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Assessment of Soil Characteristics and Contamination Status Due to Leachate Migration from Open Dumping Site in Chattogram City, Bangladesh

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Abstract

The management of solid waste poses a significant challenge for Chattogram city, as the daily generation of substantial amounts of waste often leads to direct disposal in landfills or open dumping areas, resulting in the creation of landfill leachate. This study centers on investigating the distinct geotechnical and chemical attributes of soil from two significant dumping sites in Chattogram city (Ananda Bazar and Arefin Nagar), along with assessing pollution levels due to leachate migration. The examination unveiled notable distinctions in the soil characteristics at the dumping site compared to regular soil. Additionally, the analysis of grain size distribution pointed to the suboptimal grading of the soil found at the dumping site. The results from SEM-EDX analysis revealed that oxygen (O) and carbon (C) are notably present, constituting a substantial fraction of 48.01% and 40.10%, respectively, of the overall atom composition at the dumping sites. The recorded parameters encompassing pH, total dissolved solids (TDS), dissolved oxygen (DO), electrical conductivity (EC), and salinity exhibit ranges spanning from 6.39 to 7.4, 79 to 3750 mg/L, 1.73 to 6.53 mg/L, 83 to 7470 µS/cm, and 0.0 to 3.8 ppt, respectively. The heavy metal concentration order in leachate is Cr>Mn>Cu>Zn>Fe. This study underscores the imperative of implementing effective waste management approaches to mitigate environmental risks linked to solid waste disposal in Chattogram city.

Keywords: *Chattogram city, solid waste management, landfill leachate, soil properties, SEM-EDX.*

1 Introduction

The lack of appropriate facilities to manage the rising daily waste production has pushed municipal solid waste (MSW) management into a critical phase. Improper disposal of waste is not only leading to soil contamination but also posing risks to both surface and groundwater sources. Solid waste accumulation can obstruct drain systems, leading to stagnant water that breeds insects and causes flooding during the rainy season. Landfills, both in Bangladesh and globally, pose significant threats to groundwater resources. Leachate, which accumulates at the bottom of landfills, percolates through the soil and reaches the groundwater, increasing the risk of contamination in areas near landfill sites. The leachate is found biodegradable, contaminated and un-stabilized as the ratio of BOD5 and COD is 0.69 at the Alexandria landfills, Australia (Abd El-Salam & Abu-Zuid, 2015). Additionally, Negi et al. (2021) found heightened levels of NH_3-N (9.80 mg/L), COD (128 mg/L), Cl^- (115 mg/L), Na (98 mg/L), and K (42.2 mg/L) in groundwater at 9.75m depth and situated 1 km away from the landfill site. A study conducted on groundwater, soil sediment, and plant samples has revealed that the Łubna landfill in Poland does not appear to significantly contribute to environmental pollution by heavy metals (Cd, Cu, Cr, Pb, and Zn) (Gworek et al., 2016).

Diverse studies have revealed increased trace metal concentrations in leachate sourced from waste, adjacent water bodies, soil sediment samples, and landfill leachate found to contaminate groundwater to a certain degree (Igboama et al., 2022; Mishra et al., 2019; Negi et al., 2020; Zeng et al., 2021), although contrasting research (Abd El-Salam & Abu-Zuid, 2015) suggests that leachate may not be causing groundwater pollution as the values were within the standard limits (WHO, 2012). The impact of leachate movement on soil particle constituents has been thoroughly investigated in diverse research domains, encompassing areas such as pharmaceutical substances and renewable fuels (Bitra et al., 2009; Fernlund, 2005). The selected Polish landfills are reported to have moderate to modest leachate pollution index (LPI) values (7.4–15.9), with leachates inhibiting root and shoot growth, particularly at higher concentrations (50–100%) (Wdowczyk & Szymańska-Pulikowska, 2021). The Matuail landfill site in Bangladesh exhibits a notably high LPI of 19.81, similar to the polluted landfill sites in India and Malaysia (Fahmida and Tareq 2021). The study on assessing soil characteristics and contamination due to leachate migration from an open dumping site in Chattogram City, Bangladesh, is crucial for addressing the environmental repercussions of improper waste management and safeguarding local ecosystems. This research focuses on examining the specific geotechnical and chemical characteristics of soil collected from two prominent dumping sites within Chattogram city. Furthermore, an assessment will be conducted to analyze the pollution levels at both dumping sites resulting from leachate migration.

