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(Review Article)

Assessment of physicochemical properties and heavy metal contamination of soil at a central dumpsite in Effurun, Delta State, Nigeria

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Abstract

This study assessed the physicochemical characteristics and heavy metal contamination of soil at a central dumpsite in Effurun, Delta State, Nigeria. Soil samples were collected from three locations within the dumpsite and analyzed for parameters such as pH, nitrogen, phosphorus, particle size distribution, bulk density, pore size, and concentrations of heavy metals (Cr, Zn, Cd, Pb, Mn, Fe, Ni). Results revealed a predominantly sandy texture (mean sand content: 72.40%) with low clay content (10.41%), contributing to high infiltration and leaching potential. The pH was slightly acidic (mean: 5.5), enhancing the mobility of heavy metals. Nitrogen (3.15%) and phosphorus (1.49 mg/kg) levels were elevated, likely due to organic waste decomposition. Heavy metal concentrations varied widely, with chromium (25.72 mg/kg), cadmium (9.21 mg/kg), and lead (36.64 mg/kg) exceeding WHO and FEPA limits, indicating potential risks to groundwater and human health. Spatial analysis showed significant variability among sampling locations, and correlation analysis revealed strong associations between clay content and metal accumulation. Compared to a control site, dumpsite soils showed elevated levels of organic matter, electrical conductivity, and metal concentrations. The findings underscore the environmental impact of improper waste disposal and highlight the need for regular monitoring and remediation strategies to safeguard soil and water resources.

Keywords: Solid Waste Management; Soil Quality; Physicochemical Parameters; Dumpsite; Effurun; Heavy Metals; Nigeria

1. Introduction

The global population is projected to reach 10 billion by the year 2050 [1]. Nigeria, being the most populous country in Africa and the eighth in the world, has over 140 million people as of the 2006 census [1, 2]. Rapid population growth contributes significantly to increased waste generation and, consequently, environmental pollution. As long as human life continues, waste production is inevitable. Every human activity, be it production or consumption — utilizes raw materials and generates waste. These wastes differ in composition, size, nature, and environmental impact. Regardless of their form, the end result is often pollution of the environment.

Historically, soils have served as the primary sinks for solid waste disposal, especially in urban and peri-urban areas [3]. Modern civilization, through its industrial, commercial, agricultural, and domestic activities, continuously produces solid waste that eventually finds its way into the air, soil, and water bodies, thereby disrupting natural ecological processes. While the visible accumulation of waste is aesthetically unpleasant, it also leads to environmental degradation [4, 5]. Soil pollution occurs when excessive quantities of substances are introduced into the soil, impairing

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the health of organisms and diminishing the soil's functionality. Soil degradation through pollution threatens food security, biodiversity, and public health [5].

The soil is not only a physical foundation for plant growth but also a vital component of biogeochemical cycling. As pollutants accumulate in soil, the balance of natural cycles is disrupted, with implications for ecosystem health and sustainability [6]. Waste, a by-product of human activity, is influenced by several socio-economic and cultural factors, including income levels, population density, and consumption patterns. The volume and complexity of waste have increased over time, reflecting changes in lifestyles and economic development.

Municipal solid waste (MSW) in Nigeria commonly comprises organic, combustible, and non-combustible materials [7]. While in some cases waste materials can enhance soil fertility, prolonged disposal—especially of hazardous substances—can lead to contamination with heavy metals and other persistent pollutants [8]. In the case of the Central Dumpsite in Effurun, Delta State, waste materials from both residential and commercial sources are deposited indiscriminately, often without prior segregation. Hazardous materials such as used engine oil, solvents, pesticides, batteries, and chemical containers are frequently included [9].

These hazardous components leach into the soil, altering its physicochemical and biological properties. Leachates may carry heavy metals such as lead, cadmium, zinc, chromium, and nickel—metals known for their toxicity, persistence, and ability to bioaccumulate and biomagnify within food chains [10]. These elements, particularly at high concentrations, pose a risk not only to soil organisms and vegetation but also to human health through direct exposure or indirect ingestion via crops.

The growing urbanization and scarcity of arable land have led to the reclamation of former dumpsites for agriculture or residential purposes. Without proper remediation, such practices can expose humans to harmful pollutants. The threat posed by heavy metals and other toxicants from dumpsites necessitates periodic monitoring and comprehensive environmental assessment to ensure safety and sustainability. Unregulated dumping of waste at the Central Dumpsite in Effurun, Delta State, thus introduces hazardous substances into the soil, including heavy metals capable of polluting groundwater and accumulating in crops. With the increasing encroachment of urban development and the reduction of arable land, former dumpsites are often reclaimed for agriculture or habitation, posing a serious health risk.

- High concentrations of heavy metals are toxic to vegetation and can reduce agricultural productivity.
- These contaminants pose significant health hazards to both humans and animals through direct exposure and trophic transfer.
- The cost of reclaiming and remediating contaminated land is prohibitively high.
- Aesthetic degradation of the landscape further lowers the environmental and economic value of such areas.

Aim of Study

To determine the effect of some physicochemical parameters on soil quality at the Central Dumpsite, Effurun, Delta State. Specifically, the study;

- Investigated the presence of selected heavy metals in the soil.
- quantified the concentrations of heavy metals in soil samples from the dumpsite.
- Assessed and compared physicochemical parameters from dumpsite, effurun with samples from control site unaffected by waste dumping

The study focused on the collection and laboratory analysis of soil samples from the Central Dumpsite in Effurun. Parameters analyzed include physicochemical properties (pH, bulk density, texture, nitrogen, and phosphorus) and heavy metal concentrations (lead, chromium, zinc, cadmium, manganese, iron, and nickel). Comparisons will be made with samples from a control site unaffected by waste dumping.

2. Material and methods

2.1. Study Location

The study was conducted at a central dumpsite located in Effurun, Uvwie Local Government Area of Delta State, Nigeria. The geographic coordinates are latitude 5.5715700'N and longitude 5.7760200'E, with an elevation of approximately 9 meters above sea level. Delta State shares boundaries with Bayelsa State to the south, the Atlantic Ocean to the west, Southern Ondo State to the northwest, Edo State to the north, Rivers State to the southeast, Imo State to the east, and Anambra State to the northeast.

