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Ecological and Human Health Risk Assessment of Soil Samples from Vicinities of Dumpsites in Residential and Selected Industrial Layouts in Benue State, Nigeria

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Abstract

This study was undertaken to assess the ecological and human health risk assessment of soil samples from the vicinity of dumpsites in residential and selected Industrial layouts in Benue State. The physicochemical parameters of the samples, namely, pH, electrical conductivity, NO_3^-, PO_4^{3-}, hardness, and particle size for soil samples were investigated. Heavy metal concentrations were analyzed using AAS. SEM images of industrial waste soils show a regular assemblage of particles. The XRD result analysis predominantly revealed the sample contained of quartz (89%), cordierite (7%) and kaolinite (4%) in Fertilizer Dumpsite Soil Sample (FDSS); quartz (83%), gypsum (12%), Hydrophite (4%) and calcite (1%) in Battery Dumpsite Soil Sample (BDSS); quartz (74%), microcline (17%), albite (6%) and kaolinite (3%) in Paint Dumpsite Soil Sample (PDSS); quartz (51%) and oligoclase (49%) in Dye Dumpsite Soil Sample (DDSS) and quartz (92%) and albite (8%) for the control sample. The XRF shows key elemental compositions as Sr, Zr, K, Ti, Rb, Mn, Cu and Fe for FDSS; Pb, Sr, Zr, Fe, Ca, Ti, Y, and Zn for BDSS; Fe, Zr, Ca, Zn, Ti, Sn and Pb for PDSS; Fe, Sr, Zr, Ca, Cu, Pb, Sn, Zn and Ti for DDSS and Sr, Zr, K, Rb, Mn, Cu and Fe for the control sample. The mean concentrations of Fe, Pb, Cr, Cd, Zn, Mn and Cu in the soil samples were 2.39 ± 0.004, 3.05 ± 0.002, 2.21 ± 0.002, 0.121 ± 0.001, 0.115 ± 0.006, 0.481 ± 0.001 and 0.262 ± 0.003 mg/Kg respectively. The result showed that majority of the heavy metals were below the WHO permissible limit except Pb and Cr. The geo-acumulation index, contamination factor, enrichment factor and ecological risk index showed different levels of pollution of the metals in the various sampling points. The results of the soil Chronic Daily Intake (CDI) identified through ingestion, dermal contact and inhalation were less than one (<1), indicating low risk. The hazard quotients of all the heavy metals measured across the dumpsites were also less than one (<1), the related standard limit by USEPA. The hazard index (HI) values in this study also indicated no potential health hazards related to heavy metals exposure. The result of the carcinogenic risk assessment revealed that there were low or neglected chances of cancer risk.

Subject Areas

Environmental Chemistry

Keywords

Ecological Risk Index, Chronic Daily Intake, Hazard Quotients, Hazard Index, Carcinogenic

1. Introduction

Environmental pollution poses a widespread issue with significant implications for the well-being of individuals and populations worldwide. The escalating utilization of fossil fuels, improper sewage disposal practices, and indiscriminate use of agricultural pesticides contribute to the pervasive presence of environmental pollution across the globe [1].

Over the years, wastes generated due to industrial growth and complicated by their indiscriminate disposal have been a major concern in the developing countries. Some components of these wastes contain hazardous chemicals which may infiltrate and percolate into the sub-surface environment upon discharge and subsequently accumulate in the soil and bed sediment of water bodies as well as contaminating the entire ecosystem [2].

The industrial effluents can potentially affect hydrological and environmental parameters of a catchment, as well as pose significant threats to man and ecosystem. Accumulation of hazardous pollutants in soil, water and air result to health risk and environmental degradation [3] [4].

Hazardous wastes are characterized by their flammability, reactivity, explosiveness and toxicity properties. Waste from vicinities of fertilizers, paints, dye, pharmaceuticals, heavy metal-containing products, vehicle maintenance, biological infectious waste and batteries are listed as hazardous wastes subcategory [5].

The waste from the batteries industries is thrown as garbage, and they fall down and spill. Their toxins soak into soils as battery corroded and contaminate land and surface water [6].

The textile industry is responsible for an extensive list of environmental impacts [7]. The scraps of textile fabrics and yarns and discarded packagings constitute the primary solid waste. The textile sludge, on the other hand, reveals problems related to surplus volumes and unwanted composition, often presenting high loads of organic matter, micronutrients, heavy metal cations and pathogenic microorganisms [8].

Fertilizer industry is considered to be source of natural radionuclides and heavy metals as a potential source. It contains a large majority of the heavy metals like Hg, Cd, As, Pb, Cu, Ni and Cu, natural radionuclide like ^{238}U, ^{232}Th and ^{210}Po [9]. This leads to water, soil and air pollution, improper use of fertilizers and pesticides can contaminate agricultural soil with potentially toxic heavy metals causing agricultural soil a source of pollution [10].

The numerous chemicals used for the production of paints are responsible for the high concentrations of organic acid compounds, suspended solids, colored materials and hazardous pollutants like heavy metals in the generated waste [11].

Dump sites are the main receptacles for domestic and industrial waste. Abandoned dump sites are usually turned into other land uses such as crop cultivation, recreational parks or building of human residences. Sometimes, the soil is also excavated for soil amendments elsewhere because of the rich mineral and organic content but without assessing the health risks they pose to organisms and the environment. These dumpsites also emit obnoxious odours and smoke that cause illness to people living near them.

Characterization: SEM studies was also conducted to analyze the surface morphology of the soil samples. XRF analysis was carried out to determine the various compounds present in the samples and the weight percentage of the heavy metals and other elements in the samples. X-Ray diffraction study was conducted on soil samples to identify the different types of minerals present in the samples. The crystallite size was estimated using the Debye-Scherrer equation:

However, despite their widespread presence and the importance of dumpsites in the country, they have been sparsely studied especially with regard to their mineral and toxic content. The few studies so far conducted have focused on large landfills [12], dump sites at light industrial hubs [13] and e-waste recycling sites [14].

The current study is aimed at assessing the ecological and human health risk of soils and water samples from vicinities of dumpsites in residential and selected industrial layouts in Benue State, Nigeria.

2. Materials and Methods

Analytical grade reagents were procured from certified vendors. They include nitric acid, Hydrochloric acid, sulphuric acid and sodium hydroxide. The instruments used in this study were energy dispersive X-ray Fluorescence, X-ray diffractometer (XRD), Scanning Electron Spectrophotometer and Atomic Absorption Spectrophotometer (AAS) (**Table 1**).

2.1. Sampling

Soil samples (waste effluents) of topsoil (0 - 20 cm) were collected with auger

Table 1. Coordinate of sample locations.

Locations	Codes	Latitude (˚)	Longitude (˚)
Fertilizer Dumpsite Soil Sample	FDSS	1) 7.748280 2) 7.745808 3) 7.745982	8.531422 8.525397 8.525323
Dye Dumpsite Soil Sample	DDSS	1) 7.745705 2) 7.745695 3) 7.745697	8.514172 8.514149 8.514419
Battery Dumpsite Soil Sample	BDSS	1) 7.744887 2) 7.744868 3) 7.744871	8.513710 8.513618 8.513741
Paint Dumpsite Soil Sample	PDSS	1) 7.742112 2) 7.731222 3) 7.736231	8.513122 8.517217 8.517281

Key: FDWS: Fertilizer Dumpsite Water Sample, DDWS: Dye Dumpsite Water Sample, BDWS: Battery Dumpsite Water Sample, PDWS: Paint Dumpsite Water Sample, FDSS: Fertilizer Dumpsite Soil Sample, DDSS: Dye Dumpsite Soil Sample, BDSS: Battery Dumpsite Soil Sample, PDSS: Paint Dumpsite Soil Sample.

from dumpsites of paint industry: dye factory, Automobile battery repair shop and fertilizer plant industry all within Makurdi metropolis. Three (3) soil samples were collected from each site. A control soil sample was collected from a residential area within Makurdi metropolis that has no history of industrial activity or use as a dumpsite. The specific location was selected to be upwind and at a significant distance (>2 km) from the investigated dumpsites to minimize the potential for contamination via atmospheric deposition or leachate. The land use is characterized by low-density housing with minimal traffic, and the site is not used for agriculture, ensuring it represents a background baseline for the local soil conditions against which the dumpsite samples could be compared. The collected soil samples were air dried, crushed with mortar and pestle and pass through 2 mm sieve and stored in the sealed plastic bags at room temperature for 24 hrs. The soils were placed in polyethylene bags and labeled accordantly and taken to the Department of Chemistry Laboratory Joseph Sarwuan Tarka University Makurdi for preparation and analysis.

