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Probability of health hazards of toxic metals in waste-impacted soils on Environmental services workers and Scavengers in Nigeria

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Abstract: The generation and disposal of wastes is becoming serious health problems to the Environmental services workers and Scavengers in the Third world countries. The total concentrations, geochemical fractions, sources, ecological, and human health hazards of Pb, Cd, Ni, and Cr at waste-impacted soils in Nigeria were assessed in this research. Results revealed that total Pb, Ni, and Cr were within their acceptable limits, whereas the concentrations of Cd were higher than the limit. Pb and Ni existed in the waste-impacted soils in the reducible fraction, Cd in acid extractable form, while Cr occurred mainly in the oxidizable fraction. Multivariate analyses identified anthropogenic factor as being the major cause of buildup of metals in the studied soils. Pollution models revealed high level of soil contamination by the toxic metals especially Cd. These models also indicated Uyo dumpsite soil as the most contaminated site while Ikot Ekpene was the least. Higher proportions of man-induced and geogenic metals were obtained at the waste-impacted and control soils, respectively. The estimated daily intake rates of the metals via the studied soils for the adult and children classes were within their limits however; the children class had higher values. The non-carcinogenic hazards related to these toxic metals in the adult and children groups were less than one (1) but the children class was more vulnerable. The carcinogenic risks for the adult class were within the limit however, the children class had values higher than the recommended limit. The major contributor to the cancer risks in both the adult and children classes were Ni and Cd. The study showed that the Environmental services workers and Scavengers in direct contact with these wastes are vulnerable to cancer problems especially those between 1 and 15 years. Hence, working with wastes should be done according to environmental rules and regulations.

1. Introduction

In recent times, the generation and management of wastes has been one of the major problems globally. Studies have shown that, environment within the vicinity of dumpsites accumulate high levels of toxic metals (Akartasse *et al*., 2017; Ebong *et al*., 2019a; Akanchise *et al*., 2020; Adie *et al*., 2022; El Hammari *et al*., 2022; Saha *et al*., 2022). Hence, improper management of wastes can result in serious health problems within the location where such wastes are generated (Akmal *et al*., 2021; Offiong *et* *al*., 2021; Somani, 2023). The Environmental services workers and Scavengers are the people working directly with wastes at dumpsites hence; they vulnerable to the hazards related to these wastes (Adekiya, 2021; Nuripuoh *et al*., 2022; Addae *et al*., 2023). According to Nuripuoh *et al*. (2022), scavenging is common in practice among the developing nations of the world due to high rate of unemployment and prevalent poverty. Akwa Ibom State is in the developing Nation, Nigeria hence; some of the inhabitants depend on scavenging of waste materials at dumpsites for their livelihood. Others are employed as Environmental services workers to clear wastes at different locations and dump them at the open dumpsites.

The Environmental services workers are the ones cleaning the environment and disposing waste materials at the dumpsite. Scavengers are responsible for the sorting of recyclable waste products including metallic and plastic-related wastes at dumpsites. Thus, these sets of workers have direct contact with soil particles and their related health hazards at dumpsites. These Environmental services workers and Scavengers sometimes eat foods within the vicinity of these dumpsites notwithstanding the health hazards associated with the ingestion of soil particles from this highly contaminated environment. Hence, during the dry season especially harmattan period, the workers at dumpsites can inhale or ingest contaminated soil particles and their related health risks unintentionally. Consequently, the health risks associated with exposure to soil particles by these Environmental services workers and Scavenger should be properly assessed to forestall adverse health issues in our society. Reports have indicated that, toxic metals are the major contaminants in dumpsite soils (Nyiramigisha *et al*., 2021; Essien *et al*., 2022; Beinabaj *et al*., 2023). Thus, consistent exposure to soil particles from dumpsite soils exposes these Environmental services workers and Scavengers to high levels of toxic metals. Toxic metals irrespective of the source, are highly poisonous to human system and prolonged exposure may results in either cancer or non-cancer health problems (Bello *et al*., 2019; Karim *et al*., 2019; Aliyu *et al*., 2022; Etuk *et al*., 2023). Studies have revealed that metals in exist soil in different forms namely: carbonate, oxides and hydroxides, sulphides and organic matter, and silicate form (Ebong and Moses, 2016; Ataikiru and Okieimen, 2021; Ebong *et al*., 2022a). Hence, studies on metals in contaminated soils should consider the speciation aspect to establish the health hazards linked to human exposure to toxic metals. Pollution models for instance contamination factor, ecological risk index, potential ecological risk index, pollution intensity etc. should be used to identify the potential effects of toxic metals on the environment. However, most of the previous researches on the contaminated soils in Akwa Ibom State concentrated on the total concentration of metals in soil devoid of health implications of these metals (Ebong *et al*., 2008; 2014; Ukpong *et al*., 2013; Monechot *et al*., 2014; Tommy *et al*., 2021). These studies also researched on the total metals in waste-impacted soils whereas, studies have shown that metal speciation has a direct relationship with the toxicity of metals (Ebong *et al*., 2015; Templeton, 2015; Sadee *et al*., 2023).

This research evaluated the total concentrations and species of toxic metals in dumpsite soils within some local government areas in Akwa Ibom State. The study also investigated the carcinogenic and non-carcinogenic risks related to prolonged exposure to these toxic metals via soil particle by Environmental services workers and Scavengers. The ecological risks, human-induced, as well as the lithogenic proportions of these metals in dumpsite soils investigated were also assessed. The results of this study will benefit the Environmental services workers and Scavengers, government agencies in charge of the environment and the public.

2. Materials and methods

2.1 Description of study area

Akwa Ibom State is situated within the South-South Area of Nigeria between latitudes 4°32′N and 5°33′N and 7°25′E and 8°25′E as the latitudes and longitudes, respectively. The State locates in the Oil producing Region of Nigeria and as such, many industrial activities are carried in the area. Consequently, the population of the area is high and the volume of wastes generated is enormous. Akwa Ibom State has the dry and wet seasons as two predominant seasons experienced in the region. The area has abundant rainfall, high humidity, and high temperature during their respective seasons. Apart from the waste dumpsites, the activities by oil Companies has also elevated the concentrations of toxic substances in the environment. This study concentrated on the open dumpsite soils in Uyo, the State capital, Eket, Onna, and Ikot Ekpene. These locations were chosen based on their population, industrial activities, volume and type of wastes generated. The latitudes and longitudes of the studied dumpsite soils and the control plot are as follows: Uyo (05.02ºN – 07.56ºE), Eket (04.38ºN – 07.55ºE), Onna (04.37ºN - 07.51ºE), Ikot Ekpene (05.11ºN – 07.42ºE), and Etinan (Control) (04.52ºN - 07.50ºE).