2 Methods and Materials

The study was carried out (as depicted in figure 1) in the vicinity of two disposal sites (Anandabazar and Arefin Nagar) located within Chattogram city. Soil samples were gathered from these locations at depths of one (1m) and three (3m) meter from two distinct sampling points at each dump site (see figure 1 for details). These collected soil samples underwent various tests to assess their characteristics, including moisture content, particle size distribution, Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), and Atterberg Limits. The results were then compared with those from the natural soil in the area. Additionally, a Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEC-EDX) examination was conducted on a composite soil sample to ascertain the elemental composition of the different heavy elements present. Furthermore, a total of twenty (20) leachate samples were also collected from both disposal sites, and experimental analysis was carried out to identify various physicochemical parameters (pH, TDS, DO, EC, and salinity) as well as concentrations of heavy metals (Zn, Cu, Fe, Mn, and Cr).

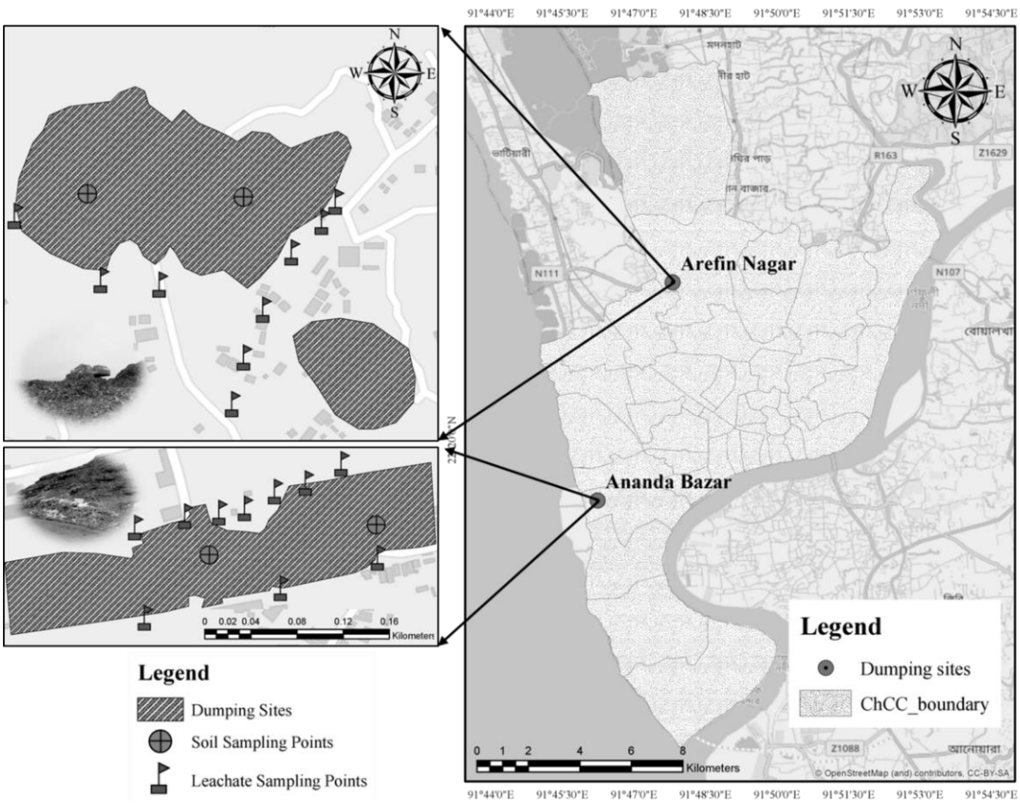


Figure 2. Geographic location of study area and sampling locations at two dumping sites of Chattogram city.

3 Results and Discussion

3.1 Properties of Soil at two dumping sites

3.1.1 Variation of Moisture Content

Moisture content denotes the quantity of water in the soil. The average moisture content (%) measurements for Ananda Bazar at 1m and 3m are around 24% and 33%, respectively. Whereas in Ananda Bazar, the moisture content for one (1m) and three (3m) meter is about 31.3% and 33%, respectively. Figure 2 shows that the soil at dump sites is 1.13–1.65 times higher than the natural soil. Furthermore, moisture content is observed to be 5–46% greater at 3–5 depths. The results show that the moisture content at dump sites is higher at deeper depths and also higher than in natural soil.

