accumulation index (Igeo), contamination factor (CF), pollution load index (PLI), and potential ecological risk index (RI), serve as common tools for grading the extent of soil contamination.

Fig. 2 illustrates the outcomes of the geo-accumulation index (Igeo) calculations for soil toxic heavy metals and their corresponding contamination levels. The computed Igeo values reveal that the average concentrations of Chromium (-0.51), Copper (-0.50), Cadmium (-0.03), & Lead (-0.58) fall within the zero class category, suggesting an absence of contamination in the soil with respect to these toxic heavy metals. Conversely, the average concentration of Ni possesses a positive Igeo value of 0.77, signifying moderately contaminated soil. The highest positive Igeo value for Ni reaches 1.26, indicating a moderate level of contamination by Nickel in the land.

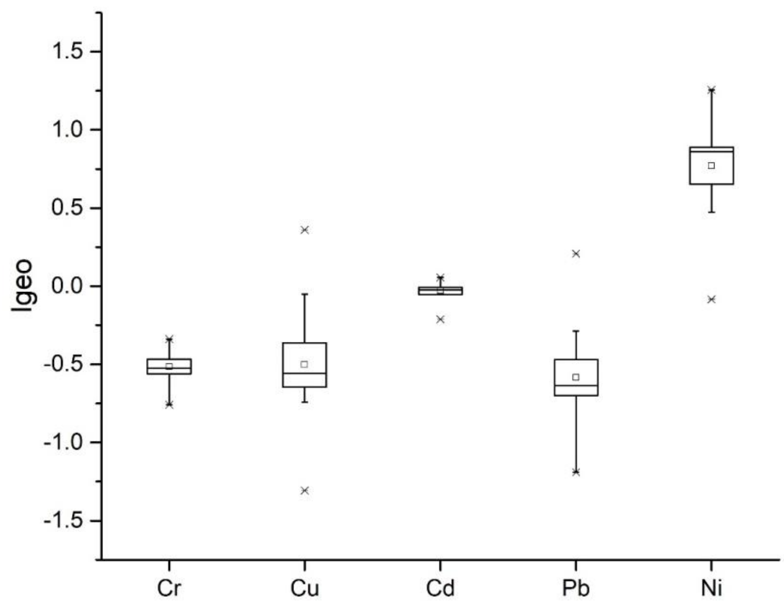

Figure 2. Geo-accumulation index (Igeo) values of toxic heavy metals in the study site.

The research area exhibited elevated concentrations of Ni and Cd in comparison to background samples, potentially attributed to human activities such as industrial discharge. The Igeo values for Ni surpassed those of other heavy metals, with Cd following closely. This suggests contamination in the research area by these heavy metals originating from human-related sources.

The contamination factor (CF) was employed to evaluate the contamination rank of heavy metals in the soil of the study area. The findings revealed that Ni exhibited the highest average contamination factor at 2.63, followed by Cd, Cu, and Cr, with Pb having the lowest CF value of 1.03 (Fig. 3). All heavy metals demonstrated a CF value exceeding one, indicative of moderate soil contamination according to Håkanson's classification (Hakanson 1980). Consequently, the study site was determined to possess a moderate level of soil pollution based on the CF results.

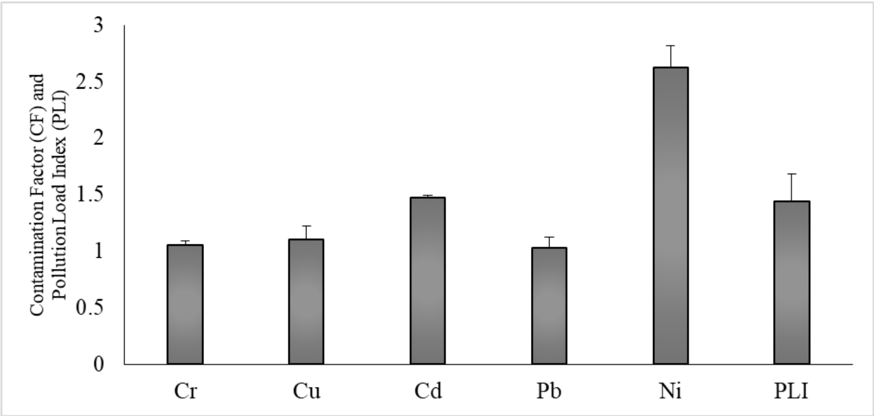

Figure 3. Contamination factor (CF) and Pollution load index (PLI) values of toxic heavy metals in the study site.

