**WASTES FINGERPRINTS IN SOILS: A STUDY OF INFLUENCE OF WASTES ON THE CONCENTRATIONS OF SELECTED HEAVY METALS IN SOILS UNDERLYING OPEN DUMPSITES**

**Abstract**

*Sustainable wastes management and heavy metals pollution are presently among the world’s leading environmental problems. When wastes become the sources of heavy metals pollution, then the problem has become complicated and a double tragedy facing mankind; as such requires a multifaceted approach to curtail the menace. This study was to assess the heavy metals release percentage (HMR) from wastes to the underlying dumpsite soils. Wastes samples were collected from open dumpsites receiving automechanic (A), paints processing (P) and abattoir (AB) wastes while soil samples were collected from the underlying soils and analyzed for contents of selected heavy metals: lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni) and vanadium (V) using standard laboratory procedures. Soil samples were also analyzed for these metals using Aqua regia as the chemical extractant. The metal released percentage was calculated using the principle of mass balance. The result revealed that the highest concentrations (mg/kg) of these metals (Pb, Cd, Ni and V )were detected in A as 8621.1, 1413.1, 563.0 and 507.0, respectively while that of Cr (1413.1) was found in P. Similarly, the A dumpsite soils had 4310.0, 179.0, and 303.0 as the highest concentrations (mg/kg) of Pb, Cd and Ni, respectively while P impacted soils had 600.0 and 240.0 for Cr and V, respectively. These represent HMR of 49.8, 41.7, 42.7, 51.8 and 48.6 for Pb, Cd, Cr, Ni and V, respectively. Transferring such levels of these dangerous substances from their laden-wastes to the soils is not healthy to the entire ecosystem. Undoubtedly, this is disastrous as it has caused pedosphere contamination by offsetting its equilibrium. This has highlighted the need for timely intervention to curtail this awkward situation by implementing sustainable wastes management policies and remedial strategies for the already degraded soils.*

Keywords*: Open dumpsite soil; wastes fingerprints; pedosphere contamination; triple planetary crisis, heavy metal release capacity*

**1.0 INTRODUCTION**

It has been established that open dumpsites have gradually become an outstanding contributing factor causing soil degradation thereby threatening the much anticipated global food security and environmental sustainability (Alao, 2022 & 2023). In a very recent study by Udo *et al*. (2025), it was discovered that open dumpsites constitute major driving force causing triple planetary crisis: problems associated with climate change, soil pollution and loss of biodiversity.

The methods of wastes disposal accounts to a great extent, their contamination levels in the environment (Akintola *et al*., 2021). Open dumpsite is one of the traditional ways of wastes disposal; other forms of such outmoded methods of managing wastes are sanitary landfilling and incineration (Sharma and Jain, 2020). The major environmental hazards associated with these traditional wastes disposal methods are penetration of leachates into surface and underground water as well as release of greenhouse gases into the atmosphere (Zhao *et al.,* 2016). Apart from the fact that some of emitted gases from open dumpsites can increase greenhouse effect, others pollute the surrounding air with characteristics offensive odours (Chen *et al*., 2016; FAO, 2018), constituting nuisance in the environment. Furthermore, Williams *et al*. (2019) reported that about 400,000 to 1 million people die annually due to diseases (diarrhea, malaria, heart disease or cancer) associated with poor wastes management. All these culminated in making open dumpsites major driver of triple planetary crisis driver as reported by Udo *et al*. (2025).

In an attempt to define the term ‘wastes’, UNEP (2024) uses words like, discards, thrash, refuse or garbage. But basically, wastes could be defined as unintended by-products of production and consumption. Sustainable wastes management is now becoming one of the greatest global challenges facing mankind. According to the report by Sharma and Jain (2020), it was projected that in the next twenty five (by 2050), the rate of global wastes generation will overtake that of population growth. A similar shocking report was made by UNEP (2024) that the annual municipal solid wastes (MSW) generation is over two billion tonnes. The report further asserts that if the wastes are packed into regular shipping containers and lined side by side, the wastes would wrap around the earth’s equator by twenty-five times or may be farther than a to and fro journey to the moon; this is quite disheartening.

Unarguably, managing such enormous quantity of wastes sustainably would be one of the greatest problems facing global populace. Sustainable wastes management, according to the authors referred to the management strategies which are environmentally, economically and socially viable. Example of this is environmental friendly method of ‘engineered landfills’. Apart from using less space, the wastes are disposed in a more secure manner that minimizes their negative impacts in the environment (Ghafourian *et al*., 2016; Ferronato *et al.,* 2018).

Unfortunately, more than two decades before 2050 projection by Sharma and Jain (2020) the problems of wastes management has already gone out of hands especially in the developing part of the world (Udo*, et al*., 2025); here dumping of wastes in the open dumpsites are the order of the day not minding their environmental implications like triple planetary crisis.

The negative impacts of indiscriminate dumping of wastes cannot be over emphasized. According to Omeiza *et al*. (2022 & 2023), incessant wastes dumping can alter soil pH, nutrient equilibrium, and overall fertility. By studying the impacts of dumpsite wastes on the properties of the underlying soils, it was observed by Udo *et al.* (2025) that there was congruence of chemical signatures of wastes and host soils; this indicated the existence of dynamic interactions between wastes and soil via leaching and infiltration. The authors opined that such negative impacts on soil health, water bodies, food security and ecosystem sustainability may not be erased within a reasonable time scale as such called for immediate remedial strategies.

Another major environmental concern associated open dumpsite is heavy metal pollution; this is because most heavy metals are inherent components of wastes (Ebong *et al*., 2020, Wuana and Okieimen, 2011; Kaparwan *et al*., 2020). It was estimated by He *et al*. (2015) that there are above 10 million pollution sites globally of which more than 50 % of that are associated with heavy metals and /or metalloids contaminations. The organic components of wastes can easily be oxidized to carbon dioxide through microbial degradation but heavy metals are not easily degraded as such can persist in the soil for a long time (Ghaderi *et al*. 2012; Yang *et al*. 2012. This single factor makes heavy metals pollution one of the greatest environmental problems confronting human race (Asmoay *et al*., 2019).

Living organisms including humans can be exposed to heavy contaminations through air, water, food and most commercially manufactured products (Kaparwan *et al.,* 2020). Some authors have reported that heavy metals contamination have toxic and carcinogenic effects in the body and can damage internal and nervous system (Maas *et al*., 2010; Jyothi, 2020); enter animals including human beings through food chain (Kahkha *et al.,* 2017); affect children’s developmental process (WHO, 2011; CAFÉ, 2024).

In view of the forgoing, there is always need to remediate heavy metal contaminated soil. In order to adequately remediate and restore heavy metals contaminated soils, there is need to characterize such soil (Wuana and Okieimen, 2011; Winegardner, 2019). Accumulations of heavy metals in soil and sediments can get to toxic levels without outward signs. Heavy metals get accumulated in the soils as a result of geological processes like ore formation, weathering of rocks, leaching, agricultural production, industrial activities, exploration and exploitation of natural resources; of course the cause of heightened levels of all these is population explosion (Ibia, 2019; UN DESA, 2018; Yawo *et al*., 2023).