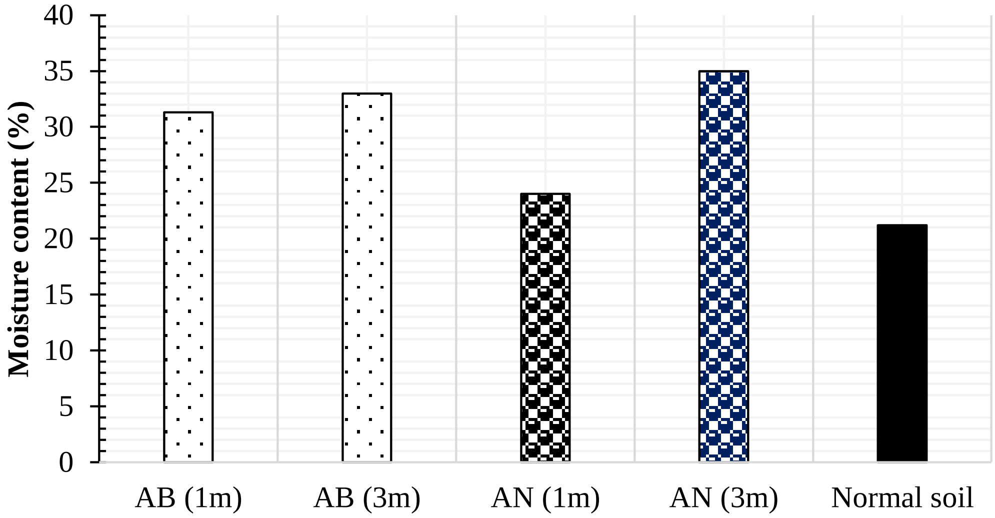


Figure 3. Comparison of moisture content (AB indicates Ananda Bazar and AN indicates Arefin Nagar)

3.1.2 Particle Size Distribution of Soil at Dumping Sites

Sieve analysis is a method utilized to assess the distribution of grain sizes within soil samples. The results of particle size distribution at two dumping stations at different depths are shown in figure 3.When dealing specifically with sand, it is categorized as well-graded if the value of Cu (coefficient of uniformity) surpasses 6, indicating a balanced range of grain sizes, and if Cc (coefficient of curvature) falls within the range of 1 to 3, suggesting a moderate curvature of the grain size distribution curve. The recorded values for Cc and Cu at both dumping sites fall within the range of 0.49–0.93 and 3.38–8.125, respectively. In contrast, the Cc and Cu values for the natural soil are determined as 1.13 and 9.76, respectively. Consequently, based on these measurements, the soil sourced from both dumping sites can be characterized as poorly graded (refer to figure 3 for detailed information). The grain size distribution graph illustrates that the percentage of clay present at the two dumping sites varies between 18.3%–32.6%, while the clay content in normal soil measures 38.7%.

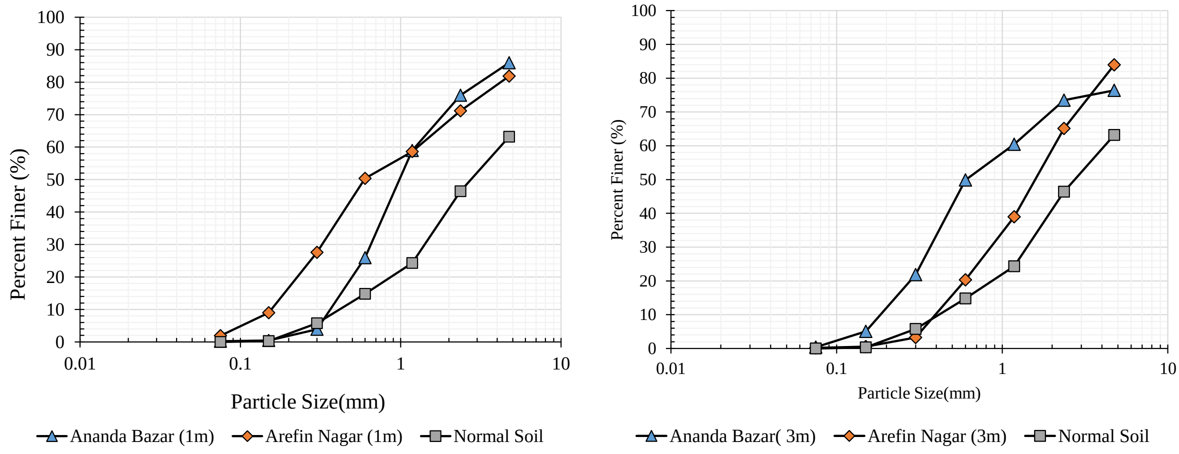


Figure 3. Results of sieve analysis of soil from two dumping sites at different depths