Sample Preparation

Exactly 1.0 g of the dried and sieved soil sample was weighed into 250 mL conical flask. A known amount of freshly prepared aqua-ragia ($HCl:HNO_3$) in a ratio of 1:3 was added. The beaker was covered with a filter paper; the solution was heated for 1 hour using a hot plate. The mixture was allowed to cool and filter with whatman filter paper into a 50 mL standard volumetric flask, the filtrate was diluted to 50 mL with de-ionised distilled water.

2.2. Physicochemical Analysis

pH, Electrical conductivity, Organic matter, Phosphate ion (PO_4^{3-}) and Nitrate ion (NO_3^-) f the samples were carried out following documented procedures [15].

2.3. Sample Characterization

Atomic Absorption Spectrophotometer (AAS): Heavy metals concentration were determined by Atomic Absorption Spectrophotometry.

X-ray Fluorescence Analysis (XRF): Quantitative analysis of the major oxides and elements within the ore was determined by X-ray Fluorescence Spectroscopy.

X-ray Diffraction Analysis (XRD): XRD analysis was conducted for the qualitative (phase identification) and quantitative analyses of the minerals in the soil samples. Diffraction pattern was presented and crystalline sizes was computed using the Debye-Scherrer equation given as:

$$\beta(2\theta) = \frac{k\lambda}{L\cos\theta} \tag{1}$$

with k as 0.94.

Scanning Electron Microscopy Analysis: Surface morphology of soil samples was determine by Scanning Electron Microscopy.

2.4. Ecological Assessment

The soil heavy metals contamination levels and ecological risk were evaluated using the various indices.

2.4.1. Geoaccumulation Index (I_{geo})

The following equation was used to calculate the geoaccumulation index (I_{geo}):

$$I_{geo} = \log_2\left[\frac{C_n}{1.5B_n}\right] \tag{2}$$

where; C_n represents heavy metal (n) concentration in the sample, Bn represents heavy metal (n) concentration in the geochemical background, 1.5 represents the background matrix correction due to lithogenic effects.

The geochemical background concentrations (Bn) used for the I_{geo} and Contamination Factor (CF) calculations were derived from the control sample collected in this study. This sample, taken from an uncontaminated residential area, provides a local baseline for pre-anthropogenic metal concentrations in the soils of the Makurdi metropolis.

2.4.2. Contamination Factor (CF)

The contamination factor (CF) was used to evaluate heavy metal contamination.

$$C_f = \frac{C_0}{C_n} \tag{3}$$

where; C_n represents the concentration of each element; C_0 is the average concentration of each element.

2.4.3. Ecological Risk Assessment

In this study, the following relationships was used to assess the ecological risk and environmental risk potential (RI) of soils.

$$\mathrm{ERI} = \mathrm{TR} \times \mathrm{CF} \tag{4}$$

where; CF is the pollution factor, ER indicates the ecological risk of each element studied, RI represents the sum of the elements. The high value of TR indicates the toxicity of heavy metals.

2.4.4. Enrichment Factor

The determination of the EF indicates the level of contamination of metals in the soil, which is a useful index for separating the natural and human sources of metals from each The EF for each metal was calculated based on the ratio between the normalized element and the background value of the elements.

$$\mathrm{EF} = \frac{\left(\frac{\mathrm{Cx}_{\mathrm{metal}}}{\mathrm{Fe}}\right)_{\mathrm{sample}}}{\left(\frac{\mathrm{Cref}_{\mathrm{metal}}}{\mathrm{Fe}}\right)_{\mathrm{Background}}} \tag{5}$$

where; Cref is the concentration of the reference element in the sample, Cx is the concentration of the element considered in the sample.

Iron (Fe) was selected as the normalizing element due to its abundance as a major constituent of the Earth's crust, its generally low mobility in soil environments, and its minimal variation from anthropogenic inputs in the study area compared to other major elements.

2.5. Human Health Risk Assessment

There are three common pathways for exposure to heavy metals related to soil including ingestion (Ing), inhalation (Inh) and dermal contact (Der). Equations below were used to calculate dose received via each of these exposure pathways:

$$D_{\mathrm{Ing}} = C \times \frac{\mathrm{IngR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \tag{6}$$

where; D_{Ing} and C are the dose contacted through ingestion of soil (mg/kg/day) and exposure point content (mg/kg) of the analyzed elements, respectively, IngR (mg/day) is the ingestion rate (200) for children and 100 for adults, EF (days/year), ED (years), BW (kg) and AT are the exposure relative frequency (300), exposure duration (six for children and 24 for adults), average body weight (15.0 for children and 70 for adults) and averaging time (exposure duration 365 days for non-carcinogens), respectively.

$$D_{\mathrm{Inh}} = C \times \frac{\mathrm{InhR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BEF}} \tag{7}$$

where; D_{Inh} (mg/kg/day) is the dose contacted through inhalation of soil sample, lnhR (m^3/day) is the inhalation rate (7.60 for children and 20.00 for adults) where,

$$D_{\mathrm{der}} = C \times \frac{\mathrm{SA} \times \mathrm{kp} \times \mathrm{ET} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{ABS}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \tag{8}$$

D_{der} (mg/kg/day) is the dose absorbed via dermal contact.

SA (cm^2) are the exposed skin area (2800 for children and 5700 for adults), ABS dermal absorption factor (0.001) for all analyzed elements, respectively.

2.5.1. Hazard Quotient (HQ)

The HQ for non-carcinogenic risk was calculated using the equation by USEPA (1999)

$$\text{HQ} = \frac{\text{CDI}}{\text{RfD}} \tag{9}$$

USEPA (1999). Guidance for performing aggregate exposure and risk assessments. Office of Pesticide Programs, Washington, DC.

where,

CDI is the daily dose of heavy metals (mg/l) to which consumers might be exposed.

RfD is the reference dose which is the daily dosage that enable individual to sustain this level of exposure over a long period of time without experiencing any harmful effects.

If HQ > 1, it represents adverse non-carcinogenic effects of concern, while HQ < 1 represents acceptable level.

2.5.2. Hazard Index

The toxic risks due to potentially hazardous substances present in the sample are assumed to be additive.

The HQs may be summed to arrive at the overall toxic risk.

$$\text{HI} = \sum_{i-1}^{n} (\text{HQ})_i \tag{10}$$

where,

HI is the hazard index for the overall toxic risk.

n is the total number of metals under consideration.

HI < 1 indicates no adverse health effects, whereas HI > 1 indicates the possible health effects.

2.5.3. Carcinogenic Risk

Cancer risk is the hazard from a lifetime average dose exposure to 1 mg/kg body weight/day of a pollutant. Cancer risk is expressed in terms of incremental lifetime cancer risk (ILCR), which is the probability that one may develop cancer over a 70-year lifetime due to a 24-hour exposure to a potential carcinogen [16]. Cancer risk is calculated as the product of CDI (mg/kg/day) and cancer slope factor (CSF) measured in (mg/kg/day)

$$\text{ILCR} = \text{CDI} \cdot \text{CSF} \tag{11}$$

where:

ILCR is the incremental life cancer risk.

CDI is the chronic intake (mg/kg/BW/day).

CSF is the cancer slope factor.

3. Results and Discussion

3.1. Physicochemical Parameters

The results of the physicochemical parameters of the soil samples; pH, Electrical conductivity, Organic matter, Phosphate ion (PO_4^{3-}) and Nitrate ion (NO_3^-) were presented in **Table 2**.

pH: The pH of the soil samples ranges from 2.81 to 7.80 across the sampling sites withthe highest pH value recorded in FDSS and lowest in BDSS. The mean value of Ph^- in this study was 6.04 ± 0.05 and it was within the acceptable limit. The result shows that, samples from BDSS and PDSS were acidic to slightly acidic, this indicate that metals may be available in their ionic species or in soluble organometallic forms therefore readily available for plant uptake as acidity decreases as also reported by [17] [18]. While samples from FDSS, DDSS and the control indicate that, the soils from the two dumpsites are alkaline which is in agreement with research reported by [19]. Soil pH is among the factors that affect the distribution and availability of heavy metals in the soil.

Electrical conductivity: The EC values of soil samples obtained in this study ranges from 259 to 4757 μS/cm with the lowest value observed in PDSS and the highest value in BDSS. The high value observed in BDSS could be attributed to the presence of soluble salts that might have leached out from the waste in the study site [20].

Organic matter: The concentrations of organic matter in the soil sample of the dumpsites range from 2.54 to 3.91 with the lowest value recorded in DDSS and the highest value observed in BDSS. That of the control sample was 3.82 ± 0.03 mg/L. The presence of the high content of organic matter in the soil can be another possible reason for the low pH observed in BDSS [21].

Phosphate ion (PO_4^{3-}): The concentrations of phosphates in the dumbsites range from 12.8 to 38.8 mg/L with DDSS recording the least value and FDSS recording the highest value. The control sample reported 46.0 ± 0.03 mg/L. The high level of phosphates in these locations especially that of FDWS is attributed to the production of synthetic fertilizers while that of DDWS, BDWS, PDWS and the control sample may also be related to the run-off from farmlands from inhabitants who engage in agricultural activities using both natural and synthetic fertilizers.