2.2. Population and Human Activities

Based on the 2006 National Population Census, Delta State has a population of approximately 4,098,391 [2, 11]. The predominant ethnic groups include the Urhobos, Itsekiris, Ijaws, and Isokos, alongside other ethnic minorities. The region's economy is driven by oil exploration, commerce, administration, banking and finance, information technology, transportation, academia, manufacturing, fishing, and agriculture. Major arable crops grown include cassava, yam, maize, cocoyam, pepper, tomatoes, groundnut, garden egg, and leafy vegetables, while tree and fruit crops include oil palm, mango, guava, citrus, and pawpaw [12].

2.3. Climate

Effurun is situated within the tropical rainforest zone and is characterized by abundant vegetation, high humidity, and heavy rainfall, largely due to its proximity to the equator. The area experiences an equatorial climate with two distinct seasons: a dry season (November–April), often influenced by the Harmattan winds, and a rainy season (May–October), typically interrupted by an August dry spell. Despite this, rainfall may still occur during the dry season. The mean annual temperature is around 32°C, with an average annual rainfall of 2600 mm [12].

2.4. Vegetation and Land Use

The study area is largely influenced by anthropogenic activities, leaving only fragments of natural vegetation. The landscape comprises a mix of arable farmlands, tree crop plantations, and patches of indigenous flora. Scattered palms, raffia palms, and other economic and medicinal plants are commonly found throughout the area.

2.5. Geology

The soils in the Niger Delta region, including the study area, are primarily hydromorphic—poorly to imperfectly drained [13]. This is owing to the low relief of the floodplains. These soils are derived from alluvial and marine deposits, with textures ranging from coarse sands on barrier ridges to finer sediments toward tidal zones. Soil types include entisols and inceptisols (USDA classification) or regosols and cambisols (FAO classification). Well-drained riverine soils are typically brown to greyish-brown sandy loams, while tidal mudflat soils are finer, more acidic, and organic-rich. Salinity is elevated near the coast due to tidal inundation.

2.6. Relief and Drainage

The Niger Delta, which includes Effurun, is one of Nigeria's major relief regions. It is drained by a network of rivers, including the Niger, Ase, Ethiope, Warri, Orashi, Sombreiro, New Calabar, and Imo Rivers. Historical data (prior to dam constructions) indicated an annual discharge of 182×10^9 m^3 at Onitsha and 176×10^9 m^3 at Aboh, with the Forcados branch handling 59% of the Aboh discharge [13]. The Atlantic Ocean contributes saline water, which seasonally infiltrates the delta. Water temperatures typically range from 22°C to 30°C year-round.

2.7. Sampling and Research Design

- A systematic random sampling approach was employed using a Completely Randomized Design (CRD) for soil sample collection. Three composite samples were obtained from three designated sites:
- **Site A**: Soil from waste deposited approximately 3 years ago
- **Site B**: Soil from waste deposited for about 10 years
- **Site C**: Control site, approximately 3 km from Site B

Each composite sample was obtained from a depth of 0–30 cm and collected at about 11:30 a.m. in early March.

2.8. Sample Collection

Soil samples were collected from the dumpsite at depths of 0–15 cm and 15–30 cm. Control samples were obtained from a non-contaminated site 500 meters away. A total of 12 composite soil samples were prepared for laboratory analysis.

2.9. Secondary Data

Secondary data were sourced from the following institutions:

- Ministry of Lands and Survey, Delta State

- Federal Ministry of Environment (FME)
- Department of Environmental Technology, FUTO
- Delta State University Library
- Delta State Environmental Protection Agency
- Ministry of Agriculture, Delta State
- Federal University of Technology Owerri Library
- Petroleum Training Institute, Effurun

2.10. Primary Data

Primary data were derived from laboratory analyses conducted on the soil samples collected from the dumpsite and the control site.

2.11. Laboratory Analysis

The following physicochemical parameters were analyzed using standard methods:

- **pH** – Measured in a 1:2.5 soil-water suspension using a pH meter.
- **Electrical Conductivity (EC)** – Measured using a conductivity meter.
- **Organic Matter (OM)** – Determined by Walkley-Black titration method.
- **Total Nitrogen (TN)** – Assessed using the Kjeldahl method.
- **Available Phosphorus (P)** – Extracted using Bray-1 solution and analyzed colorimetrically.
- **Heavy Metals (Pb, Cd, Zn, Cu)** – Analyzed using Atomic Absorption Spectrophotometry (AAS) after acid digestion.

2.12. Soil pH Determination

- Apparatus: pH meter, litmus paper, thermometer

2.12.1. Procedure

A 20 g of sieved, air-dried soil was mixed with 40 ml of distilled water in a beaker. After stirring for 10 seconds and allowing the suspension to stand for 30 minutes, the pH was measured using a calibrated electrode.

2.13. Total Nitrogen Determination (Kjeldahl Method)

2.13.1. Apparatus and Reagents

Includes digestion/distillation racks, Kjeldahl flasks, sulphuric acid, catalyst mixture, and sodium hydroxide.

2.13.2. Procedure

5 g of soil was digested with concentrated H_2SO_4 and catalyst mixture, cooled, diluted, and distilled. The distillate was titrated with standardized NaOH. A blank determination was also performed.

2.13.3. Calculation

$$\%N = ((B - A)/C) \times N \times D \times (1/1000) \times 100$$

Where A = sample titration, B = blank, C = sample weight, N = normality of NaOH, D = 14 mg/meq

2.14. Available Phosphorus

2.14.1. Procedure

Aliquots were treated with reagents and absorbance measured at 880 nm using a spectrophotometer. A calibration curve was used to determine phosphorus concentration.

Heavy Metal Determination (Pb, Cr, Zn, Cd, Mn, Fe, Ni)

Apparatus: Atomic Absorption Spectrophotometer (AAS)

2.14.2. Procedure

Samples were aspirated after calibration with standard solutions. Concentrations were read directly or from calibration curves.