Sometime in the twentieth century, there was a bittersweet experience in Romania; as noted by Nescu *et al*. (2022) there was heightened progress in mining industry which provided over a million jobs to the populace. Though this was seen as a major economic breakthrough, it was not without serious environmental consequences. A few years later, about 138 million tons of pollutants were released into the environment annually. Those pollutants included some non-ferrous compounds and particles which posed severe harmful effects on the ecosystem. As further reported, the cause of these was mostly due to mismanagement and obsolete technologies and working facilities. This occurrence has strongly correlated with the findings of Udo, (2025) and Udo *et al*., (2025) where properties of wastes materials (including the heavy metals concentrations) from dumpsites were seen to have significantly correlated with those of the underlying soils. This study is therefore proposed to assess the heavy metals release capacities of various waste materials into the host soil. It is believed that the outcome of the study will give an evident-based warning for environmental and agricultural managers to appropriately manage heavy metals laden wastes in eco-friendly ways for agricultural and environmental sustainability.

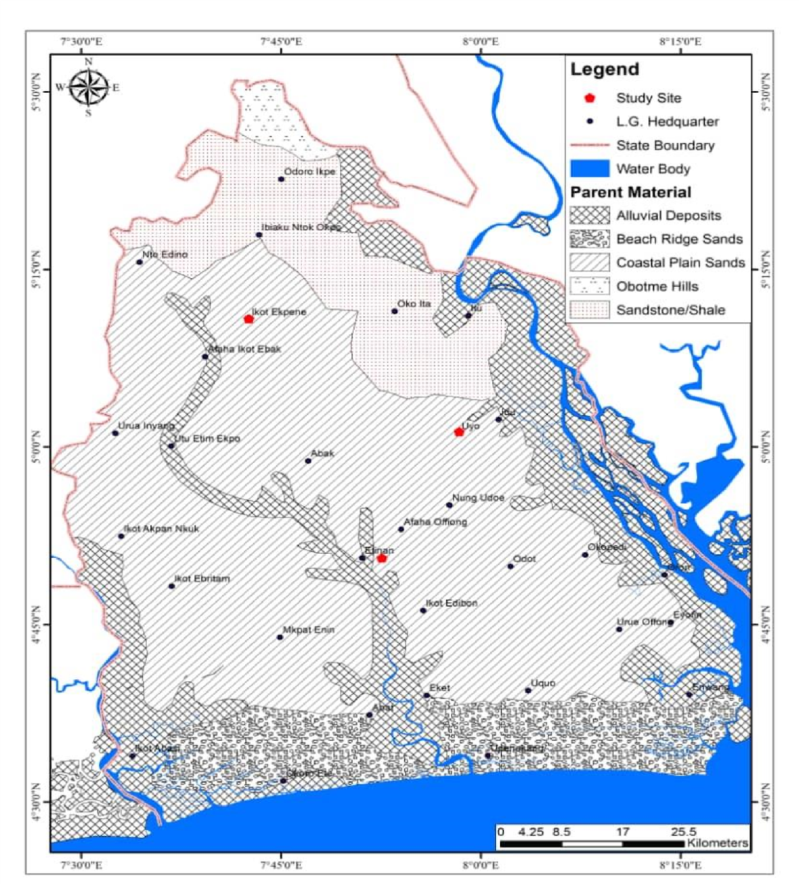
**2.0 MATERIALS AND METHODS**

**2.1 Location of Akwa Ibom State**

Akwa Ibom State is in Nigeria, located in the Southeastern part of the country along the Coast of Guinea. The State is being wedged between Abia, Rivers and Cross River States; on the southern margin stretching from Oron to Ikot Abasi Local Government Areas (LGAs) is the Atlantic Ocean. The State has a triangular shape; Ini LGA is at the apex, while Ikot Abasi, Onna, Eket, Uquo Ibeno and Oron form the base (Ekpoh, 1994). It is estimated that the State covers an approximate land mass of 8,412 km2.

**2.2 Soil Sampling and Laboratory Analyses**

Three LGAs (Etinan, Uyo and Ikot Ekpene) designated as Locations 1, 2 and 3, respectively were used for the study. The coordinates of the dumpsites are presented on Table 1; Fig. 1 presents the map of the State and the locations of the dumpsites. Three dumpsites each in the three LGAs were selected (each for abattoir, paints processing and automechanic wastes) and used for the study. An area believed to have no history of any of these wastes contamination was chosen as a control in the respective location (Dan *et al*., 2018; Udo *et al*., 2025). A total of 12 locations [9 for waste dumpsites (3x3) and 3 controls (3x1)] were used for the study. Three sections within each dumpsite were randomly designated; wastes were cleared from the portions and soil samples collected with soil auger at from the top soil (0-20) cm. At the control locations, bulk samples were equally collected from three portions from the top soil (0-20 cm). A total of 12 bulk samples were collected from the 12 locations (9 dumpsites and 3 controls).



**Figure 1: Map of Akwa Ibom State showing the different parent materials and the Local Government Areas used for the study  
Source: Udo *et al*. (2025)**

**2.3 Samples processing and laboratory analyses**

Soil samples were air-dried, and sieved (<2 mm). Samples of wastes from each of the nine dumpsites were taken in sample bottles for laboratory analyses. The soil and wastes samples were subjected to laboratory analyses.

**2.4 Heavy metals analyses in the soil**

**Extraction with Aqua Regia [Conc. Hydrochloric and Nitric Acids (HCl/HNO3) in the Ratio of 3:1:** This procedure is outlined by Abegunde *et al*. (2018). 1 g of soil sample was weighed into digestion flask. Then 20 ml of aqua regia was added into the flask; the digestion was done on a heating mantle in the fume cupboard. The temperature was gradually increased while it was occasionally agitated till the volume of the content decreased to about 5 ml. The flask was covered with watch class to prevent excessive evaporation. The remaining solution was then filtered, washed with deionized and double distilled water before being turned into a 50 ml volumetric flask, then some distilled water was added up to the mark then analyzed with AAS.

**Table 1: Locations of dumpsites and their coordinates used for the study**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No.** | **LGA** | **Dumpsite** | **Latitude** | **Longitude** |
| 1 | Etinan | A1 | 4˚49’52”N | 7˚51’9"E |
| P1 | 4˚48’33”N | 7˚53’1”E |
| AB1 | 4˚52’14”N | 7˚50’40”E |
| C1 | 4˚56’8” N | 7˚50’29”E |
| 2 | Uyo | A2 | 5˚1’24”N | 7˚53’52”E |
| P2 | 5˚1’39” N | 7˚56’33”E |
| AB2 | 5˚3’23”N | 7˚53’4”E |
| C2 | 4˚58’1”N | 7˚58’46”E |
| 3 | Ikot Ekpene | A3 | 5˚9’43”N | 7˚43’54”E |
| P3 | 5˚9’47”N | 7˚43’57”E |
| AB3 | 5˚6’49”N | 7˚47’16”E |
| C3 | 5˚9’25”E | 7˚44’41”E |

**Keys: A1, A2, A3 = Auto mechanic wastes dumpsites; P1, P2, P3 = Paints processing wastes dumpsites; AB1, AB2, AB3 =Abattoir wastes dumpsites; C1, C2, C3 = Controls; LGA = Local Government Area**

**2.5 Heavy metals analyses in the wastes material**

0.2g of the waste materials was weighed into a 50 cl conical flask; then 10 ml of H2SO4 and Salicylic solution was added, the mixture was then allowed to stand for overnight (18 hours). The mixture was heated on a digestion block at 100˚C for 2 hours in a fume cupboard. After being allowed to cool, 5 ml of perchloric acid was added to the mixture and was heated continuously until the sample was fully digested (with clear colour). The sample was allowed to cool and made up to 50 ml in the in a volumetric flask with deionized water. The extract analyzed for Pb, Cd, Cr, Ni and V determination using atomic absorption spectrophotometer (AAS) under optimal condition with air acetylene flame.