Nitrate ion (NO_3^-): The concentration of nitrates across the sampling points range from 2.11 to 7.25 mg/L with FDSS observed to be the lowest value and BDSS recorded the highest value. The control sample reported 8.56 ± 0.03 mg/L. These results suggest that, there is no high amount of macro-nutrients of Nitrogen, Phosphorus from the dumpsites. The value of nitrate obtained in the soil of paint dumbsite (2.56) correspond with the work of [22].

3.2. Concentrations of Heavy Metals

The results of the mean concentrations of the heavy metals (Fe, Pb, Cr, Cd, Zn, Mn and Cu) in soil samples were presented in **Table 3**.

Table 2. Physicochemical parameters of soil samples from selected vicinities of dumpsites around residentials/industrial areas.

Location	pH	Electrical Conductivity (μS/cm)	Organic Matter	NO_3^- (mg/L)	PO_4^{3-} (mg/L)
FDSS	7.80 ± 0.04	363 ± 0.68	3.49 ± 0.05	2.11 ± 0.01	38.8 ± 0.35
DDSS	7.60 ± 0.04	318 ± 0.79	2.54 ± 0.02	2.93 ± 0.01	12.8 ± 0.68
BDSS	2.81 ± 0.00	4757 ± 0.81	3.91 ± 0.03	7.25 ± 0.03	18.1 ± 0.19
PDSS	5.94 ± 0.11	259 ± 0.59	2.56 ± 0.06	3.14 ± 0.04	26.2 ± 0.18
Control	6.20 ± 0.00	123 ± 0.53	3.82 ± 0.03	8.56 ± 0.03	46.0 ± 0.03

FDSS: Fertilizer Dumpsite Soil Sample, DDSS: Dye Dumpsite Soil Sample, BDSS: Battery Dumpsite Soil Sample, PDSS: Paint Dumpsite Soil Sample.

Fe: The mean concentrations of Fe in the soil sample of the dumpsites range from 0.471 to 4.06 mg/kg with the lowest value in BDSS and the highest value recorded in PDSS respectively. The control sample was observed to be 1.54 ± 0.001 mg/kg. The result of Fe in dumbsites is lower than that of [23].

Pb: The mean concentration of Pb in the soil samples collected around the different dumpsites range from 0.337 to 2.47 mg/kg with the lowest and highest values recorded in FDSS and PDSS respectively. There was a slight difference between the levels of Pb in the dumpsites soil and the control sample which was reported to be 0.289 ± 0.001 mg/kg. The concentrations of Pb in the various dumbsites were higher than the value found in the control site, indicating the impact of anthropogenic activities in and around the dumpsites. The results obtained from the analysis exceed the WHO permissible limit of 0.01 mg/kg. The presence of lead in the soil beyond the permissible level may be due to the disposal of wastes material such as paint, textiles, lead acid batteries waste or spillage of leaded fuel, food packaging materials and Polyvinylchloride materials (PVC), scrap metals, oil from mechanic workshop and other automobile part deposited on the dumpsites [24]. The mean concentrations of Pb in this study were higher when compared with that of Awotan dumpsite in Ibadan (0.49 mg/kg and 0.10 mg/kg respectively). [25] who worked on the heavy metal contents in soils at dumpsites. This result on Pb concentration around the battery dumpsite agreed with previous reports on similar environments [26].

Cr: The mean concentrations of Cr across the various dumpsites range from 2.05 to 2.37 mg/Kg with the lowest value in PDSS and the highest value recorded in DDSS respectively. The value of the control sample was observed to be 0.025 ± 0.001 mg/Kg. Exposure to Cr is associated with allergic dermatitis in humans, it also causes mutagenic, carcinogenic and teratogenic effects on humans [27]. The values of Cr obtained in this study were lower than 16.33 ± 3.51 to 66 ± 14.11 mgkg reported by [28] in selected dumpsites in Nasarawa, Kogi and Niger States. Similarly, low levels of chromium have been observed in surface soils under waste dumps in Onitsha, Nigeria [29].

Cd: Cadmium mean concentrations ranged from 0.094 to 0.143 with the lowest and highest concentrations recorded in FDSS and DDSS respectively. The value of the control sample was observed to be 0.012 ± 0.001 mg/kg. The mean value of Cd was 0.121 ± 0.001 mg/kg and this was within the acceptable limit. The Concentrations of Cd may be attributed to various sources, some of which include automobile tire dust, burning of oil and tyre, plastic wrappings, paints, dyes, and especially, refuse dumps and commercial activities [30]. The result observed in this study was lower than that of [31] on the study on selected dumpsites.

Zn: The mean concentration of Zn in the soil samples range from 0.023 to 0.228 mg/Kg with the lowest and highest concentrations recorded in BDWS and PDWS respectively. The control sample recorded 1.76 ± 0.002 mg/Kg. The presence of Zn in the soil at the different dumpsites could be credited to the disposal of dry cells in the municipal waste, the burning of electronic waste materials containing alloys of brass and bronze, empty cans of fungicides, pigments and pesticides as well as the disposal of metallic objects containing galvanizing steel and iron in the dumpsites. With regard to the paint-industry contaminated site, the value reported here was higher than that of [32] and this may be due to different geological locations. Long term exposure to Zn can result in gastrointestinal irritation and interference of physiological processes. In adversely affects plant health, extreme intake by humans aggravates Cu deficiency. It can also interrupt microbial activity in soils, as it harmfully influences the activity of microorganisms and earthworms and as a result, retards the breakdown of organic matter [27].

Mn: The mean concentrations of Mn range from 0.094 to 1.03 mg/Kg with the lowest value in PDSS and the highest value recorded in DDSS respectively. The value of the control sample was observed to be 0.148 ± 0.001 mg/Kg. The results obtained from this analysis are below the WHO permissible limit of 100 mg/Kg. The presence of Mn in the various dumbsites could be due to the composition of metal alloys and other manganese compounds in batteries; Potassium permanganate as oxidant for cleaning, bleaching and disinfection purposes, other manganese compounds are also used in fertilizer. Manganese is equally essential for plants and animals but poisonous at high concentrations. The harmful effect in humans is always related with severe psychiatric disorder resembling schizophrenia, followed by permanently crippling neurological disorder clinically similar to Parkinson's disease [27].

Cu: The mean concentrations of Cu across the various dumpsites range from 0.026 to 0.883 mg/Kg with the lowest value in BDSS and the highest value recorded in PDSS respectively. The value of the control sample was observed to be 0.005 ± 0.001 mg/Kg. The presence of copper in the soils can be linked to anthropogenic activities such dumping of copper containing wastes like electrical wires, fertilizers, textile, plumbing materials and migration of leachate rich in copper into the nearby soils. Excessive dietary copper intake in mammals causes nausea, vomiting and diarrhea. It also causes pathological changes in brain tissue. Copper accumulates in the liver, kidney, cornea, and brain [33]. The accumulation of Cu in the brain leads to trauma and eventual death. The results obtained for Cu in this study from paint dumpsite were also similar to that of [34].

Table 3. Mean concentration (mg/Kg) of selected heavy metals in soil samples.

Heavy Metals	FDSS	DDSS	BDSS	PDSS	Control	WHO (mg/Kg)
Fe	4.06 ± 0.002	1.72 ± 0.002	0.471 ± 0.004	3.31 ± 0.002	1.54 ± 0.001	0.5 - 50
Pb	0.337 ± 0.003	1.81 ± 0.003	1.48 ± 0.002	2.47 ± 0.002	0.289 ± 0.001	0.01
Cr	2.30 ± 0.002	2.37 ± 0.001	2.12 ± 0.001	2.05 ± 0.002	0.025 ± 0.001	0.05
Cd	0.094 ± 0.001	0.143 ± 0.001	0.110 ± 0.000	0.136 ± 0.001	0.012 ± 0.001	1 - 3
Zn	0.044 ± 0.006	0.166 ± 0.003	0.023 ± 0.004	0.228 ± 0.005	1.76 ± 0.002	95
Mn	0.483 ± 0.001	1.03 ± 0.001	0.317 ± 0.001	0.094 ± 0.001	0.148 ± 0.001	100
Cu	0.057 ± 0.001	0.083 ± 0.001	0.026 ± 0.001	0.883 ± 0.007	0.005 ± 0.001	100 - 200

FDSS: Fertilizer Dumpsite Soil Sample, DDSS: Dye Dumpsite Soil Sample, BDSS: Battery Dumpsite Soil Sample, PDSS: Paint Dumpsite Soil Sample.