2.15. Particle Size Distribution

2.15.1. Procedure

A hydrometer method was used. Soil was dispersed, stirred, and placed in a cylinder. Hydrometer readings were taken after 40 seconds and 2 hours.

2.15.2. Calculation

$$\% \text{ Silt} = [(H_1 + 0.3(T_1 - T_0) - 2.0) \times 100]/50$$

$$\% \text{ Clay} = [(H_2 + 0.2(T_2 - T_0) - 2.0) \times 100]/50$$

$$\% \text{ Sand} = 100 - (\% \text{ Silt} + \% \text{ Clay})$$

2.16. Bulk Density

2.16.1. Procedure

5 g of soil was added to a burette containing water. The displaced volume was used to calculate bulk density:

Bulk Density = $5 / (X_2 - X_1)$

2.17. Infiltration Rate

2.17.1. Procedure

Soil-filled funnels were placed in graduated cylinders. Equal volumes of water were poured through, and infiltration rates monitored over time. Pore volume was estimated by measuring air trapped.

2.18. Statistical Analysis

Descriptive statistics such as mean, range, standard deviation, and standard error were computed using SPSS (v17.0) and MS Excel. One-way ANOVA was applied to test for significant differences among means, while Pearson's correlation coefficient was used to assess inter-parameter relationships. Graphical visualizations and means plots were also generated to further interpret data trends.

3. Results

Table 1 Variations in Physicochemical parameters

PARAMETERS	Min	Max	Range	Mean	S.D	SE	FEPA Standard
pH	5.0	6.3	1.3	5.5	0.54	0.18	-
Nitrogen %	2.06	3.91	1.85	3.15	0.73	0.24	-
Phosphorus (mg/kg)	1.17	1.80	0.63	1.49	0.24	0.08	-
Silt %	15.10	18.80	3.70	17.19	1.32	0.44	-
Clay %	10.12	10.90	0.78	10.41	0.28	0.09	-
Sand %	70.60	74.40	3.80	72.40	1.31	0.44	-
Bulk density g/l	2.01	2.36	0.35	2.15	0.11	0.04	-
Pore size %	26.70	29.70	3.00	27.90	0.89	0.30	-
Cr (mg/kg)	4.22	42.42	38.20	25.72	15.21	5.07	0.03

Zn (mg/kg)	7.39	25.36	17.97	17.80	7.47	2.49	-
Cd (mg/kg)	0.52	14.60	14.08	9.21	6.49	2.16	0.01
Pb (mg/kg)	8.56	55.20	46.64	36.64	20.56	6.85	0.05
Mn (mg/kg)	0.66	12.49	11.83	7.51	5.02	1.67	-
Fe (mg/kg)	15.20	77.84	62.64	50.46	26.49	8.83	-
Ni (mg/kg)	0.82	15.11	14.29	9.54	6.55	2.18	0.10

Narrow variations were observed in some of the parameters analyzed. These include; pH which varied between 5.0 and 6.3 (5.5 ± 0.18), Nitrogen varied between 2.06% and 3.91% (3.15 ± 0.24), Phosphorus varied between 1.17 m/kg and 1.80 m/kg (1.49 ± 0.08), Silt content varied between 15.10% and 18.80% (17.19 ± 0.44), Clay content between 10.12% and 10.90% (10.41 ± 0.09), Sand content 70.60% and 74.40% (72.40 ± 0.44), while Bulk density varied between 2.01g/l and 2.36g/l (2.15 ± 0.04) and Pore size between 26.70% and 29.70% (27.90 ± 0.30) respectively (table 1). However, wide variations were also observed in some parameters analyzed. They include chromium which varied between 4.22 mg/kg and 42.42 mg/kg (25.72 ± 5.07), zinc varied between 7.39mg/kg and 25.36 mg/kg (17.80 ± 2.49), cadmium varied between 0.52 mg/kg and 14.60 mg/kg (9.21 ± 2.16). Others include lead 8.56 mg/kg and 55.20 mg/kg (36.64 ± 6.85), manganese between 0.66 mg/kg and 12.49 mg/kg (7.51 ± 1.67), iron varied between 15.20 mg/kg and 77.84 mg/kg (50.46 ± 8.83) and nickel varied between 0.82 mg/kg and 15.11 mg/kg (9.54 ± 2.18) respectively as shown in table 1

3.1. Spatial Changes in Mean of Physical and Chemical Parameters

Spatial variations were observed in the physical and chemical parameters measured. For textural classification, silt composition was highest in sampling location B (18.6%), while least value was recorded in sampling location A (15.73%), clay composition was highest in sampling location A (10. 53%), while least value (10.19%) was recorded in sampling location C, and for sand composition, location A had highest value (73.73%), while least value (70.90%) was recorded in location B (fig. 1).

The highest pH value was recorded at location C (6.2) while least value was recorded at location B (5.1). However, for soil macronutrient, nitrogen recorded highest value (3.72%) at location B, while least value (2.20%) was recorded at sampling location C, phosphorus has it highest value at location A (1.64 mg/kg) while least value (1.20 mg/kg) was recorded at location C (Fig. 2).

Bulk density recorded highest value (2.26g/l) at location A, while least value (2.04g/l) was recorded at location B, pore size revealed (28.68%) at location A as its highest value, while least value (26.97%) was recorded at location B (fig. 3).

