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Source Apportionment and Ecological Risk Assessment of Heavy Metals in Urban Dumpsite Soils

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Abstract

Heavy metal contamination in solid waste dumpsites represents a significant environmental concern due to its persistence and potential ecological risks. This study assessed the concentrations, distribution patterns, and associated risks of selected heavy metals, together with key physicochemical properties, in soils from two major dumpsites (Arefin Nagar and Ananda Bazar) within Chittagong City Corporation, Bangladesh. A total of ten soil samples (five from each site) were collected at depths of 3–7 m and analyzed for Pb, Zn, Cd, Cu, Cr, and Ni using nitric acid digestion followed by atomic absorption spectrometry. The mean concentrations (mg kg^{-1}) in Ananda Bazar were 74.04 (Pb), 146.96 (Zn), 1.22 (Cd), 51.24 (Cu), 130.32 (Cr), and 51.76 (Ni), while Arefin Nagar recorded 44.16 (Pb), 97.42 (Zn), 1.54 (Cd), 172.98 (Cu), 26.28 (Cr), and 18.48 (Ni). The order of metal abundance was Cr > Zn > Ni > Pb > Cu > Cd in Ananda Bazar and Cu > Zn > Pb > Cr > Ni > Cd in Arefin Nagar. Contamination was evaluated using the geo-accumulation index (I_{geo}), degree of contamination (C_d), pollution index (PI), and ecological risk index (RI), which collectively indicated higher contamination levels at Ananda Bazar compared to Arefin Nagar. The results suggest that anthropogenic inputs, particularly from industrial, medical, and commercial waste disposal, are the dominant sources of contamination. Moderate to strong pollution levels were observed for Cr and Zn at Arefin Nagar and for Cu at Ananda Bazar, indicating potential ecological risks. These findings underscore the necessity for regular monitoring and appropriate remediation measures prior to the agricultural use of dumpsite soils.

Keywords: Heavy metal contamination, dumpsite soils, pollution indices, ecological risk assessment.

1. Introduction

Rapid urbanization, population growth, and industrial expansion have significantly increased municipal solid waste (MSW) generation worldwide, particularly in developing countries. Global MSW generation has risen from approximately 0.68 billion tons per year in 2000 to about 1.3 billion tons in 2010 and is projected to reach nearly 2.2 billion tons by 2025 and 4.2 billion tons by 2050 (Abubakar et al., 2022; Kumari & Raghubanshi, 2023; Sharma & Jain, 2019). This rapid increase has placed immense pressure on waste management systems, especially in low- and middle-income countries where infrastructure development has not kept pace with urban growth. In South Asia, including Bangladesh, inefficient waste collection, lack of engineered landfills, and widespread open dumping practices have become major contributors to environmental degradation (Akther et al., 2025; Ali & Rafizul, 2024; Hossain & Haque, 2026; Sarker et al., 2024).

Open dumpsites are widely recognized as significant sources of environmental pollution due to the uncontrolled accumulation and decomposition of heterogeneous waste materials. These sites receive a mixture of municipal, industrial, medical, and commercial wastes, which often contain hazardous substances, including heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), and zinc (Zn) (Ghosh et al., 2023; Jolly et al., 2025; Saha et al., 2022). Unlike organic pollutants, heavy metals are non-biodegradable, persistent, and capable of accumulating in soils and sediments over long periods (Shehu et al., 2026). Once introduced into the soil system, they can migrate vertically through leaching processes or laterally via runoff, eventually contaminating groundwater and nearby agricultural lands (Alemayehu et al., 2019; Correia & Rasteiro, 2025). Their mobility and persistence make them particularly concerning from both environmental and public health perspectives.

Soil acts as a primary sink for heavy metals; however, excessive accumulation can significantly alter its physicochemical properties, reduce fertility, and impair its ecological functions (Nyiramigisha et al., 2021). Contaminated soils may subsequently act as secondary sources of pollution, releasing toxic elements into the food chain through plant uptake or into the atmosphere through resuspension of contaminated dust particles. Human exposure occurs through ingestion of contaminated food and water, inhalation of airborne particulates, and dermal contact, leading to adverse health effects such as neurological disorders, renal dysfunction, respiratory diseases, and carcinogenic risks (Gunarathne et al., 2024; Kant et al., 2021). The ecological impacts are equally severe, affecting soil microorganisms, plant growth, and overall ecosystem stability.