**2.6 Heavy metals released percentage (HMR)**

The heavy metals released percentage (from the wastes to soil) was estimated using the mass balance principle (de Vries and Bakker, 1996). It was calculated from the equation bellow:

Where HMR = heavy metal release percentage from the wastes into the soil; Soil (conc) = concentration of heavy metal in the impacted soil; B (conc) = background concentration of the heavy metal in the soil or concentration in the control soil; W (conc) = concentration of heavy metal in the waste materials

**2.7 Physicochemical properties of the soil**

This is just for mentioning, the physicochemical properties of the dumpsite soils had already been determined. Please refer to Table 5 in this work.

**3.0 RESULTS AND DISCUSSION**

**3.1 Concentrations of heavy metals in the various waste materials**

The results of the analyses for the concentrations of the heavy metals in various wastes materials from the dumpsites are presented on Table 2. The concentrations (mg/kg) of Pb in the wastes could be arranged in decreasing order as follows: 8621.1, 4359.0 and 166.0 for automechanic, paints processing and abattoir wastes, respectively with LSD (0.05) value of 1329.8. These values are significantly different from each other in that order, meaning automechanic wastes had the highest level of Pb while abattoir wastes had the least. Cadmium had its values in the order of increasing statistical order as 393.2, 270.0 and 60.2 for automechanic, paint processing and abattoir wastes, respectively with LSD value of 50.8 which also indicated that automechanic wastes had the highest level of Cd while abattoir had the least. The concentrations (mg/kg) of Cr were 1413.1, 1051.0 and 243.0 (decreasing order) for paints processing, automechanic and abattoir wastes, respectively with LSD (0.05) of 309.0.

**Table 2: Mean concentrations of the heavy metals in the wastes from different dumpsites**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Dumpsite** | **Pb** | **Cd** | **Cr** | **Ni** | **V** |
|  | **mg/kg** | | | | |
| **Automechanic** | 8621.1 | 393.2 | 1051.0 | 563.0 | 507.0 |
| **Paints** | 4359.0 | 270.0 | 1413.1 | 345.0 | 487.0 |
| **Abattoir** | 166.0 | 60.2 | 243.0 | 262.0 | 226.0 |
| **LSD (0.05)** | **1329.8** | **50.8** | **309.0** | **164.8** | **121.3** |

**Key: LSD = Least significance difference**

This has revealed that the highest concentration of Cr was found in the paints processing wastes. The concentrations of Ni obtained were 563.0, 345.0 and 262.0 for automechanic, paints processing and abattoir wastes, respectively with LSD (0.05) value of 164.8. Though there was no significant difference between the values for paints processing wastes and abattoir wastes, both of them were significantly smaller than that of A. This also indicated that automechanic wastes had the highest level of Ni. The values for the concentrations (mg/kg) of V obtained from automechanic, paints processing and abattoir wastes were 507.0, 487.0 and 226.0, respectively with LSD (0.05) value of 121.0. This has revealed that the values for automechanic wastes and paint processing wastes are statistically the same but are all greater than that of abattoir wastes.

Generally, the concentrations of Pb, Cd, Ni and V in the wastes materials follow this order: automechanic > paints processing > abattoir wastes while that of Cr is paints processing > automechanic > abattoir wastes. The possibly reason for having the highest levels of Pb and Cd in the automechanic wastes could be from the different sources of the wastes. For instance, Pb can come from lead-acid batteries and pigments (WHO, 2011); Pb added to gasoline during production (OECD, 1999; Angrand *et al*., 2022). It was observed by Akpoveta and Osakwe (2014) that unused petroleum products contained high level of lead. Other reports by Kaparwan *et al*. (2020) and Nwakife *et al*. (2022) had revealed a similar that used petroleum products can increase the concentration of Pb as was evident in the impacted soils.

High level of cadmium in the wastes could be from the used lubricating oils, vehicle metallic parts and metal alloys used for hardening the engine parts. Angerville *et al*. (2005) and Nascimento *et al*. (2011**)** had reported the presence of lead and cadmium in paints effluents. Nickel is a natural component of hydrocarbon compounds (Kabata-Pendias and Pendias, 2001) so there should not be any doubt if a high level of the metal detected in the waste materials. In their reports, Bencheng *et al*. (2014) noted that used petroleum products could increase Ni level in the soil.

Kabata-Pendias and Pendias (2001) and Olaolorun *et al*. (2021) reported that V is also contained in hydrocarbon compounds naturally. In related developments, high concentration of V was detected in automechanic wastes polluted soils which the cause was attributed to the used petroleum products (Zharskiy *et al*., 2015; Orjiakor *et al*., 2020). It could most probably be concluded that the high contents of Ni and V came as natural components of the waste materials or the metals were added to some products during production.

The highest of chromium in paints wastes could be traceable to some chromic compounds used as raw materials in paints production. For instance, chromic acids are used as paint pigments. Some authors had given reports of detecting chromium in paint effluents (Okafor *et al*., 2015; Ahenda *et al*., 2020). Udo (2025) equally recorded a higher chromium concentration in paints wastes impacted soils than as was obtained from automechanic and abattoir dumpsite soils; this was attributed to the high contents of the metal in the wastes materials.

The implication of having these elevated levels of the heavy metals in the wastes is that these contaminants could be released into the environment (Ji *et al*., 2012; Udo, 2025). This was also the view of Winegardner (2019) that soil is vulnerable to contamination because it naturally allows pollutants to infiltrate through it thereby causing contaminations. Unfortunately most of these wastes are dumped indiscriminately especially in the less developed world (Sharma and Jain (2020); polluting the environment to create one of the most challenging problem facing mankind (Tolera and Alemu, 2020). It is also more disturbing that almost all the studied dumpsites well located within the residential areas; this makes the possibility of human exposure to these contaminations so high.

**3.2 Concentrations of the heavy metals in the top soil (0-20 cm) of different dumpsite soil**

The results on the concentrations of the heavy metals in the top soil of the dumpsite are presented on Table 3. This shows that cadmium concentrations (mg/kg) were 26.5, 179.0, 122.9 and 0.8 for abattoir (ABS), automechanic (AS) and paints processing (PS) wastes dumpsites soils and the control soil (CS), respectively with LSD value of 31.5. These indicate that the values were significantly different from each other and in the increasing order as: CS, ABS, and PS and AS. In all the dumpsite soils, their concentrations of Cd are significantly higher than in the CS. While the level of Cd in the CS could be described as the natural background of the metal in the soil which could be due to natural process; those of the dumpsites are deemed to be caused by the released of the metals from their respective materials (Angerville *et al*., 2005; Igwe and Nwachukwu, 2016; Ebong *et al*., 2020; Nwakife *et al*., 2022). This fact can be exemplified by Figure 2 which has illustrated similar trends exhibited by the concentrations of the metal in the wastes and that of the soils (Borgese *et al*., 2013; Udo *et al*., 2025). Also, it should be noted that the concentration of Cd in all the dumpsites are higher than 5 mg/kg maximum limit for dangerous substances in residential zones established by FAO (2004). In their study Amos-Tautua *et al*. (2014) observed higher concentrations of lead and chromium in the soils of municipal dumpsites than in the control soil. But they reported a trace level of cadmium which was far below the metal’s critical limit. This does not totally agree with the findings of this work as all the tested metals have excessive levels in all the dumpsite soils and also significantly higher than the control values as was observed by Udo (2025). With these submissions, a conclusion could be drawn that the nature of the wastes, sources, and the concentrations of analytes in the wastes among other things could determine the concentration of the analytes in the tested soil.