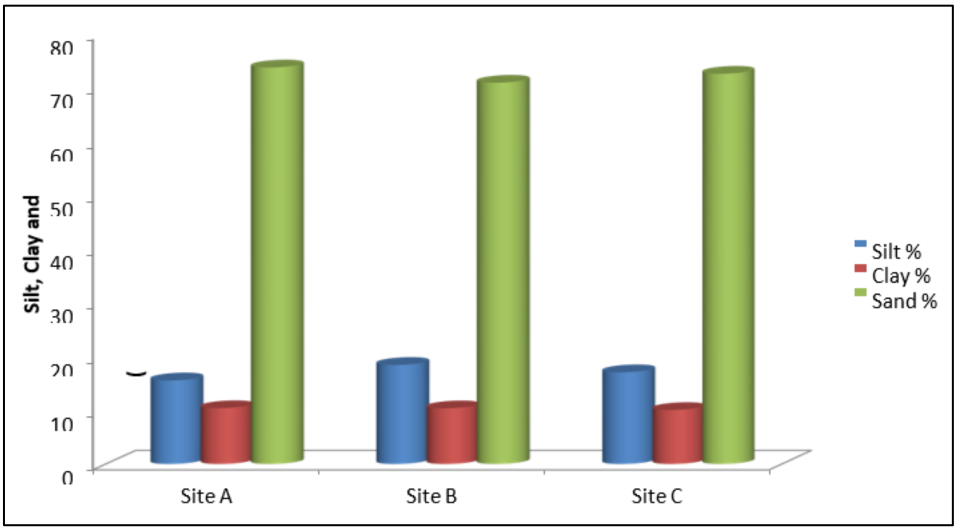

Figure 1 Spatial variation in mean of Silt, Clay and Sand content

For heavy metal classification, chromium and zinc have their highest values (39.44 and 22.69) mg/kg at location A while least values (6.11 and 8.10) mg/kg) at location C, while cadmium has its highest value (13.57 mg/kg) at location B and least value (0.61 mg/kg) at location C (fig. 4). Lead had highest value (52.87 mg/kg) at location B while least value (9.49 mg/kg) was recorded at location C. However, manganese and iron have their highest value (11.16 and 71.54) mg/kg at location A, while least values (0.89 and 15.62) mg/kg were recorded at location C respectively (fig. 5). Although, nickel also has its highest value (14.85) mg/kg at location A and least value (0.89mg/kg) at location C.

Results show that sand was highest in the three sites, followed by silt and lastly clay.

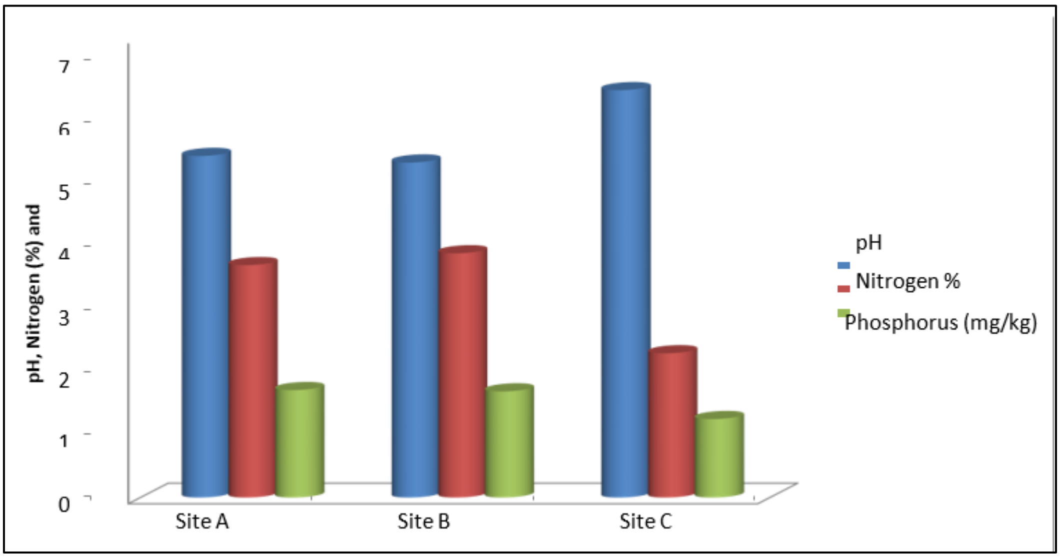

Figure 2 Spatial variation in mean pH, Nitrogen and Phosphorus content

Results here showed that in the three sites A B and C pH is highest followed by nitrogen and phosphorus.

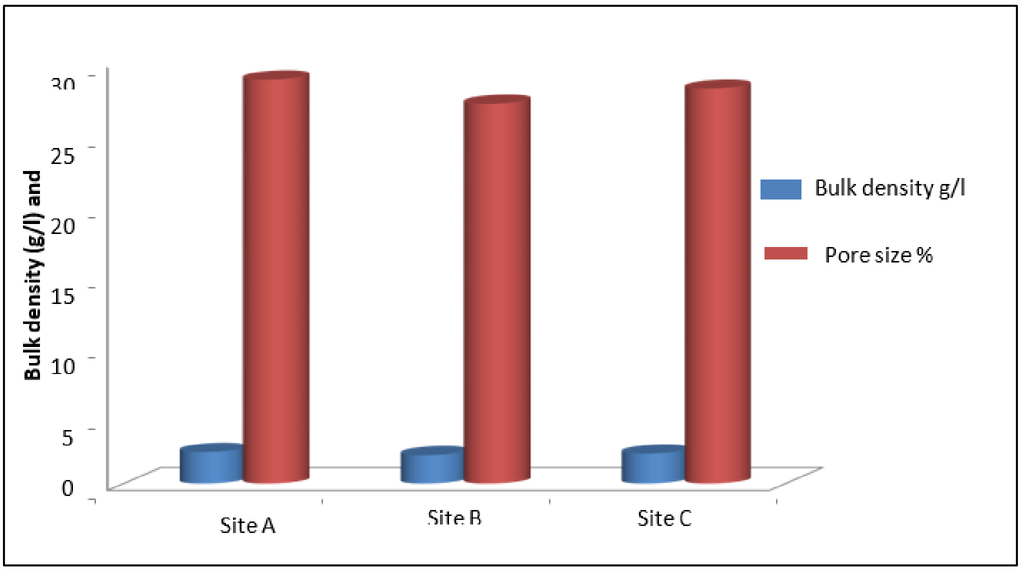

Figure 3 Spatial variation in mean of Bulk density (g/l) and Pore size (%)

In fig 3 Mean variation in bulk density(g/l) and pore size (%), the three sites had very high bulk density and low pore size.

