**Physicochemical Characteristics And Heavy Metals Pollution Of Soil Around Solid Waste Dumpsites In Abuja Metropolis, Nigeria**

**ABSTRACT**

There has been an increase in solid waste generation due to urbanization and improper dumping of wastes in developing countries like Nigeria causing severe adverse effects and impact on human health and the environment. This study was conducted to determine the level and associated risk of heavy metals (Cr, Mn, Pb, Cu, Fe, Cd, Zn) pollution of soils around solid waste dumpsites in Abuja Metropolis using standard methods. Soil samples were collected from ten municipal solid waste dumpsites within Abuja metropolis and a control sample was also collected and studied. The mean pH of soil in this study ranged from 5.81 to 7.64 for the ten dumpsites with the control site recorded 7.14. This indicates that the soils at the dumpsites are slightly acidic to neutral. The pH of a soil is known to be a very unstable property that is easily influenced by other properties. The mean electrical conductivity (EC) values of the various sampling points were significantly different (p < 0.05) ranging from 259.22 µs/cm to 439.15 µs/cm, with the control location recording 263.10 µs/cm EC. From the results, the mean concentration of all the studied metals in the dumpsite soils was higher compared to local background values and international threshold except for Fe and Mn in sites DS3 and DS10 respectively. Further, the differences in the levels of heavy metals in soils of different dumpsites were not statistically significant ( <0.05). The values of the single pollution index (Pi) showed that the study area is most considerably polluted by Cd, Cu and Pb. Based on the Nemerow pollution index (PN), over 70.2% of soil sampling sites had moderate contamination levels. According to the results of the pollution load index (PLI), it was revealed that the PLI was greater than unity showing that there was minimum pollution in the studied dumpsite soils. However, the results of the potential ecological risk evaluation indicated that the soil samples were at low risk with the studied heavy metals. This study suggested that the dumpsites contributed to soil metal loads and due to the toxicity of heavy metals, there is a need for government to establish a monitoring program that addresses indiscriminate dumping of waste in the FCT.

**Keywords:** Soil pollution, dumpsite, pollution index, heavy metal, Abuja

**1. INTRODUCTION**

“The significant increase in the generation of municipal solid waste worldwide, has made the disposal of these materials a crucial point for sustainably maintaining current activities. The exponential increase in the world population, associated with the development of industry and technology, as well as the continuous and growing use of natural resources, are key factors contributing to the significant increase in solid waste generation” (de Souza et al., 2023; Mohasin et al., 2022). “Urban soils have become highly influenced by anthropogenic activities as a result of rapid urbanization and industrialization. The rural-urban drift due to population increase has led to an increase in the quantity of waste generated within the urban areas” (Chen *et al.,* 2007; Gujre *et al.,* 2021). “Solid waste generation and their poor disposal mechanism in the urban areas of most developing countries like Nigeria have become a threat to the environment” (Mata *et al.,* 2020). “It is estimated that municipal solid waste generation in South Asia, Latin America, and Sub-Saharan Africa will double or triple by 2050, making up to 35% of the world’s municipal solid waste” (World Bank Report, 2018). “Nigeria is characterized by ineffective solid waste management because of poor infrastructure and planning, paucity of funds, technical expertise, community attitude and inappropriate policy execution capacity” (Essien *et al.,* 2019; Karkarna and Matazu, 2020; Ojiego *et al.,* 2022). “More so, the most common method used for the disposal of solid wastes is open dumping without treatment or sorting to lessen soil and groundwater contamination” (Ikpe *et al.,* 2018; Yahaya *et al.,* 2021. “Wastes are dumped irresponsibly with no regard to their environmental implications despite the efforts of waste management authorities in Nigeria” (Ogunmodede *et al.,* 2016; Ogoko *et al.,* 2021). “Open dumping, incineration, open burning, poorly regulated landfills, composting as well as dumping of solid waste into drain channels, streams and rivers are still the methods used for municipal waste disposal in Nigeria. Consequently, such waste dumps become a point source for soil pollution as they serve as host for leachate from dumpsites” (Useh and Dauda, 2018).

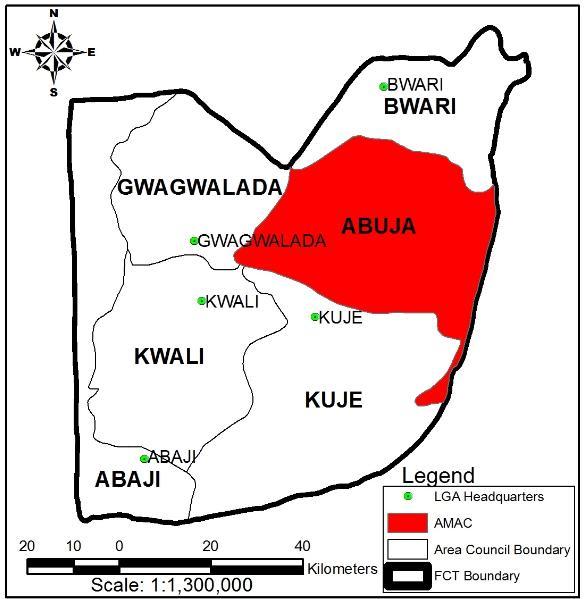
“Rainfall facilitates the percolation of organic and inorganic leachates into the soil close to refuse dumps which ultimately contaminate the groundwater. The inorganic leachates are mainly mineral elements which include heavy metals. Heavy metals are hazardous to health, non-biodegradable and most persistent contaminants of the ecosystem” (Useh *et al.,* 2015; Fonge *et al.,* 2017; Mata *et al.,* 2020; Seyyed *et al.,* 2023). “Municipal solid waste is characterized by different fractions including electronic wastes, food wastes, plastics, textile materials, industrial and biomedical wastes, glasses, tins, wood wastes, ceramics, batteries, papers, the inorganic fraction containing hazardous substances such as toxic metals and organic pollutants” (Davidson, 2013; Nyika *et al.,* 2019; Makuleke and Ngole-Jeme, 2020; Gujre *et al.,* 2021). “There is increased concern on soil contamination by heavy metals because soil plays an important role in ecological stability. The term ―heavy metal is generally used to describe a group of metals and metalloids with a density greater than 5.0 g/cm3 and is toxic or poisonous even at low concentrations” (Nartey *et al.,* 2012; Ali *et al.,* 2016). The origin of heavy metals in the environment could be from both natural or anthropogenic sources (Chen *et al.,* 2007; Soleimannejad *et al.,* 2016; Jinal *et al.,* 2017). “These metals find their way to the soil through the application of fertilizer and pesticides, mining and smelting of metallic elements and metal scraps, electroplating, sludge dumping and municipal solid waste disposal” (Akanchise *et al.,* 2020; Cittadino *et al.,* 2020; Proshad *et al.,* 2017; Onue *et al.,* 2021).

“Heavy metals have been reported to produce mutagenic, teratogenic, neurotoxic and carcinogenic effects even at very low concentrations” (Getachew and Habtamu, 2015; Waheshi *et al.,* 2017; Adamcová *et al.,* 2017; Wu *et al.,* 2020). “The Agency for Toxic Substances and Disease Registry (ATSDR, 2015), reported that cadmium and lead are carcinogenic, and that prolonged exposure to low concentrations of cadmium could lead to kidney disease, lung damage, fragile bones, and of Lead, nervous disorder” (Navas-Acien, 2007; Sadeghi *et al.,* 2020). When heavy metals are incorporated into products which will subsequently be disposed of in landfills, there is a high possibility that with time, they will be released into the surrounding ecosystems mainly through soil and water. Shittu et al. (2017) examined the heavy metal contamination in the dumpsites environment using pollution indices and their results showed that the soils are highly polluted with heavy metals. Ediene and Umoetok (2017) “determined the concentration of heavy metals in soils at the municipal dumpsite in Calabar metropolis using the pollution index and their results indicated that the concentration of heavy metals in the dumpsites was greater than that of the control soil.” The analysis of soils about their toxic metals content is helpful for the assessment of environmental pollution and provide crucial information on the potential risks to the residents living around. Hence, this study aimed to determine the level and associated risk of heavy metals (Cr, Mn, Pb, Cu, Fe, Cd, Zn) pollution of soils around solid waste dumpsites in Abuja Metropolis using ecological risk assessment methods.