**Table 3: Heavy metals in the top soil (0-20 cm) of different dumpsites**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Heavy metal** | **Abattoir Automechanic Paints**  **mg/kg** | | | **Control** | **LSD** |
| Cadmium | 26.5 | 179.0 | 122.9 | 0.8 | **28.7** |
| Chromium | 109.3 | 467.5 | 600.7 | 1.5 | **65.1** |
| Nickel | 129.0 | 303.0 | 195.0 | 6.0 | **93.5** |
| Lead | 73.0 | 4310.0 | 1745.0 | 10.0 | **954.7** |
| Vanadium | 99.5 | 227.6 | 240.0 | 2.2 | **58.5** |

**Key: LSD = Least significance difference**

**Figure 2: Concentrations of Cadmium in waste material and top soil (0-20 cm) of different dumpsite soils.**

Table 2 has also revealed that level of contamination of the dumpsite soils by chromium. In the increasing order, the levels of chromium recorded in the studied soils are 1.5, 109.3, 467.5 and 600.7 (mg/kg) for CS, ABS, AS and PS; indicating chromium as the greatest contaminants in PS. A similar observation was made by Udo (2025). The results have clearly shown that all the wastes had contaminated the soils by raising the background level (1.5 mg/kg) of chromium (being that of the control soil) to the present levels (Igwe and Nwachukwu, 2016; Ebong *et al*., 2020; Nwakife *et al*., 2022). The levels of contaminations in the PS and AS soils are beyond the limits (300 mg/kg) for residential zone set by FAO (2004). Figure 3 has shown similar trend established for the concentrations of chromium both in the wastes and in the top soil. This positive correlation can attest to the fact that elevated levels of Cr in the soils are the consequences of wastes dumped on the soil (Angerville *et al*., 2005; Borgese *et al*., 2013).

**Figure 3: Concentrations of chromium in waste material and the top soil (0-20 cm) of different dumpsite soils.**

The concentrations of nickel present in the top soils of the dumpsite are equally indicated in Table 3. The values as arranged in increasing order is 6.0, 129.0, 195.0 and 303.0 for CS, ABS, PS and AS, respectively with LSD value of 93.5. It has been shown from the result that the levels of nickel in all the impacted soils are significantly higher than that of CS (6.0 mg/kg) which can be acknowledged as the natural background level. This has proven the fact that various wastes have significantly contributed to the levels of the metal’s contaminations in the soils (Igwe and Nwachukwu , 2016; Tang and Goh, 2022). Apart from in ABS, all others have nickel levels higher than 150 mg/kg being a safe limit for dangerous substances in residential zone (FAO, 2004). Figure 4 has served as an additional evidence corroborating this fact; this figure has highlighted correlations between the levels of nickel in the both wastes and the impacted soils as earlier observed by Udo (2025) and Udo *et al*. (2025).

**Figure 4: Concentrations of nickel in waste material and the top soil (0-20 cm) of different dumpsite soils.**

The concentrations of lead in the top soil of the dumpsite are also on Table 3; this has revealed concentrations (mg/kg) in an increase order as 10.0, 73.0, 1745.0 and 4310.0 for CS, ABS, PS and AS, respectively with LSD value of 954.7. This has indicated the there was no significant difference between levels of the metal in CS and ABS but those of PS and AS were significantly higher than the levels in CS and ABS. Also, it is good to note that the value of AS was higher than those of all other soils. This has shown that all the wastes had contributed to the higher levels of lead in the impacted soils (Okafor *et al*., 2015; Igwe and Nwachukwu, 2016; Ebong *et al*. 2020; Johnbosco *et* *al*., 2020; Tang and Goh, 2022). Figure 5 has furthered substantiated this fact as it has indicated a similar trend and by implication, a correlation between the concentrations of lead in the wastes and in the soils. Similar observations had already been made (Borgese *et al*., 2013).

**Figure 5: Concentrations of lead in waste material and the top soil (0-20 cm) of different dumpsite soils**

Table 3 equally has highlighted the results of the concentrations of vanadium in the top soils of the dumpsites. From the results and in an increasing order, (2.2, 99.5, 227.6, 240.0) mg/kg were noted for CS, ABS, AS and PS, respectively with 58.5 as LSD value. Vanadium is natural component of hydrocarbons (Pawlak, 1980; Kabata-Pendias and Pendias, 2001; Olaolorun *et al*., 2021). This can be affirmed by these results; values of the impacted soils are all significantly different from that of the CS indicating that the wastes had enriched the soil with the metal (Zharskiy *et al*., 2015; Orjiakor *et al.,* 2022). It is equally revealed that PS was the highest vanadium contaminated soil followed by AS. Correlations between the concentrations of the metal in the wastes and in the soils (Figure 6) can attest to the fact that the wastes had influenced the metal contents in the soils.

**Figure 6: Concentrations of vanadium in waste material and the top soil (0-20 cm) of different dumpsite soils**

**3.3 Heavy metals release percentage (HMR)**

The results of the heavy metals release percentage from the waste materials to the soil are presented on Table 4. The HMR was estimated using the principle of mass balance. Some authors (de Vries and Bakker, 1996; Michaud *et al*., 2020; Carne *et al*., 2021) had used this method to asses some polluting agents in the soils.

The HMR of cadmium percentages in the increasing order is 43.1, 43.1 and 44.9 for AS, ABS and PS soils, respectively with LSD value of 10.5.Interestingly, there was no significantly different in the values. This might be due to the fact that all the three dumpsite soils have equivalent abilities in regulating the amount of pollutants they can absorb or allowed to infiltrate through them. For instance all the soils are relatively sandy having originated from coastal plain sands (Udo *et al*., 2009a&b; Akpan-Idiok, 2012; Obi *et al*., 2020); there is no significantly different in the amount of clay contents in the soils (Table 5). It was observed that soil texture is an important property that regulates the amount of solutes in the soil (de Vries and Bakker, 1996).

**TABLE 4: Percentages of release of heavy metals into the top soil (0-20 cm) of different dumpsites**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Heavy metal** | **Abattoir Automechanic Paints**  **%** | | | **LSD** |
| Cadmium | 43.1 | 41.7 | 44.9 | **10.5** |
| Chromium | 44.3 | 44.8 | 42.7 | **5.8** |
| Nickel | 46.2 | 51.8 | 56.0 | **14.7** |
| Lead | 38.2 | 49.8 | 38.5 | **12.6** |
| Vanadium | 43.5 | 45.3 | 48.6 | **8.3** |

**Key: LSD = Least significance difference**

The HMR for chromium as indicated on Table 4 has these values: 42.7, 44.3 and 44.8 for PS, ABS and AS, respectively when arranged in increasing order with LSD value of 5.8. As it was in the case of cadmium, there was no significant different among the values. The reason could also be attributed sandy nature of the soils as they are all situated on coastal plain sands as parent materials. The percentage of nickel released from the wastes to the soils: ABS, AS, and PS could be arranged as 46.2, 51.8 and 56.0, respectively with LSD value of 14.7. Equally, there was no significant difference existing among these values. This has suggested that there is a degree of similarity existing amongst the soils; these give then equivalent abilities in regulating themselves by controlling the amount of pollutants that can infiltrate or absorbed within their systems.