Chittagong, the second-largest city and principal seaport of Bangladesh, provides a critical context for investigating waste-induced environmental contamination. The Chittagong City Corporation (CCC) area covers approximately 160.99 km^2 (Kaiser & Akter, 2025). With a population exceeding five million (CCC, 2024), the city generates a substantial amount of solid waste daily, a large fraction of which remains untreated due to limited waste processing and recycling facilities. Consequently, most of the waste is disposed of in open dumpsites without proper environmental safeguards. The two major dumpsites in the CCC area—Ananda Bazar and Arefin Nagar—receive diverse waste streams, including industrial residues, hospital waste, and household refuse (Masum et al., 2018; Rokonuzzaman & Tan, 2025). These sites lack engineered liners, leachate collection systems, and proper management practices, increasing the risk of heavy metal leaching into surrounding soils and groundwater (Chowdhury et al., 2015; Kaiser & Akter, 2025; Masum et al., 2018; Rokonuzzaman & Tan, 2025). Previous studies in Bangladesh have primarily focused on surface water and landfill leachate contamination, with comparatively limited attention given to the accumulation of heavy metals in dumpsite soils. Furthermore, comprehensive assessments employing multiple pollution indices—such as the geo-accumulation index (Igeo), contamination degree (Cd), pollution index (PI), and ecological risk index (RI)—remain scarce for the Chittagong region. These indices provide essential quantitative tools for evaluating contamination levels, identifying pollution sources, and assessing ecological risks in a systematic and comparable manner.

Despite increasing environmental pressure from unmanaged solid waste in Chittagong City Corporation, detailed and depth-specific data on heavy metal contamination in dumpsite soils remain limited. Open dumping of mixed and hazardous waste has elevated risks of soil degradation, groundwater contamination, and public health impacts. Moreover, inadequate monitoring and limited use of integrated pollution assessment approaches hinder accurate evaluation of contamination and ecological risks. This knowledge gap constrains the development of effective waste management and remediation strategies, posing long-term threats to environmental sustainability. This study aims to evaluate the concentration and distribution of selected heavy metals (Pb, Zn, Cd, Cu, Cr, and Ni) in soils collected from major dumpsites of Chittagong City Corporation at depths of 3–7 m, and to assess the extent of contamination using established pollution indices, including the geo-accumulation index (Igeo), contamination degree (Cd), pollution index (PI), and ecological risk index (RI). It further seeks to compare contamination levels between Ananda Bazar and Arefin Nagar in order to identify spatial variation, dominant pollution patterns, and potential anthropogenic sources, thereby providing a basis for environmental risk evaluation and improved waste management strategies.

2. Methods and Materials

Study Area

The study was conducted at two major municipal solid waste dumpsites (**Figure 1**), Arefin Nagar (AN) and Ananda Bazar (AB), located within Chittagong City Corporation (CCC), Bangladesh. Chittagong is the second-largest city and principal port of the country. The city generates about 3000-3200 tons of solid waste per day, which is disposed of at these two primary dumpsites (YPSA, 2025). Both sites operate as open dumping facilities without engineered liners or leachate collection systems, receiving mixed waste streams including municipal, industrial, and medical wastes. The waste composition is predominantly organic (71.7%) with a smaller fraction of inorganic materials (28.3%) (Chowdhury et al., 2015; Masum et al., 2018). The lack of proper waste management practices and the proximity of these dumpsites to residential and agricultural areas increase the risk of environmental contamination.