3.3. Assessment of Ecological Risk Indices

Geo-accumulation index: The geo-accumulation index of the soil samples was presented in Table 4 FDSS shows that, Pb and Zn were unpolluted, that of Fe fell within unpolluted to moderately polluted; Mn were moderately polluted, Cd and Cu were moderately to strongly polluted while Cr fell within the extremely polluted of the geo-accumulation index interpretation scale. That of DDSS shows that, Fe and Zn were unpolluted; Pb, Cd and Mn were moderately to strongly polluted; Cu was strongly polluted and Cr extremely polluted. The I_{geo} values for BDSS indicated that, the dumpsite soil was not polluted by Fe and Zn meaning that these two metals did not cause contamination, unpolluted to moderately polluted was observed by Mn, moderately polluted was observed by Pb and Cu, moderately to strongly polluted was noticed by Cd and extremely polluted observed by Cr. The I_{geo} values for PDSS shows that, dumpsite soil was not polluted by Zn and Mn, unpolluted to moderately polluted was noticed by Fe and strongly polluted was observed by Pb and Cd while extremely polluted was observed by Cr and Cu. Increasing anthropogenic activities cause increased geo- accumulation of these metals in the soil that are known carcinogenic and mutagenic to flora and faunas, when in extreme concentrations thereby impacting the natural manageable level that is assimilated to prevent adverse ecological impact [35].

Contamination factor: The contamination factor of the metals is tabulated in Table 4. The result shows that, CF of Cr and Cd in all the dumpsites were greater than 6 (CF > 6) and were considered highly contaminated. The CF of Zn in all the dumpsites was within the classification; CF < 1 signifying low contamination. Moderate CF was observed by Fe in all the studied sites excerpt BDSS (0.306) which report Low CF. Low CF was observed by Mn in PDSS, Moderate contamination in FDSS and BDSS respectively. The high metal contamination of Cr, Cd, Pb, Cu and Mn in the different dumpsite could be due to presence of these elements from anthropogenic activities. These results are similar to the work reported by [36].

Enricment factor (EF): The values of the enrichment factor (EF) of the analysed metals with respect to natural background concentrations are presented in **Table 5**. The result shows, no enrichment in FDSS, moderate enrichment in PDSS, moderately severe enrichment in DDSS and severe enrichment in BDSS for Pb. The result observed for Pb in DDSS and BDSS were similar to that reported by [37]. In the case of Cr, dumpsites FDSS and PDSS shows very severe enrichment while that of DDSS and BDSS were observed to be extremely severe enrichment. The enrichment of Cd was observed to be; moderate enrichment in FDSS; moderately severe enrichment in PDSS; severe enrichment in DDSS and very severe enrichment reported in BDSS. Zn recorded no enrichment in all the studied dumpsites indicating that there was no enrichment with this metals in the study sites. The enrichment factor of Mn was observed to be; no enrichment in FDSS and PDSS, moderately severe enrichment in DDSS and BDSS. While that of Cu reported moderate enrichment in FDSS, severe enrichment in DDSS and BDSS and extremely severe enrichment in PDSS, this observation was for Cu was similar to that of [37].

Ecological risk index (ERI): **Table 6** present the Eri assessment of the analyzed heavy metals from dumpsites. Soil samples from studied dumpsites indicated low Eri for the heavy metals (Fe, Zn and Mn) except for Cd which reported very high potential ecological risk in DDSS and PDSS and high potentical ecological risk in FDSS and BDSS, Cr recorded high potentical ecological risk in all the sampled sites. The results of the Er revealed that Fe, Zn and Mn were less than 40 ($Er < 40$) across the study sites indicating low ecological risk. While Cr, Cd and Cu were more than 320 and therefore pose a very high ecological risk. These results disagree with that of [36]. Furthermore, the ecological risk showed considerate ecological risk ($300 \leq Eri < 600$) in FDSS and BDSS and very high ecological risk (≥ 600) in DDSS and PDSS respectively. This could be due to anthropogenic activities around the dumpsites. Furthermore, the ecological risk showed considerate ecological risk ($300 \leq Eri < 600$) in FDSS and BDSS and very high ecological risk (≥ 600) in DDSS and PDSS respectively. This could be due to anthropogenic activities around the dumpsites. The comprehensive potential ecological risk index (RI) shows that FDSS and BDSS have considerate ecological risk while DDSS and PDSS have very high ecological risk therefore exhibit high risk of pollution (669 and 1134). This indicates that, considering the soils studied and other matters (both living and non-living), the environment are at high risk of various degrees of pollution which will cause serious health problem to the habitants and other living things in the dumpsite.

Table 4. Geoaccumulation Index (I_{geo}) of heavy metals in soil samples.

Heavy Metals	FDSS	DDSS	BDSS	PDSS
Fe	0.816	−0.425	−2.29	0.516
Pb	−0.366	2.06	1.77	2.51
Cr	5.92	5.96	5.80	5.75

Continued

Cd	2.38	2.99	2.61	2.92
Zn	−5.88	−3.99	−6.97	−3.54
Mn	1.12	2.21	0.516	−1.24
Cu	2.83	3.38	1.70	6.78

Contamination factor: The contamination factor of the metals is tabulated in Table 5.

Table 5. Contamination Factor (Cf) of heavy metals in soil samples.

Heavy Metals	FDSS	DDSS	BDSS	PDSS
Fe	2.64	1.12	0.306	2.15
Pb	1.17	6.26	5.12	8.55
Cr	92.0	94.8	84.8	82.0
Cd	7.83	11.9	9.17	11.3
Zn	0.025	0.066	0.013	0.129
Mn	3.26	6.96	2.14	0.635
Cu	11.4	16.6	5.20	177

Enrichment factor (EF): The values of the enrichment factor (EF) of the analysed metals with respect to natural background concentrations are presented in Table 6.

Table 6. Enrichment Factor (EF) of heavy metals in soil samples.

Heavy Metals	FDSS	DDSS	BDSS	PDSS
Pb	0.441	5.59	16.7	3.97
Cr	35.4	86.3	281	38.7
Cd	3.29	11.9	33.4	5.86
Zn	0.009	0.085	0.043	0.061
Mn	1.24	6.24	7.01	0.292
Cu	4.67	16.0	18.3	89.0

Table 7. Ecological Risk Index (ERI) of heavy metals in soil samples.

Heavy Metals	FDSS	DDSS	BDSS	PDSS
Fe	2.64	1.12	0.306	2.15
Pb	5.85	31.3	25.6	42.8
Cr	184	190	170	164
Cd	235	357	275	339
Zn	0.025	0.066	0.013	0.129

Continued

Mn	3.26	6.96	2.14	0.635
Cu	57.0	83.0	26.0	585
R_1	488	669	499	1134

Chronic Daily Intake (CDI): The results of assessment of human exposure to the heavy metals through calculating the Chronic Daily Intake (CDI), Hazard quotient (HQ) and Hazard index (HI) through ingestion, dermal contact and inhalation pathways are presented in Tables 7-9 respectively.

Table 8. Chronic Daily Intake (CDI) of selected heavy metals in soil samples.