**2. MATERIALS AND METHODS**

**2.1 Study Area**

Abuja Municipal Area Council (AMAC) in Federal Capital Territory (FCT) Nigeria is geographically located at 8°92′N and 9°02′N of the Equator and 7°34′E and 7°54′E of the meridian (Figure 1.0). The FCT has a total population of about 1,406,239 and land area of 7753.85 km2 (NPC 2012). AMAC experiences two climate seasons, wet and dry season with an average annual temperature of 21–30 °C and a brief harmattan, occasioned by the movement of the northeast trade wind, with the main features of intensified coldness, dust haze and dryness. Rainfall is between March and October and the rainy season is associates with high humidity and moderate temperature. It has a mean rainfall and humidity of about 119.2 mm and 58.4%, respectively, with the highest in August and the lowest between November and March, respectively.



**Figure 1: Map of FCT showing the Study Area**

The dry season sets in between November and April with very low humidity and high temperatures due to free cloud cover. The soil in Abuja Metropolis supports agricultural activities (Ojiego *et al.,* 2022; Mohammed *et al.,* 2022). Five uncontrolled dumpsites were selected for this study and these dumpsites are located within the municipal area, namely: Area 2 Dumpsite, Durumi Central Dumpsite, Garki New Market Dumpsite, Trade Moore Estate Dumpsite, Utako Dumpsite.

**2.2 Sampling Procedure**

The random method of sampling was used for the gathering of data around the dumpsites. The sampling sites were chosen based on the different anthropogenic activities within the zone. A total of fifty surface soil samples were collected from ten solid waste dumpsites (Area 2 Dumpsite, Durumi Central Dumpsite, Garki New Market Dumpsite, Trade Moore Estate Dumpsite, Utako Dumpsite, Jabi Dumpsite, Guzape Dumpsite, Gaduwa junction Dumpsite, Apo resettlement Market Dumpsite, Chika 2 Dumpsite and were coded DS1, DS2, DS3, DS4, DS5, DS6, DS7, DS8, DS9 and DS10 respectively) of Abuja metropolis at a depth of 0-20cm using soil auger. The soil auger was cleaned after soil sampling at each sample location. Soil samples from each part per dumpsite were pooled to form composite samples from where representative samples were taken for analysis. A control sample was also collected from a reserved area (Katampe) within the metropolis where no dumping activities have been carried out. The samples were stored using polythene bags, appropriately labelled and taken to the laboratory for pre-treatment and analysis. Sample collections were done in March, 2024 during the dry season to avoid leaching of metals into sub-soil. The soil samples were air-dried for two weeks, rolled manually, mixed and sieved with 2 mm mesh to remove stones and debris. These were properly stored in well-labeled air-tight containers until analysis. A table depicting the identity, geographical location, and some characteristics of soils are presented in (Table 2).

**2.3 Physicochemical Analysis**

Some physicochemical properties such as pH, electrical conductivity, soil texture, organic matter, cation exchange capacity (CEC) were determined. The pH and electrical conductivity were measured in a soil suspension (1:10 w/v dilution) by a digital pH meter (Jenway model 3015) and conductivity meter (Systronics-304), respectively. Organic matter (OM) was determined by the potassium dichromate titration method (Useh *et al.,* 2017). Cation exchange capacity (CEC) of soil was determined as per the procedure outlined by Useh *et al.,* (2015). The texture of the soil was determined by using the hydrometer method (Saxena *et al.,* 2013). All chemicals and reagents were of analytical grade and they were supplied by BDH Labs (UK). BDH Chemicals Limited Poole England.

**2.4 Heavy Metals Analysis**

A test portion of 1.00 g of each soil sample was digested using the conventional aqua regia (3:1, v/v, HCl to HNO3) digestion procedure as described by Useh *et al.,* (2018) and Kuok & Zhu (2022). All digestions were carried out in triplicates for each sample and the amounts of trace metals were recorded as the mean value. The extracts were analyzed for heavy metals (Cr, Mn, Pb, Cu, Fe, Cd, Zn) using an atomic absorption spectrophotometer (AAS) iCE 3000 Series 3000 [Useh *et al.,* 2018].

**2.5 Contamination and Ecological Risk Assessment Methods**

In this study, the assessment of soil pollution was conducted using two single indices, namely, the single pollution index (Pi) or contamination factor () and ecological risk factor (), as well as three integrated indices including the Nemerow pollution index (PN), pollution load index () and potential ecological risk index () to comprehensively evaluate the pollution levels of heavy metal elements in topsoil.

1. **The Single Pollution Index (Pi)**

The single pollution index (Pi) is used to determine which heavy metal poses the greatest threat to the soil environment. The pollution level by a given heavy metal (i), is evaluated with the single pollution index (Pi), and calculated as the ratio between the metal concentration (Ci) in a soil sample and its reference value (Si). It exhibits the pollution degree of each heavy metal, which is expressed as shown in Equation 1.

(1)

where Ci and Si are the concentrations of the ith heavy metal in the soil sample and the concentration of the same heavy metal in the background sample, respectively (which in this case was the sample from the control site). It is interpreted as presented in Table 1.

1. **The Nemerow Pollution Index (PN)**

The PN is a multi-factor environmental quality index that takes into account extreme values, especially considering the most polluting factors. PN describes the integrated pollution level in the study area and is calculated as follows:

(2)

where PNemerow is PN, Pimean is the calculated average value for the Single Pollution Index, Pimax is the maximum value of the Single Pollution Indexes of all heavy metals, and n is the number of heavy metals. According to PN, the degree of contamination of heavy metals is classified as presented in Table 1.

1. **The Pollution Load Index (PLI)**

The pollution index (PLI) is the load capacity of a pollutant for a region and it is usually used to evaluate the pollution degree of all heavy metals in soil, which is calculated according to the following equation

(3)



Where n is the number of metals evaluated. It is interesting to note that a pollution load index (PLI) value greater than 1 (PLI > 1) indicates that the soil is polluted while PLI value less than 1 (PLI < 1) indicates no pollution. Four categories are recognized for PLI as indicated in Table 1.

**(iv) Ecological Risk Factor ()**

The potential ecological risk index method (RI) was proposed in 1980 by Hakanson Lars, a Swedish scientist ([Hå](http://?)kanson, 1980). This method is used to assess the potential risk for the ecological environment by heavy metals in soil/sediment. It reflects also the ecological sensitivity and toxicity of the concentration of contaminants (Hakanson, 1980; Suresh *et al.,* 2012). “It was originally used as an evaluation tool for sediment pollution in the aquatic environment. It has been successfully used for risk assessment of soils, dust and air” (Suresh *et al.,* 2012; Riyad *et al.,* 2015; Bienvenu *et al.,* 2022). For a single metal, the ecological risk factor is determined by the following equation:

(4)

Where is the single factor potential ecological risk index and is the toxic response factor for a given substance . = 30 for Cd, 5 for Cu, 5 for Pb, 2 for Cr, 1 for Zn, Mn and Fe (Hånkanson, 1980; Bienvenu *et al.,* 2022). Five categories are recognized for as indicated in Table 1.

**(v) The Potential Ecological Risk Index ()**

“The potential ecological risk index was comparable to the level of contamination defined as the sum of the single potential ecological risk factor for several heavy metals in the soil. This method reflects the toxic level, concentration of the heavy metals, synergy and ecological sensitivity of heavy metals widely” (Singh et al., 2002). It signifies the sensitivity of numerous biological communities and likely the hazards caused by these heavy metals. The of all the heavy metals determined was calculated using the following equation:

(5)



Where is the integrated potential ecological risk index, is the single index of ecological risk factor, and n is the count of the type of heavy metal. Five categories are recognized for as indicated in Table 1.

**Table 1. Classification of soil contamination Indexes**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **SOIL STATUS** | **PN** | **SOIL STATUS** | **PLI** | **SOIL STATUS** |  | **SOIL STATUS** |  | **SOIL STATUS** |
|  | low contamination | PN ≤ 0.7 | Uncontaminated | PLI ≤ 1 | Uncontaminated |  | Low risk | <150 | Low risk |
|  | moderate contamination | 0.7 < PN ≤ 1 | Danger range | 1 < PLI ≤ 2 | Low | 40 ≤ < 80 | Moderate risk | 150 ≤ <300 | Moderate risk |
|  | considerable contamination | 1 < PN ≤ 2 | Low contamination | 2 < PLI ≤ 3 | Medium | 80 ≤ < 160 | High risk | 300 ≤ < 600 | High risk |
|  | high contamination | 2 < PN ≤ 3 | Moderate contamination | 3 < PLI ≤ 5 | Strong | 160 ≤ < 320 | Very high risk | 600 ≤ <1200 | Very high risk |
|  |  | PN ≥ 3 | Severe contamination | PLI > 5 | Very Strong | ≥ 320 | Extremely high risk | ≥ 1200 | Extremely high risk |

**2.6 Statistical Analysis**

To evaluate the significant difference on the effects of dumpsite on soil physicochemical (e.g. pH, EC, OM, and CEC) properties and heavy metal concentrations (Cr, Mn, Pb, Cu, Fe, Cd and Zn) at the various sampling locations, data recorded were subjected to one-way analysis of variance (ANOVA) using statistical software SPSS Windows version 22.0 with a level of significance of p < 0.05.