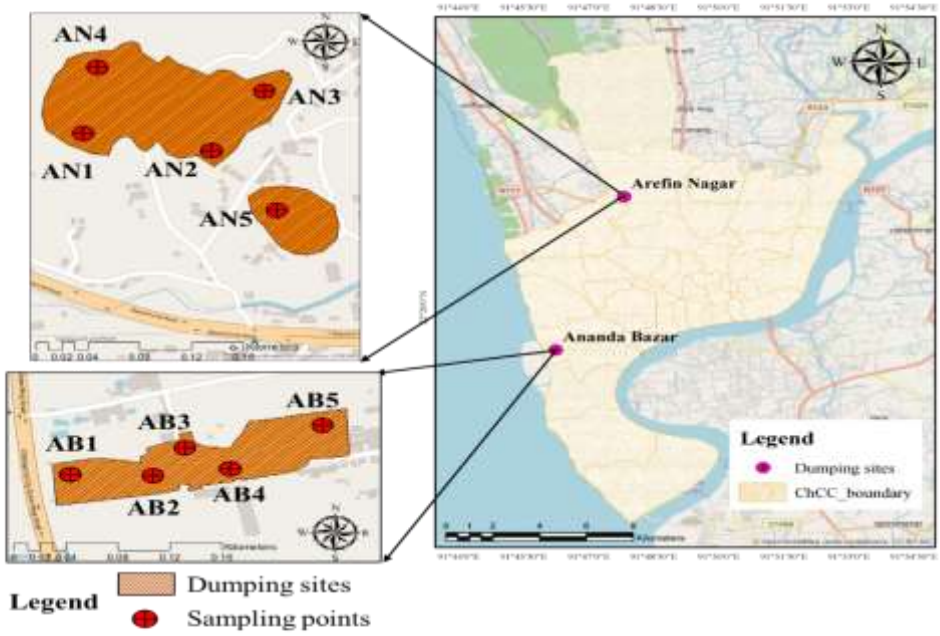


Figure 1. Location of the study area showing the municipal solid waste dumpsites Arefin Nagar (AN) and Ananda Bazar (AB) within Chittagong City Corporation (CCC), Bangladesh, along with the soil sampling points.

Sample Collection and Preparation

A total of ten soil samples (**Figure 1**) were collected from the two dumpsites, with five samples from each site. Sampling was conducted at depths ranging from 3 to 7 m to evaluate subsurface contamination. At each location, composite samples were obtained by collecting soil from multiple points within an approximate 10 m radius to ensure representativeness. The samples were stored in clean polyethylene bags, labeled, and transported to the laboratory. In the laboratory, samples were air-dried and then oven-dried at 105–110°C for 24 hours to remove moisture. The dried samples were crushed and sieved through a 200-mesh (75 µm) sieve to obtain homogeneous fine particles. The processed samples were stored in airtight containers prior to analysis.

Analytical Methods

Heavy metal concentrations were determined following acid digestion and instrumental analysis. Approximately 5 g of each prepared soil sample was digested using aqua regia (HNO_3:HCl = 3:1, v/v) on a hot plate at 150–180°C until complete digestion (Pal et al., 2018; Pal & Roy, 2021). The digested samples were cooled, filtered, and diluted to a known volume with deionized water. The concentrations of selected heavy metals (Pb, Zn, Cd, Cu, Cr, and Ni) were measured using Atomic Absorption Spectrometry (AAS), which is based on the absorption of element-specific wavelengths by free atoms in the gaseous state. Calibration was performed using standard solutions, and appropriate quality control procedures were followed to ensure analytical accuracy.

Pollution Assessment Indices

A comprehensive assessment of heavy metal contamination in dumpsite soils was conducted using established quantitative indices, including the contamination factor (Cf), degree of contamination (Cdeg), ecological risk factor (Er), risk index (RI), integrated pollution index (IPI), and geo-accumulation index (Igeo). The reference (background) values for heavy metal assessment used in this study were adopted from (M. S. Islam et al., 2015; S. Islam et al., 2015). The contamination factor (Cf) evaluates the level of metal enrichment relative to background concentrations and is classified as: Cf < 1 (low contamination), 1 ≤ Cf < 3 (moderate contamination), 3 ≤ Cf < 6 (considerable contamination), and Cf ≥ 6 (very high contamination). The overall contamination status is represented by the degree of contamination (Cdeg), calculated as the sum of individual Cf values, and categorized as: Cdeg < 6 (low), 6 ≤ Cdeg < 12 (moderate), 12 ≤ Cdeg < 24 (considerable), and Cdeg ≥ 24 (very high contamination) (Hakanson, 1980; Suryawanshi et al., 2016). To evaluate ecological implications, the ecological risk factor (Er) and the cumulative risk index (RI) were applied, incorporating toxic-response coefficients for each metal. The classification of Er is defined as: Er < 40 (low risk), 40 ≤ Er < 80 (moderate risk), 80 ≤ Er < 160 (considerable risk), 160 ≤ Er < 320 (high risk), and Er ≥ 320 (very high risk)**,** while RI values are interpreted as: RI < 50 (low risk), 50 ≤ RI < 100 (moderate risk), 100 ≤ RI < 200 (considerable risk), and RI ≥ 200 (high ecological risk) (Darko et al., 2017; Hakanson, 1980).