Chronic Daily Intake									
Sample Site	Pathways	Recipients	Fe	Pb	Cr	Cd	Zn	Mn	Cu
FDSS	Ingestion	Children	5.19×10^{-5}	4.31×10^{-6}	2.94×10^{-5}	1.20×10^{-6}	5.63×10^{-7}	6.18×10^{-6}	7.29×10^{-7}
		Adult	5.56×10^{-6}	4.53×10^{-7}	3.15×10^{-6}	1.29×10^{-7}	6.03×10^{-8}	6.62×10^{-7}	7.81×10^{-8}
	Dermal	Children	1.74×10^{-8}	1.45×10^{-9}	1.98×10^{-8}	4.04×10^{-10}	1.13×10^{-9}	2.07×10^{-6}	2.45×10^{-10}
		Adult	4.40×10^{-9}	3.66×10^{-10}	4.99×10^{-9}	1.02×10^{-10}	2.86×10^{-10}	5.24×10^{-10}	6.18×10^{-11}
	Inhalation	Children	1.97×10^{-9}	1.64×10^{-10}	1.12×10^{-9}	4.57×10^{-11}	2.13×10^{-11}	2.35×10^{-10}	2.77×10^{-11}
		Adult	8.45×10^{-10}	7.02×10^{-11}	4.79×10^{-10}	1.96×10^{-11}	9.16×10^{-12}	1.01×10^{-10}	1.19×10^{-11}
DDSS	Ingestion	Children	2.19×10^{-5}	2.31×10^{-5}	3.03×10^{-5}	1.83×10^{-6}	2.12×10^{-6}	1.32×10^{-5}	1.05×10^{-6}
		Adult	2.36×10^{-6}	2.48×10^{-6}	3.25×10^{-6}	1.96×10^{-7}	2.27×10^{-7}	1.41×10^{-6}	1.12×10^{-7}
	Dermal	Children	7.39×10^{-9}	7.78×10^{-9}	2.04×10^{-8}	6.14×10^{-10}	4.28×10^{-9}	4.42×10^{-9}	3.52×10^{-10}
		Adult	1.87×10^{-9}	1.96×10^{-9}	5.14×10^{-9}	1.55×10^{-10}	1.08×10^{-9}	1.12×10^{-9}	8.89×10^{-11}
	Inhalation	Children	8.36×10^{-10}	8.79×10^{-10}	1.15×10^{-9}	6.95×10^{-11}	8.06×10^{-11}	5.00×10^{-10}	3.98×10^{-11}
		Adult	3.58×10^{-10}	3.77×10^{-10}	4.93×10^{-10}	2.98×10^{-11}	3.46×10^{-11}	2.14×10^{-10}	1.71×10^{-11}
BDSS	Ingestion	Children	6.02×10^{-6}	1.89×10^{-5}	2.71×10^{-5}	1.41×10^{-6}	2.94×10^{-7}	4.05×10^{-6}	3.32×10^{-7}
		Adult	6.45×10^{-7}	2.03×10^{-6}	2.90×10^{-6}	1.51×10^{-7}	3.15×10^{-8}	4.34×10^{-7}	3.56×10^{-8}
	Dermal	Children	2.02×10^{-9}	6.36×10^{-9}	1.82×10^{-8}	4.73×10^{-10}	5.93×10^{-10}	1.36×10^{-9}	1.12×10^{-10}
		Adult	5.11×10^{-10}	1.61×10^{-9}	4.60×10^{-9}	1.19×10^{-10}	1.49×10^{-10}	3.44×10^{-10}	2.82×10^{-11}
	Inhalation	Children	2.29×10^{-10}	7.19×10^{-10}	1.03×10^{-9}	5.34×10^{-11}	1.12×10^{-11}	1.54×10^{-10}	1.26×10^{-11}
		Adult	9.81×10^{-11}	3.08×10^{-10}	4.41×10^{-10}	2.29×10^{-11}	4.79×10^{-12}	6.59×10^{-11}	5.41×10^{-12}
PDSS	Ingestion	Children	4.23×10^{-5}	3.16×10^{-5}	2.62×10^{-5}	1.74×10^{-6}	2.92×10^{-6}	1.20×10^{-6}	1.13×10^{-5}
		Adult	4.53×10^{-6}	3.38×10^{-6}	2.81×10^{-6}	1.86×10^{-7}	3.12×10^{-7}	1.29×10^{-7}	1.21×10^{-6}
	Dermal	Children	1.42×10^{-8}	1.06×10^{-8}	1.76×10^{-8}	5.84×10^{-10}	5.88×10^{-9}	4.04×10^{-10}	3.79×10^{-9}
		Adult	3.59×10^{-9}	2.68×10^{-9}	4.45×10^{-9}	1.48×10^{-10}	1.71×10^{-9}	1.02×10^{-10}	9.58×10^{-10}
	Inhalation	Children	1.61×10^{-9}	1.19×10^{-9}	9.96×10^{-10}	6.61×10^{-11}	1.11×10^{-10}	4.57×10^{-11}	4.29×10^{-10}
		Adult	6.89×10^{-10}	5.14×10^{-10}	4.27×10^{-10}	2.83×10^{-11}	4.75×10^{-11}	1.96×10^{-11}	1.89×10^{-10}
Control	Ingestion	Children	1.97×10^{-5}	3.69×10^{-6}	3.19×10^{-7}	1.53×10^{-7}	2.25×10^{-5}	1.89×10^{-6}	6.39×10^{-8}
		Adult	2.11×10^{-6}	3.96×10^{-7}	3.42×10^{-8}	1.64×10^{-8}	2.41×10^{-6}	2.03×10^{-7}	6.85×10^{-9}

The Chronic Daily Intake (CDI) of the heavy metals in **Table 8** shows that, ingestion, dermal and inhalation values for children and adults were also less than 1 indicating low contamination. This shows that, there were no-non carcinogenic risks after the selected metals in both adults and children; this assertion was similar to that reported by [38]. Although, it is observed that, the magnitude of risks of the heavy metals toxicity for children were higher than for adults for almost all heavy metals in this study. The reason could be the lower body weight of children, differences in physiological factors, contact frequency and dietary habits.

Table 9. Hazard Quotient (HQ) and Hazard Index (HI) of selected heavy metals in soil samples.

			HQ							
Sample Site	Pathways	Recipients	Fe	Pb	Cr	Cd	Zn	Mn	Cu	HI
FDSS	Ingestion	Children	7.41×10^{-5}	1.23×10^{-3}	0.009	0.001	1.88×10^{-6}	1.34×10^{-4}	1.82×10^{-5}	0.011
		Adult	7.94×10^{-6}	1.29×10^{-4}	0.001	1.29×10^{-4}	2.01×10^{-7}	1.44×10^{-5}	1.95×10^{-6}	0.001
	Dermal	Children	2.49×10^{-8}	2.76×10^{-6}	3.30×10^{-4}	8.80×10^{-7}	1.88×10^{-8}	0.001	2.04×10^{-8}	0.001
		Adult	6.29×10^{-9}	6.97×10^{-7}	8.32×10^{-5}	2.04×10^{-7}	4.77×10^{-9}	2.85×10^{-7}	5.15×10^{-9}	8.44×10^{-5}
	Inhalation	Children	2.46×10^{-9}	5.05×10^{-8}	3.92×10^{-5}	8.02×10^{-7}	7.10×10^{-11}	1.64×10^{-5}	6.89×10^{-10}	5.65×10^{-5}
		Adult	1.06×10^{-9}	2.16×10^{-8}	1.67×10^{-5}	3.43×10^{-7}	3.05×10^{-11}	7.06×10^{-6}	2.96×10^{-10}	2.41×10^{-5}
DDSS	Ingestion	Children	3.13×10^{-5}	0.007	0.010	0.002	7.07×10^{-6}	2.87×10^{-4}	2.63×10^{-5}	0.019
		Adult	3.13×10^{-5}	7.09×10^{-4}	1.08×10^{-3}	1.96×10^{-4}	7.57×10^{-7}	3.07×10^{-5}	2.80×10^{-6}	0.002
	Dermal	Children	1.06×10^{-8}	1.48×10^{-5}	3.40×10^{-4}	1.23×10^{-6}	7.13×10^{-8}	2.40×10^{-6}	2.93×10^{-8}	3.59×10^{-4}
		Adult	2.67×10^{-9}	3.73×10^{-6}	8.57×10^{-5}	3.10×10^{-7}	1.80×10^{-8}	6.09×10^{-7}	7.41×10^{-9}	9.04×10^{-5}
	Inhalation	Children	1.05×10^{-9}	2.70×10^{-7}	4.02×10^{-5}	1.22×10^{-6}	2.69×10^{-10}	3.49×10^{-5}	9.90×10^{-10}	7.66×10^{-5}
		Adult	4.48×10^{-10}	1.16×10^{-7}	1.72×10^{-5}	5.23×10^{-7}	1.15×10^{-10}	1.49×10^{-5}	4.25×10^{-10}	3.27×10^{-5}
BDSS	Ingestion	Children	8.60×10^{-5}	0.005	9.03×10^{-3}	0.001	9.80×10^{-7}	8.80×10^{-5}	8.30×10^{-6}	0.015
		Adult	9.21×10^{-7}	5.80×10^{-4}	9.67×10^{-4}	1.51×10^{-4}	1.05×10^{-7}	9.43×10^{-6}	8.90×10^{-7}	0.002
	Dermal	Children	2.89×10^{-9}	1.21×10^{-5}	3.03×10^{-4}	9.46×10^{-7}	9.88×10^{-9}	7.39×10^{-7}	9.33×10^{-9}	3.17×10^{-4}
		Adult	7.30×10^{-10}	3.07×10^{-6}	7.67×10^{-5}	2.38×10^{-7}	2.48×10^{-9}	1.87×10^{-7}	2.35×10^{-9}	8.02×10^{-5}
	Inhalation	Children	2.86×10^{-10}	2.21×10^{-7}	3.60×10^{-5}	9.37×10^{-7}	3.73×10^{-11}	1.08×10^{-5}	3.13×10^{-10}	4.79×10^{-5}
		Adult	1.22×10^{-10}	9.48×10^{-8}	1.54×10^{-5}	4.02×10^{-7}	1.59×10^{-11}	4.61×10^{-6}	1.35×10^{-10}	2.05×10^{-5}
PDSS	Ingestion	Children	6.04×10^{-5}	9.03×10^{-3}	8.73×10^{-3}	0.002	9.73×10^{-6}	2.61×10^{-5}	2.83×10^{-4}	0.020
		Adult	6.47×10^{-6}	9.66×10^{-4}	9.37×10^{-4}	1.86×10^{-4}	1.04×10^{-6}	2.80×10^{-6}	3.03×10^{-5}	0.002
	Dermal	Children	2.03×10^{-8}	2.02×10^{-5}	2.93×10^{-4}	1.17×10^{-6}	9.80×10^{-8}	2.19×10^{-7}	3.16×10^{-7}	3.15×10^{-4}
		Adult	5.13×10^{-9}	5.10×10^{-6}	7.42×10^{-5}	2.96×10^{-7}	2.85×10^{-8}	5.54×10^{-8}	7.98×10^{-8}	7.98×10^{-5}
	Inhalation	Children	2.01×10^{-9}	3.66×10^{-7}	3.48×10^{-5}	1.16×10^{-6}	3.70×10^{-10}	3.19×10^{-6}	1.07×10^{-8}	3.95×10^{-5}
		Adult	8.61×10^{-10}	1.58×10^{-7}	1.49×10^{-5}	4.96×10^{-7}	1.58×10^{-10}	1.37×10^{-7}	4.70×10^{-9}	1.57×10^{-5}
Control	Ingestion	Children	2.81×10^{-5}	1.05×10^{-3}	1.06×10^{-4}	1.53×10^{-4}	7.50×10^{-5}	4.11×10^{-5}	1.59×10^{-6}	0.001
		Adult	3.01×10^{-6}	1.13×10^{-4}	1.14×10^{-5}	1.64×10^{-5}	8.03×10^{-6}	4.41×10^{-6}	1.71×10^{-7}	1.56×10^{-4}
	Dermal	Children	9.46×10^{-9}	2.36×10^{-6}	3.58×10^{-6}	1.03×10^{-7}	7.57×10^{-7}	3.57×10^{-7}	1.79×10^{-9}	7.24×10^{-6}
		Adult	2.39×10^{-9}	5.98×10^{-7}	9.03×10^{-7}	2.60×10^{-8}	1.92×10^{-7}	8.75×10^{-8}	4.52×10^{-10}	1.81×10^{-6}
	Inhalation	Children	9.35×10^{-10}	4.31×10^{-8}	4.23×10^{-7}	1.02×10^{-7}	2.85×10^{-9}	5.03×10^{-6}	6.04×10^{-11}	5.60×10^{-6}
		Adult	4.01×10^{-10}	1.85×10^{-8}	1.82×10^{-7}	4.37×10^{-8}	1.22×10^{-9}	2.15×10^{-6}	2.59×10^{-11}	2.39×10^{-6}