Table 4 has also presented the HMR of lead as 38.2, 38.5 and 49.8 for ABS, PS and AS, respectively in an increasing order having the LSD value of 12.6. Just as in the cases of other metals, there was no significant difference existing amongst the values; this suggests that the soils had similar capacities to regulate the amount of pollutants or solutes passing through or being absorbed by them. In the case of vanadium, its HMR for ABS, AS and PS are 43.5, 45.3 and 48.6, respectively when arranged in an increasing order with LSD value of 8.3; this does not reflect any significant difference amongst the values.

Overall, the values for HMR for the five metals ranged from 38.2 (for lead) and 56.0 (for nickel). Though there was no significant difference in all the values of HMR across all the impacted soils, PS had highest values for Cadmium, nickel and vanadium while lead had its highest mean value in AS.

**Table 5: Physicochemical properties of different dumpsite soils**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Soil property** |  | **Dumpsite** | |  |
| **Control** | **Automechanic** | **Paints** | **Abattoir** |
| **San d (k/kg)** | 739.00a | 795.66a | 795.88a | 826.33a |
| **Silt (k/kg)** | 63.33a | 65.56a | 66.44a | 73.00a |
| **Clay (k/kg)** | 187.67a | 138.78ab | 139.67ab | 107.89b |
| **pH (H2O)** | 4.63d | 7.36b | 7.99a | 6.49c |
| **EC (µS/cm)** | 56.73b | 146.01b | 166.40b | 536.42a |
| **OC (g/kg)** | 13.57c | 21.31b | 4.98d | 37.10a |
| **OM (g/kg)** | 23.37c | 36.74b | 8.58d | 63.96a |
| **TN (k/kg)** | 1.77b | 1.31b | 0.67b | 13.22a |
| **Available P. (mg/kg)** | 20.53b | 24.58b | 39.79b | 48.30a |
| **Ca (Cmol/kg)** | 2.49d | 20.47b | 7.20c | 32.53a |
| **mg (cmol/kg)** | 1.20c | 8.47b | 4.00c | 12.71a |
| **K (Cmol/kg)** | 0.10c | 2.77b | 0.58c | 4.80a |
| **Na (Cmol/kg)** | 0.07c | 2.35b | 0.48c | 3.06a |
| **EA (Cmol/kg)** | 1.68a | 0.41c | 0.42c | 0.68b |
| **ECEC (Cmol/kg)** | 5.43c | 33.30b | 12.54c | 53.78a |
| **BS (%)** | 67.91c | 98.63a | 96.21b | 98.69a |

*Note: a, b, c and d indicate means which are statistically different and are compared horizontally across the table*

*Source: Udo et al. (2025)*

**3.4 Mean concentrations of heavy metals in top soils of the dumpsite at different locations**

The results of the concentrations of heavy metals present in top soils of the dumpsites at different locations are presented on Table 6. According to the results, the concentrations of cadmium were 89.8, 114.3 and 124.0 for Etinan, Ikot Ekpene and Uyo, respectively when arranged in an increasing order and with LSD value of 31.5. This reveals that the concentration of cadmium in the dumpsites of Uyo was higher than that of Etinan but it was not significantly different from that of Etinan. In the Uyo dumpsites, especially in one of the automechanic wastes dumpsite (Mechanic Village), the soil was visibly seen to have been contaminated with the used hydrocarbon compounds more than in anywhere else. Probably this could be the reason for the high cadmium contamination (Daniel *et al*, 2025). Cadmium as well as its compounds is classified in Group ‘1’ among carcinogenic substances (IARC, 2012. The concentrations of cadmium in the entire impacted soils are by far higher than 5 mg/kg permissible limit by FAO, (2004) for residential zone. The implication of this is that these dumpsite soils have constituted themselves as serious threats to humans having direct or indirectly having links with those soils. As reported by EFSA (2009) cadmium can easily get distributed in the body and accumulated over a long time having gotten biological half-life that ranged between 10 to 30 years.

The chromium concentrations (mg/kg) of the soils as presented on Table 6 are 358.0, 373.0 and 432 in the increasing order for Etinan, Ikot Ekpene and Uyo, respectively with LSD value of 77.8. This means that there was no significant difference among these values. However all the values are higher than the limit (300 mg/kg) for residential zone (FAO, 2004). Sharma *et al*. (2021) opined that the toxic nature of chromium makes it to be classified as a class ‘A’ carcinogen. Shanker *et* *al*. (2005) noted that a long term exposure to chromium can cause kidney and liver damage; mutation and gastrointestinal and respiratory related problems.

The impacted soils in all the three locations (Etinan, Uyo and Ikot Ekpene) have the concentrations of nickel as (174.0, 215.0 and 236.0) mg/kg, respectively when arranged in an increasing order with 123.0 as the LSD value. This signifies that there was no significant difference among the values. However the values were all above 150 mg/kg limit established for residential areas by FAO (2004). This is not healthy for the environment the metal can be inhaled by animals into their bodies. Nickel poisoning as reported by Cavani (2005) can kill or damage cells by oxidative reaction especially in lung, kidney and bone marrow. According to Wuana and Okieimen (2011), in acidic soils, the mobility of nickel increases making it leached into both surface and underground water bodies.

The concentrations (mg/kg) of lead in the soils were 1682.0, 2152.0 and 2293.0 when arranged in an increasing order for Etinan, Uyo and Ikot Ekpene, respectively with LSD value of 1251.1. These values were extremely high when compared to 300 mg/kg regulatory limit for residential areas (FAO, 2004). According to the report of CAFÉ (2024), when a soil has these levels of lead contamination (400 to 1000 mg/kg), it is classified as medium risk and children should be restricted from having access to such places. Perhaps, this was why Wuana and Okiemen (2011) said that exposing children to lead poisoning can impair their developments, reduce their intelligent quotient (IQ), shortened their attention span, cause mental deterioration and hyperactivity; children under six years may face greater risks of such exposure.