3.1.3 Variation of Atterberg Limits

The Atterberg limits offer a fundamental insight into the crucial moisture levels within fine-grained soils. Notably, the soil from Ananda Bazar samples presents the highest liquid limit value at 41%, indicating its propensity for higher moisture retention, whereas the soil from Arefin Nagar samples at three (3m) meter depth records the lowest liquid limit value of 24%, implying a comparatively drier composition (see table 1). This differentiation classifies the soil from Ananda Bazar samples as relatively moist, while the soil from Arefin Nagar samples leans toward a drier nature.

Table 4. Atterberg Limits of Soil at two dumping sites at Chattogram city.

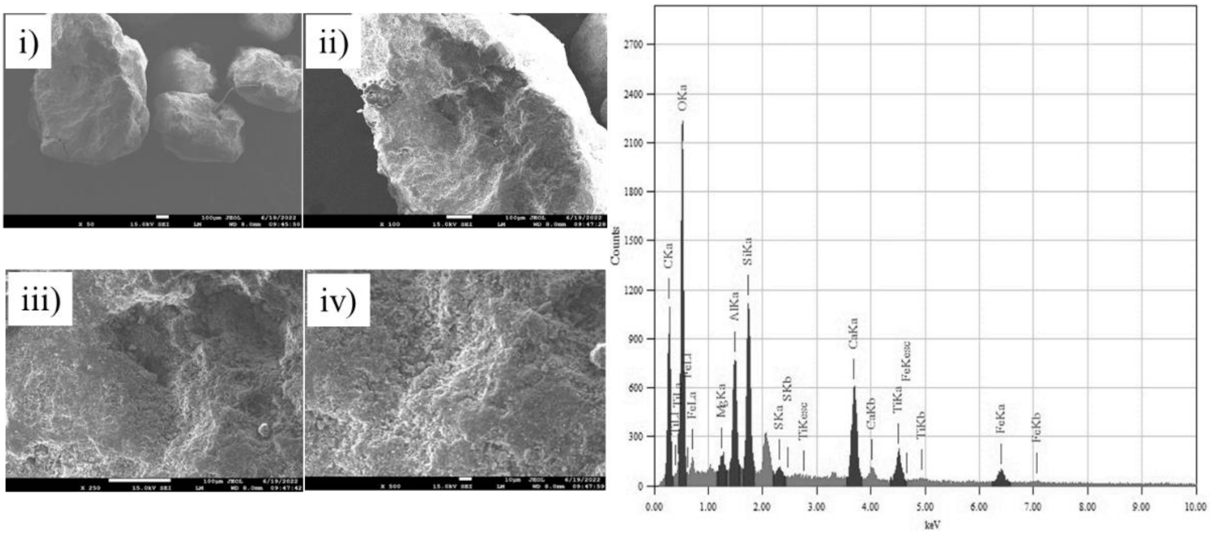
Parameter	AB(1m)	AB(3m)	AN(1m)	AN (3m)	Normal soil
LL	41	41	36	24	36
PL	28	26	22	16	20
PI	13	15	14	08	16

The Plastic Limit (PL) values of the soil from Ananda Bazar and Arefin Nagar dumping sites at different depths offer significant insights into their moisture-related behaviors. The Plastic Limit represents the moisture content at which a soil transitions from a plastic, moldable state to a more solid consistency. In the case of the soil from Ananda Bazar dumping site, the Plastic Limit (PL) values are 28-26 at depths of one (1m) and three (3m) meter, respectively. This suggests that the soil from Ananda Bazar retains its moldable properties at slightly lower moisture content when sampled from greater depths. On the other hand, the soil from Arefin Nagar demonstrates PL values of 22-16 at the corresponding depths of one (1m) and three (3m) meter. This indicates that, the soil from Arefin Nagar dumping site, while maintaining its plastic characteristics, requires comparatively less moisture at the greater depth to achieve the plasticity threshold. The divergence in Plastic Limit values between the soil from Ananda Bazar and Arefin Nagar dumping sites signify their distinct plasticity responses to varying moisture levels at different depths. This nuanced understanding of plasticity aids in assessing how each soil type behaves under different moisture conditions, further contributing to the broader comprehension of their physical properties and behaviors.