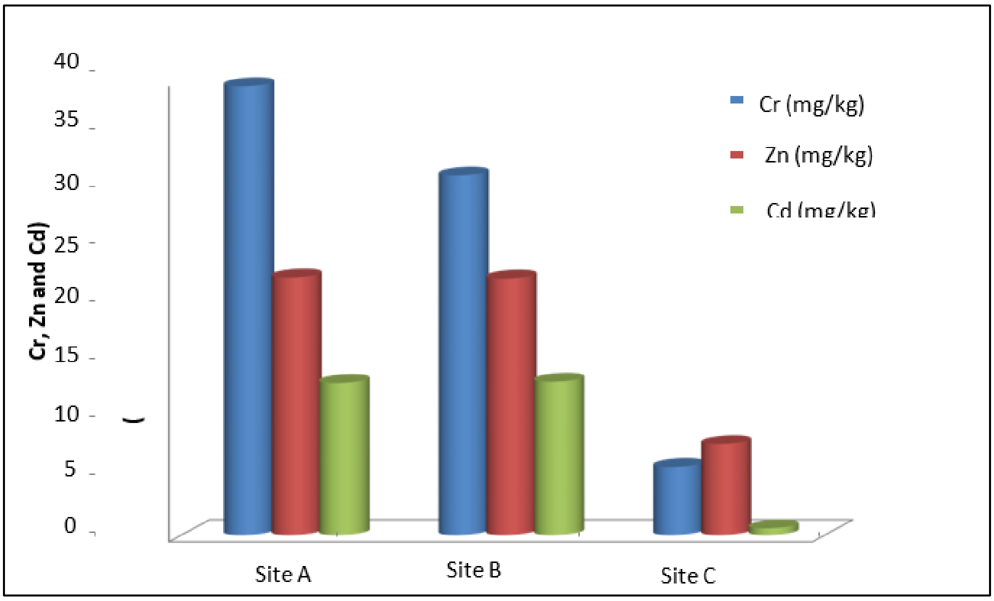

Figure 4 Spatial variation in mean of Cr, Zn and Cd content

Results on Spatial variation in mean of Cr, Zn and Cd content showed that in sites A and B cr and zinc were highest followed by cadnuim while in site C, zinc was highest, followed by cr and lastly by cadnuim.

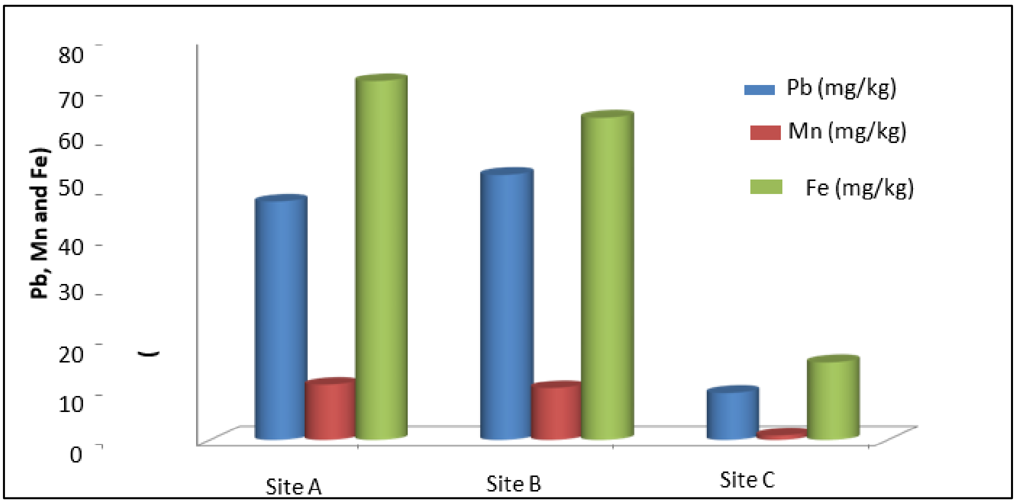

Figure 5 Spatial variation in mean of Pb, Mn and Fe content

Spatial variation in mean of Pb, Mn and Fe content showed that lead is highest in site A site B and site C .

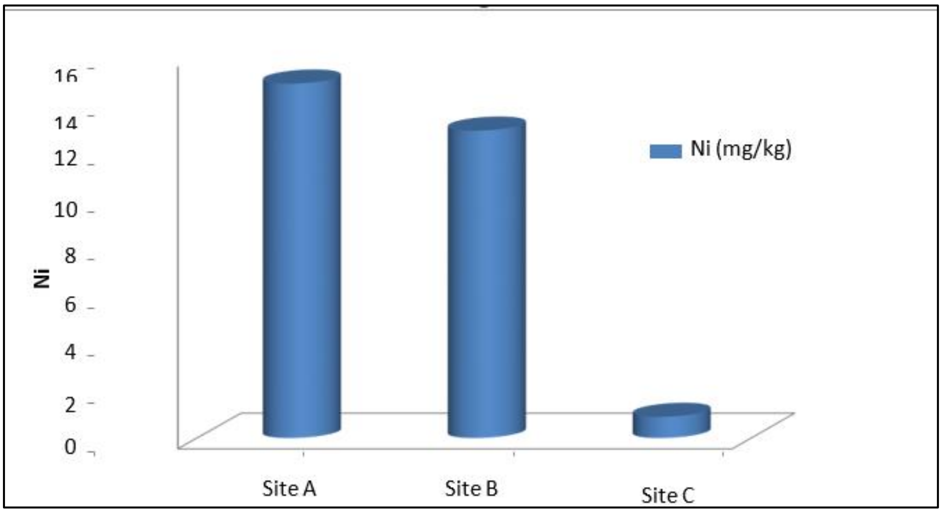

Figure 6 Spatial variation in mean of Ni content

Spatial variation in mean of Ni content revealed that Ni was highes in site A followed by site B and lastly by site C

3.2. Test of Homogeneity

The test of homogeneity of variance in means of the physical and chemical parameters revealed significant spatial inequality $F_{(29.73)} > F_{crit(3.95)}$ at $P < 0.05$ across the sampling sites. Further structure detection of group means using means plots, and using site C as the predictor variable, revealed that sand, iron, lead and chromium were most responsible for the observed heterogeneity (figs. 7 and 8).