2.2. Sample Collection and Treatment

Top soils were obtained from Uyo, Eket, Onna, and Ikot Ekpene dumpsite soils using soil Auger. At each location, soil samples were collected at four points and combined together to form composite sample for the site. Similar samples were also collected at an uncontaminated location in Ikot Udoabia, Etinan and used as the Control. Sample collection was done during the dry season from December 2010 to February 2011. Samples and Control collected were exposed to sun for three (3) days, ground, and sieved with a 2 mm stainless steel mesh. These samples were digested by the addition of 10 mL of Aqua reqia to 1 g of the dry sample in a conical flask and placed the mixture on a hot plate. On completion of digestion, the mixture was cooled, and 20 mL of deionized water added to the flask. The flask was stirred vigorously, filtered into a clean container, and preserved at 4 °C for metal analysis. Total concentrations of Pb, Cd, Ni, and Cr were analysed for by the use of Unicam 939/959 atomic absorption spectrophotometer.

2.3. Sequential extraction procedures of toxic metals

The modified BCR sequential extraction methods of Rauret *et al*. (2000) were employed for the sequential extraction of toxic metals into their different fractions as shown below.

Fraction 1 (Acid extractable fraction) (Aex): This fraction of toxic metals was extracted by the addition of 40 mL of acetic acid (CH_3COOH) to 1 g of the dried sample in a 50 mL tube. This mixture was shaken for 16 hours at 25 °C then the extract was removed from the residue using a Centrifuge. Fraction 2 (Reducible fraction) (Red): The fraction was obtained by the addition of 40 mL of hydroxylammonium chloride (NH_3OHCl) containing 2.5 mL 2 M HNO_3 to the residue obtained from step 1. The mixture was shaken for 16 hours at 25 °C and separated as done in first step. Fraction 3 (Oxidisable fraction) (Ox): This fraction was obtained by the addition of 10 mL of hydrogen peroxide (H_2O_2) to the residue from the second stage and allowed for digestion for 1 hour. The mixture was then evaporated to dryness and 50 mL of 1 M ammonium acetate (NH_4OAc) added. Then 2M HNO_3 was added to the mixture, shaken and centrifuged at 25 °C for the residue to be separated from the extract. Fraction 4 (Residual fraction) (Res): This fraction was obtained by adding 20 mL of Aqua reqia to the residue from step 3 and placed on a plate to digest. On completion of digestion, the mixture was filtered into a volumetric flask.

2.4. Pollution class of toxic metals in dumpsite soils investigated

2.4.1. Metal pollution index (MPI)

MPI was employed to appraise the existing relationship amongst the toxic metals in the studied soils and Control (Lacatusu, 2000). Metal pollution index of the toxic metals was determined with Eqn. 1.

$$MPI = \frac{\text{Concentration of toxic metals in dumpsite soils}}{\text{Concentration of toxic metals at the Control}} \quad \textbf{Eqn. 1}$$

The classifications of MPI by Lacatusu (2000) indicate that, MPI range of < 0.1 – 1.00 may not have negative effects on the plant, soil, and the environment, 1.00 – 2.00 may have negative effects on plant, soil and environment, while MPI values between 2.10 and > 16.00 will impact negatively on the soil.

2.4.2. Degree of Contamination (DC) of the studied dumpsite soils

The DC was used for the evaluation of the environmental hazards related to the dumpsite soils investigated due to the impact of all the toxic metals (Essien *et al*., 2019). The CD of the various locations was determined with Eq. (2) following the methods of Håkanson (1980).

$$CD = \Sigma Pb + \Sigma Cd + \Sigma Ni + \Sigma Cr \quad \textbf{Eqn. 2}$$

Where $\Sigma Pb + \Sigma Cd + \Sigma Ni + \Sigma Cr$ denotes the sum of the entire toxic metals in the studied dumpsite soils. Based on Håkanson (1980) classifications, the different classes of DC are as follows: $DC \leq 6$ belongs to the low degree of contamination, $6 < DC \leq 12$ is in the moderate degree of contamination, $12 < DC \leq 24$ belongs to the considerable degree of contamination and $24 > DC$ belongs to the very high degree of contamination.

2.4.3. Pollution intensity (Ipoll)

As reported by Kowalska *et al*. (2018), Ipoll is a tool used for a comprehensive assessment of the pollution status of the studied soils concerning the toxic metals. The Ipoll of the metals was evaluated in this study using Eqn. 3 following the procedures of Karbassi *et al*. (2008)

$$Ipoll = Log_2 (Bc/Lp) \quad \textbf{Eqn. 3}$$

Bc in Equation 3 is the total concentration of the metals and Lp indicates the lithogenic segment obtained from the results of sequential extraction of metals (Karbassi *et al*., 2008). The different categories of Ipoll as reported by Karbassi *et al*. (2008) are < 0 - 1 represents unpolluted, 1 - 2 is lowly polluted, 2 - 3 shows moderately polluted, 3 - 4 indicates the highly polluted, 4 -5 signifies strongly polluted, whereas > 5 is extremely polluted.

2.4.4. Pollution load index (PLI)

The PLI was used as a tool for the evaluation of contamination rate of the dumpsite soils (Rabee *et al*., 2011). PLI of the studied soils was determined by Eqn. 4.

$$PLI = (MPIPb \times MPICd \times MPINi \times MPICr)^{1/4} \quad \textbf{Eqn. 4}$$

Where MPI is the metal pollution index for each of the studied dumpsite soil. Based on Tomilson *et al*. (1980) classifications, PLI is categorized into the following:

PLI < 1 signifies no pollution, 1 < PLI < 2 shows moderate pollution, 2 < PLI < 3 represents heavy pollution, while 3 < PLI denotes extremely heavy pollution.

2.4.5. Ecological risk factor (ERF) of toxic metals in the studied dumpsite soils

Ecological risk factor was employed to assess the ecological risks related to the buildup of toxic metals in dumpsite soils examined. The ERF was calculated in this research with Eqn. 5 according to Håkanson (1980).

$$ERF = Tr \times MPI \qquad \textbf{Eqn.5}$$

Where Tr indicates the toxic-response factor and MPI is the metal pollution index of the metals. Toxic response factors of the toxic metals are Pb (5.00), Cd (30.0), Ni (5.00), and Cr (2.00) (Mavakala *et al*., 2022). Based on the classifications of ERF by Rostami *et al*. (2021), ERF is categorized into : ERF < 40 belongs to the low ecological risk, 40 ≤ ERF < 80 is in the moderate potential risk, 80 ≤ ERF < 160 denotes the considerable potential risk, 160 ≤ ERF < 320 signifies the high potential risk, while ERF ≥ 320 indicates the significantly very high-risk class.