**3. RESULTS AND DISCUSSION**

**3.1. Physicochemical Characteristics of Soil**

The results of the physicochemical properties of soils in this study were determined as presented in Table 2. The mean pH of the soil in this study ranged from 5.81 in site DS8 to 7.64 in site DS2 for the ten dumpsites with the control site recorded 7.14. This indicates that the soils at the dumpsites are slightly acidic to neutral with sites DS2, DS7 and DS9 tending towards alkaline nature with pH values of 7.64, 7.30 and 7.32 respectively. Most metals in the pH range of 6.0-9.0 are not always in the free form (Weihua *et* *al.,* 2010; Njagi *et al.,* 2016) and most pHs of the soil samples from the dumpsites studied fell within this range. This would eventually influence the lower release of heavy metals into subsoil and groundwater (Varol, 2011; Murana *et al.,* 2019). “The pH of a soil is known to be a very unstable property that is easily influenced by other properties. When conditions become favourable, there could be higher release of heavy metals down the horizons” (Ogunkunle and Fatoba, 2013; Zhang *et al.,* 2017). From Table 2, the mean electrical conductivity (EC) values of the various sampling points were significantly different (p < 0.05) ranging from 259.22 µs/cm to 439.15 µs/cm, with the control location recording 263.10 µs/cm EC. The high EC values indicate the presence of soluble salts which could be associated with the disposal of metallic scraps at the dumpsite. A study on dumpsites by Mekonnen *et al.,* (2020) reported similar EC values with its associated increase in soluble salts in the soils.

Concerning soil texture, the percentage of sand ranged from 60.8% in site DS1 to 75.3% in site DS6; silt 7.6% in site DS10 to 25.5% in site DS1; clay 12.9% in site DS3 to 25.4% in site DS8. The percentage composition of these three components revealed that the soils in the study area could be texturally classified as sandy loam to loamy sand. This indicated a higher sand content than silt and clay. The relatively high sand but predominantly silt and clay contents of the soils in the study location were also reported by Kusin *et al.,* (2018). Other authors (Waseem, 2014; Onyedikachi *et al.,* 2018; Karimi and Borquaye, 2020) also reported similar high sand contents as obtained in this study from the dumpsites relative to the control sites. “Generally, soils with high sand and lower clay contents are highly permeable to water and leachates and thus have high pollutant leaching potentials” (Ogundele *et al.,* 2020; Yahaya et al., 2021).

**Table 2. Sampling sites and some physicochemical parameters of studied samples.**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **CODE** | **SAMPLING SITE** | **Longitude** | **Latitude** | **pH** | **Conductivity (µs/cm)** | **Sand (%)** | **Silt (%)** | **Clay (%)** | **CEC (mmolc/kg)** | **OM (%)** |
| DS1 | Area 2 Dumpsite | 7.477784 | 9.035921 | 6.48 | 275.02 | 60.8 | 25.5 | 13.7 | 0.93 | 0.83 |
| DS2 | Durumi Central Dumpsite | 7.462317 | 8.994915 | 7.32 | 347.05 | 64.5 | 20.9 | 14.6 | 1.42 | 1.62 |
| DS3 | Garki New Market Dumpsite | 7.491566 | 9.026657 | 6.61 | 284.14 | 67.3 | 19.8 | 12.9 | 0.86 | 0.74 |
| DS4 | Trade Moore Estate Dumpsite | 7.368128 | 8.957015 | 6.29 | 259.22 | 65.2 | 20.1 | 14.7 | 0.95 | 1.52 |
| DS5 | Utako Dumpsite | 7.435675 | 9.064516 | 5.95 | 328.01 | 63.4 | 22.5 | 14.1 | 1.79 | 0.71 |
| DS6 | Jabi Dumpsite | 7.418701 | 9.061701 | 6.48 | 439.15 | 75.3 | 9.5 | 15.2 | 0.64 | 1.68 |
| DS7 | Guzape Dumpsite | 7.5118 | 9.017635 | 7.30 | 416.03 | 66.1 | 14.6 | 19.3 | 0.75 | 1.57 |
| DS8 | Gaduwa junction | 7.464111 | 9.003276 | 5.81 | 273.01 | 61.3 | 13.3 | 25.4 | 1.36 | 0.75 |
| DS9 | Apo resettlement Market | 7.503818 | 8.977583 | 7.64 | 362.16 | 71.2 | 12.7 | 16.1 | 0.99 | 1.38 |
| DS10 | Chika 2 Dumpsite | 7.409847 | 8.992845 | 6.33 | 295.27 | 73.0 | 7.6 | 19.4 | 1.62 | 0.66 |
| Control | Katampe | 7.45296 | 9.002121 | 7.14 | 263.10 | 69.2 | 20.3 | 10.5 | 0.75 | 0.65 |

The cation exchange capacities (CEC) of the soils from all the dumpsites ranged from 0.64 mmolc /kg in site DS6 to 1.79 mmolc /kg in site DS5. According to Sadeghi *et al.,* (2020) and Samadder *et al.,* (2017), soil CEC increases with OM and clay content in soils. Though the soils had some amount of clay, the CEC values fall within the range of values reported for 2:1 clay minerals (Essien *et al.,* 2019; Karkarna *et al.,* 2021). “The clay fraction of the soils is most likely dominated by these minerals which are characterized by low CEC. The low cation exchange capacity exhibited by soils in this study could be due to the high proportion of sand. CEC is known to proportionally decrease with an increase in sand content in most soil samples for there are always lesser exchange sites that affect heavy metals retention in sand compared to clay and organic matter” (Onue *et al.,* 2021; Bienvenu *et al.,* 2022; Fonge *et al.,* 2017). “Organic matter (OM) content in the soils was also relatively low. Soil organic matter has pH-dependent charges which tend to be high when the soil is alkaline and low when soil pH is low due to protonation and deprotonation of functional groups contained in organic matter” (Waheshi *et al.,* 2017; Bienvenu *et al.,* 2022). “Deprotonation caused by the acidic nature of the soils would have reduced the pH- negative charge density of the soil, reducing the fraction of CEC contributed by soil OM. The low CEC observed in the soils despite the moderate clay content could therefore have been caused by the mineralogical composition of the soils and their pH. The role of low-soil CEC on -high-soil heavy metal mobility and their uptake by plants has been highlighted in several studies” (Harmanescu *et al.,* 2011; Getachew and Habtamu, 2015; Shittu *et al.,* 2018; Onyedikachi *et al.,* 2018) Heavy metal migration and leaching of nutrients around the dumpsites are mostly like to be high due to the low CEC.

The values of OM in soil samples from the dumpsites studied ranged from 0.66% in site DS10 to 1.68% in site DS6 with the control site recorded 0.65%. “The tendency for exchangeable cations to bind to the organic phase will be low due to low organic content value. Also, the low organic matter exhibited in these dumpsites could be a result of the high net percentage of nonbiodegradable solid wastes present in all the dumpsites studied” (Kamunda *et al.,* 2016; Useh and Dauda, 2018; Mekonnen *et al.,* 2020). “Organic matter in soil is associated with soil textures (sand, silt, clay) and soil decomposition, and it is also a good indicator of soil health” (Obiajunwa *et al.,* 2002; Akanchise *et al.,* 2020). Therefore, low organic matter in soil samples studied may be associated with the low silt and clay content in dumpsites.

**3.2. Heavy Metals Concentrations in the Soils**

The mean concentrations of heavy metal (in mg/kg) in soil samples collected from the study area are presented in Table 3. Results showed that the concentrations of heavy metals (Cr, Mn, Pb, Cu, Fe, Cd, Zn) in the soil at the dumpsites were significantly (p < 0.05) higher than the control site except for Mn, Pb and Fe in sites DS10, DS2 and DS3 respectively. This is in agreement with the results obtained from similar studies by Useh *et al.,* (2015) and Mekonnen *et al.,* (2020) on a dumpsite and it could be attributed to the availability of metal-containing wastes at dumpsites which have eventually leached into the underlying soils. “Compared to the EU and WHO values, most of the heavy metal values in the soil were higher than the permissible limits recommended by WHO but lower than the EU limits. This could be attributed to leachate migration from the decomposing waste from the dumpsites” (Riyad *et al.,* 2015; Seyyed *et al.,* 2023).