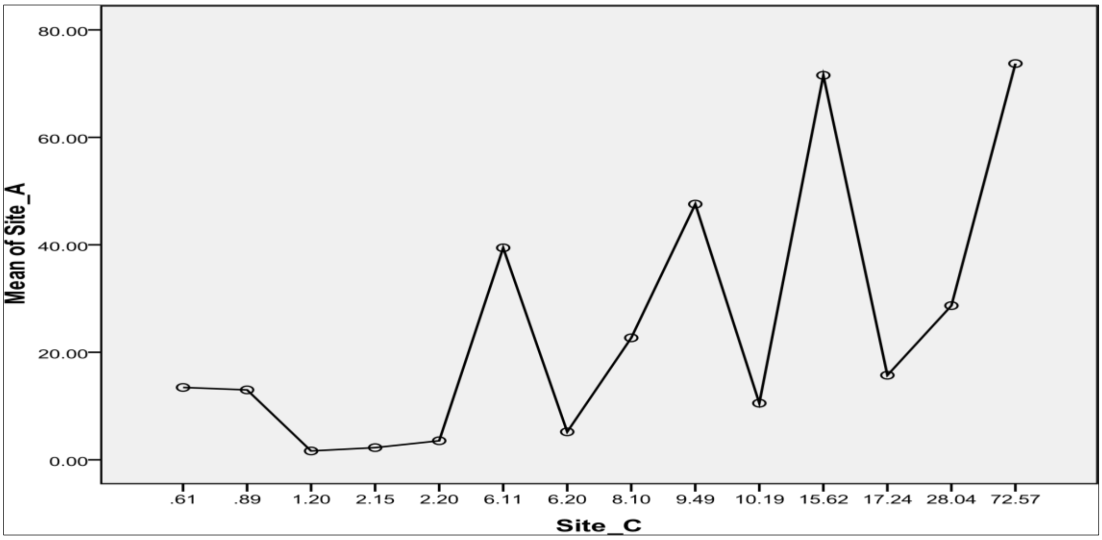

Figure 7 Structure of group means plot (Site A)

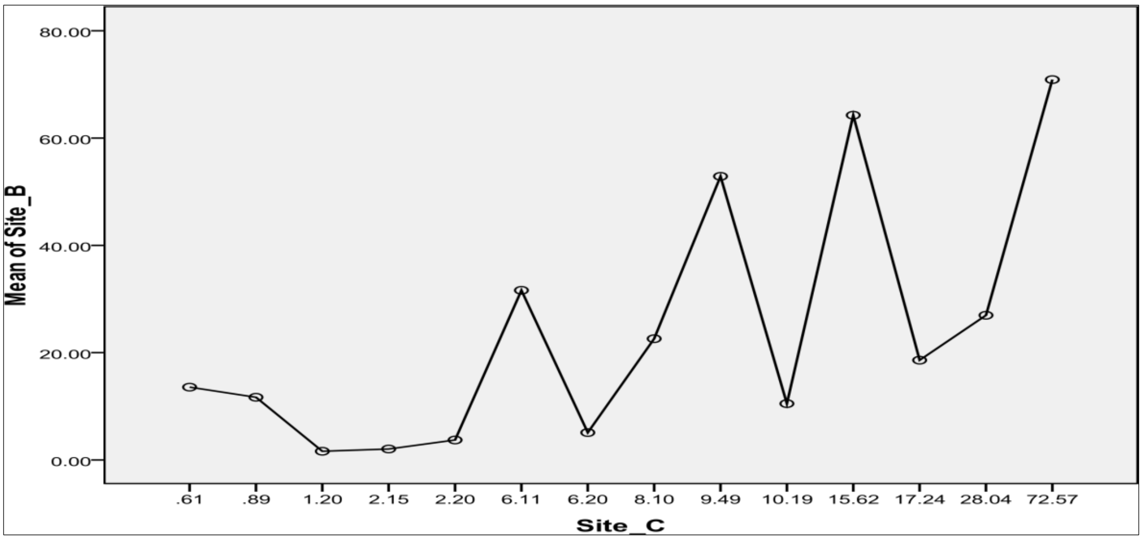

Figure 8 Structure of group means plot (Site B)

3.3. Relationship between the Physical and Chemical Parameters

Several parameters correlated with one another as shown in table 2. At P < 0.05 i.e. 95% confidence limit, phosphorus correlated positively with clay (r = 0.999), zinc (r = 0.99), cadmium (r = 0.999) and manganese (r = 1.000). Clay correlated with zinc (r = 0.997), manganese (r = 1.000), iron (r = 0.999) and nickel (r = 0.999). Sand correlated with pore size (r = 0.999). Zinc correlated with manganese (r = 0.999). Cadmium correlated with manganese (r = 0.998). Manganese correlated with iron (r = 0.998) and nickel (r = 0.997). However, negative correlations were also observed between pH and nitrogen, cadmium and lead, between silt and bulk density at P<0.05. Other correlations were observed with lead (r = 1.000). Zinc correlated with cadmium (r = 1.000), and iron correlated with nickel also at (r = 1.000).

Table 2 Comparative differences in Physicochemical Parameters between Sites

Parameter	Dumpsite (Mean ± SD)	Control Site (Mean ± SD)	WHO Limit
pH	6.5 ± 0.2	7.0 ± 0.1	6.0–8.0
EC (µS/cm)	410 ± 35	210 ± 18	-
OM (%)	6.7 ± 0.4	2.6 ± 0.3	-
TN (%)	0.41 ± 0.03	0.13 ± 0.01	-
P (mg/kg)	18.2 ± 1.5	8.7 ± 0.9	-
Pb (mg/kg)	73.5 ± 6.4	18.1 ± 2.0	50
Cd (mg/kg)	1.9 ± 0.2	0.3 ± 0.1	3
Zn (mg/kg)	112.4 ± 9.7	45.3 ± 3.5	300
Cu (mg/kg)	48.2 ± 4.1	19.8 ± 2.2	100

4. Discussion

The assessment of physicochemical parameters from the central dumpsite revealed considerable variability in both physical and chemical characteristics of the soil across different sampling locations. These variations are indicative of the nature, extent, and duration of waste disposal activities at the site.