2.4.6. Potential ecological risk index (PERI) of toxic metals in dumpsite soils

According to Tisha *et al*. (2020), PERI is an environmental tool used for the comprehensive evaluation of ecological risks of toxic metals in the dumpsite soils. The potential ecological risks of toxic at the different dumpsite soils investigated was determined with Eqn. 6 according to Saha *et al*. (2022).

$$PERI = \Sigma(ERF) \qquad \textbf{Eqn.6}$$

Where Σ(ERF) represents the sum of the ecological risk factor of toxic metals at dumpsite soil. Based on Kang *et al*. (2020), PERI is classified into the following categories: RI < 150 is the low ecological risk class, 150 ≤ RI < 300 belongs to the moderate ecological risk class, 300 ≤ RI < 600 is in the considerable ecological risk class, while RI ≥ 600 belongs to the high ecological risk class.

2.4.7. Anthropogenic fractions (AF) of toxic metals

The AF of toxic metals in soil is the percentage of individual metal that originated from human activities. In this study, AF of the metals was computed using Eqn. 7 according to Maxhuni *et al*. (2023).

$$AF = \frac{F1+F2+F3}{TM} \times 100 \qquad \textbf{Eqn.7}$$

Where F1, F2, and F3 are the acid extractable, reducible, and oxidisable fractions of toxic metals, respectively and TM is the total concentration of individual toxic metal.

2.4.8. Lithogenic fraction (LF) of toxic metals

The lithogenic segment of the toxic metals indicates the percentage of the metals that emanated from the geogenic processes of the soil. The LF of the soil was determined in this study using Eqn. 8 following the procedures of Maxhuni *et al*. (2023).

$$LF = 100 - AF \qquad \textbf{Eqn. 8}$$

AF is the anthropogenic percentage of the toxic metals in the studied dumpsites soils.

2.5. Percentage recovery of the toxic metals

The proportion of toxic metals recovered from sequential extraction procedures was computed using Eqn. 9 as reported by Liu *et al*. (2022).

$$\text{Percentage of recovery} = \frac{\sum n\ BCR\ Speciation\ Method}{Digestion\ with\ Aqua\ Regia} \times 100 \qquad \textbf{Eqn. 9}$$

In the Eqn. 9 above, ∑nBCR Speciation method represents the acid extractable, reducible, oxidisable, and the residual fractions (F1, F2, F3, and F4, respectively) and digestion-using Aqua regia indicates the bulk concentration of the individual toxic metal.

2.6. Review of health hazards related to exposure to these toxic metals

The health problems related to exposure to toxic metals via soil particles from dumpsite soils examined by the Environmental services workers and Scavenger was assessed by computing the estimated daily intake rate (EDI), non-cancer and cancer risks. Hazard quotient (HQ) and hazard index (HI) were used for the evaluation of non-carcinogenic risks (Onoyima *et al*., 2022; Moradnia *et al*., 2024). While the carcinogenic risks were assessed by the use of incremental lifetime cancer risk (ILCR) as well as total cancer risks (TCR) (Alsafran *et al*., 2021; Emmanuel *et al*., 2022; Demissie *et al*., 2024).

2.6.1. Estimated daily intake rate (EDI) of toxic metals

The estimated daily intake rate was used assess the level at which the Environmental services workers and Scavengers were exposed these metals through the ingestion of soil particles from dumpsite soils investigated (Hassan *et al*., 2022). The EDI of metals via exposure to soil particles from the dumpsite soils examined by the Environmental services workers and Scavengers was calculated with Eqn. 10.

$$\text{EDI} = \frac{C\ x\ RI}{BW} \qquad \textbf{Eqn.10}$$

Where C is the total metals within the dumpsite soils investigated, RI indicates the daily intake rate of metals through soil particles from the studied locations, and BW signifies the body weight. The values of RI = 0.0001 mg $kgday^{-1}$ and 0.0002 mg $kgday^{-1}$ for the adult and children classes, respectively. While BW = 70 kg and 15 kg for the adult and children classes, respectively (USEPA, 2011; Dan *et al*., 2023).

2.6.2. Hazard Quotient (HQ) of toxic metals

The hazard quotient of toxic metals via the ingestion of soil particles from the studied dumpsite soils by the Environmental services workers and Scavengers was evaluated with Eqn. 11.

$$\text{HQ} = \frac{EDI}{Rfd} \qquad \textbf{Eqn.11}$$

Where EDI is the estimated daily intake rate of the metals, and Rfd indicates the acceptable oral reference dose of the toxic metals. The Rfd for the metals are 1.40E-03, 1.00E-03, 2.00E-02, and 3.00E-03 for Pb, Cd, Ni, and Cr, respectively (USEPA IRIS, 2011).

2.6.3. Hazard Index (HI) of toxic metals

Hazard index of toxic metals via the ingestion to soil particles from the studied dumpsite soils was determined with Eqn. 12.

$$\text{HI} = \Sigma\text{HQ} = \text{HQPb} + \text{HQCd} + \text{HQNi} + \text{THQCr} \qquad \textbf{Eqn.12}$$

ΣHQ is the sum of the HQ of the entire toxic metals determined in dumpsite soils assessed.

2.6.4. Carcinogenic risks assessment of toxic metals

Cancer risk indicates the increasing likelihood of a person developing cancer during his or her lifetime as result of exposure to a cancer-causing metal. The incremental lifetime cancer risk (ILCR) and total cancer risk (TCR) of the Environmental services workers and Scavengers toxic metals due to exposure to metal carcinogens via soil particles from the studied dumpsite soils of were assessed.

2.6.5. Incremental lifetime cancer risk (ILCR) of the metal carcinogens

The ILCR of the metals related to the exposure to soil particles at the studied soils by the Environmental services workers and Scavengers was determined using Eqn. 13.

$$ILCR = CSF \times EDI \qquad \textbf{Eqn. 13}$$

CSF here signifies cancer slope factor of the toxic metals and EDI is the calculated estimated daily intake rate of the metals. CSF values are 8.50E-03, 5.00E-01, 1.70E+00, and 5.01E-01 for Pb, Cd, Ni, and Cr, respectively (USEPA IRIS, 2011).