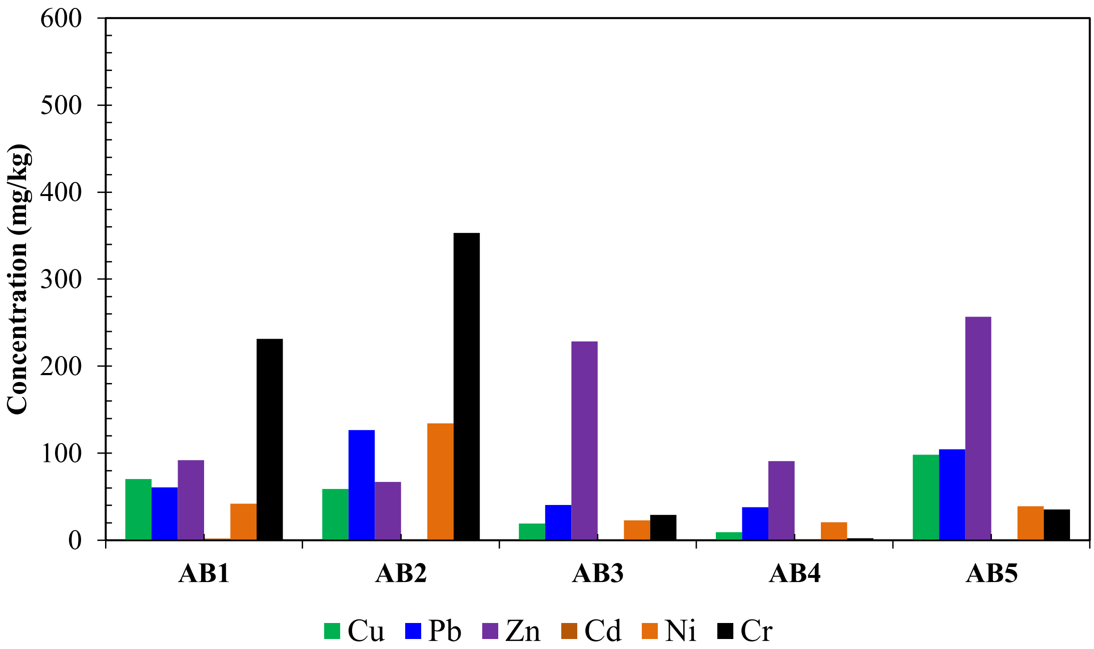
In addition, the integrated pollution index (IPI) was employed to assess the cumulative effect of multiple heavy metals based on individual pollution indices (PI). The PI classification is given as: PI ≤ 1 (no contamination), 1 < PI ≤ 2 (low contamination), 2 < PI ≤ 3 (moderate contamination), and PI > 3 (high contamination), whereas IPI values are categorized as: IPI ≤ 0 (no contamination), 0 < IPI ≤ 6 (low contamination), 6 < IPI ≤ 18 (moderate contamination), and IPI > 18 (high contamination) (Bai et al., 2009; Huang, 1987). Furthermore, the geo-accumulation index (Igeo) was used to distinguish between natural and anthropogenic contributions, with classification ranges defined as: Igeo ≤ 0 (uncontaminated), 0 < Igeo < 1 (uncontaminated to moderately contaminated), 1 < Igeo < 2 (moderately contaminated), 2 <

Igeo < 3 (moderately to heavily contaminated), 3 < Igeo < 4 (heavily contaminated), 4 < Igeo < 5 (heavily to extremely contaminated), and Igeo ≥ 5 (extremely contaminated) (Müller, 1981). These indices collectively provide a robust framework for evaluating contamination levels, ecological risks, and anthropogenic impacts in soil environments.