3.2 Pollution Status at Dumping Sites

3.2.1 Chemical and Elemental Composition of Soil at Dumping Sites

Figure 4 presents SEM imagery of the soil samples collected from the dumping site, accompanied by the corresponding Energy Dispersive X-ray (EDX) spectrum. A comprehensive grasp of the soil's texture, shape, and structural attributes was investigated in this study upon conducting observations of soil particles through a Scanning Electron Microscope (SEM) at varying magnification levels. The general physical attributes of the paint sludge notably exhibit an irregular shape, while the surface texture displays a slightly rough nature (as depicted in figure 4a). An evident hollow appearance becomes discernible upon closer scrutiny at elevated magnification.



(a) (b)

Figure 4. (a) SEM images of composite soil at i) 50, (ii) 100, iii) 250, iv) 500 times magnification, (b) Representative EDX spectrum and relevant elements of soil collected from dumping sites.

The atom counts of each element within the samples are elucidated in Figure 4(b). The provided information offers a comprehensive breakdown of the elemental constituents present in the soil samples collected from the dumping sites, along with their corresponding mass and atom percentages. For instance, oxygen (O) and carbon (C) constitute a significant proportion, accounting for 48.01% and 40.10% of the total atoms found in the sample, respectively. In addition, the soil also has notable proportions of various elements, including magnesium (Mg), aluminum (Al), silicon (Si), sulfur (S), calcium (Ca), titanium (Ti), and iron (Fe), with values spanning 0.4%, 2.24%, 3.42%, 0.27%, 3.03%, 1.29%, and 1.19%, respectively. This detailed elemental analysis provides valuable insights into the composition of the soil, contributing to a more thorough comprehension of its structural characteristics and potential implications.

3.2.2 Physicochemical and Heavy Metal Pollution from Leachate

Figures 5 and 6 depict the concentrations of physicochemical properties and heavy metals in the collected leachate. Physicochemical data indicates greater pollution in Ananda Bazar leachate compared to Arefin Nagar. pH, TDS, DO, EC, and Salinity range from 6.39 to 7.4, 79 to 3750 mg/L, 1.73 to 6.53 mg/L, 83 to 7470 µS/cm, and 0.0 to 3.8 ppt, respectively. Pollution at urban dumping sites originates from waste breakdown, chemical reactions, improper toxic waste disposal, and rainwater seepage, leading to environmental and groundwater contamination. The decomposition of organic and inorganic waste materials results in pollutants dissolving in leachate as rainwater permeates waste piles.

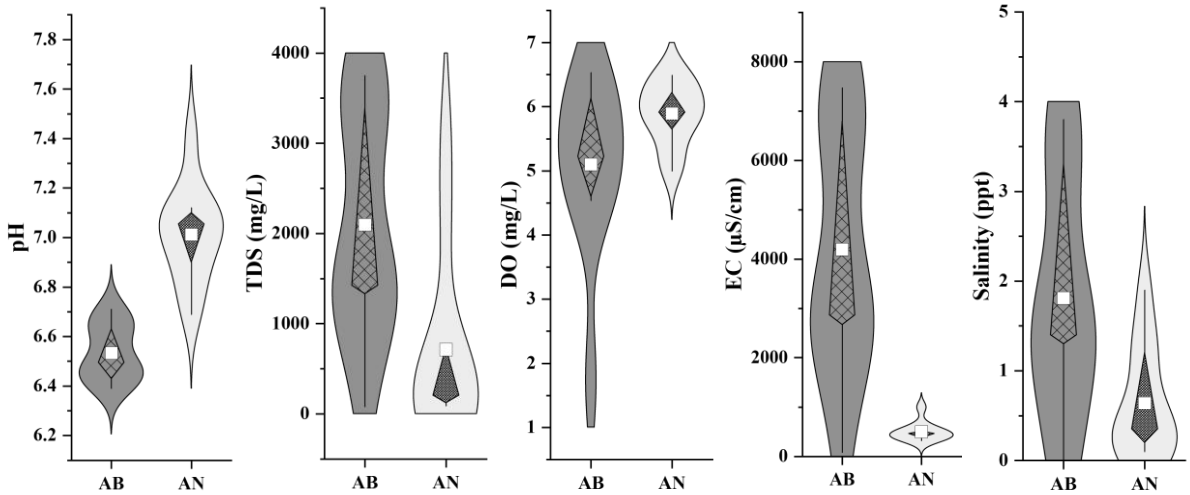


Figure 5. Physicochemical properties of the collected leachate from two dumping sites of Chatttogram city.