The dumpsites in Ikot Ekpene were seen to have been the highest contaminated soil with vanadium having had the highest concentration (230.8 mg/kg). This was followed by Uyo (177.1 mg/kg) then Etinan (159.2 mg/kg) in a decreasing order with LSD value of 63.2. The vale from Ikot Ekpene was significantly higher than that of Etinan. Vanadium toxicity has been observed in various organ and systems in the body like central nervous system (Olaolorun *et al*.,2021)

**Table 6: Heavy metals in the top soil (0-20 cm) of dumpsites at different locations**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Heavy metal** | **Etinan Ikot Ekpene Uyo**  **mg/kg** | | | **LSD** |
| Cadmium | 89.8 | 114.3 | 124.0 | **31.5** |
| Chromium | 358.0 | 373.0 | 432.0 | **77.8** |
| Nickel | 174.0 | 236.0 | 215.0 | **123.0** |
| Lead | 1682.0 | 2293.0 | 2152.0 | **1251.1** |
| Vanadium | 159.2 | 230.8 | 177.1 | **63.2** |

**Key: LSD = Least significance difference**

Overall, Uyo and Ikot Ekpene were more highly contaminated with the metals than Etinan. Uyo is the Capital City of Akwa Ibom State and of course the most populous. Ikot Ekpene urban is one the fast growing cities in the State. It is expected that there are more wastes generating activities as well as higher volume of heavy metals-wastes generated; these might have contributed to the high contamination in dumpsite soils of Uyo and Ikot Ekpene as similar observation had been made by Johnbosco *et al*. (2020) and Sharma *et al*., (2021). This is also in line with the opinion of Daniel *et al*. (2025) that certain factors which can influence the level of contamination in automechanic dumpsite soils are volume of work done, type of automobile service or repairs, types of lubricants used, the method of wastes disposal as well as the type of soil. The findings of this work have agreed with those of Umoh and Etim (2013); from their findings on impact of dumpsites on heavy metals concentrations in soil within Ikot Ekpene, they noted an increase in heavy metals levels in dumpsite soil as compared to control. They opined that the level of soil contamination is directly proportional to distance away from the source of contamination.

**4.0 CONCLUSION**

This research has confirmed that waste materials generated from automechanic workshop related activities, paints processing and abattoir have left unwarranted footprints which may not easily erased within a reasonable timescale in the dumpsite soil. The wastes materials especially those of automechanic and paints processing has excessive high levels of lead, cadmium, chromium, nickel and vanadium. These same dangerous substances were also detected in astronomical levels in the top soils underlying the wastes. This has caused pedosphere contamination by offsetting its equilibrium. Strong positive correlations existed between the levels of these hazardous elements in the wastes and in the soils, suggesting that the wastes as the sources of these pollutants in their host soils. It was found that automechanic and paints processing wastes had higher polluting tendencies than those of abattoir in terms of these heavy metals transferred into the soils. While lead, cadmium and nickel were the highest detectable ones in automechanic wastes polluted soils, chromium and vanadium constituted the highest contaminants in paints processing wastes polluted soils. The congruence of heavy metals signatures of the wastes and the host soils indicates nothing but existence of dynamic interactions between wastes and soils through leaching and infiltration. This has created a serious environmental concern considering the impacts these might have soil health, water quality, food safety, agriculture and the entire ecosystem. In the light of this, multifaceted approached should be employed in curtailing this menace. There is urgent need to intervene in sustainable wastes management strategies like segregation of wastes, controlled disposal, recycling or reuse of reusable ones. The already degraded soils have to be remediated using eco-friendly techniques. Furthermore, protection of our environment is sacrosanct; there should be strategic policies with legal frameworks to empower them for sustainable wastes management in line with international best practices.

**REFERENCES**

Abegunde, S. M., Oyebanji, A. O. and Osibanjo, O. (2018) Evaluation of Digestion Procedures on Heavy Metals in Soil of a Dumpsite in Ibadan, South-western Nigeria. *Suan Sunandha Science and Technology Journal*, 5(2): 1-5.

Ahenda, S. O., Wangeci, A . N., Nyang’au, J. O. (2020). Physico-Chemical and Heavy Metal Assessment of Paint Industry Effluents in Nairobi County, Kenya. *Global Scientific Journal*, 8(3): 2573-2580

Akintola, O. O., Adeyemi, G. O., Olokeogun, O. S. and Bodede, I. A. (2021). Impact of Wastes on Some Properties of Soil around an Active Dumpsite in Ibadan, Southwestern Nigeria. *Journal of Bioressources*, 8(3): 27-40.

Akpan-Idiok, A. U. (2012). Physicochemical Properties, Degradarion Rate and Rate of Vulnerability Potential of Soil Formed in Coastal Plain Sands in Southeast Nigeria. *International Journal of Agricultural Research*, 7(7): 358-366.

Akpoveta, O. V., and Osakwe, S. A. (2014). Determination of Heavy Metal Contents in Refined Petroleum Products. *Journal of Applied Chemistry*, 7(6): 1-2.

Alao, J. O., Otorkpa, O. J., Ayejoto, D. A. and Saqr, A. M. (2025). Assessing the community knowledge on waste management practices, drinking water source systems, and the possible implications on public health systems. Cleaner Waste Systems, 11, 100295. <https://doi.org/10.1016/j.clwas.2025.10029>

Alao, J.O., (2024). The Factors Influencing the Landfill Leachate Plume Contaminants in Soils, Surface and Groundwater and Associated Health Risks: A Geophysical and Geochemical View. *Public Health and Environment*, 1 (1): 20-43: <https://doi.org/10.70737/7ejde223>

Amos-Tautua, B. M. W., Onigbinde, A. O. and Ere, D. (2014). Assessment of Some Heavy Metals and Physicochemical Properties in Surface Soils of Municipal Open Waste Dumpsite in Yenagoa, Nigeria. African Journal of Environmental Science and Technology, 8(1): 41-47.

Angerville, R., Joseph, O, Emmanuel, E., and Perrodin, Y. (2005). Ecological Risk Assessment of Heavy Metals in Paint Manufacturing Effluents of Port-au-Prince. Conference: SETAC Europe 2005. <https://www.researchgate.net/publication/339310610_Ecological_risk_assessment_of_heavy_metals_in_paint_manufacturing_effluents_of_Port-au-Prince#:~:text=Conference%3A%20SETAC%20Europe%202005> [Retrieved on 4/8/2025]

Asmoay, A. S. A., Salman, A. S., El-Gohary, A. M. and Sabet, H. S. (2019). Evaluation of heavy metal mobility in contaminated soils between Abu Qurqas and Dyer Mawas Area, El Minya Governorate, Upper Egypt. *Bulletin of the National Research Centre,* 43(88): 1-13*.*

Bencheng, W., Jianhua, Z. and Xiaohui, L. (2014).Distribution of Calcium, Nickel, Iron, and Manganese in Super-Heavy Oil from Liaohe. *Petroleum Science*, 11: 590-595.

Borgese, L., Federici, S., Zacco, A., Gianoncelli, A., Rizzo, L., Smith, D. R., Donna, F., Lucchini, R., Depero, L. E., and Bontempi, E. (2013). Metal Fractionation in Soils and Assessment of Environmental Contamination in the Vallecamonica, Italy. *Environmental Science and Pollution Research International*, 20(7): 5067–5075.

CAFE (2024). Center for Agriculture, Food and Environment. Soil and Plant Testing Laboratory, Soil Lead Fact Sheet. https://ag.umass.edu/soil-plant-nutrient-testing-laboratory/fact-sheets/soil-lead-fact-sheet (Retrieved on 5/02/2025).

Carne, G., Leconte, S., Sirot, V., Breysse, N., Badot, P., Bispo, A., Deportes, I., Dumat, C., Riviere, G. and Crepet, A. A. (2021).Mass Balance Approach to Assess the Impact of Cadmium Decrease in Mineral Phosphate Fertilizers on Health Risk: The Case-study of French Agricultural Soils. *Science of the Total Environment*, 2021, 760: 1-11

Cavani A. (2005). Breaking Tolerance to Nickel. *Toxicology*, 209 (2): 119.

Chen, P., Xie, Q., Addy, M., Zhou, W., Liu, Y., Wang, Y., Cheng, Y., Li, K. and Ruan, R. (2016), “Utilization of municipal solid and liquid wastes for bioenergy and bioproducts production”, *Bioresource Technology*, 215: 163-172.