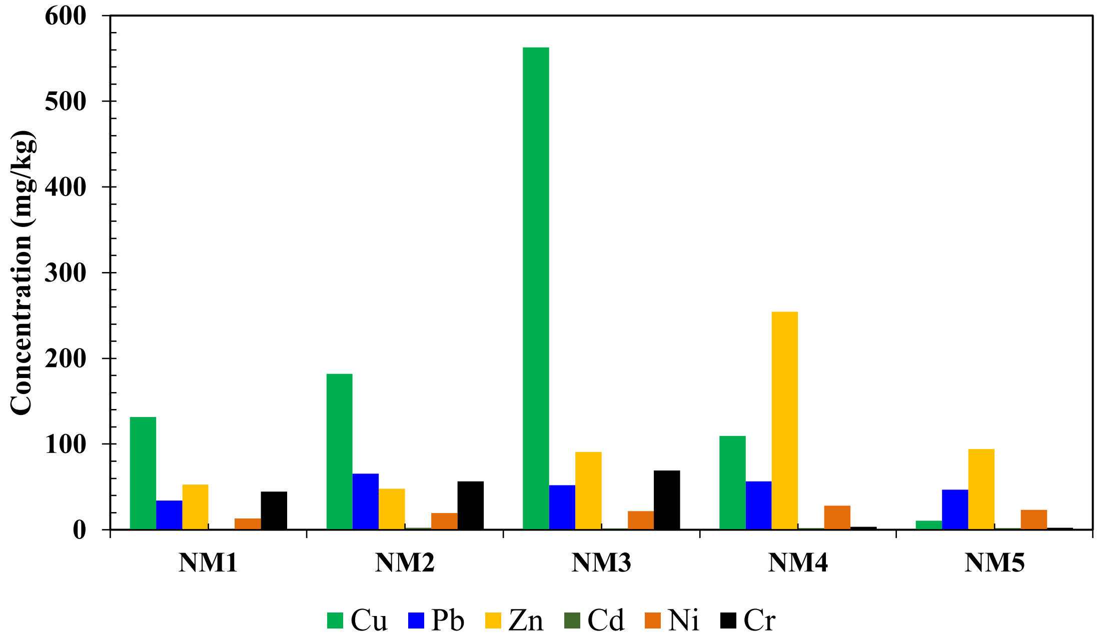
3. Results and Discussion

Heavy Metal Concentrations in Dumpsite Soils

The distribution of heavy metals (Pb, Zn, Cd, Cu, Cr, and Ni) in dumpsite soils is presented in **Figure 2**, revealing pronounced spatial variability between Ananda Bazar and Arefin Nagar. Overall, the concentrations indicate significant anthropogenic enrichment relative to background levels, reflecting the influence of mixed municipal, industrial, and medical waste inputs. Among the analyzed elements, chromium (Cr) and lead (Pb) exhibit notably elevated concentrations at Ananda Bazar, suggesting strong contamination likely associated with industrial discharges and urban waste streams. Zinc (Zn) and nickel (Ni) also show comparatively higher levels at this site, indicating cumulative inputs from heterogeneous waste materials. In contrast, cadmium (Cd), although present at lower absolute concentrations, exceeds background values in several samples, underscoring its environmental significance due to high toxicity and mobility.



(a)



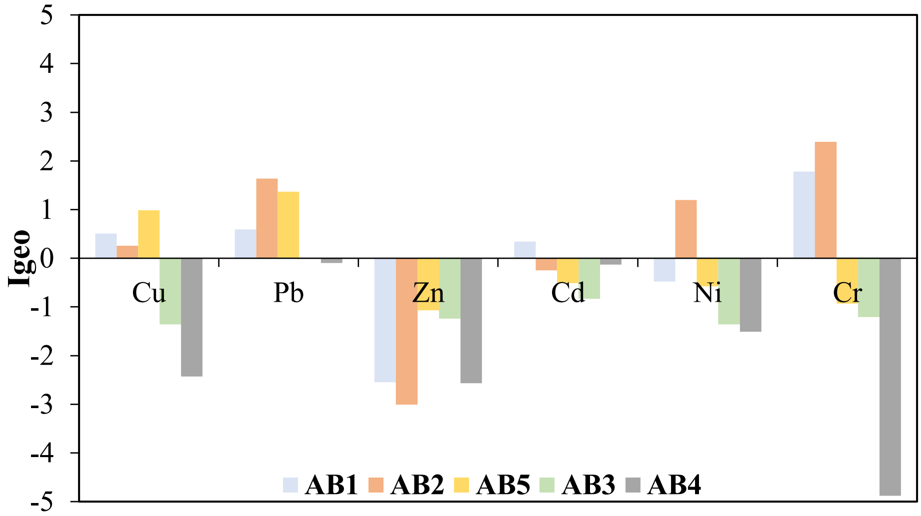
(b)