The result of the HQ and HI tabulated in **Table 9** revealed that the highest individual target Hazard Quotient (HQ) of the dumpsites was contributed by Pb while the least was Zn. However, the hazard quotients of all the heavy metals measured in both water and soil samples across the dumpsites were less than one (<1), the related standard limit by USEPA. This indicates less non-carcinogenic risks present in the samples or acceptable levels of non-carcinogenic health risks. It was observed that, higher HQ values were revealed for children compared to adults, similar observation was also reported by [39]. Similarly, hazard index (HI) of the analyzed heavy metals in the soil sample from the dumbsites were below the acceptable safe level of one (<1) as set by USEPA. This indicated that there is no likelihood of non-carcinogenic health risks effects [40]. [41] also reported Hazard Index of less than one (< 1) in the soil samples but [42] [43] reported an elevated hazard index estimate above the acceptable safe level.

Table 10. Carcinogenic risk assessment of selected heavy metals in soil samples.

		Carcinogenic Risk Assessment			
Sample Site	Pathways	Recipients	Pb	Cr	Cd
FDSS	Ingestion	Children	3.69×10^{-7}	2.52×10^{-6}	1.03×10^{-7}
		Adult	1.65×10^{-7}	1.13×10^{-6}	4.59×10^{-8}
	Dermal	Children	1.24×10^{-10}	1.69×10^{-9}	3.46×10^{-11}
		Adult	1.31×10^{-10}	1.78×10^{-9}	1.52×10^{-12}
	Inhalation	Children	1.40×10^{-11}	9.58×10^{-11}	3.91×10^{-12}
		Adult	2.51×10^{-11}	1.71×10^{-10}	7.0×10^{-12}
DDSS	Ingestion	Children	1.98×10^{-6}	2.59×10^{-6}	1.57×10^{-7}
		Adult	8.86×10^{-7}	1.16×10^{-6}	6.99×10^{-8}
	Dermal	Children	6.66×10^{-10}	1.75×10^{-9}	5.27×10^{-11}
		Adult	7.01×10^{-10}	1.84×10^{-9}	5.54×10^{-11}
	Inhalation	Children	7.54×10^{-11}	9.87×10^{-11}	5.95×10^{-12}
		Adult	1.35×10^{-10}	1.76×10^{-10}	1.06×10^{-11}
BDSS	Ingestion	Children	1.62×10^{-6}	2.32×10^{-6}	1.21×10^{-7}
		Adult	7.24×10^{-7}	1.04×10^{-6}	5.38×10^{-8}
	Dermal	Children	5.45×10^{-10}	1.56×10^{-9}	4.05×10^{-11}
		Adult	5.73×10^{-10}	1.64×10^{-9}	4.26×10^{-11}
	Inhalation	Children	6.16×10^{-11}	8.83×10^{-11}	4.54×10^{-12}
		Adult	1.10×10^{-10}	1.58×10^{-10}	8.19×10^{-12}
PDSS	Ingestion	Children	2.71×10^{-6}	2.25×10^{-6}	1.49×10^{-7}
		Adult	1.21×10^{-6}	1.00×10^{-6}	6.65×10^{-8}
	Dermal	Children	9.09×10^{-10}	1.51×10^{-9}	5.01×10^{-11}
		Adult	9.57×10^{-10}	1.59×10^{-9}	5.27×10^{-11}

Continued

	Inhalation	Children	1.03×10^{-10}	8.54×10^{-11}	5.66×10^{-11}
		Adult	1.84×10^{-10}	1.53×10^{-10}	1.01×10^{-11}
Control	Ingestion	Children	3.17×10^{-7}	2.74×10^{-8}	1.32×10^{-8}
		Adult	1.41×10^{-7}	1.22×10^{-8}	5.87×10^{-9}
	Dermal	Children	1.06×10^{-10}	1.84×10^{-11}	4.42×10^{-12}
		Adult	1.12×10^{-10}	1.94×10^{-11}	4.65×10^{-12}
	Inhalation	Children	1.20×10^{-11}	1.04×10^{-12}	4.99×10^{-13}
		Adult	2.15×10^{-11}	1.86×10^{-12}	8.94×10^{-13}

Table 10 present Carcinogenic Risk Assessment (CRA) of the soil sample showed that, carcinogenic risk assessment of the heavy metals in the dumpsites across the age groups and entry routes ranged from 2.71×10^{-6} to 7.54×10^{-11}; 2.59×10^{-6} to 9.87×10^{-11} and 1.57×10^{-7} to 8.19×10^{-12} for Pb, Cr and Cd respectively. All the values reported in this study were low risk (CR < 1) and below the [39]. This may be due to low activities of the heavy metals assessed at the dumpsite. Therefore, soils around the dumbsites are safe from cancer for both adults and children. A related outcome was stated by [44] and [45] who specified cancer risk to be of low value. The carcinogenic risk levels for children and adult generally fell within the acceptable range for carcinogens, which typically ranges from 10^{-6} to 10^{-4} according to [46] Li *et al.,* (2017). This finding is similar with the work previously reported by [47] but contradict the work of [48].