In this study, the pollution load index (PLI) was employed to evaluate the quality and overall toxicity of soil samples. The computed PLI values varied from 1.21 to 1.80, with the higher value (1.80) indicating slight contamination and/or pollution in the soils of the research area (Fig. 3). Likewise, the mean PLI value (1.44) proposed that the study area experienced light contamination and/or pollution. The PLI serves as a crucial tool for residents seeking a better understanding of environmental quality, and for decision-makers aiming to assess the pollution or contamination status, as highlighted by Islam et al. in 2015 and Suresh et al. in 2012. Consequently, the PLI results from this study should raise awareness among policymakers and the public regarding the ongoing discharge of toxic heavy metals from industries in the research area, emphasizing the necessity for future remediation efforts.

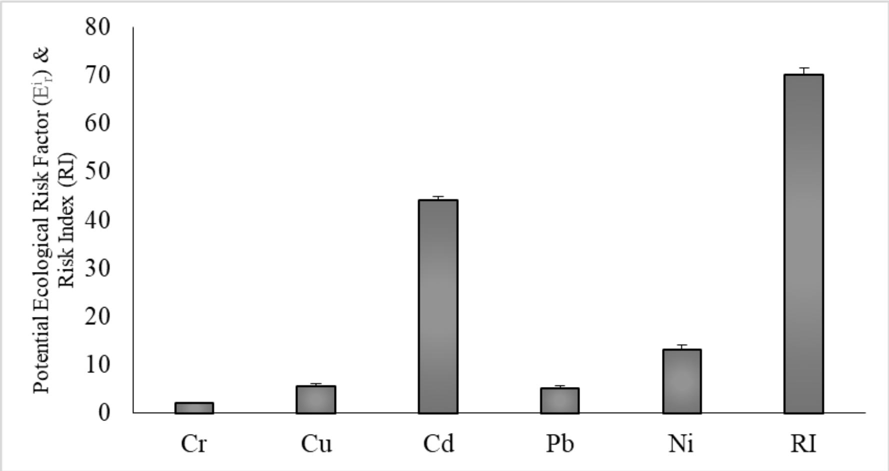

Figure 4. Potential ecological risk factor (E^i_r) and risk index (RI) values of toxic heavy metals in the study site.

To assess the degree of heavy metal contamination in the study area, an ecological risk index (RI) was calculated based on the toxicity and environmental response of these metals. The potential ecological risk factor (E^i_r) and the risk index (RI) were depicted in Fig. 4. The E^i_r values for individual heavy metals exhibited notable variation, signifying potential ecological hazards associated with these metals. The avg. E^i_r values for Cr, Cu, Ni, and Pb were all below 40, the minimum grade for ecological risk, indicating minimal potential ecological risk from these toxic heavy metals. However, the mean E^i_r value for Cd, at 44.14, surpassed 40, indicating a significant ecological risk. The mean potential ecological risk index (RI) for the Mirzapur area was 70.07, indicative of a moderate risk, with the maximum RI reaching 76.45, also signaling moderate ecological risk. The E^i_r values suggest low potential ecological risk, except for Cd, likely attributable to industrial activities (as suggested by Luo et al. in 2012). The RI values underscore the susceptibility of diverse biological communities to toxic compounds and the potential ecological risk posed by toxic heavy metals, as emphasized by Islam et al. in 2017. Overall, the range of RI values falls between 64.23 and 76.45, indicating a moderate ecological risk. These findings underscore the imperative for future remediation efforts to address the persistent discharge of toxic heavy metals from industrial sources in the research area, as identified by the PLI, RI, CF, and E^i_r.

Conclusions

The evaluation of toxic heavy metal pollution in the study area using diverse indices indicated a range from uncontaminated to moderately contaminated soil, with particular concern surrounding Ni and Cd. Both the contamination factor and pollution load index highlighted a moderate level of contamination. The potential ecological risk index underscored a moderate risk associated with heavy metal contamination in the study area's environment. In summary, these results suggest the potential necessity for remediation measures in the land of the study site to mitigate the risks associated with heavy metal contamination.

Acknowledgements

The authors extend their thanks to the Ministry of Science and Technology, Government of the People's Republic of Bangladesh (Grant number 185 BS), for the financial assistance.

Conflict of Interests

The authors have no disclosure to make that qualifies as a conflict of interest.

Author contributions

Minhaz Ahmed played a role in conceptualizing and designing the study, as well as in the preparation of materials and samples, conducting analyses, and drafting the initial manuscript. Md. Abiar Rahman supervised the research efforts. Muhammad Ziaul Hoque contributed to mapping the study site and participated in subsequent reviews. Shohana Parvin, Md. Shamim Hossain, and Md. Tanbir Rubayet assisted in preparing and revising the manuscript. All authors critically reviewed and granted final approval for the manuscript.

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