2.6.6. Total cancer risk (TCR) of the toxic metals

The TCR of the metal carcinogens via the ingestion of soil particles from the studied dumpsite soils by the Environmental services workers and Scavengers was calculated by using Eqn. 14.

$$TCR = \Sigma ILCR = ILCRPb + ILCRCd + ILCRNi + ILCRCr \qquad \textbf{Eqn.14}$$

Where ΣILCR represents the sum of all the incremental lifetime cancer risk (ILCR) of the metals in the dumpsite soils examined.

2.7. Statistical treatment of Data

In the course of the research, the data obtained were treated statistical with IBM SPSS Statistic version 29.0.2.0 (20) Software and the mean, minimum, maximum, and standard deviation values were obtained. Principal Component Analysis (PCA) was done using Varimax Factor analysis on four (4) toxic metals and values lower than 0.729 were considered insignificant. Hierarchical Cluster Analysis (HCA) was carried out on the data with Dendrograms using average linkage.

3. Results and discussion

3.1. Total concentrations of toxic metals in waste-impacted soils

Results of total concentrations of toxic metals in waste-impacted soils examined are indicated in Table 1. The results of total concentrations of toxic metals in dumpsite soils examined are in Table 1. The total concentrations of lead (Pb) obtained ranged from 28.519 to 35.518 $mgkg^{-1}$ between Ikot Ekpene and Uyo dumpsite soils, respectively. This is below 291.22-352.36 $mgkg^{-1}$ reported for Pb by Adie *et al*. (2022), but higher than 10.47 – 15.62 $mgkg^{-1}$ obtained by Ebong and Ekong, (2015). Table 1 also indicates that, the average concentration of Pb (31.510±2.949 $mgkg^{-1}$) is much higher than 2.478 $mgkg^{-1}$ obtained at the control plot. This could indicate the significant contribution of metals contaminants to the underlying soil by wastes at these dumpsites (Ebong *et al*., 2019b; Hussein *et al*., 2021). Total cadmium (Cd) in dumpsite soils examined varied between 22.605 and 29.846 $mgkg^{-1}$. The range of Cd obtained is higher than 0.049 - 2.54 $mgkg^{-1}$ recorded by Chinonso *et al*. (2020) but lower than 2.30 – 41.7 obtained in waste-impacted soils by Gyabaah *et al*. (2023).

Table 1: Total concentration of metals in the studied dumpsite soils

	Pb	Cd	Ni	Cr
Uyo	35.518	29.846	22.667	13.747
Eket	31.531	28.802	20.486	11.433
Onna	30.470	24.709	18.328	10.386
Ikot Ekpene	28.519	22.605	19.085	11.119
Mean	31.510	26.491	20.142	11.671
Min	28.519	22.605	18.328	10.386
Max	35.518	29.846	22.667	13.747
SD	2.949	3.410	1.906	1.452
Control	2.478	0.441	0.968	0.329

Min = Minimum; Max = Maximum; SD = Standard deviation

The mean concentration obtained (26.491±3.410 mgkg^{-1}) is above 0.441 mgkg^{-1} recorded for Cd in the control plot. Consequently, waste products at dumpsites investigated might have added considerable levels of Cd to the studied soils (Agbeshie *et al*., 2020). Total nickel (Ni) within the studied soils ranged from 18.328 to 22.667 mgkg^{-1} at waste-impacted soils at Onna and Uyo, respectively. The reported range is lower than 367.8 – 593.3 mgkg^{-1} obtained by Onwukeme and Eze, (2021) but higher than 2.912 – 8.961 mgkg^{-1} recorded at waste-impacted soils by Ibrahim *et al*. (2020) and Ad *et al.* (2016). The mean concentration of Ni recorded (20.142±1.906 mgkg^{-1}) is above 0.968 mgkg^{-1} obtained at the control plot. Consequently, wastes at dumpsites examined might have added high levels of Ni to the soil environment (Nyiramigisha *et al*., 2021).
Levels of total chromium (Cr) in waste-impacted soils assessed varied from 10.386 to 13.747 mgkg^{-1} obtained at Onna and Uyo, respectively. The range is consistent with 2.53 – 12.33 mgkg^{-1} obtained by Ezemonye *et al*. (2020). However, higher than 0.4 – 4.6 mgkg^{-1} reported by Ukpong *et al*. (2013), but lower than 15.33 – 23.23 mgkg^{-1} reported at dumpsite soils by Jiya *et al*. (2019). The obtained mean Cr (11.671±1.452 mgkg^{-1}) is relatively higher than 0.329 mgkg^{-1} obtained at the control plot. Hence, higher levels of Cr could have been contributed by wastes at these dumpsites as reported by Ojiego *et al*. (2022).

Generally, the concentrations of Pb, Cd, and Ni at all the dumpsite soils investigated were within their permissible limits by FEPA (1999) and NESREA, (2009). However, levels of Cd at all the locations assessed were higher than the permissible limit set for unpolluted soil by FEPA (1999) and NESREA, (2009). Notwithstanding the low levels of these metals, the health problems associated with the metals should be monitored as they are highly poisonous and can buildup in biological cells overtime (Balali-Mood *et al*., 2021). Consequently, prolonged contact with soil particles from the studied dumpsite soils by the Environmental workers and Scavengers may not result in adverse health problems related with Pb, Ni, and Cr. Conversely, persistent exposure to soil particles from these dumpsite soils can result in adverse health problems associated with Cd to the Environmental workers and Scavengers (Okon *et al*., 2023). It could also be inferred from the results that, the dumpsite soil at Uyo was the one with the highest levels of the entire toxic metals. Relatively, higher concentrations of toxic metals were reported for Uyo dumpsite soil and it might be due to the high population growth and the site being a municipal dumpsite with various sources of wastes (Naluba and Igwe, 2022; Azuka and Ezeme, 2023).

3.2. Results of Multivariate analyses

The results of Pearson Correlation analysis in Table 2 indicates that at $p < 0.10$, Pb related positively and significantly with Cd, Ni, as well as Cr (r values = 0.894, 0.900, and 0.880, respectively). Cd correlated positively and strongly with Ni and Cr with r-values of 0.852 and 0.731, correspondingly, Ni correlated positively with Cr at $p < 0.01$ with r-value of 0.973. This shows that, the concentrations of all the metals were directly proportional to one another and it indicates related properties for the toxic metals (Shen *et al*., 2022).

The principal component analysis (PCA) revealed a singular factor accountable to the levels of toxic metals obtained in dumpsite soils examined (Table 2). The factor had an Eigenvalue of 3.62 and a total variance of 90.4%. The factor had strong positive loadings on all the toxic metals analysed for in the studied soils (Table 2). This might be due to the impacts of waste products on the host soil environment (Ebong *et al*., 2019b; Huang *et al*., 2021). The strong positive loadings of all the toxic metals confirm some common source for the metals as reported by the correlation analysis (El Behairy *et al*., 2022; Liu *et al*., 2023).

