

ZIBELINE INTERNATIONAL™  
P U B L I S H I N G

ISSN: 2521-0920 (Print)

ISSN: 2521-0602 (Online)

CODEN: MJGAAN

DOI: <http://doi.org/10.26480/mjg.01.2026.09.19>

## RESEARCH ARTICLE

**GEOCHEMICAL AND MINERALOGICAL CHARACTERIZATION OF SOME SELECTED DUMPSITE SOILS IN BENIN CITY NIGERIA: IMPLICATIONS FOR ENVIRONMENTAL AND HUMAN HEALTH RISKS**Omorogieva<sup>a</sup>, Osakpolor Marvellous Ilevbare<sup>a</sup>, Martins Badmus<sup>b\*</sup>, Ganiyu Olabode<sup>c</sup><sup>a</sup>Department of Marine Geology, Nigeria Maritime University, Delta State, Nigeria<sup>b</sup>Department of Geology, Afe Babalola University, Ado Ekiti, Nigeria<sup>c</sup>Department of Mathematical and Physical Sciences, Afe Babalola University, Ado-Ekiti, Nigeria\*Corresponding Author Email: [martins.ilevbare@abuad.edu.ng](mailto:martins.ilevbare@abuad.edu.ng)

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## ARTICLE DETAILS

## Article History:

Received 19 October 2025

Revised 27 November 2025

Accepted 15 December 2025

Available online 23 January 2026

## ABSTRACT

In some metropolitan districts of Benin City, Nigeria, dumpsites were studied to determine the concentration of some major and trace elements as well as the health implications to the residents and agricultural activities. Various compounds found in dumpsites have the potential to harm both people and the environment when they seep into the ground. The impact on individuals and anthropogenic activities was evaluated using 45 soil samples (15 from each dumpsite) that were taken from a bored borehole at different depths. Iron, calcium, potassium, titanium, and manganese were the major elements examined of which iron had the highest concentration (reaching 26149 mg/l) of the group. In soil, iron toxicity may prevent the uptake of vital trace elements, but in people, it can cause cell death and gastrointestinal system degradation. Some of the trace elements analysed included ; zirconium, yttrium, zinc, vanadium, nickel, strontium, etc., with zirconium, zinc and nickel having highest average concentration values (497ppm, 65.67ppm and 43.3ppm respectively). These metals at toxic concentrations result in respiratory illnesses, diarrhoea, and other symptoms. The XRD results show that the minerals found in the dumpsites include; quartz, kaolinite, halloysite, zircon, albite, calcite, anatase and hematite of which quartz, kaolinite and haematite were the most common. The composite bar chart data for Otofure had percentages 38%, 25%, 16%, 12% and 9% for quartz, kaolinite/halloysite, hematite, zircon and anatase respectively. Relevant recommendations were made to policy makers, public health practitioners and the general public in managing dumpsites to minimize health risks.

## KEYWORDS

Dumpsites, health risk, public health, respiratory illness, seepages.

## 1. INTRODUCTION

Waste is defined as any unwanted object that resembles trash or garbage or items that the owner does not perceive to be value. Municipal solid wastes are undesirable items that come from municipalities in the form of solid waste. Large amounts of home, municipal, and industrial trash are produced as a result of the growing global population and the high industrial activity that goes along with it (Sadeghi et al., 2020). In underdeveloped nations like Nigeria, non-sanitary landfilling, especially open tipping dumpsites, is the most widely used waste management technique. For the proper handling of municipal solid wastes, non-engineered and unmanaged landfills without suitable bottom liners, leachate collection systems, or treatment systems are often used. A municipal solid waste dumpsite is not a healthy storage for trash; rather, it is a biochemically active area where hazardous materials are slowly released into the environment over through leaching (Essien et al., 2019). Due to this, landfill leachates have been produced, which are particularly harmful to the environment due to their high levels of inorganic and organic pollutants. Any material drained from degraded garbage is

referred to as leachate. When water combines mostly with accumulated waste at dumpsites, landfill leachates are created (Gujre et al., 2021). According to several studies, leachates typically contain xenobiotic organic materials (such as PAHs, halogenated organic compounds, pharmaceuticals, etc.), virulent microorganisms, resulting organic pollutants, heavy metals, and other inorganic compounds (Jagaba et al., 2021 ; Luo et al., 2020). These leachates frequently end up in soils, subterranean water, open water bodies, and other biophysical elements of the ecosystem, where they have a negative impact on people, aquatic life, flora and fauna. The generation of compounds containing hazardous substances as a result of the inappropriate removal, combustion, or degradation of some wastes is a significant modern problem. This could cause certain chemical pollutants like major and trace elements, which tend to build up in the soil beyond the permissible limit, to degrade the soil. Most hazardous elements passed into the ecosystem are thought to be absorbed by soils (Sulaiman et al., 2019). As a result, frequent dumping of municipal solid waste on soil could raise its toxic element content. Currently, there have been a significant increase in global awareness of the environmental issue of soil pollution caused by trace metals (Okoro et al.,