The mean concentration of chromium in the studied soil ranged from 7.97±0.52 in site DS3 to 25.14±0.71 in site DS9 higher than the mean value of 6.85±0.13 mg/Kg at the control site. High levels of Cr at the dumpsites compared to the control site have also been reported in other dumpsites studies (Fonge *et al.,* 2017; Ojiego *et al.,* 2022) and have been attributed to leachate migration from the dumpsites. “This implies that the high concentrations at the dumpsite are the result of the dumping of Cr-containing waste. Sources of chromium might be due to wastes from household chemicals and cleaners, diesel engines utilizing anti-corrosive agents, rubber, candles, and matches, etc. Anthropogenic input of Cr comes from solid wastes, where approximately 30% of Cr originates from plastics, packaging materials, and lead chromium batteries” (Useh and Dauda, 2018; Essien *et al.,* 2019). The values of Cr obtained in this study were lower than the 900 – 2000 mg/kg reported by Getachew and Habtamu, (2015) in a dumpsite in Shasshmane.

“Manganese is found naturally in most soil as it is one of the most essential minerals for life” (Adamcová, 2017). “Manganese is naturally present in soil at concentrations of 20 to 3000 ppm, or 20–3000 mg per kg of soil. Normally it exists as Mn2+ in soil with the tendency to form complexes with organic compounds” (Seifi, 2019; Gujre *et al.,* 2021). Its availability in soil is affected by pH, and lower pH results in higher solubility, hence availability to plants (Chen *et al.,* 2007; Ali *et al.,* 2016). The manganese concentrations were observed for all the samples with the ranges between 70.94±5.24 in site DS10 and 153.08±2.81 in site DS2 while the control site recorded 71.53±1.32 mg/kg. The result from this study is similar to the result from Proshad *et al.,* (2017) on the distribution and enrichment of heavy metals in soils from waste dumpsites in Chittagong, Bangladesh. “Electrical and electronic waste, which was also disposed of at the dumpsite, might have been a source of manganese. All the concentration of manganese values was found to be lower than the World Health Organization standard for manganese in the soil. It serves as an activator for enzymes in growth processes and assists iron in chlorophyll formation” (Useh *et al.,* 2017). “Manganese is one of the toxic essential trace elements, which means that it is not only necessary for humans to survive, but it is also toxic when consumed in high concentrations by humans. Excess exposure to this metal can cause damage to the respiratory tract and the brain” (Ogunmodede *et al.,* 2016; Samadder *et al.,* 2017).

**Table 3. Heavy metals concentrations of the samples (mg/kg).**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sampling Sites** | **Cr** | **Mn** | **Pb** | **Cu** | **Fe** | **Cd** | **Zn** |
| DS1 | 11.46±3.53b | 97.35±4.27a | 63.20±3.53b | 38.47±0.26b | 5946.58±3.61a | 0.75±0.01a | 264.10±1.47b |
| DS2 | 15.35±0.13b | 153.08±2.81b | 25.85±1.93a | 22.36±1.39b | 9413.32±4.38c | 0.59±0.00a | 232.73±2.84b |
| DS3 | 7.97±0.52a | 136.92±0.56b | 39.26±0.51a | 17.86±0.74a | 3886.45±2.17b | 1.36±0.05b | 158.77±1.43a |
| DS4 | 20.41±1.72c | 82.17±8.62a | 55.81±1.36b | 52.16±2.36c | 6357.92±0.48b | 0.72±0.01a | 271.02±0.38b |
| DS5 | 13.82±0.38b | 137.26±4.21b | 84.10±1.72c | 40.27±5.10b | 8465.59±5.29c | 1.51±0.04b | 184.63±2.75a |
| DS6 | 23.01±1.59c | 74.38±0.68a | 47.24±0.32b | 15.48±3.27a | 7452.46±2.57b | 0.59±0.00a | 346.18±5.32c |
| DS7 | 16.85±1.04b | 93.76±2.57a | 81.20±0.68c | 19.73±3.10a | 6835.17±3.11b | 0.84±0.00a | 285.73±0.24b |
| DS8 | 9.88±0.02a | 152.02±1.39b | 45.23±1.26b | 47.55±2.19b | 8164.24±0.56c | 1.46±0.01b | 246.25±0.01b |
| DS9 | 25.14±0.71c | 148.56±1.87b | 38.50±3.71a | 28.35±0.84b | 5829.01±3.84a | 1.62±0.01b | 194.38±0.51a |
| DS10 | 20.57±1.63c | 70.94±5.24a | 65.14±5.12b | 23.59±1.35b | 7463.62±7.21b | 0.77±0.03a | 175.94±2.42a |
| Control | 6.85±0.13a | 71.53±1.32a | 37.59±2.10a | 12.45±0.14a | 3975.86±3.46a | 0.28±0.00a | 114.57±0.35a |
| WHO Limits | 0.10 | 200 | 0.10 | 1.5 | 50000 | 0.01 | 15 |
| EU Limits | 150 | - | 300 | 140 | - | 3 | 300 |

*Results are expressed as Means ± standard deviation for triplicate determinations. Within columns, means with different alphabets are statistically different at p < 0.05*

The concentration of lead (Pb) ranged from 25.85±1.93 in site DS2 to 84.10±1.72 in site DS5 with a mean control value of 37.59±2.10 which was found to be high above the WHO recommended maximum limit of 0.10 but lower than the EU limits of 70 except in sites DS5 and DS7. “This could be linked to the regional geochemistry of rock types that underlain the study area, as well as contributions from anthropogenic sources. The high concentration could be attributed to burning of electronic waste materials such as refrigerators, used computers, cables, printers, photocopy machines, automobile tyres, batteries, and air condition among others” (Edokpayi *et al.,* 2018; Boateng *et al.,* 2019). “Lead is a toxic heavy metal, which can be taken up by plants from the soil thereby interfering with the food chain. It is reported to exert its most significant effect on the nervous system” (Navas-Acien *et al.,* 2007). “Lead ingestion has been associated with deleterious effects including disorder of the central nervous system and lead is widely known to be toxic even at low concentrations, especially in young children. Lead toxicity causes cancer and anaemia by impairment of haemo-biosynthesis and acceleration of red blood cell destruction” (Nieboer *et al.,* 2007; Tchounwou *et* *al.,* 2012; Oskarsson, 2015).

Concentrations of copper in the analyzed soil samples varied from 15.48±3.27 in site DS6 to 52.16±2.36 in site DS4 with the control site recording 12.45±0.14 which was higher than the WHO permissible limits of 1.5 mg/kg and EU limits of 20 mg/kg except in sites DS3, DS6 and DS7. The mean concentration recorded could be attributed to the burning of electronic gadgets and other copper-based wastes such as automobile spare parts (Kamunda *et al.,* 2016; Useh *et al.,* 2018). “Copper is essential to organisms, cofactor in redox enzymes and is necessary to maintain blood chemistry. However, copper can be toxic at high concentrations” (Onyedikachi *et al.,* 2018). “Anthropogenic sources are equally an underlining factor in the enrichment of copper, particularly leachate from electric wiring, roofing, various alloys, pigments, and cooking utensils which were dumped as refuse at the respective sites under investigation” (Wijesekara et al., 2014; Cittadino *et al.,* 2020).

Sampling sites DS2, DS6 and DS9 had the least (0.59±0.00) and highest (1.62±0.01) cadmium concentrations respectively with the control site recording 0.28±0.00 which was higher than the WHO permissible limits of 0.01 mg/kg. Cadmium is very much connected with non-residual fractions of heavy metals thus makes them mobile and potentially bio-available for uptake by plants (Akanchise *et al.,* 2020; Kuok and Zhu, 2022; Useh and Linus, 2022). “The high concentrations of Cd especially at site DS9 might be a result of the burning of electronic waste containing cadmium-nickel batteries, pigments and paints. Cadmium is one of the most eco-toxic metals, with highly undesirable effects on soil health, plant metabolism, and humans and animal health” (Varol, 2011; Mavakala *et al.,* 2016). At very low concentrations, chronic exposure to cadmium can result to anaemia, anosmia, cardiovascular diseases and renal problems (Weihua *et al.,* 2010; Jinal *et al.,* 2017). “Cadmium is toxic and exposure at higher concentrations could result in flu-like illness- chills, fever, and myalgias, chest pain, cough, dyspnea, Bronchospasm, hemoptysis, liver and kidney dysfunction” (Ali *et* *al.,* 2017; Karkarna and Matazu, 2020) The levels of Cadmium observed in sites DS5, DS8 and DS9 were similar to values reported for soils of municipal waste dump in South Western Ethiopia (Mekonnen *et al.,* 2020).