The results of Hierarchical Cluster analysis (HCA) of the locations investigated are shown in Figure 1. The HCA showed two (2) outstanding Clusters namely: (i) Cluster 1 that connects Onna and Ikot Ekpene dumpsite soils together and (ii) Cluster 2 contains Uyo and Eket dumpsite soils. Consequently, Onna and Ikot Ekpene dumpsite soils might have some similarities, while Uyo and Eket dumpsite soils also have some peculiarities different from those of members of Cluster 1 (Zolfaghari *et al*., 2019; Minh *et al*., 2023). These variations could be attributed to the differences in composition, degree of soil contamination, and volume of wastes at dumpsites within each Cluster. The results affirm that the different dumpsite soils assessed had varied degree of soil contaminations and health problems on Environmental workers and Scavengers.

Table 2: Results of Pearson Correlation analysis and Principal Component analysis (PCA) of Toxic Metals in the studied soils

	Pb	Cd	Ni	Cr
Pb	1.000			
Cd	0.894	1.000		
Ni	0.900	.852	1.000	
Cr	0.880	.731	0.973	1.000

Principal Component analysis	
Component	Factor
Pb	0.966
Cd	0.913
Ni	0.980
Cr	0.944
% Total Variance	90.4
Eigenvalue	3.62

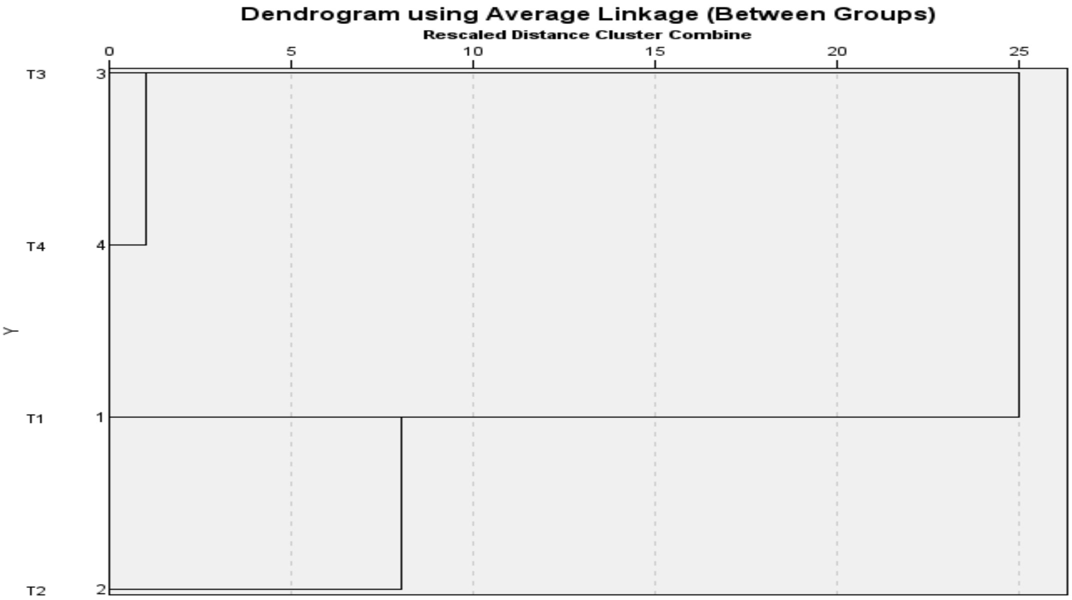

Figure 1: Hierarchical Clusters of Dumpsite Soils Examined

3.3. Results of Pollution status of toxic metals and the dumpsite soils examined

The results of metal pollution index (MPI) of toxic metals in dumpsite soils assessed are shown in Figure 2. The mean MPI values obtained for Pb, Cd, Ni, and Cr were 12.72, 16.07, 20.81, and 35.48, respectively. Thus, Pb belongs to the very severe pollution category, while Cd, Ni, and Cr belong to the excessive pollution category (Lacatusu, 2000). Accordingly, the entire toxic metals have the potentials to cause harmful consequences on the soil, plants, and the entire food chain. By implication, wastes at these dumpsites might have contributed high levels of these toxic metals to the underlying soils. The mean values of MPI reported can also affect negatively on the health of Environmental workers and Scavengers exposed to these dumpsite soils.

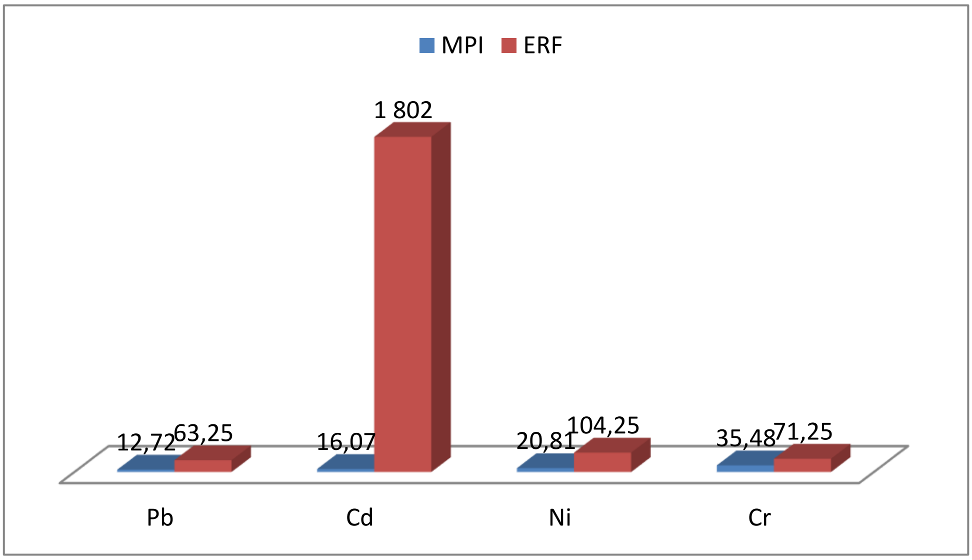

Figure 2: Mean concentrations of metal pollution index and ecological risk factor of toxic metals

The results of ecological risk factor (ERF) for toxic metals in the dumpsite soils examined are in Figure 2. The ERF values for Pb, Cd, Ni, and Cr ranged as follows: 58 – 72, 11,538 – 2,030, 95 – 117, and 63 – 84, respectively. The mean Values of ERF for Pb, Cd, Ni, and Cr were 63.25, 1,802, 104.25, and 71.25, correspondingly. According to Rostami *et al*. (2021) categorizations of ERF, Pb belongs the moderate potential risk category, while Cd belong to the significantly very high-risk category, while Ni and Cr belong to the considerable potential risk class. Consequently, prolonged exposure to soil particles from these dumpsite soils by Environmental workers and Scavengers could be affected by these metals. The mean results of ERF for the toxic metals decreased as follows: Cd > Ni > Cr > Pb. The relative higher ERF values of Cd reported is consistent with the result obtained by Olatunde *et al*. (2020).