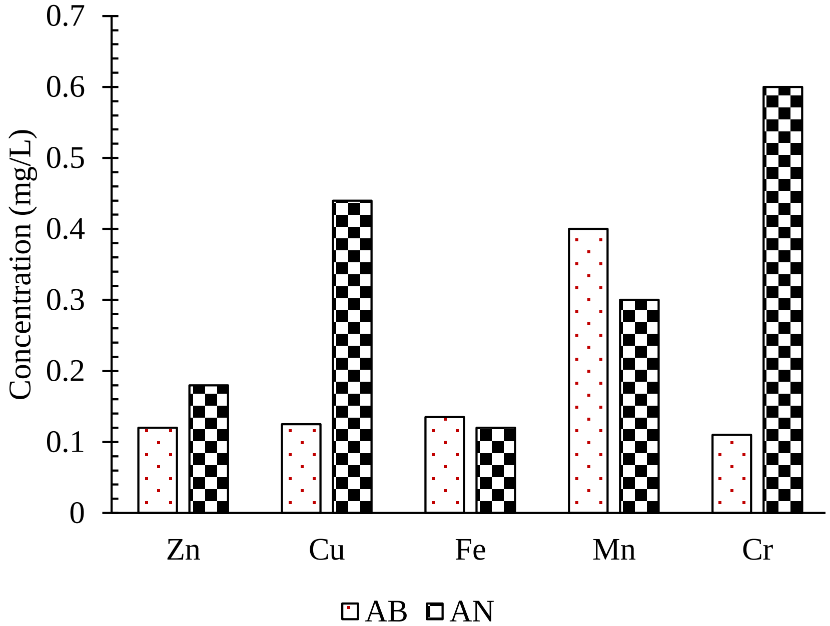


Figure 6. Heavy metal concentration at two dumping sites of Chatttogram city.

Figure 6 illustrates the mean levels of various elements (Zn, Cu, Fe, Mn, and Cr) at two disposal sites within Chattogram City. Considerable variations in heavy metal concentrations exist between these dumping locations. Specifically, at Ananda Bazar, the concentrations of Zn, Cu, and Cr exceed those at Arefin Nagar by 1.50, 3.52, and 5.45 times respectively. In contrast, Arefin Nagar demonstrates Fe and Mn concentrations that are 1.13 and 1.13 times higher than those at Ananda Bazar. These notable deviations in heavy metal content imply a potential for heavy metal contamination in the region. Possible contributors include industrial waste discharge, improper disposal of electronic waste, and agricultural runoff containing fertilizers or pesticides.

4 Conclusion

The focal point of this study revolves around an investigation into the geotechnical properties of soil and the pollution status stemming from leachate migration at dumping sites. Soil property analysis at these locations reveals a subpar quality compared to that of natural soil, with a noteworthy aspect being the relatively higher moisture content, which indicates partial saturation at increased depths. Findings from SEM-EDX examinations further shed light on irregular soil shapes, rough textures, and the presence of substantial voids, which could potentially contribute to expansion during periods of rainfall. An important revelation is the substantial presence of heavy metals within the soil, a factor that compounds its pollution potential. A notable observation within this research lies in the substantial occurrence of oxygen (O) and carbon (C), comprising 48.01% and 40.10% of the total atom composition, respectively. Furthermore, the measured parameters, including pH, TDS, DO, EC, and salinity, manifest distinct ranges, signifying varying levels of contamination. The distinctions in concentrations of heavy metals between the two dump sites are evident, with Zn, Cu, Fe, Mn, and Cr concentrations falling within the ranges of 0.12-0.18mg/L, 0.125-0.44mg/L, 0.12-0.135mg/L, 0.30-0.40mg/L, and 0.11-0.60 mg/L, respectively. The implications of this study underscore the significant soil quality degradation and potential environmental hazards associated with leachate migration at urban dumping sites, highlighting the urgent need for effective waste management strategies and pollution control measures.

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