It was observed that sampling site DS6 recorded the maximum concentration (346.18±5.32) of zinc whereas site DS3 had the least (158.77±1.43) zinc concentration among the sampling stations assessed. “Zinc is a metal with several agricultural, industrial and biological applications. Industrially, zinc is used in the corrosion protection of steel” (Useh and Linus, 2022). “Zinc is an essential element for both plant and animal growth, but the excessive concentration in the soil may result in phytotoxicity. Phyto-toxicity affects the activity of weeds, earthworms and microorganisms in the soil” (Wijesekara *et al.,* 2014). Acute zinc intoxication could lead to nausea, vomiting, severe anaemia and renal failure (Oskarsson , 2015; Akanchise *et al.,* 2020).

The concentrations of Iron in the dumpsites studied ranged between 3886.45±2.17 in site DS3 and 9413.32±4.38 in site DS2, which was higher than the value obtained in the control site (3975.86±3.46mg/kg) except in site DS3 (3886.45±2.1 mg/kg) which had lowest Fe content. However, “all the studied sites recorded Fe concentrations below a normal range in soil and the WHO recommended limit of 50000. Iron is essential to all organisms, a cofactor in many enzymes and especially in proteins, it is an essential trace metal in human metabolism necessary for the oxygen-carrying ability of blood” (Tchounwou *et al.,* 2012; Seifi, 2019). “The major sources of iron in these sites include metallic scraps being co-deposited with domestic wastes. The high concentration of Fe could be partly due to the natural Fe content of soil and partly due to the high content of Fe-based waste materials generated through domestic and industrial wastes. Most of the Fe is bound to organic matter and residuals” (Suresh *et al.,* 2012; Ojiego *et al.,* 2022).

**3.2. Soil Heavy Metal Contamination Evaluation**

Based on the background values, three methods (Pi, PN, PLI,) were adopted to systematically evaluate the soil pollution around the dumpsites. The pollution levels of soil heavy metals in different sampling sites are shown in Table 4. The maximum values of Pi for each sampling site was in the order 3.59 (Pb), 2.37 (Fe), 4.86 (Cd), 4.19 (Pb), 5.39 (Cd), 3.36 (Cr), 4.62 (Pb), 5.21 (Cd), 5.79 (Cd), 3.70 (Pb) for sites DS1 to DS10 respectively. For site DS1, the Pi values of Cd, Cr, Zn, Mn, and Fe were in the range of , which was classified as moderate contamination. Pb and Cu with Pi , was classified as considerable contamination in the study area. For DS2 and DS3, all metals were in the range of , which was classified as moderate contamination except Fe and Cd in DS3 which were in the class of low and considerable contamination respectively. In sites DS4 and DS5, all metals were in the range of , which was classified as moderate contamination except Pb and Cu, as well as Cd in DS5 which were in the class of considerable contamination. Further, all the heavy metals from sites DS6 to DS10 fell within the range of, except Cr and Zn in DS6, Pb and Cd in DS7, Cu and Cd in DS8, Cr and Cd in DS9 and Cr and Pb in DS10 which were in the range of being classified as considerable contamination.

**Table 4. Pollution indicators of heavy metals contamination of the dumpsite impacted soil.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | | **PN** |  |
| **Sampling Sites** | **Cr** | **Mn** | **Pb** | **Cu** | **Fe** | **Cd** | **Zn** |  |  |
| DS1 | 1.67 | 1.36 | 3.59 | 3.09 | 1.50 | 2.68 | 2.31 | 3.05 | 2.17 |
| DS2 | 2.24 | 2.14 | 1.47 | 1.80 | 2.37 | 2.11 | 2.03 | 2.20 | 2.01 |
| DS3 | 1.16 | 1.91 | 2.23 | 1.43 | 0.98 | 4.86 | 1.39 | 3.60 | 1.77 |
| DS4 | 2.98 | 1.15 | 3.17 | 4.19 | 1.60 | 2.57 | 2.37 | 3.61 | 2.34 |
| DS5 | 2.02 | 1.92 | 4.78 | 3.23 | 2.13 | 5.39 | 1.61 | 4.61 | 2.69 |
| DS6 | 3.36 | 1.04 | 2.69 | 1.24 | 1.87 | 2.11 | 3.02 | 2.89 | 2.00 |
| DS7 | 2.46 | 1.31 | 4.62 | 1.58 | 1.72 | 3.00 | 2.49 | 3.70 | 2.20 |
| DS8 | 1.44 | 2.13 | 2.57 | 3.82 | 2.05 | 5.21 | 2.15 | 4.20 | 2.52 |
| DS9 | 3.67 | 2.08 | 2.19 | 2.28 | 1.47 | 5.79 | 1.70 | 4.34 | 2.51 |
| DS10 | 3.00 | 0.99 | 3.70 | 1.89 | 1.88 | 2.75 | 1,54 | 3.09 | 2.00 |

Only Mn, with , in site DS10 was classified as low contamination in the study area. From the study, about 70.2% of sampling sites were classified as moderate contamination, and 26.8% of sampling sites were classified as considerable contamination while only 3% had low contamination. The result of the Single Pollution Index is in agreement with the work of Ojiego *et al.,* (2022) who reported very high concentrations of heavy metals in soil samples from dumpsites located at Kuje and Kwali area councils, Abuja, Nigeria and Shittu *et al.,* (2018) who reported “higher contamination of heavy metals and pollution load index at Ilokun dumpsite, Ado Eki, Nigeria. According to the field investigation, research shows that various reasons, such as vehicle emissions and electronic waste materials among others, can cause the lead content in the soil on all sides to exceed the standard”.

According to the Nemerow comprehensive pollution index principle, 2 < PN ≤ 3 can be judged as moderate contamination, while the survey results in this study showed that most of the average values are within the range of PN ≥ 3 indicating severe contamination. In terms of the total amount of heavy metals, the pollution of soils around the dumpsites in this area is serious, and the main contributors to exceeding heavy metals are Pb, Cu and Cd as well as Cr and Zn. “Heavy metals are potential long-term pollutants in soil, which cannot be decomposed by soil microorganisms but can be enriched, which often makes heavy metals accumulate gradually in the soil environment and is difficult to remove. The leachate from the waste dump will also cause heavy metal pollution to the surrounding soils through surface runoff and underground runoff” (Davidson, 2013; Fonge *et al.,* 2017). The impact of heavy metals on soil contamination can be identified by comparing their concentration with the geochemical background. The results of such investigations in the soil around the dumpsite showed an increase in the concentration of heavy metals in the soil, these conditions caused moderate to high contamination levels in the soil, which was mostly caused by metals such as lead, copper and cadmium.

Pollution load index values for all sites around the dumpsites were above unity. According to Weihua *et* *al.,* (2010) and Ogundele *et al.,* (2020), PLI values > 1 imply that there is pollution, whereas PLI values < 1 indicate no pollution. Table 4 showed the summary of pollution load index (PLI) values of the studied heavy metals (Zn, Pb, Cd, Cr, Mn, Cu and Fe) in the ten studied sites which fell within the range of 2 < PLI ≤ 3 indicating that there is medium pollution load in the study sites (PLI greater than 1) except site DS3 that had PLI within 1 < PLI ≤ 2 signifying low pollution. The results of the pollution load index obtained in the present study were in consonant with the work of Ikpe *et al.,* (2018) who reported PLI ranged between (1.83-8.26) in the soils of three auto mechanic villages in Abuja and also agreed with the value reported by Yahaya *et al.,* (2021) in contaminated soils of three mining villages in Zamfara State, Nigeria but higher than the work of Karkarna and Matazu, (2021) around Kano municipal solid waste dumpsites who reported PLI less than unity.