Figure 2. Spatial distribution of heavy metal concentrations (Pb, Zn, Cd, Cu, Cr, and Ni) in dumpsite soils of (a) Ananda Bazar and (b) Arefin Nagar, Chittagong City Corporation.

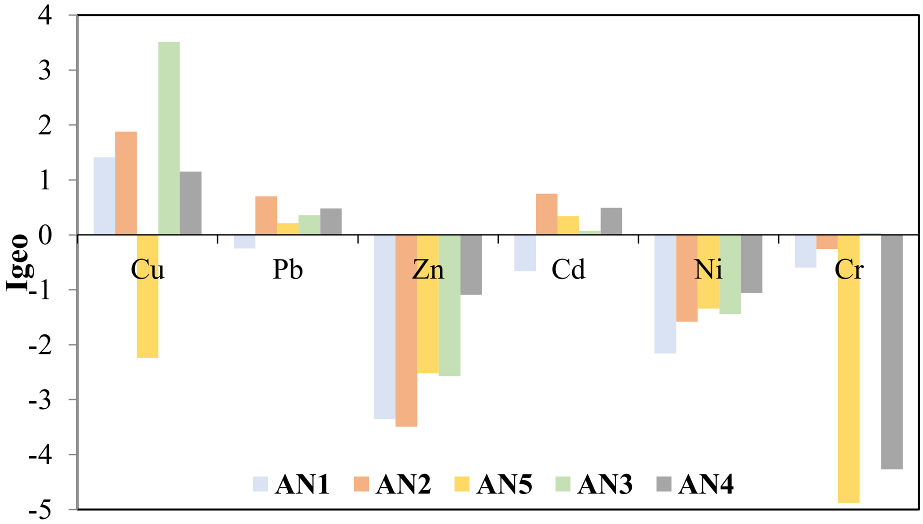
A distinct contamination pattern is observed at Arefin Nagar, where copper (Cu) exhibits exceptionally high concentrations (**Figure 2**), indicating localized but severe enrichment. This anomaly is likely linked to site-specific disposal of Cu-rich wastes such as electrical, electronic, and industrial materials. Compared to Ananda Bazar, other metals at Arefin Nagar show relatively lower but still notable concentrations, highlighting heterogeneous contamination dynamics across the two dumpsites. The contrasting distribution patterns suggest that Ananda Bazar is primarily impacted by Cr-, Pb-, Zn-, and Ni-related pollution, whereas Arefin Nagar is dominated by Cu and Cd contamination. These findings indicate moderate to severe pollution levels and emphasize the role of unregulated dumping practices in driving site-specific heavy metal accumulation. The observed contamination poses potential risks to soil quality, groundwater systems, and human health, necessitating continuous monitoring and targeted remediation strategies.

Geo-Accumulation Index (Igeo) Assessment

The geo-accumulation index (Igeo) values for the investigated heavy metals are presented in **Figure 3**, providing an assessment of contamination intensity relative to background levels. The results indicate variable degrees of contamination across the two dumpsites, with clear spatial differences between Ananda Bazar and Arefin Nagar. At Ananda Bazar, chromium (Cr) shows the highest Igeo values, reaching up to Class 3, indicating moderate to strong contamination. Lead (Pb) also exhibits moderate contamination (Class 1–2) in several samples, while copper (Cu) generally falls within Class 1, suggesting slight to moderate enrichment. In contrast, zinc (Zn), cadmium (Cd), and nickel (Ni) predominantly display Igeo values ≤ 0, indicating unpolluted conditions. These findings suggest that Cr and Pb are the principal contributors to contamination at Ananda Bazar.



(a)



(b)

Figure 3. Geo-accumulation index (Igeo) of heavy metals (Cu, Pb, Zn, Cd, Ni, and Cr) in dumpsite soils of (a) Ananda Bazar and (b) Arefin Nagar.