Dan, E. U., Raymond, K. and Okon, M. U. (2018) Comparative Proximate, Nutrient Density, Minerals and Trace Metals Composition of Vegetables from Abattoir Wastes Impacted Soils. *Journal of Scientific and Engineering Research*, 5: 90-101

Daniel D. O., Udofia I. M., Agwo M. U. and Asiwe T. N. (2025). Evaluation of Heavy Metals Contamination from Automobile Workshops in Uyo Local Government Area, Akwa Ibom State. *Journal of Materials and Environmental Science*, 16(1): 102-111

De Vries. W. and D.J. Bakker, 1996. Manual for calculating critical loads of heavy metals for soils and surface waters. Preliminary guidelines for environmental quality criteria, calculation methods and input data. Wageningen (The Netherlands), DLO Winand Staring Centre. Report 114.

Ebong, G. A., Ettesam, E. S. and Dan, E. U. (2020) Impact of Abattoir Wastes on Trace Metal Accumulation, Speciation, and Human Health–Related Problems in Soils Within Southern Nigeria. *Air, Soil and Water Research,* 13: 1–14.

Ekpoh, I. J. (1994). Physiography, Climate and Vegetation. In: S. W. Petters, E. R. Iwok and O. E. Uya (eds). Akwa Ibom State: The Land of Promise. The Compendium. Gabumo Publishing Co. Ltd., Lagos.

European Food Safety Authority, EFSA. (2009). Cadmium in Food. Scientific Opinion of the Panel on Contaminants in the Food Chain. The EFSA Journal 980, 1-139. <https://doi.org/10.2903/j.efsa.2009.980>

FAO, (2004). Maximum Limits for Dangerous Substances in Soil and Groundwater. Regulation of the Minister of the Environment No. 12 of 2 April 2004. (RTL[1] 2004, 40, 662). https://faolex.fao.org/docs/pdf/est97999E.pdf [Retrieved on 24/11/2024]

FAO (2018). “Food loss and waste and the right to adequate food: making the connection right to food discussion paper [WWW document]”, Food Agric. Organ. United Nations, Rome, available at: [www.fao](http://www.fao).org/3/ca1397en/CA1397EN.pdf [Retrieved on 05/08/ 2025].

Ferronato N, Gorritty Portillo MA, Guisbert Lizarazu EG, Torretta V, Bezzi M, Ragazzi M. (2018). The Municipal Solid Waste Management of La Paz (Bolivia): Challenges and Opportunities for a Sustainable Development. *Waste Management & Research*, 36(3):288-299.

Ghaderi A. A., Abduli, M. A., Karbassi, A. R., Nasrabadi, T., Khajeh, M. (2012) Evaluating the Effects of Fertilizers on Bioavailable Metallic Pollution of Soils: A Case Study of Sistan Farms. *Iran Int J Environ Res.,* 6(2):565–570.

Ghafourian, K., Mohamed, Z., Ismail, S., Malakute, R. and Abolghasemi, M. (2016), “Construction and demolition waste management”, *Research Journal of Applied Sciences, Engineering and Technology*, 13 (9): 741-749.

He, Z.; Shentu, J.; Yang, X.; Baligar, V.C.; Zhang, T.; Stofella, P.J. (2015). Heavy Metal Contamination of Soils: Sources, Indicators, and Assessment. *J. Environ. Indic*., 9: 17–18.

IARC, International Agency for Research on Cancer. (2012). Cadmium. Vol 100C.121-145.

Ibia, T. O. (2019) Soil Erosion and Environmental Concerns in Akwa Ibom State. A paper presented on 2019 World Soil Day Celebration on December 5, 2019 Held at TETFUND 1000 Lecture Theatre, Main Campus, University of Uyo, Akwa Ibom State, Nigeria. https://niss.gov.ng/wp-content/uploads/2020/08/SOIL-EROSION-AND-ENVIRONMENTAL-CONCERNS-IN-AKWA-IBOM-STATE-1.pdf (Retrieved on 27/06/2024).

Igwe, A. C. and Nwachukwu, O. I. (2016). Soil Health, Our Health: Effect of Paint Effluent Contaminated Soil on the Heavy Metal Content of Okra (Abelmoschus esculentus Moench). Nigerian Journal of Soil Science, 26: 68 -77.

Ji, W., Yang, T., Ma, S. and Ni, W. (2012). Heavy Metal Pollution of Soils in the Site of a Retired Paint and Ink Factory. 2012 International Conference on Future Energy, Environment, and Materials, *Energy Procedia,* 16 (2012) 21 – 26

Johnbosco, U., Chimezie, A. B., Njoku, R. E. (2020). Impact of Used Motor Oil on Soil Qualities of Orji Mechanic Village Owerri, Nigeria. International Journal of Engineering Technology and Management Research, 7 (2)1-12

Jyothi, N. R. (2021). Heavy Metal Sources and their Effects on Human Health. In: M. K. Nazal and H. Zhao (eds). Heavy Metal Sources and their Effects on Human Health. Heavy Metals – Their Environmental Impacts and Mitigation. IntechOpen. http://dx.doi.org/10.5772/intechopen.95370. (Retrieved on 23/02/2004).

Kabata-Pendias, A. and Pendias, H. (2001). Trace Elements in Soils and Plants. Third Edition, CRC Press LLC.

Kahkha, M. R. R., Bagheri, S., Noori, R., Piri, J. and Javan, S. (2017). Examining Total Concentration and Sequential Extraction of Heavy Metals in Agricultural Soil and Wheat. *Pol. J. Environ. Stud.,* 26 (5): 2021-2028.

Kaparwan, D.,Rana, N. S. and Dhyani, B. P. (2020). Heavy Metals Toxicity in Agricultural Soils – Critical Review of Possible Sources, Influence on Soil Health and Remedial Measures to Remove, Reduce and Stabilize Contaminants in Soil. *International Journal of Current Microbiology and Applied Sciences*, 9 (6): 1467-1482.

Maas S, Scheifler R, Benslama M, Crini N, Lucot E, Brahmia Z, Benyacoub S, Giraudoux P (2010). Spatial distribution of heavy metal concentrations in urban, suburban and agricultural soils in a Mediterranean city of Algeria. *Environ Pollut,* 158:2294–2301.

Michaud, A. M., Cambier, P., Sappin-Didier, V., Deltreil, V., Mercier, V., Rampon, J. and Houot, S. (2020). Mass Balance and Long-term Soil Accumulation of Trace Elements in Arable Crop Systems Amended with Urban Composts or Cattle Manure During 17 years. *Environmental Science and Pollution Research,* (2020) 27:5367–5386.

Nascimento**,** F. C., Ribeiro, M. A**.**, Minamidani, P. T., Cátia C.Guzella, C. C. and Duarte, C. L. (2011). Mitigation of Solid Waste and Reuse of Effluent from Paint and Varnish Automotive and Industrial Treated by Irradiation at Electron Beam Accelerator. 2011 International Nuclear Atlantic Conference - INAC 2011Belo Horizonte,MG, Brazil, October 24-28, 2011Associação Brasileira de Energia Nuclear – ABEN

Nescu, V., Ciulca, S., Sumalan, R. M., Berbecea, A., Velicevici, G., Negrea, P., Gaspar, S., Sumalan, R. L. (2022). Physiological Aspects of Absorption, Translocation, and Accumulation of Heavy Metals in Silphium perfoliatum L. Plants Grown in a Mining-Contaminated Soil. *Minerals*, 12 (334): 1-29.