**Table 5 Ecological risk factor ) and potential ecological risk index (RI) in the study area**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | |  |
| **Sampling Sites** | **Cr** | **Mn** | **Pb** | **Cu** | **Fe** | **Cd** | **Zn** |
| DS1 | 3.34 | 1.36 | 17.95 | 15.45 | 1.50 | 80.4 | 2.31 | 122.31 |
| DS2 | 4.48 | 2.14 | 7.35 | 9.00 | 2.37 | 63.30 | 2.03 | 90.67 |
| DS3 | 2.32 | 1.91 | 11.15 | 7.15 | 0.98 | 145.80 | 1.39 | 170.70 |
| DS4 | 5.96 | 1.15 | 15.85 | 20.95 | 1.60 | 77.10 | 2.37 | 124.98 |
| DS5 | 4.04 | 1.92 | 23.90 | 16.15 | 2.13 | 161.70 | 1.61 | 211.45 |
| DS6 | 6.72 | 1.04 | 13.45 | 6.20 | 1.87 | 63.30 | 3.02 | 95.6 |
| DS7 | 4.92 | 1.31 | 23.10 | 7.90 | 1.72 | 90.00 | 2.49 | 131.44 |
| DS8 | 2.88 | 2.13 | 12.85 | 19.10 | 2.05 | 156.3 | 2.15 | 197.46 |
| DS9 | 7.34 | 2.08 | 10.95 | 11.4 | 1.47 | 173.70 | 1.70 | 208.64 |
| DS10 | 6.00 | 0.99 | 18.50 | 9.45 | 1.88 | 82.50 | 1.54 | 120.86 |

Table 5 presents the results of the ecological risk factor and potential ecological risk index (RI). The mean value of the ecological risk factor () ranged from 0.98 of Fe in site DS3 to 173.70 of Cd in site DS9. Based on the Value in soils as computed from Eq. (4) ), Cd (173.70) in site DS9 was the most severe which fell within the range of 160 ≤ < 320 and it implied a very high-risk condition, followed by (161.70) in site DS5, whereas Fe showed the lowest value (0.98) in site DS3. Also, Pb and Cu presented their highest values of 23.90 (DS5) and 20.95 (DS4), respectively. It was found that ecological risk factors for all the studied metals Zn, Pb, Mn, Cr, Fe, and Cu except Cd in all the studied sites were in the range of , thus indicating low ecological risk. The content of Cd in dumpsite soil in this area is high. Therefore, the potential ecological risk caused by Cd is very serious, although heavy metal pollution exceeds the standard to varying degrees, the potential ecological risk is relatively low.

“Cadmium is a non-essential element of the human body which can accumulate in the liver and kidney, resulting in cadmium poisoning. It is more easily absorbed by crops than other heavy metals and is easy to be discharged as well into the environment through waste gas, wastewater, and residue, resulting in pollution” (Essien *et al.,* 2019; Seyyed *et al.,* 2023). “Pollution sources are mainly mining and transportation of mineral resources, smelting and electroplating of non-ferrous metals, and factories using cadmium compounds as raw materials or catalysts” (Makuleke and Ngole-Jeme, 2020). “Another main reason may be closely related to the application of phosphorus fertilizers and pesticides, which have a long history and large amounts of cadmium. Therefore, cadmium from phosphorus fertilizers and some pesticides in crops may exceed cadmium from other pollution sources” (Jiang *et al.,* 2014; Soleimannejad *et al.,* 2019).

The potential ecological risk index (RI) showed that soils such as DS3 (170.70), DS5 (211.45), DS8 (197.46) and DS9 (208.64) are much more hazardous than soils in sites DS1, DS2, DS4, DS6, DS7 and DS10. The results of the potential ecological risk index (RI) of the later six dumpsites were 122.31, 90.67, 124.98, 95.6, 131.44 and 120.86 respectively and these values showed low ecological risk of the investigated sites since they were within the range of <150. The former four dumpsites were within the class of 150 ≤ <300 indicating moderate ecological risk. However, the dumpsites need to be evacuated with immediate effect as heavy metal enrichment was evident in those areas.

**CONCLUSION**

This study was carried out to evaluate heavy metals pollution of soil around solid waste dumpsites in Abuja metropolis using single and integrated pollution indices. Municipal solid waste has been found to significantly increase the concentrations of the heavy metals studied in the environment. Generally, heavy metal (Cr, Mn, Pb, Cu, Fe, Cd, Zn) concentrations in the soils investigated were mostly at a critical level, exceeding the set limits by WHO though some were below the permissible limits set by EU. The distribution of metals in soil can vary significantly because of the diversity of the wastes which are not homogeneous in dumpsites. Besides, soil/sediment physicochemical properties can influence heavy metals distribution in contaminated sites. The results of the single pollution index showed that about 70.2% of sampling sites were classified as moderate contamination, and 26.8% of sampling sites were classified as considerable contamination while only 3% had low contamination. The values of the integrated pollution index in the studied dumpsites revealed that the metals were found in the range of low contamination except Cd. It is therefore recommended, that the regulation and legislation on environmental issues, including effective solid waste management strategies and enforcement standards should be emphasized to stop the indiscriminate dumping and burning of the wastes at the site which leads to the accumulation of heavy metals.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**REFERENCES**

Adamcová, D. (2017). Environmental assessment of the effects of a municipal landfill on the content and distribution of heavy metals in Tanacetum vulgare L. *Chemosphere* 185, 1011–1018.

Akanchise T., Boakye S., Borquaye L. S., Dodd M. & Darko G. (2020). Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghan. Sci. African, 10(2020): e00614.

Ali, M. L., Islam, M. S., & Rahman, M. Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring & Management,* 5,27–35.

Ali. A.F, Young R.J. & A. I. Tanko, A.I. (2017). Distribution of Dumpsites as a Threat to Sustainable Urban Environment in Nigeria. Proceedings Sardinia International 2015, Fifteenth Waste Management and Landfill Symposium S. Margherita di Pula, Cagliari, Italy.

Bienvenu, K. M., Periyasamy, S., Amandine, L., Crispin, K. M., Gregory, G., Pius, T. M. & John P. (2022). Evaluation of heavy metal content and potential ecological risks in soil samples from wild solid waste dumpsites in developing country under tropical conditions. *Environmental Challenges,* 7 (2022): 100461.

Boateng, T. K., Opoku, F. & Akoto, O. (2019). Heavy metal contamination assessment of groundwater quality: A case study of Oti landfill site, Kumasi. Appl. *Water Sci.* 9, 33.

Chen, C. W., Kao, C. M., Chen, C. F. & Dong, C. D. (2007). Distribution and Accumulation of heavy metals in the sediments of Kaohsiung Habor, Taiwan, *Chemosphere*. 66:1431–1440.

Chonokhuu, S. (2019). Contamination and health risk assessment of heavy metals in the soil of major cities in mongolia. *Int. J. Environ. Res. Public. Health* 16, 2552.

Cittadino, A.; Ocello, N.; Majul, M.V.; Ajhuacho, R.; Dietrich, P. & Igarzabal, M.A. (2020). Heavy metal pollution and health risk assessment of soils from open dumps in the Metropolitan Area of Buenos Aires, Argentina. Environmental Monitoring and Assessment, 192(5), 291.

Costa, F. S. (2020). Multivariate optimization of an ultrasound-assisted extraction procedure for the determination of Cu, Fe, Mn, and Zn in plant samples by flame atomic absorption spectrometry. Anal. Methods 12, 2509–2512.

Davidson, C.M. (2013). Methods for the determination of heavy metals and metalloids in soils, in: Heavy Metals in Soils, *Springer*, 2(5): 97–140.

Edokpayi, J. N., Durowoju, O. S. & Odiyo, J. O. (2018). Assessment of heavy metals in landfill leachate: A case study of Thohoyandou landfill, Limpopo Province South Africa. *Heavy Met.* 16, 214–227.

Essien, J. P., Inam, E. D., Ikpe, D. I., Udofia, G. E. & Benson, N.U. (2019). Ecotoxicological status and risk assessment of heavymetalsin municipal solid wastes dumpsite impacted soil in Nigeria, *Environmental Nanotechnology, Monitoring & Management,* 11,

Federation, W. E. & Association, A. P. H. Standard Methods for the Examination of Water and Wastewater (American Public Health Association (APHA), 2005).

Fonge, B. A., Nkoleka, E. N., Asong, F. Z., Ajonina, S. A. & Che, V. B. (2017). Heavy metal contamination in soils from a municipal landfill, surrounded by banana plantation in the eastern flank of Mount Cameroon. *African Journal of Biotechnology*, 16(25):1391-1399.

Getachew, D. & Habtamu, D. (2015). Heavy metals Pollution of Soil around Solid waste Dumping Sites and Its Impact on Adjacent Community; The Case of Shasshmane Open land fill, Ethopia. *Journal of Environment. & Earth Science*, 5(15): 169-178.