4.1. Soil Physicochemical Characteristics

The soil pH ranged from 5.0 to 6.3 (mean: 5.5 ± 0.18), indicating slightly acidic conditions. Acidic soils are known to influence the solubility and mobility of heavy metals, potentially increasing their bioavailability. Macronutrients such as nitrogen (2.06–3.91%, mean: 3.15 ± 0.24) and phosphorus (1.17–1.80 mg/kg, mean: 1.49 ± 0.08) were present in moderately high concentrations, which may be attributed to the presence of decomposed organic waste and refuse of agricultural origin.

Soil texture across all sampling sites was dominated by sand (70.60–74.40%, mean: 72.40 ± 0.44), followed by silt (15.10–18.80%, mean: 17.19 ± 0.44) and clay (10.12–10.90%, mean: 10.41 ± 0.09). This composition suggests good permeability but low water retention and nutrient-holding capacity. Bulk density values (2.01–2.36 g/l, mean: 2.15 ± 0.04) and pore size (26.70–29.70%, mean: 27.90 ± 0.30) further support the sandy nature of the soil, which may facilitate leaching of contaminants into deeper layers or surrounding groundwater systems.

4.2. Heavy Metal Concentrations

Heavy metals exhibited wide variations in concentration. Chromium ranged from 4.22 to 42.42 mg/kg (mean: 25.72 ± 5.07), zinc from 7.39 to 25.36 mg/kg (mean: 17.80 ± 2.49), and cadmium from 0.52 to 14.60 mg/kg (mean: 9.21 ± 2.16). Lead (8.56–55.20 mg/kg), manganese (0.66–12.49 mg/kg), iron (15.20–77.84 mg/kg), and nickel (0.82–15.11 mg/kg) also showed marked spatial differences. The high levels of these metals, some of which exceeded permissible limits set by FEPA and WHO (e.g., Pb and Cd), raise concerns about the potential ecological and human health impacts of the dumpsite, particularly in terms of soil contamination, bioaccumulation, and groundwater pollution.

4.3. Spatial Variation Across Sampling Sites

Significant spatial differences in physicochemical properties were observed across the three sampling locations:

- **Location A** exhibited the highest sand (73.73%) and clay (10.53%) content, along with elevated concentrations of Cr, Zn, Mn, Fe, and Ni, suggesting a concentration of metallic and industrial waste.
- **Location B** recorded the highest levels of nitrogen (3.72%) and cadmium (13.57 mg/kg), as well as lead (52.87 mg/kg), likely due to a higher proportion of organic and battery-related waste.
- **Location C**, by contrast, consistently had the lowest values for most parameters, possibly due to lower waste load or improved natural attenuation.

The test of homogeneity of variances revealed statistically significant spatial heterogeneity ($F = 29.73 > F_{crit} = 3.95$, $P < 0.05$). Structure plots showed that sand, iron, lead, and chromium were the primary contributors to this observed variation.

4.4. Correlations Among Parameters

Correlation analysis revealed strong positive relationships between several parameters. Phosphorus correlated positively with clay ($r = 0.999$), zinc ($r = 0.990$), cadmium ($r = 0.999$), and manganese ($r = 1.000$), suggesting shared sources or synergistic interactions in soil retention and mobility. Similar strong correlations were noted among clay, zinc, manganese, iron, and nickel, indicating interlinked behavior and possibly similar geochemical pathways. Conversely, negative correlations between pH and nitrogen, and between cadmium and lead, suggest complex interactions possibly influenced by competing adsorption or pH-mediated mobility.

4.5. Comparison with Control Site

When compared with a nearby control site, the dumpsite soils showed significantly higher values across most parameters. Notably, organic matter (6.7 ± 0.4%), total nitrogen (0.41 ± 0.03%), and phosphorus (18.2 ± 1.5 mg/kg) were substantially elevated at the dumpsite compared to the control (2.6 ± 0.3%, 0.13 ± 0.01%, and 8.7 ± 0.9 mg/kg, respectively). Heavy metals such as lead (73.5 ± 6.4 mg/kg), cadmium (1.9 ± 0.2 mg/kg), and zinc (112.4 ± 9.7 mg/kg) also far exceeded their respective values at the control site and, in some cases, surpassed international safety thresholds.

Many factors influence soil quality, particularly its physical properties such as structure, texture, infiltration and water-holding capacity, air permeability, and bulk density. These properties play crucial roles in determining the soil's suitability for various uses [14].

The results obtained in this study revealed a high sand content (72.40%) and a low clay content (10.41%), which corresponded with a relatively large pore size (27.90%). Soils with high sand and low clay content typically exhibit greater infiltration and leaching capacities, making them more prone to groundwater contamination. The clay fraction, which acts as an impermeable barrier, is significantly low in this case, thereby facilitating rapid water movement and potential pollutant transport into aquifers. These findings align with the work of Nyles and Ray (2019), who reported similar outcomes in sandy soils, highlighting the elevated risk of leaching and pollution.

The pH values recorded in this study were slightly acidic, a condition that can enhance the solubility and mobility of heavy metals in the soil. This increased mobility presents a higher risk of groundwater contamination. Comparable findings were reported by the Niger Delta Environmental Survey (NDES, 1997) in the Sombreiro-Effurun Deltaic Plains, supporting the current study's results [14].

Two essential macronutrients—nitrogen (3.15%) and phosphorus (1.49 mg/kg)—were analyzed. Their elevated levels in the dumpsite soils are likely due to the substantial presence of organic and biodegradable waste, including animal waste. These nutrient concentrations, combined with the over-application of fertilizers in surrounding agricultural lands, contribute to eutrophication in aquatic ecosystems and groundwater contamination through surface runoff and infiltration.

Soils naturally contain trace levels of heavy metals; however, elevated concentrations can pose serious risks to human, animal, and plant health. While some trace metals are essential in small amounts, excessive levels can be hazardous. Human exposure may occur through the ingestion of edible plants that absorb metals, the consumption of plants contaminated with metal-laden soil particles, or direct ingestion of soil—particularly by children.