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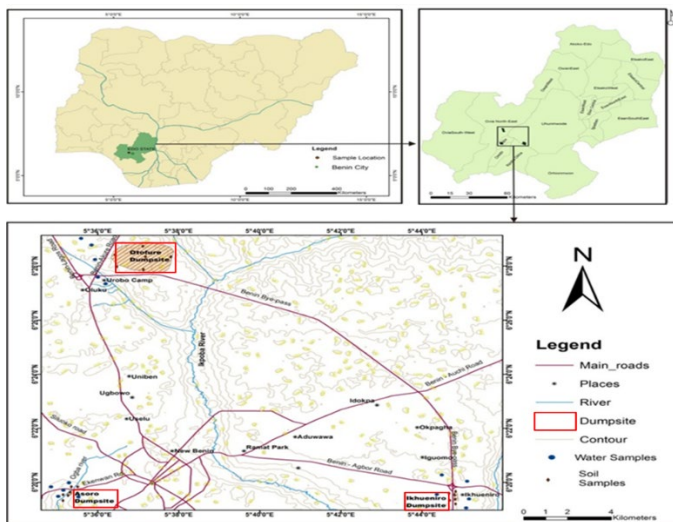
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10.26480/mjg.01.2026.09.19

2020). Using a variety of methods, research studies have assessed the effects of garbage disposal facilities on the ecosystem (Badmus et al., 2022). Due to their toxicity, non-compostable characteristics and bioaccumulation tendencies, some main elements and trace metals, such as potassium, calcium, molybdenum, iron, zinc, vanadium, strontium etc., constitute huge environmental concern (Mohanty and Das, 2021). These pollutants are formed as a result of the presence of potentially harmful elements and other ions at waste disposal sites and a likelihood that these pollutants will migrate to uncontaminated areas, endangering the health of people living nearby. Chest aches, tetanus, dengue fever, diarrhea, infections of the skin, typhoid fever, cholera, dysentery and eczema are a few of the possible negative health effects that could result from human exposure to polluted water. Humans are especially susceptible to the harmful effects of zinc when they are exposed through inhaling high amounts of zinc compounds either occupationally or inadvertently, such as those found in smoke bombs or metal fume fever (Kahal et al., 2021). This study aims to assess the effects of dumpsite on the health of the residents in Asoro (ASR), Ikhueniro (IKH) and Otufure (OTF) communities in Benin.

**1.1 Study Area**

The study area comprises of three dumpsite communities in Edo State. The location map and its accessibility are shown in Fig. 1. The study covers three Local Government Areas namely, Oredo, Ovia North-East, and Uhumwode. Asoro (ASR) component of the study belongs to Oredo (6° 19' 20" N, 005° 35' 20" E), Otufure (OTF) belongs to Ovia North-East (6° 27' 44.6"N, 005° 36' 03.9"E while Ikhueniro (IKH) is in Uhumwode (6° 19' 38.1"N, 005° 44' 50.2"E).



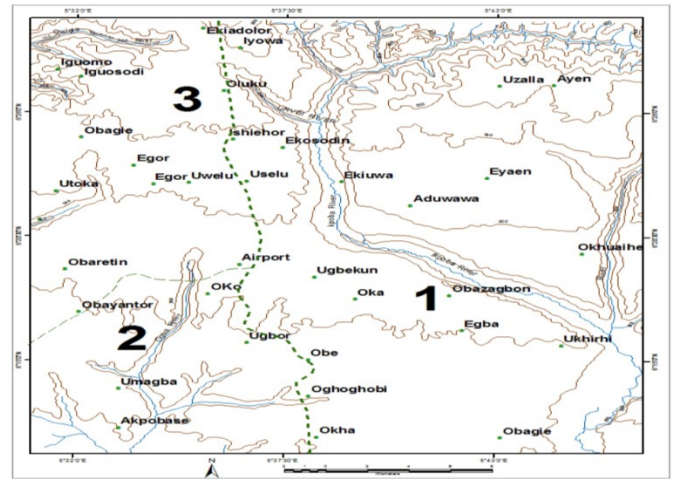
**Figure 1:** Map showing location of study area

**1.2 Location and Accessibility**

The lands are relatively accessible and in some places are lightly vegetated. The main roadways that provide access to the communities under consideration are the Benin - Agbor - Asaba road, the Benin - Auchu road, the Benin - Ekehuan road, and the Benin City bypass (Omorogieva, 2016). The research locations can also be reached via other footpaths and roads.