The results of contamination degree (DC) of all the dumpsite soils investigated are indicated in Figure 3. The DC values obtained were 147, 134, 119, and 116 for Uyo, Eket, Onna, and Ikot Ekpene dumpsite soils, respectively. Based on the groupings by Hakanson (1980), the entire dumpsite soils investigated were in the very high degree of contamination class. The DC of the studied dumpsite soils followed a decreasing order of Uyo > Eket > Onna > Ikot Ekpene. This indicates that these metals can have adverse effects on the Environment workers and the Scavengers exposed soil particles from these dumpsite soils. The level of soil pollution by these metals can also affect the environment negatively.

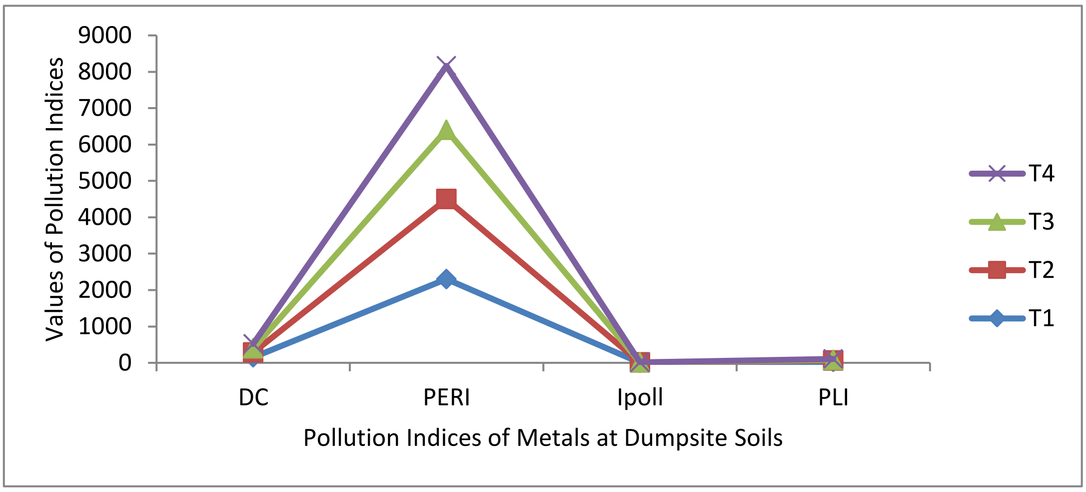

Figure 3: Results of degree of contaminations (DC), potential ecological risk index (PERI), pollution intensity, as well as pollution load index of toxic metals at dumpsite soils examined.

Results of potential ecological risk index (PERI) of toxic metals within the studied soils are shown in Figure 3. The mean PERI of metals in the dumpsite soils investigated were as follows: 2,303, 2,196, 1,901, and 1,763 for Uyo, Eket, Onna, and Ikot Ekpene, respectively. Thus, all the waste dumpsite soils examined belong to the moderate ecological risk category, while Ikot Ekpene belongs to the high ecological risk class (Kang *et al*., 2020). Hence, Environmental workers and Scavengers exposed to soil particles at these dumpsite soils are vulnerable to health problems related to these toxic metals. Values of PERI obtained followed a decreasing order of Uyo > Eket > Onna > Ikot Ekpene. This corroborates the findings by contamination degree and pollution load index.

The results of the mean pollution intensity (Ipoll) of toxic metals in dumpsite soils investigated are indicated in Figure 3. The average Ipoll values recorded for Pb, Cd, Ni, and Cr were 3.02, 3.13, 3.25, and 2.74, respectively. The Ipoll results revealed that, Pb, Cd, as well as Ni belong to the highly polluted category, whereas, Cr belongs to the moderately polluted category (Karbassi *et al*., 2008). This indicates that wastes at the studied locations might have released substantial quantities of these toxic metals into the soil. It could also be deduced from the Ipoll results that, all the toxic metals can adversely affect the Environmental workers and Scavenger if exposed to consistently via soil particles from the studied locations. The sequence for Ipoll followed a decreasing order of Ni > Cd > Pb > Cr.

The results of pollution load index (PLI) of toxic metals in the studied soils are shown in Figure 3. The PLI results indicated the following values 31.2, 28.0, 25.4, and 25.0 for Uyo, Eket, Onna, and Ikot Ekpene dumpsite soils, respectively. Consequently, the entire dumpsite soils examined were in extremely heavy polluted class (Tomilson *et al*., 1980). Hence, prolonged exposure to soil particles from these locations can pose severe health problems to the Environmental workers and Scavengers. The level of soil contamination due to these toxic metals might also affect the environment. Trend for the level of soil contamination by these metals followed the order: Uyo > Eket > Onna > Ikot Ekpene. Thus, Uyo dumpsite soil was the most highly polluted site while Ikot Ekpene was the least.

Table 3: Fractions of toxic metals (TF), total concentrations (TM), percentage of recovery (% REC), proportions of man-induced (MF) and natural metals (NF)

	Aex	Red	Ox	Res	TF	TM	% REC	MF	NF
					Dumpsite Soils				
Pb	8.032	11.167	5.549	3.877	28.625	31.510	91	81	19
Cd	10.124	7.027	5.103	3.032	25.286	26.491	95	79	21
Ni	3.135	5.301	7.793	2.120	18.349	20.142	91	81	19
Cr	2.374	2.435	3.502	1.735	10.046	11.671	86	71	29
					Control Plot				
Pb	0.884	0.675	0.520	0.299	2.378	2.478	96	28	72
Cd	0.228	0.163	0.021	0.014	0.426	0.441	97	31	69
Ni	0.117	0.258	0.086	0.451	0.912	0.968	94	16	84
Cr	0.022	0.024	0.098	0.150	0.294	0.320	92	15	85