At Arefin Nagar, a contrasting pattern is observed, where copper (Cu) exhibits the highest Igeo values, reaching Class 4, which corresponds to strong to very strong contamination (**Figure 3**). This indicates significant localized anthropogenic input. Other metals, including Pb and Cd, show low to moderate contamination (Class 1–2), whereas Zn, Ni, and Cr largely remain within the unpolluted category. The observed differences between the two sites highlight the influence of site-specific waste composition and disposal practices on heavy metal accumulation. Overall, the Igeo assessment confirms that Cu at Arefin Nagar and Cr and Pb at Ananda Bazar are the dominant contaminants, reflecting the impact of uncontrolled dumping activities and emphasizing the need for site-specific management and remediation strategies.

Pollution Assessment Using Cd, RI, and IPI

The box plot distributions of degree of contamination (C_{deg}), ecological risk index (RI), and integrated pollution index (IPI) for Ananda Bazar (AB) and Arefin Nagar (AN) are presented in Figure 4,

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providing a comparative assessment of contamination magnitude and variability. The C_{deg} values range from 3.88 to 19.22 for AB and 4.85 to 22.90 for AN. The box plots indicate a higher median and wider interquartile range for AN, reflecting greater variability and elevated contamination levels relative to AB. In contrast, AB exhibits a comparatively narrower spread, suggesting more uniform contamination conditions. The presence of higher upper-range values in AN further indicates localized accumulation of heavy metals, consistent with site-specific pollution inputs.

A similar trend is observed for the ecological risk index (RI), with values ranging from 41.14 to 106.84 at AB and 58.78 to 148.91 at AN. The box plot for AN shows a higher median and broader dispersion, indicating increased ecological risk and greater heterogeneity compared to AB. These elevated RI values at AN suggest a stronger contribution from high-toxicity metals, particularly Cu and Cd, which significantly influence risk levels. Conversely, AB demonstrates relatively moderate and consistent RI values, indicating lower but persistent ecological risk across the site.