3.4. Reconciliation of Ecological and Human Health Risk Assessments

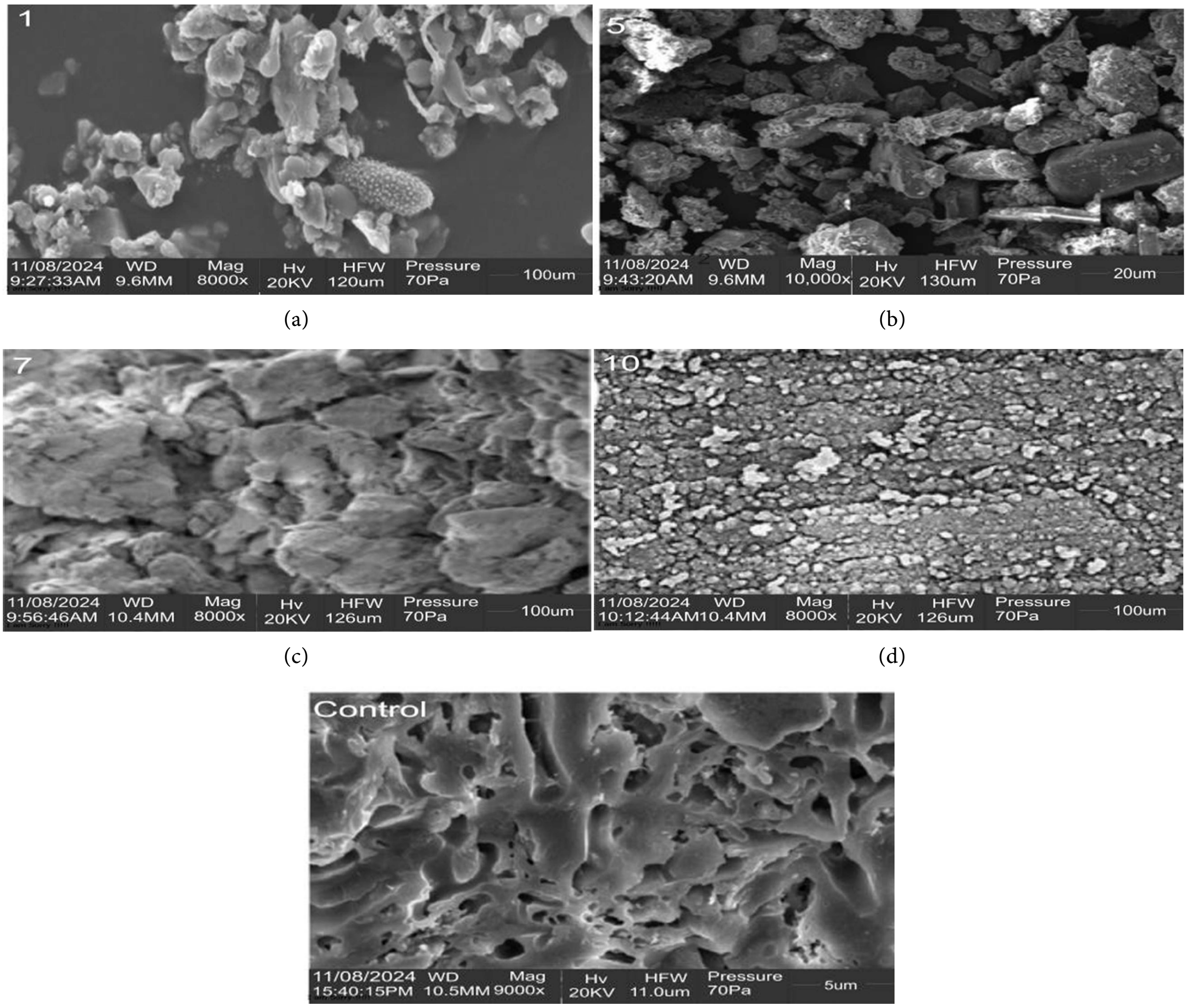
The apparent discrepancy between high ecological risk (RI = 488 – 1134) and low human health risk stems from their distinct assessment frameworks. Ecological risk reflects the total metal concentration and its inherent toxicity to soil ecosystems, indicating significant degradation and potential for biodiversity loss. In contrast, human health risk is based on specific, current exposure pathways (ingestion, dermal, inhalation), which presently result in a daily intake below harmful thresholds.

However, the low human health risk is conditional. The high ecological contamination represents a latent public health threat. Persistent metals like Pb, Cd, and Cr can bioaccumulate in crops and livestock, potentially entering the food chain at concentrations far exceeding direct soil exposure. Furthermore, changes in land use—such as agricultural expansion, residential development, or groundwater use—could create new exposure pathways.

Thus, while current exposure levels are low, the degraded soil ecosystem poses a clear future risk. Preventive measures, such as restricting agriculture and settlement on these sites, are urgently needed to mitigate potential health impacts from bioaccumulation or altered land use. Continuous monitoring is recommended.

4. Chemical Characterization SEM

The results of the surface morphology are presented in **Figure 1** and it shows that SEM analysis of the soil samples were grain like micro aggregates which could be as a result to fragmentation and leaching of contents for FDSS, BDSS and DDSS while that of the PDSS and the control sample appear compact with irregular shape.



(a) (b)

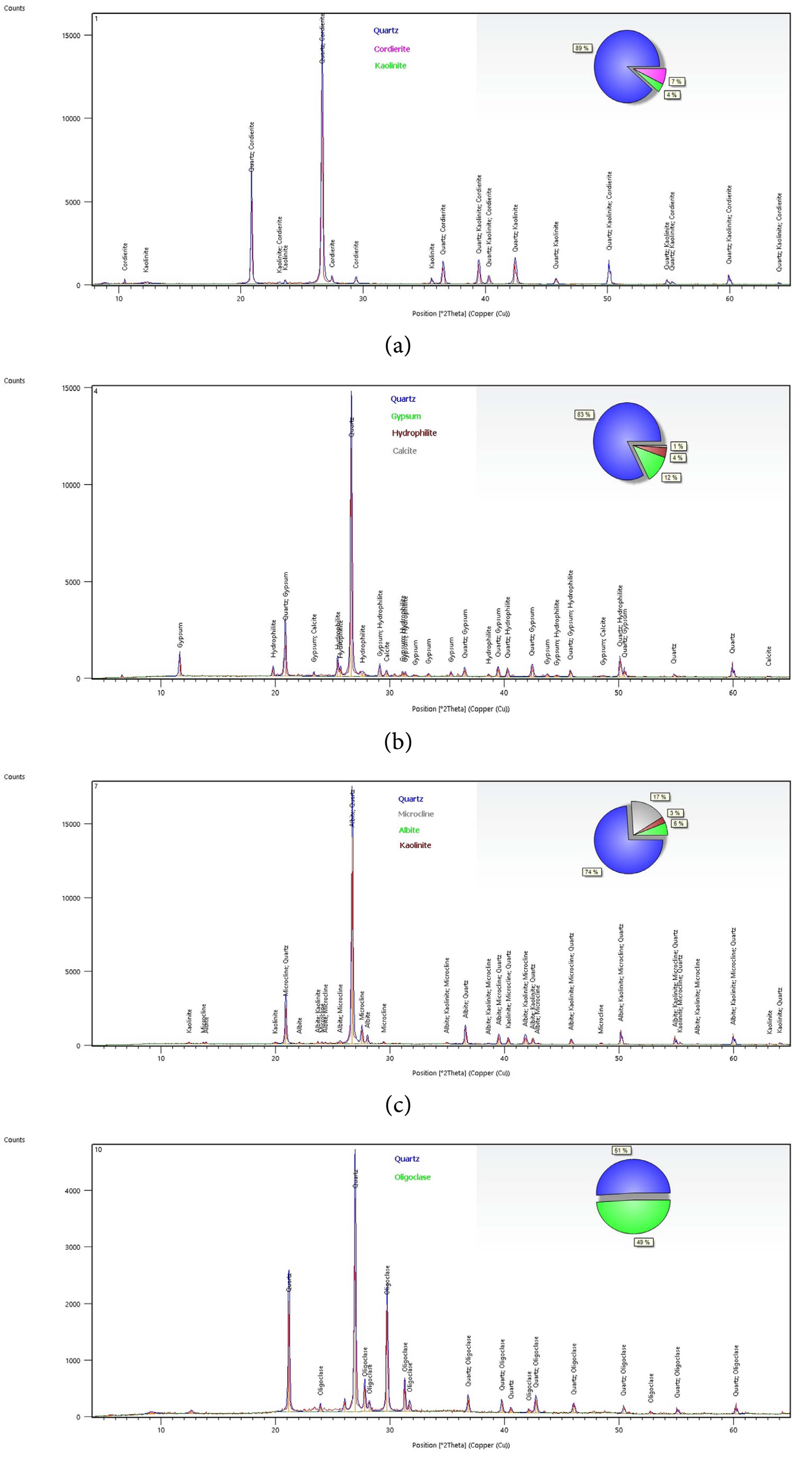
(c) (d)

(e)

Figure 1. (a) SEM Image of FDSS at 8000×; (b) SEM Image of BDSS at 10,000 Magnification Magnification; (c) SEM Image of PDSS at 8000× Magnification; (d) SEM Image of DDSS at 8000× Magnification; (e) SEM Image of Control at 9000× Magnification.

XRD

The XRD results of the soil samples collected from various dumbsites are presented in **Figure 2** and tabulated in **Table 10**. The results showed that the main chemical compositions in FDSS are predominantly composed of quartz (89%), cordierite (7%) and kaolinite (4%); BDSS contains quartz (83%), gypsum (12%), Hydrophite (4%) and calcite (1%); PDSS is composed of quartz (74%), microcline (17%), albite (6%) and kaolinite (3%); DDSS composed of quartz (51%) and oligoclase (49%) while the control sample has the following composition quartz (92%) and albite (8%). The results of the crystallite size are presented in **Table 10**.