Gujre, N., Mitra, S., Soni, A., Agnihotri, R., Rangan, L. & Rene, E. R. (2021). Speciation, contamination, ecological and human health risks assessment of heavy metals in soils dumped with municipal solid wastes. *Chemosphere,* 262,128013.

Håkanson, L. , (1980). An Ecological Risk Index for Aquatic Pollution Control: A Sedimen-tological Approach. Water Res. 14, 975–1001 .

Hanfi, M. Y. & Yarmoshenko, I. V. (2020). Health risk assessment quantification from heavy metals contamination in the urban soil and urban surface deposited sediment. *J. Taibah Univ. Sci.* 14, 285–293.

Harmanescu, M., Alda, L. M., Bordean, D. M., Gogoasa, I. & Gergen, I. (2011). Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County, Romania. *Chem. Cent. J.* 5, 64.

Ikpe, N. C, Kenechukwu, E. C, & Ikechukwu,E. C. (2018) Use of integrated pollution indices in assessing heavy metals pollution in soils of three auto mechanic villages in Abuja. *African Journal of Environmental Science and Technology,* 12(10):370-376.

Jia, Z., Li, S. & Wang, L. (2018). Assessment of soil heavy metals for eco-environment and human health in a rapidly urbanization area of the upper Yangtze Basin. *Sci. Rep.* 8, 1–14.

Jiang X., Lu W. X., Zhao H. Q., Yang Q. C., and Yang Z. P. (2014). Potential ecological risk assessment and prediction of soil heavy metal pollution around coal gangue dump, Nat. *Hazards Earth Syst. Sci.,* 14: 1599- 1610.

Jinal, L., Esha,T. & Sulekha, G. (2017). Assessment of metal Contamination using Single and Integrated pollution Indices in soil samples of Nashik District, *India International Journal of Development Research*, 7(9):15016 15024.

Jung, C. H., Matsuto, T. & Tanaka, N. (2006). Flow analysis of metals in a municipal solid waste management system. *Waste Manage.* 26:1337-1348.

Kamunda, C., Mathuthu, M. & Madhuku, M. (2016). Health risk assessment of heavy metals in soils from Witwatersrand Gold Mining Basin, South Africa. *Int. J. Environ. Res. Public. Health* 13, 663.

Karimi, A. et al. (2020). Assessment of human health risks and pollution index for heavy metals in farmlands irrigated by effluents of stabilization ponds. *Environ. Sci. Pollut. Res.* 27, 1–11.

Karkarna, M. Z., & Matazu, M. A. (2021): Assessment of Heavy Metal contamination in Surface and Sub-surface soil from Dumpsite in Kano Metropolis, Nigeria, *Dutse Journal of Pure and Applied Sciences,* 7(1): 260-270.

Karkarna,M. Z., & Matazu, M. A. (2020). Heavy Metal spatial variability among Dumpsites Kano Metropolis, Nigeria, *FUDMA Journal of Pure and Applied Sciences,* 7(1): 260-270.

Kuok H. T. & Zhu H. G. (2022). The Levels of Heavy Metals in the Soil of Illegal Open Dumpsites in Malaysia. *Tropical Aquatic and Soil Pollution*, 2(2):109-125.

Kusin, F. M., Azani, N. N. M., Hasan, S. N. M. S. & Sulong, N. A. (2018). Distribution of heavy metals and metalloid in surface sediments of heavily-mined area for bauxite ore in Pengerang, Malaysia and associated risk assessment. *CATENA* 165, 454–464.

Makuleke, P., & Ngole-Jeme, V.M. (2020). Soil heavy metal distribution with depth around a closed landfill and their uptake by Datura stramonium, *Appl. Environ. Soil Sci.* 8872475.

Mata, H. K., Al Salah, D. M., Ngweme, G. N., Konde, J. N., Mulaji, C. K., Kiyombo, G. M., Poté, J. W. (2020). Toxic metal concentration and ecotoxicity test of sediments from dense populated areas of Congo River, Kinshasa, Democratic Republic of the Congo. J. Environ. Chem. Ecotoxicol. 2: 83–90.

Mavakala, B. K., Le Faucheur, S., Mulaji, C. K., Laffite, A., Devarajan, N., Biey, E. M., Giuliani, G., Otamonga, J. P., Kabatusuila, P., Mpiana, P. T. & Pote, J. (2016). Leachates draining from controlled municipal solid waste landfill: detailed geochemical charac- terization and toxicity tests. Waste Manag. 5(5): 238–248.

Mekonnen, B., Haddis, A. & Zeine, W. (2020). Assessment of the effect of solid waste dump site on surrounding soil and river water quality in Tepi TOWN, Southwest Ethiopia. *J. Environ. Public Health* 2020, Article ID 5157046, 9.

Mohammadi, A. A. (2019). Assessment of heavy metal pollution and human health risks assessment in soils around an industrial zone in Neyshabur, Iran. *Biol. Trace Elem. Res.* 630, 1–10.

Mohammed, O., Ogah, A. T. & Mahnoud, A. (2022). Geospatial Distribution of Waste Dumpsites for Sustainable Solid Waste Management In Abuja Municipal Area Council (AMAC), Federal Capital Territory, Nigeria. *International Journal of Innovative Science and Research Technology*, 7(11): 123-130.

Murana, K. A., Shuaibu, A. M., Ajibade, I. I. (2019). Index Models Assessment of Heavy Met- als Contamination and Pollution in Waste Dumpsite Soils within Gusau Metropolis, Northwestern Nigeria. Niger. Res. J. Eng. Environ. Sci. 4: 309–320.

Mwanamoki, P. M., Devarajan, N., Niane, B., Ngelinkoto, P., Thevenon, F., Nlandu, J. W., Mpiana, P. T., Prabakar, K., Mubedi, J. I., Kabele, C. G., Wildi, W. & Poté, J. (2015). Trace metal distributions in the sediments from river-reservoir systems: case of the Congo River and Lake Ma Vallée, Kinshasa (Democratic Republic of Congo). Environ. Sci. Pollut. Res. 2(2): 586–597.

Nartey, V. K., Hayford, E. K., & Ametsi, S. K. (2012). Assessment of the impact of solid waste dumpsites on some surface water systems in the Accra metropolitan area, Ghana. *J. WaterResour. Protect.,* 04, 605–615.

National Population Commission Nigeria, NPC, (2012). Retrieved from: www.population.gov.ng.

Navas-Acien, A., Guallar, E., Silbergeld, E. K. & Rothenberg, S. J. (2007). Lead exposure and cardiovascular disease—A systematic review. Environ. *Health Perspective,* 115, 472.

Nieboer, E., Tsuji, L. J., Martin, I. D. & Liberda, E. N. (2007). Human biomonitoring issues related to lead exposure. *Environ. Sci. Process. Impacts,* 15, 1824–1829 *(2013)*.

Njagi, J. , Akunga, D. , Njagi, M. , Ngugi, M. , Njagi, E. , (2016). Heavy Metal Pollution of the Environment by Dumpsites: A Case of Kadhodeki Dumpsite. Int. J. Life Sci. Sci. Res. 2(4): 191–197.

Nyika, J. M., Onyari, E. K., Dinka, M. O., & Mishra, S. B. (2019). Heavy metal pollution and mobility in soils within a landfill vicinity: a South African case study. *Oriental Journal of Chemistry*, 35(4), 1286–1296.

Obiajunwa, E. I., Pelemo, D. A., Owolabi, S. A., Fasasi, M. K. and Johnson-Fatokun, F. O. (2002). Characterization of heavy metal pollutants of soils and sediments around a crude oil production terminal using EDXRF. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms. 19(4): 61-64.

Ogoko, E. C., Kelle H. I. & Njoku, C. P. (2021). Heavy metals contamination of solid waste disposal sites in Umuahia, Abia State. Journal of Chem. Soc. Nigeria, 46(6): 0978 – 0984.

Ogundele, L.T. , Ayeku, P. , Adebayo, A. , Olufemi, A. , Adejoro, I.A. , (2020). Pollution Indices and Potential Ecological Risks of Heavy Metals in the Soil: A Case Study of Municipal Wastes Site in Ondo State, Southwestern, Nigeria. Polytechnica 3(5): 78–86.

Ogunkunle, C. O., Fatoba, P. O. (2013). Pollution loads and the ecological risk assessment of soil heavy metals around a mega cement factory in Southwest Nigeria. Polish J. Environ. Std. 22: 487–493.