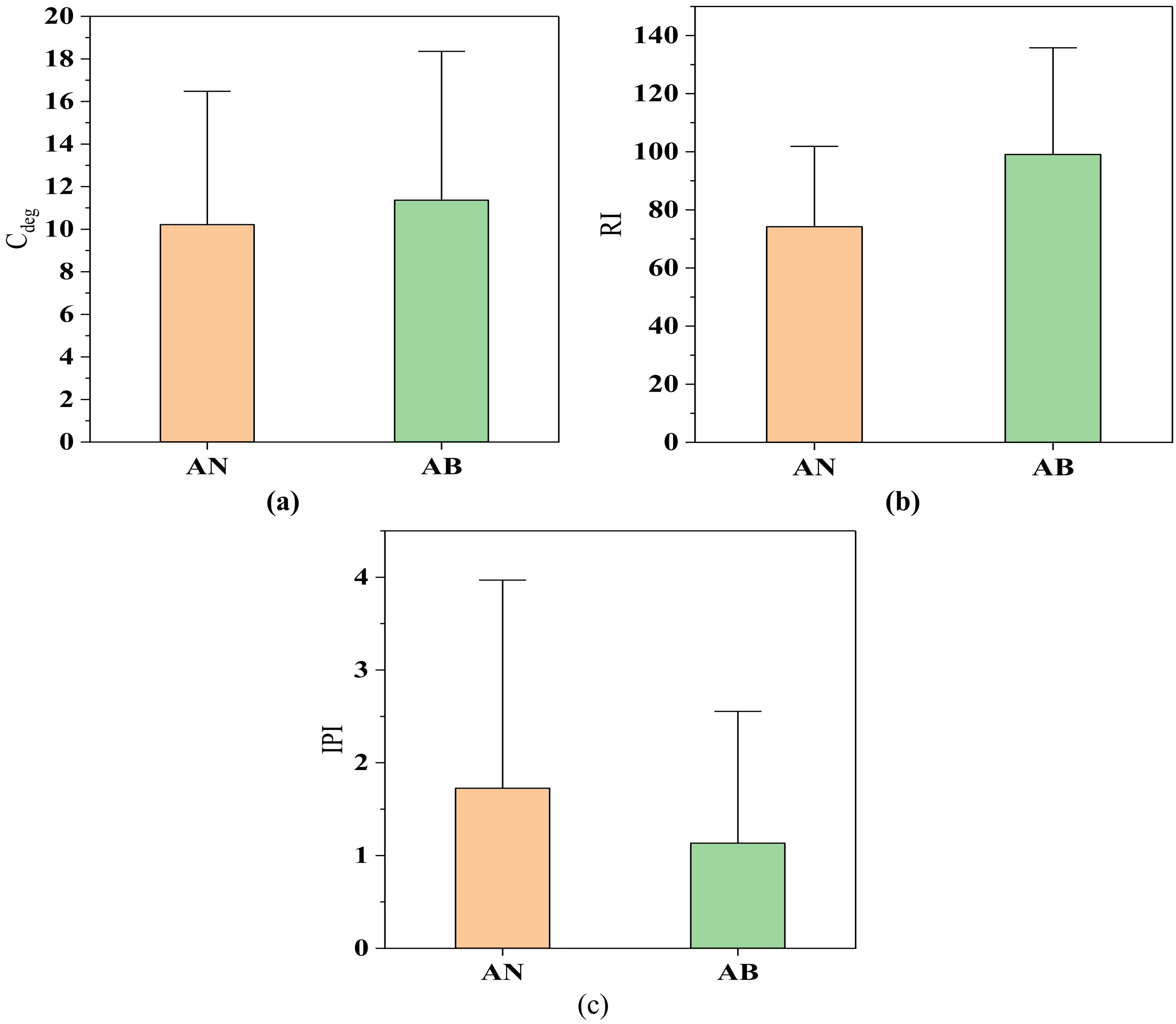

Figure 4: Box plot distribution of (a) degree of contamination (C_{deg}), (b) ecological risk index (RI), and (c) integrated pollution index (IPI) for Ananda Bazar (AB) and Arefin Nagar (AN) dumpsite soils.

The integrated pollution index (IPI) values range from −1.85 to 3.88 for AB and −0.96 to 2.62 for AN, with both sites generally indicating moderate pollution conditions. However, the wider spread and variability observed in AN highlight heterogeneous contamination sources, likely associated with industrial, electrical, and electronic waste inputs. In contrast, AB shows relatively stable IPI values, suggesting more uniform contributions from mixed municipal and commercial wastes, including Pb, Zn, and Ni. Overall, the box plot analysis demonstrates that Arefin Nagar (AN) is characterized by higher variability and localized high-risk contamination, whereas Ananda Bazar (AB) exhibits comparatively consistent but moderate pollution, emphasizing the need for site-specific pollution management strategies.

4. Conclusion

This study assessed heavy metal contamination in soils from two major dumpsites, Ananda Bazar and Arefin Nagar, within Chittagong City Corporation using concentration analysis and established pollution indices (Igeo, Cd, RI, and IPI). The results demonstrate significant anthropogenic influence, with distinct spatial variation between the two sites. Ananda Bazar is mainly characterized by elevated Cr, Pb, Zn, and Ni, whereas Arefin Nagar shows pronounced enrichment of Cu and Cd. The applied indices indicate moderate to considerable contamination, with relatively higher variability and ecological risk observed at Arefin Nagar. These findings reflect the influence of heterogeneous waste composition and unregulated disposal practices. The observed contamination levels have important environmental implications, as heavy metal accumulation in soils may lead to groundwater contamination and potential human exposure through multiple pathways. The results highlight the need for systematic monitoring and improved waste management practices, including controlled disposal of industrial and hazardous wastes. In addition, the implementation of engineered landfill systems and appropriate remediation approaches is essential to minimize long-term environmental risks. This study provides baseline information that can support future assessments and contribute to the development of effective management strategies for sustainable urban environments.

5. Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper. The research was conducted independently, and the results were not influenced by any external organization or sponsor.

6. Acknowledgement

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7. Generative AI Statement

The authors acknowledge the use of generative artificial intelligence (AI) tools, specifically ChatGPT (OpenAI), to assist in improving the clarity, grammar, and organization of the manuscript. The AI tool was not used for data generation, analysis, or interpretation. All results, discussions, and conclusions presented in this study are solely those of the authors, who take full responsibility for the accuracy and integrity of the work.

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