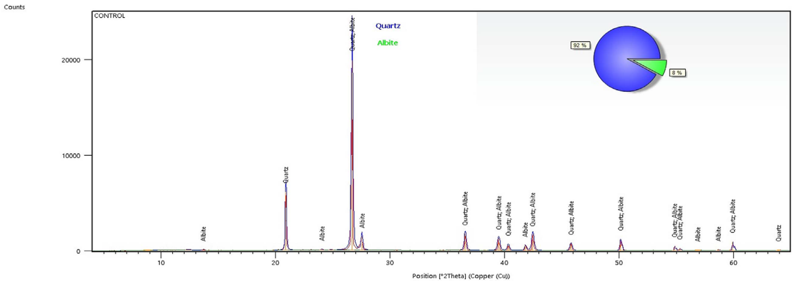


(a)

(b)

(c)

(d)



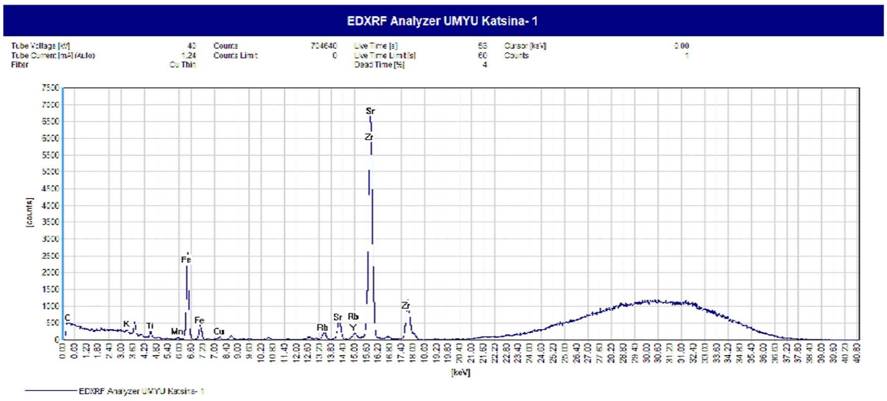
(e)

Figure 2. XRD Measurement of FDSS; (b) XRD Measurement of BDSS; (c) XRD Measurement of PDSS; (d) XRD Measurement of DDSS; (e) XRD Measurement of Control Soil Sample.

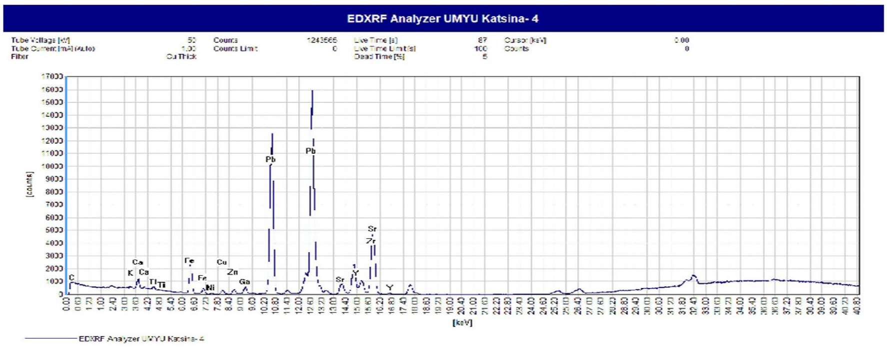
Figure 3 present elemental composition of FDSS, DDSS, BDSS, PDSS and the Control samples. The result presents the XRF it shows that, the major elements are Ca, Fe, K, Mn, Ti while these Sr, Zr, Rb, Cu, Pb, Sn, Zn are the minor elements. Pb, Cu and Zn present in the dumbsites are also toxic for human health across the sampling sites.

5. Conclusion

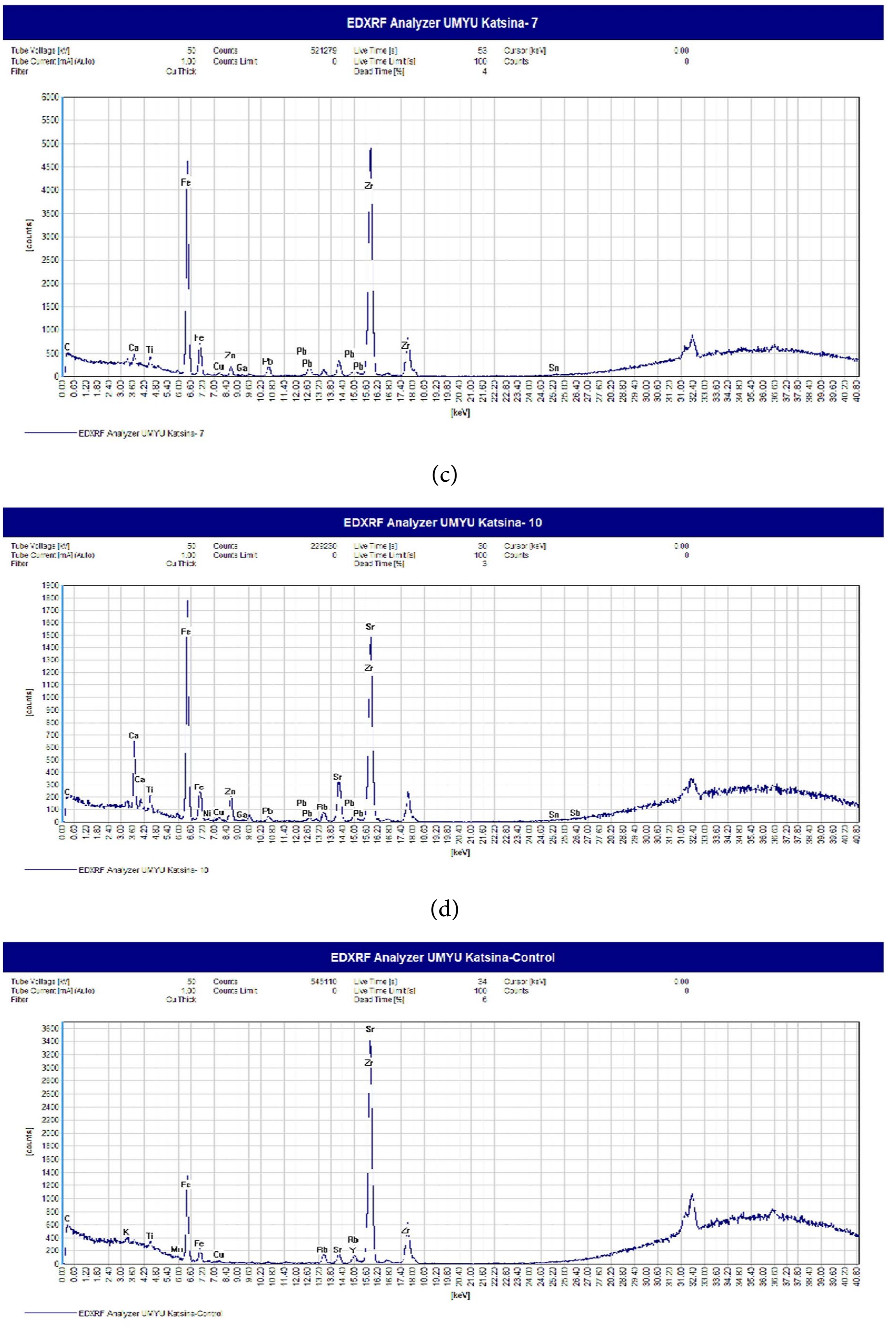
This study investigated the ecological and human health risk assessment of soils and water samples from vicinities of fertilizer, dye, batteries and paint dumpsites.



(a)



(b)



(c)

(d)

(e)

Figure 3. (a) XRF Measurement of FDSS; (b) XRF Measurement of DDS; (c) XRF Measurement of BDSS; (d) XRF Measurement of PDSS; (e) XRF Measurement of Control sample.

The soil samples were investigated for their physicochemical parameters; pH, Conductivity, Organic matter, PO_4^{3-}, and NO_3^-. The SEM analysis of the soil samples revealed grain like micro aggregates which could be prone to fragmentation and leaching of contents for FDSS, BDSS and DDSS while that of the PDSS and the control sample appear compact with irregular shape. The XRF showed various elemental composition. The trend of heavy metals concentration in soil around the dumpsites was in this order: **Fe > Cr > Pb > Mn > Cu > Zn > Cd**. The contamination characteristics (geo-accumulation index, contamination factor, enrichment factor, degree of ecological risk index) of the soil samples ranged from low contamination to very high condition. It was observed that ingestion pathway constitutes the highest portion of chronic daily Intake of the heavy metals in all the dumpsites followed by dermal contact pathway for the case of the soil samples. The hazard quotients and hazard index of all the heavy metals across the dumpsites were less than one (<1), indicative that there is no likelihood of non-carcinogenic health risks effects. The results of the carcinogenic risk assessment revealed that, there were low or neglected chances of cancer risk across the age group (Children and Adults) for both ingestion, dermal and inhalation routes.

Conflicts of Interest

The authors declare no conflicts of interest.

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