Nwakife C. N., Esther U., Musah M., Morah E. J., Inobeme A. and Andrew A. (2022). Determination of the Physicochemical Properties and some Heavy Metals in Soils Around Selected Automobile Workshops in Minna, Nigeria. *African Journal of Environment and Natural Science Research,* 5(1): 69-81

Obi, J. C., Ibia, T. O. and Ikott, I. E. (2020). Effects of Land Use on Forms of Phosphorus in Coastal Plain Sands of Nigeria. *Nigerian Journal of Soil Science*, 30(3): 31-41.

Okafor, J. O., Agbajelola, D. O., Peter, S., Adamu, M. and David, G. T. (2015). Studies on the Adsorption of Heavy Metals in a Paint Industry Effluent Using Activated Maize Cob. *Journal of Multidisciplinary Engineering Science and* *Technology*, 2 (2): 39-46.

Olaolorun, F. A., Olopade, F. E., Usende, I. L., Lijoka, A. D., Ladagu, A. D. and Olopade, J. O. (2021). Chapter Ten – Neurotoxicity of Vanadium. M. Ascsher, L. G. Costa (eds). *Advances in Neurotoxicity*, 5:299-327.

Omeiza, A. J., Lawal, H. A., & Nur, M. (2023). Investigation of Groundwater Vulnerability to Open Dumpsites and its Potential Risk Using Electrical Resistivity and Water Analysis. *Heliyon* 8, e09855: <https://doi.org/10.1016/j.heliyon.2023.e13265>.

Omeiza, J. A., Abdulwahab, O. O., Nur, M. S., et al., (2022). Effect of an Active Open Dumpsite on the Earth’s Subsurface and Groundwater Resource. *Asian Journal of Physical and Chemical Sciences*, 10(2): 15-24; DOI:10.9734/AJOPACS/2022/v10i230152

Organisation for Economic Co-operation and Development (OECD) (1999). Phasing Lead out of Gasoline : An Examination of Policy Approaches in Different Countries. 1st ed. Paris: Environmental Health and Safety Division., and Industry United Nations Environment Programme. Division of Technology.

Orjiakor, P. I, Ikhajiagbe, B. and F. O. Ekhaise, F. O. (2020). Impact of Acrylic-Based Paints effluent on the Physicochemical and Bacteriological quality of soil in Ado-Ekiti, Nigeria. *Journal of Materials and Environmental Science*, 11(8): 1230-1240.

Pawlak, L. (1980). Trace Element Pollution of Soils and Plants in the Vicinity of the Oil Refinery Plant near Plock. PhD Thesis, Agricultural University, Warsaw.

Shanker, A. K., Cervantes, C., Loza-Tavera, H., and Avudainayagam, S. (2005). Chromium Toxicity in Plants. Environment International, 31(5): 739–753.

Sharma, K. D. and Jain, S. (2020). Municipal Solid Waste Generation, Composition, and Management: The Global Scenario. *Social Responsibility Journal*, 16 (6):917-948

Sharma, N., Sodhi, K., Kumar, M., and Singh, D. (2021). Heavy Metals Eco-toxicity with Major Concern to Chromium and Recent Advancement in Remediation Technologies. *Environmental Nanotechnology, Monitoring and Management*. 15 (2021): 100388 (Retrieved on 8/4/2025).

Tang, K. H. D. and Goh, Z. H. (2022). The Levels of Heavy Metals in the Soil of Illegal Open Dumpsites in Malaysia. *Tropical Aquatic and Soil Pollution*,2(2): 109-125

Udo, B. U., Ibia, T. O. and Akpan, U. S. (2025). Analysis and Characteristics of Soils Underlying Open Dumpsites in Akwa Ibom State, Nigeria: Their Agricultural and Environmental Implications. *Asian Soil Research Journal*, 9 (3): 90-106.

Udo, B. U. (2025). Evaluation of Concentration and Geochemical Speciation of Heavy Metals in Dumpsite Soils of Coastal Plain Origin of Akwa Ibom State, Nigeria. A PhD Dissertation, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

Udo, B. U., Ibia, T. O. and Udoh, B. T. (2009a) Evaluation of inland depression and floodplain (wetland) soils for rice and maize cultivation in a humid tropical climate of South-eastern Nigeria. International Journal of Agriculture Vol. 1(2) pp.13-22.

Udo, Bassey U., Utip, Kufre E. Inyang, Monday T. and Idungafa, Monday A. (2009b). Fertility Assessment of Some Inland Depression and Floodplain (Wetland) Soils in Akwa Ibom State. Agro-Science, 8 (1):14 – 19.

Umoh, S. D. and Etim, E. E. (2013). Determination of Heavy Metal Contents from Dumpsites within Ikot Ekpene, Akwa Ibom State, Nigeria Using Atomic Absorption Spectrophotometer. Journal of Engineering and Science, 2(2): 123-129.

UN-DESA (2018), “Population division (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420) [WWWdocument]”, United Nations, Dep. Econ. Soc. Aff. (UN DESA), Available at: https://doi.org/10.4054/demres.2005.12.9

United Nations Environment Programme (2024). Global Waste Management Outlook 2024: Beyond an Age of Waste – Turning Rubbish into a Resource. Nairobi. https://wedocs.unep.org/20.500.11822/44939 (Retrieved on 27/06/2025).

WHO (2011). Children's Health and the Environment WHO Training Package for the Health Sector World Health Organization www.who.int/ceh WHO/HSE/PHE/EPE/11.01.07 (Retrieved on 2/10/2025).

Williams, M., Gower, R., Green, J., Whitebread, E., Lenkiewicz, Z. and Schröder, P. (2019). No Time to Waste: Tackling the Plastic Pollution Crisis Before It’s Too Late. Teddington, United Kingdom: Tearfund. https://learn.tearfund.org/en/resources/policy-reports/no-time-to-waste (Retrieved 26/ 01/ 2024).

Winegardner, D. L. (2019). An Introduction of Soils for Environmental Professionals. CRC Press.

Wuana, R. A. and Okiemen, F. E. (2011). Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. *Ecology*. 2011 (Article ID 402647): 1-20.

Yang Y, Chen F, Zhang L, Liua J, Wu S, Kang M (2012) Comprehensive assessment of heavy metal contamination in sediment of the Pearl River Estuary and adjacent shelf. *Mar Pollut Bull* 64:1947–1955

Yawo, O. J., Ubulom, S. R., Akpan, I. O., Amodu, A. E., Akpan, U. B., Ubak, E. A. (2025). Estimating the Pollution Status and Toxicity of Heavy Metals in Water of Ukwuyok Drinking Stream of Okorombokho, Eastern Obolo, Southeastern Nigeria. I*nternational Journal of Research Publication and Reviews*, 6 (4): 11843-11862.

Zhao, X., Gang, Jiang, G., Wu, Li, A. and Wang, L. (2016), “Economic Analysis of Waste-to-Energy Industry in China”, *Waste Management*, 48: 604-618.

Zharsskiy, M., Kurilo, I. I., Kryshilovich, Y. V., and Kharitonov, D. S. (2015). Synthesis of Pigments Using Products of Vanadium Containing Industrial Waste Utilization. *Chemistry and Technology of Non-organic Materials and Substances*, 3: 119-125