To manage these risks, the United States Environmental Protection Agency (USEPA, 2002) has established threshold values for heavy metals in soils to guide remediation decisions. Table 3 compares the average concentrations of heavy metals found in the study area with standards from USEPA, the Federal Environmental Protection Agency (FEPA), and the World Health Organization (WHO).

All the heavy metals assessed in this study were within USEPA permissible limits. However, they exceeded the much lower FEPA and WHO thresholds, suggesting potential environmental and health risks. Notably, there are currently no universally agreed-upon safe metal concentration limits for soils in vegetable gardens (Hanlon et al., 2003). Previous compilations by Moen et al. (1986), the UK Department of Environment (1987), the Canadian Council of Ministers of the Environment (1992), and MAAF [15] indicate that regulatory standards for heavy metals vary widely between countries.

Chromium levels were found to be relatively high (25.72 mg/kg), likely due to its extensive industrial use in electroplating and alloy manufacturing. Chromium in its hexavalent form is especially concerning due to its carcinogenic properties.

Zinc concentration was recorded at 17.80 mg/kg, slightly lower than the 27.2 mg/kg reported by Hardy et al. (2008) [13]. This discrepancy may be attributed to differences in environmental conditions and waste management practices. The presence of zinc in the dumpsite is consistent with its application in galvanization and other industrial processes.

Cadmium was detected at a mean concentration of 9.21 mg/kg, surpassing FEPA and WHO safety guidelines. It likely originates from industrial sources such as pigments, electroplating, and battery production. Cadmium is known to be toxic and carcinogenic at elevated levels.

Lead concentrations were relatively high (36.64 mg/kg), which may be due to its widespread use in lead-acid batteries, pigments, and dyes. Lead is a persistent environmental contaminant and a cumulative toxin in mammals.

Manganese levels (7.51 mg/kg) are likely linked to its industrial applications, particularly in electroplating. Nickel (9.54 mg/kg) and iron (50.46 mg/kg) were also present at significant levels. Nickel is commonly used in alloy production, while iron is a basic component of many industrial and domestic materials. The variation between this study's findings and those of Hardy et al. (2008) [16] may result from differences in environmental settings and waste handling efficiency.

5. Conclusion

This study has shown that the central dumpsite in Effurun, Delta State, has significantly impacted the physicochemical characteristics and heavy metal concentrations of the surrounding soil. The predominance of sandy soil with low clay content increases porosity and infiltration, which in turn facilitates the leaching of contaminants into groundwater. The recorded acidic pH enhances the solubility and mobility of toxic metals, thereby posing a serious threat to groundwater quality and public health. Notably, the concentrations of chromium, cadmium, and lead exceeded the permissible limits set by WHO and FEPA, suggesting potential environmental and health risks. Spatial variation and strong correlations among parameters indicate that waste type and distribution greatly influence soil contamination patterns. Comparisons with a control site further confirmed that the elevated nutrient and metal levels are largely due to anthropogenic activities, particularly the indiscriminate dumping of waste.

To mitigate these impacts, several recommendations are proposed. Authorities should enforce stricter regulations on waste segregation and disposal at dumpsites. Soil remediation strategies, such as phytoremediation and amendments, should be employed to reduce metal accumulation. Regular monitoring of soil and groundwater is essential to track contamination trends. Public awareness campaigns on proper waste management are also crucial. Ultimately, relocating or upgrading the dumpsite to a well-managed sanitary landfill is recommended to protect environmental and human health.

Compliance with ethical standards

Disclosure of conflict of interest

Authors declare that no conflict of interest exist in the original work submitted to this journal

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] U.N (2018). Population of Nigeria. <http//:www.un.org/../wp 2008_highlights. Pdf>/Retrieved 28-08-2011.

[2] National Population Commission NPC (2015). Nigeria's census figure.

[3] Afolabi, T.A. and Ogundiran, O. (2018). Assessment of the Physicochemical Parameters and Heavy Metals Toxicity of Leachates from Municipal Solid Waste, Open Dumpsites. Journal of Applied Science and Environmental Management, 5(2):243-350.

[4] Agwu, E.I.C., (2015). Environmental Sciences, A planner's view 1st Ed. Mishbet (Nigeria) Limited, Festac Town, Lagos, Nigeria.

[5] Mbagwu (2018). Pollution of the soil ecosystem is a major source of soil degradation. Int. J. Environ. Sci. Tech., 6(3), 337-346.

[6] Adewole (2008). Soil Ecosystem Comm. Soil Sci. Plant Anal., 34 (17-18), 2419-2439.

[7] Isirimah, N.O. (2012). Understanding the Nature, Properties and Sources of Wastes for Quality Environment. Tom & Harry Publication Ltd. Port-Harcourt Nigeria pp. 6,22 and 144.

[8] Nyles, C. B. and Ray, R. N. (2019). The nature and properties of soils. 12th eds. United states of America pp743-785.

[9] Chatterjee, A. K. (2010). Water Supply, Waste Disposal and Environmental Engineering, Khanna, New Delhi. P. 205.

[10] Uchegbu, A. N. (2015). Environmental Management and Protection. Precision Publishers Enugu, Nigeria. P. 108 – 133.

[11] USEPA (2020). Supplemental guidance for developing soil screening levels for superfund sites. Office of solid waste and emergency response, Washington, D.C.

[12] World Bank (2015). Environmental and Socio-Economic Characteristics of the Niger Delta. World Bank Report on the Niger Delta Region of Nigeria.

[13] Wagner, H. Richard (2024). Environment and Man. Toronto: W.W. Norton and Company, Inc. p. 54 – 55.

[14] Khitoliza, R. K. (2014). Environmental pollution, management and control for sustainable development. 1st ed., S. Chand (ed.) S. Chand and Co. Ltd., New Delhi. P. 309.

[15] Kiely, G. (2017). "Environmental Engineering International Edition McGraw Hill International Ltd. UK. P. 623 – 642.

[16] Linsley, R. K. and Joseph, B. E. (2015). "Soil and Water Resource Engineering" McGraw Hill Book Company. P. 416 – 533.