The results of BCR speciation of toxic metals in dumpsite soils assessed are indicated in Table 3. Table 3 indicates that, Pb occurred principally in the reducible fraction in dumpsite soils examined (Makanjuola *et al*., 2019; Ebong *et al*., 2022a). Cd existed mainly in the acid extractable form in the studied locations (Ebong *et al*., 2022b; Onokebhagbe *et al*., 2022; Xu *et al*., 2023). Ni occurred primarily in the reducible form at the studied dumpsite soils similar to the report by Ebong *et al*. (2020). Cr existed mostly in the fraction bound to the organic and sulphide components of the soil (oxidisable fraction) in contaminated soils examined (Gattullo *et al*., 2020). However, in the control plot Pb and Cd occurred outstandingly in acid extractable fraction, whereas most of Ni and Cr were obtained in the residual fraction. The results revealed that, Cd could be highly available in the dumpsite soils investigated. This might result in the relative high pollution class associated with Cd as revealed by the various pollution models used. The results could also indicate that, wastes at the studied dumpsite soils might have affected the physicochemical properties of the underlying soils hence; the variations between the contaminated and control plot (Akintola *et al*., 2021; Nyiramigisha *et al*., 2021). The trend for the bioavailability of toxic metals in waste-impacted soils examined followed the order Cd > Pb > Ni > Cr. Hence, Cd was the most highly available toxic metal in the waste-impacted soils examined similar to the results of Makanjuola *et al*. (2019). The results in Table 3 show high percentage of recoveries for the metals. This could indicate the efficiency of methods used and reliability of the results obtained.

3.4. Results of man-induced and natural fractions of toxic metals in waste-impacted soils examined

The results of the man-induced and natural fractions of toxic metals in waste-impacted soils examined are shown in Table 3. The results show that higher proportions of man-induced fractions were recorded for all the metals (Mavakala *et al*., 2022). This confirms that, these toxic metals emanated mainly from the wastes at these dumpsites (Ebong *et al*., 2016; Hao *et al*., 2021; Sarpong *et al*., 2023). Conversely, these metals showed higher proportions of the natural fractions at the control plot. Thus, wastes at dumpsites can influence the geochemical nature of metals in the host soil environment (Otabor, 2019; Mekonnen *et al*., 2020). This study has shown that, the dumpsite soils assessed might have higher levels of metal mobility and toxicity than the control plot. Consequently, Environmental workers and Scavengers could be exposed to high levels of these metals in the dumpsite soils examined.

3.5. Results of health risk assessment of toxic metals

Table 4 indicates the results of estimated daily intake (EDI) rates of toxic metals in dumpsite soils via ingestion of soil particles by Environmental workers and Scavengers. The mean EDI values for the adult class were 4.50E-5, 3.76E-5, 2.88E-5, and 1.67E-5 for Pb, Cd, Ni, and Cr, respectively. Whereas, the mean EDI values of Pb, Cd, Ni, and Cr for the children class were 4.20E-4, 3.53E-4, 2.69E-4, and 1.56E-4, correspondingly. Hence, the average EDI values of these metals for the children class was higher than the values obtained for the adult class. However, the mean EDI of the metals for the adult and children classes were within their acceptable oral reference doses (RfDs) as proposed by USEPA (2000). This is consistent with the results reported by Rakib *et al*. (2021) and Begum *et al*. (2023). Thus, exposure to soil particles from the studied dumpsite soils might not cause immediate health problems to the Environmental workers and Scavengers. However, the children class with higher EDI values could be more vulnerable to problems relating to high levels of these toxic metals (Meseret *et al*., 2020). The sequence for the EDI values followed a decreasing order of Pb > Cd > Ni > Cr for both classes. Consequently, the EDI values of Pb were the highest while those of Cr were the lowest. The relatively higher EDI values of Pb reported is in agreement with the results obtained by Ogunkunle *et al*. (2022).

Table 4: Estimated daily intake (EDI) rate of toxic metals by Environmental services workers and Scavengers

	Pb	Cd	Ni	Cr
		ADULT CLASS		
Uyo	5.07E-5	4.26E-5	3.24E-5	1.96E-5
Eket	4.50E-5	4.12E-5	2.93E-5	1.63E-5
Onna	4.35E-5	3.44E-5	2.62E-5	1.48E-5
Ikot Ekpene	4.07E-5	3.23E-5	2.73E-5	1.59E-5
MEAN	4.50E-5	3.76E-5	2.88E-5	1.67E-5
		CHILDREN CLASS		
Uyo	4.74E-4	3.98E-4	3.02E-4	1.83E-4
Eket	4.20E-4	3.84E-4	2.73E-4	1.52E-4
Onna	4.06E-4	3.30E-4	2.44E-4	1.39E-4
Ikot Ekpene	3.80E-4	3.01E-4	2.55E-4	1.48E-4
MEAN	4.20E-4	3.53E-4	2.69E-4	1.56E-4

Table 5: Hazard quotient (HQ) and hazard index (HI) of toxic metals on Environmental services workers and Scavengers

	Pb	Cd	Ni	Cr	THI
			ADULT CLASS		
Uyo	3.62E-2	4.26E-2	1.62E-3	6.53E-3	8.70E-2
Eket	3.21E-2	4.12E-2	1.15E-3	5.43E-3	7.99E-2
Onna	3.11E-2	3.44E-2	1.31E-3	4.93E-3	7.17E-2
Ikot Ekpene	2.91E-2	3.23E-2	1.15E-3	5.30E-3	6.79E-2
MEAN	3.21E-2	3.76E-2	1.31E-3	5.55E-3	7.66E-2
			CHILDREN CLASS		
Uyo	3.39E-1	3.98E-1	1.51E-2	6.10E-2	8.13E-1
Eket	3.00E-1	3.84E-1	1.37E-2	5.07E-2	7.48E-1
Onna	2.90E-1	3.30E-1	1.22E-2	4.63E-2	6.79E-1
Ikot Ekpene	2.71E-1	3.01E-1	1.28E-2	4.93E-2	6.34E-1
MEAN	3.00E-1	3.53E-1	1.35E-2	5.18E-2	7.19E-1

Table 5 shows the results of mean hazard quotient (HQ) of toxic metals via exposure to soil particles by the adult and children classes. The average HQ values of Pb, Cd, Ni, as well as Cr for the adult class were 3.21E-2, 3.76E-2, 1.31E-3, and 5.55E-3, respectively. For the children class, the mean HQ values were 3.00E-1, 3.53E-1, 1.35E-2, and 5.18E-2 for Pb, Cd, Ni, and Cr, correspondingly. The HQ obtained for both the adult and children classes were less than one (1) as reported by Okorie *et al*. (2024). Consequently, exposure to these metals through soil particles from the studied locations by Environmental workers and Scavengers might result in low non-carcinogenic health problems however; the children class was more vulnerable. HQ values of the toxic metals followed the sequence Cd > Pb > Cr > Ni for both the adult and children classes. The High HQ value of Cd reported is similar to the results of Kaba *et al*. (2020).