Ogunmodede, O. T, Ojo, A. A. & Jegede, R. O. (2016). Evaluation of pollution loads in and around Municipal solid waste Dumpsites, *World Applied Sciences Journal,* 34(6):720-732.

Ojiego B. O., Ojiego, O. P., Ilo, J. C., Okolo, J. C., Igborgbor, T., Ishaku, S. A., Abdullahi, I. M. K., Gadzama, L. & P. Bolorunduro. (2022). Concentrations of heavy metals in soil samples from dumpsites located at Kuje and Kwali area councils, Abuja, Nigeria. *Journal of Materials and Environmental Sciences,* 13(9): 1037-1046.

Onue, E., James, I. U., Anas, A. S., Aliyu, M. & Bulus. M. (2021): Assessment of heavy metals contamination in a farmland near a Market Dumpsite in Zaria, Nigeria, *Dutse Journal of Pure and Applied sciences*, 7(1):271-279.

Onyedikachi, U. B., Belonwu, D. C. & Wegwu, M. O. (2018). Human health risk assessment of heavy metals in soils and commonly consumed food crops from quarry sites located at Isiagwu, Ebonyi State. *Ovidius Univ. Ann. Chem.* 29, 8–24.

Oskarsson, A. (2015). Handbook on the Toxicology of Metals, *Elsevier,* 625–634.

Pradhan, J. K., & Kumar, S. (2014). Informal e waste recycling: Environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. *Environmental Science Research, and Pollution,* 21(13), 7913–7928.

Proshad, R., Ahmed, S., Rahman, M. & Kumar, T. (2017). Apportionment of hazardous elements in agricultural soils around the vicinity of brick kiln in Bangladesh. *Journal of Environmental and Analytical Toxicology.* 7: 439.

Riyad, A. , Abdul Hammed, M. J. & Fatima, H. A. (2015). Pollution loads and ecological risk assessment of heavy metals in the urban soil affected by various anthropogenic activities. *Int. J. Adv. Res.* 3, 104–110.

Sadeghi, H., Fazlzadeh, M., Zarei, A., Mahvi, A. H. & Nazmara, S. (2020). Spatial distribution and contamination of heavy metals in surface water, groundwater and topsoil surrounding Moghan’s tannery site in Ardabil, Iran. *Int. J. Environ. Anal. Chem.* 9, 1–11.

Samadder, S., Prabhakar, R., Khan, D., Kishan, D. & Chauhan, M. (2017). Analysis of the contaminants released from municipal solid waste landfill site: A case study. *Sci. Total Environ.* 580, 593–601.

Saxena S, Srivastava RK, Samaddar AB. (2013). Environmental analysis -water, soil and air. 2nd edition, Agro Botanical Pulishers (India). 2013;123-148.

Seifi, M. (2019). Spatial distribution, enrichment and geo-accumulation of heavy metals in surface sediments near urban and industrial areas in the Persian Gulf. Desalin. *Water Treat.* 158, 130–139.

Seyyed, M., Hosseini, B., Ali, H., Hossein H. & Hamed M. A. (2023). Concentration of heavy metals in leachate, soil, and plants in Tehran’s landfill: Investigation of the effect of landfill age on the intensity of pollution. *Heliyon*, 9 (2023) e13017.

Shittu, O. S., Ayodele, O. J., Augustus, O. A., Ilori, A. O., Filani, A. & Afuye, T. (2018). Heavy Metal Contamination of a Dumpsite Environment as Assessed with Pollution Indices. *International Journal of Agricultural and Biosystems Engineering,* 12(1): 25- 37.

Soleimannejad, Z., Abdolzadeh, A., & Sadeghipour, H. R. (2016). Heavy metal concentrations in industrial area soils and landfill site, Ghaemshahar, Iran. *Journal of Mazandaran University of Medical Sciences,* 26(136), 196–201.

Suresh, G. , Sutharsan, P. , Ramasamy, V. , Venkatachalapath, R. , (2012). Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of veeranam lake sediments, India. Ecotoxicol. Environ. Saf. 84: 117–124 .

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. & Sutton, D. J. (2012). Molecular, Clinical and Environmental Toxicology, *Springer,* 133–164.

Useh M. U., Etuk-Udo G. A., and Dauda M. S., (2015). Evaluating the Physico-chemical Properties and Heavy Metals in Soils of Municipal Waste Dumpsites at Kubwa, Abuja, Nigeria. *Journal of Chemistry and Chemical Sciences,* 5: 654 662.

Useh, M. U. & Linus, E. (2022). Analysis of Heavy Metals in Some Food Crops and Soils Impacted with Crude Oil in Southern Nigeria. *Communication in Physical Sciences,* 8(4): 543-555.

Useh, M. U. and Dauda, M. S. (2018). Heavy Metals Contamination and their Potential Toxicity in Petroleum Sludge Impacted Soils from Itsekiri Communities, Delta State, Nigeria Chemical Science International Journal. 24(1): 1-15.

Useh, M. U. and Ikokoh, P. P. (2016). Assessment of Heavy Metals Concentration of Crude Oil Polluted Soil and Water in Some Coastal Communities of Akwa Ibom State, Nigeria. *International Journal of Environmental Chemistry,* 1(1): 9 13.

Useh, M. U., Useh, U. J. & Dauda, M. S. (2017). Characterization of environmental samples around an indigenous refinery in Nigeria. *Biochemistry and Molecular Biology*, 2(6):73-79.

Varol, M. (2011). Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. J. Hazard. Mater. 195: 355–364.

Waheshi, Y. A., El-Gammal, M. I., Ibrahim, M, & Okbah, M. A. (2017). Distribution and Assessment of Heavy Metal Levels using Geoaccumulation Index and Pollution Load Index in Lake, Edku Sediments Egypt. *International Journal of Environmental Monitoring and Analysis,* 1:1-8.

Waseem, A. (2014). Pollution status of Pakistan: A retrospective review on heavy metal contamination of water, soil, and vegetables. *BioMed Res. Int.,* Article ID 813206, 29.

Weihua, G., Liu, X., Liu, Z. & Li, G. (2010). Pollution and potential ecological risk evaluation of heavy metals in the sediments around Dong Jiang Harbour, Tianjin. International Society for Environmental Information Sciences Annual conference. Procedia Environ. Sci. 2: 729–736.

Wijesekara, S. M.; Mayakaduwa, S.S.; Siriwardana, A.R.; de Silva, N.; Basnayake, B.F.A.; Kawamoto, K. & Vithanage, M. (2014). Fate and transport of pollutants through a municipal solid waste landfill leachate in Sri Lanka. Environmental Earth Sciences, 72(5), 1707–1719.

World Bank Report, (2018). What a Waste: An Updated Look into the Future of Solid Waste Management. World Bank, NW Washington, DC 1818 H Street20433 USA.

Wu, Z., Zhang, L., Xia, T., Jia, X. & Wang, S. (2020). Heavy metal pollution and human health risk assessment at mercury smelting sites in Wanshan district of Guizhou Province, China. *RSC Adv.* 10, 23066–23079.

Yahaya, S. M, Abubakar, F. & Abdu,N. (2021).Ecological risk assessment of heavy metal contaminated soils of selected villages in Zamfara State, Nigeria. *Applied Sciences,* 3:168.

Zhang, L. & Liu, J. (2014). In situ relationships between spatial–temporal variations in potential ecological risk indexes for metals and the short-term effects on periphyton in a macrophyte-dominated lake: A comparison of structural and functional metrics. *Ecotoxicol ogy*, 23, 553–566.

Zhang, L. P., Ye, X., Feng, H., Jing, Y. H., Yang, T. O., Yu, X. T., Liang, R. Y., Gao, C. T. & Chen, W. Q. (2007). Heavy Metal Contamination in Western Xiamen Bay Sediments and Its Vicinity, China. Mar. Pollut. Bull. 5(4): 974–982.

de Souza VB, Hollas CE, Bortoli M, Manosso FC, de Souza DZ. Heavy metal contamination in soils of a decommissioned landfill southern Brazil: Ecological and health risk assessment. Chemosphere. 2023 Oct 1;339:139689.

Mohasin M, Habib K, Rao PS. Heavy Metals Pollution in Soil and Their Remediation Techniques: A Review. Int. J.Environ. Clim. Change. [Internet]. 2022 Dec. 29 [cited 2025 Feb. 19];12(12):1231-50. Available from: <https://journalijecc.com/index.php/IJECC/article/view/1563>