The results of hazard index (HI) of toxic metals through soil particles from the studied dumpsite soils for the adult and children classes are shown in Table 5. The mean HI values obtained varied from 6.79E-2 to 8.70E-2 and 6.34E-1 to 8.13E-1 for the adult and children classes, respectively. Hence, the children class had higher mean HI values than the adult class and might have been more vulnerable to non-cancer risks. However, the HI values for the both classes were less than one (1) as reported by Rezapour *et al*. (2022). Thus, exposure to soil particles from these dumpsite soils may not cause adverse non-cancer risks immediately, but the younger ones were more susceptible to non-cancer risks (Khan *et al*., 2022). The highest mean HI values for the adult and children classes were recorded for Uyo dumpsite soil while the lowest were at Ikot Ekpene dumpsite soil. Consequently, the Environmental workers and Scavengers working at the Uyo dumpsite soil were more susceptible to the non-carcinogenic risks than those at the other studied locations were. However, the younger ones working at Uyo dumpsite soil could be more exposed to the non-carcinogenic health problems than the older ones. The sequence for the HI values followed the order Uyo > Eket > Onna > Ikot Ekpene dumpsite soils. Accordingly, since the non-carcinogenic risks are directly proportional to the value of HI, workers at Uyo dumpsite could be more exposed to these risks. Cd contributed 49% to the HI value obtained at each dumpsite soil followed by Pb with 42%. This is similar to the results previously obtained by Emmanuel *et al*. (2022).

Table 6: Incremental lifetime cancer risk (ILCR) of carcinogens on Environmental services workers and Scavengers

	Pb	Cd	Ni	Cr	TCR
ADULT CLASS					
Uyo	4.31E-7	2.13E-5	5.51E-5	9.82E-6	8.67E-5
Eket	3.83E-7	2.06E-5	4.98E-5	8.17E-6	7.90E-5
Onna	3.70E-7	1.72E-5	4.45E-5	7.42E-6	6.95E-5
Ikot Ekpene	3.46E-7	1.62E-5	4.64E-5	7.97E-6	7.09E-5
MEAN	3.83E-7	1.88E-5	4.90E-5	8.35E-6	7.65E-5
CHILDREN CLASS					
Uyo	4.03E-6	1.99E-4	5.13E-4	9.17E-5	8.08E-4
Eket	3.57E-6	1.92E-4	4.64E-4	7.62E-5	7.36E-4
Onna	3.91E-6	1.65E-4	4.15E-4	6.96E-5	6.54E-4
Ikot Ekpene	3.23E-6	1.51E-4	4.34E-4	7.42E-5	6.62E-4
MEAN	3.69E-6	1.77E-4	4.57E-4	7.79E-5	7.15E-4

Table 6 indicates the results of incremental lifetime cancer risk (ILCR) of cancer-causing metals (Pb, Cd, Ni, as well as Cr) within dumpsite soils examined. The mean values of ILCR for Pb, Cd, Ni, plus Cr for the adult class were 3.83E-7, 1.88E-5, 4.90E-5, and 8.35E-6, respectively. Mean ILCR values for the children class were 3.69E-6, 1.77E-4, 4.57E-4, and 7.79E-5 for Pb, Cd, Ni, and Cr, correspondingly. Thus, higher ILCR values of the carcinogens were recorded for the younger class than the older ones. Consequently, the exposure to soil particles from the dumpsite soils investigated by both classes may cause cancer in the children class hence; the children class might be more susceptible to cancer risks than those in the adult class may. The average ILCR values of the toxic metals for the adult class varied between negligible and medium cancer risk classes (USEPA, 1999). However, the average ILCR values of the entire toxic metals were within the permissible limit of $10^{-6} - 10^{-4}$ (USEPA, 2011; Masri *et al*., 2021). The average ILCR values of the metals for the younger class ranged from low to the high cancer risk classes (USEPA, 1999). Accordingly, the mean ILCR values of Cd and Ni in the dumpsite soils assessed for the children class were higher than the recommended limit (1 x 10^{-4}). Consequently, prolonged exposure to soil particles at dumpsite soils examined might cause cancer risks associated with Cd and Ni in Environmental workers and Scavengers between the ages of 1 to 15 years. For both the children and adult classes, the ILCR values followed a decreasing trend of Ni > Cd > Cr > Pb. The results also indicated that, Uyo dumpsite soil had the highest ILCR value thus; consistent exposure to Uyo dumpsite could results in cancer risks especially in the younger people mostly during the dry season.

The results of total cancer risk (TCR) for the toxic metals in the dumpsite soils for the adult and children classes are shown in Table 6. TCR results for the studied locations ranged between 6.95E-5 and 8.67E-5 for the adult class. The highest TCR value was recorded for Uyo dumpsite soil whereas the lowest was reported at Onna dumpsite soil. The range of TCR obtained for the adult class belong to the medium cancer risk category. The TCR values for the children class varied from 6.54E-4 to 8.08E-4 between Onna and Uyo dumpsite soils, respectively. The reported range of TCR for the adult class is below the acceptable limit (1 x 10^{-4}) by USEPA, (1999). Whereas, the range of TCR values for the children class belong to the high cancer risk class and is higher than 1 x 10^{-4} recommended by USEPA (1999). Accordingly, the TCR values for the children class were relatively higher than those of the elderly. Consequently, the younger ones exposed consistently to these dumpsite soils could be more prone to cancer risks than the elderly could. The TCR values for the different dumpsite soils investigated followed the order Uyo > Eket > Ikot Ekpene > Onna. The TCR results also showed that for both the adult and children classes, Ni was the major contributor with 64% followed by Cd with 25%. The high contribution of Ni to the total TCR for both classes is consistent with the reports by Tombere *et al*. (2023) and Okon *et al*. (2023).

4. Conclusion

The study has shown that, waste dumpsite soils at Uyo, Eket, Onna, and Ikot Ekpene are highly contaminated with toxic metals. The ecological risks associated with the metals have also been revealed. The cancer and non-cancer potentials of the toxic metals on the Environmental services workers and Scavengers are also indicated. The major sources of these toxic metals in waste-impacted soils examined and the control plot has been identified. The geochemical fractions of these metals at both the studied soils and Control have been evaluated and documented. The study has indicated that Uyo dumpsite could a source of cancer problems to the Environmental services workers and Scavengers especially the children class. The general study has shown the risks involved in being constantly exposed to waste materials and soil particles at dumpsites. The outcome has shown the need for the workers to apply the necessary rules guiding exposure to dumpsites.

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