**1.3 Drainage**

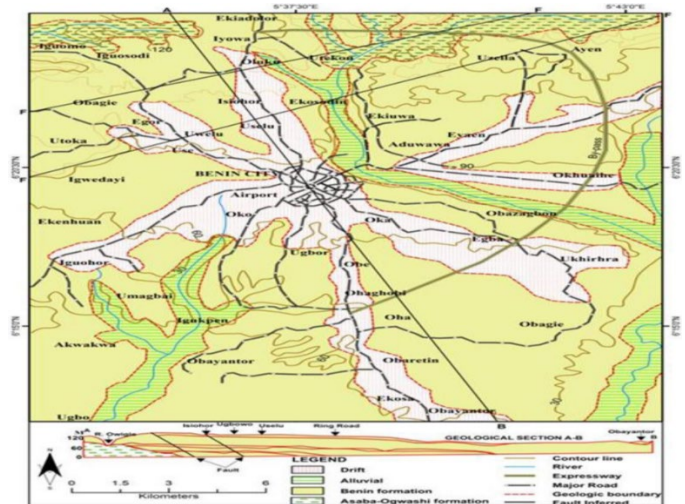
Benin City is drained by three (3) major river systems: The Ogba, Ikpoba, and Owegie-Ogbovben River systems (Akujieze, 2004 ; Ikhile, 2016). According to the highland region in the Ugbiyokho axis of the Ekehuan quarters served as the Ogba River's source (Ikhile, 2016). The river travels southwest for about 12 kilometers, is between 1 and 3 meters wide, and has an estimated size of 40 km<sup>2</sup> (Ikhile, 2016). However, the Owegie-Ogbovben River system drains the basin's northwest, as indicated by mark 3 in (Fig. 2). It is perennial and has an estimated area of 10 km<sup>2</sup>, just like the Ogba River. The Ikpoba River is the greatest of the rivers that drain the capital city of Benin. It originates in the northeastern part of the area, in the western highlands. The flow runs in an east-to-west direction, meanders at Utekon to flow southward through Ekosodin, Ugbowo, Okhoro, and the New Benin axis, and then joins Temboga before flowing through Ikpoba-Okha for 48 kilometers across its sub-drainage basin, which is estimated to be 722 kilometers in size. The drainage systems in the Benin region absorb surface and subsurface wastewater delivered by runoff and storm water, and they interact with the groundwater system.



**Figure 2 :** Benin region sub-basin extracted from Ikhile, 2016

**1.4 Local Geology**

According to several writers, the Benin Area is covered by the South Sedimentary Basin, a sedimentary formation that is typically identified by its top reddish earth, which is made up of laterized or ferruginized clayey sand and dips at an angle of 2° to 8° south (Ikhile, 2016, Akujieze, 2004). The phrase "Benin sand" to characterize the reddish earth that makes up the Paleo-Coastal Environment of the Paleocene-Pleistocene Era and is underlain by sands, sandy clays, and ferruginized sandstone (Parkinson, 1907). According to these sediments were exposed in Calabar, Owerri, Onitsha, and the Benin Region with the age Oligocene-Pleistocene (Tattam, 1943). Tattam used the name "Coastal plain sands" to describe the Formation (FM) of red earth underlain by sands and clays that mark an ancient coastal plain environment. To distinguish the reddish-brown-yellow, often white sands with clayey and pebbly layers with type-locality near Benin, the name Benin Formation (Reyment, 1965). The Formation was further established by the logging of the well drilled on shore by Shell Petroleum Development Company (SPDC) at the Elele1, 39km Northwest of Port Harcourt and defined the base of the Benin Formation by the first marine foraminifera within shales as the formation is non-marine in origin, (Short and Stauble, 1967). Fig. 3 shows the Geology of Benin City and neighbouring communities.



**Figure 3:** Geological map guide X-section A-B of Benin City and environs (Akujieze, 2004)

**2. MATERIALS AND METHODS**

**2.1 Samples Collection Techniques**

Forty-five (45) soil samples were collected at different depths of a drilled borehole, meticulously labeled and were immediately stored in Ziploc polyethylene bag and preserved at room temperature. Samples were air dried for about two weeks and later disaggregated using porcelain mortar and pestle. Samples were analysed geochemically for major elements, trace elements and heavy metals. Some of the equipment utilized for the field exercise included a GPS, a ruler and measuring tape, matches, sample bags, maker and masking tape, plastic bottles of nitric and sulphuric acid,

polythene bags, and field boots.

**2.2 X-ray Fluorescence Spectrometry (XRF)**

X-ray fluorescence spectrometry and instrumental neutron activation analysis were used for sample preparation, as well as major and trace element analysis, in accordance with Gary (2008). The major elements (K, Ca, Mn, Fe and Ti) as well as some trace elements (Ba, Sr, V, Th, Mo, Zn, Cr, Zr, Rb, Ta, Nb, Cu, Y, Ni and Co) were determined using Phillips PW-1800 X-ray fluorescence (XRF) analyser.

**2.3 X-ray Diffraction Study**

Additionally, X-ray diffraction studies on minerals were conducted as described by (Bundy, 1993). X-ray diffraction analysis (XRD) was used to determine the mineralogical composition of these samples. Representative samples from five different sandstone deposits were analysed to assess their whole-rock geochemical compositions.

**3. RESULTS AND DISCUSSION**

The results of the geochemical analysis are presented in tables and charts to facilitate clear and thorough data interpretation. The data is structured in the sequence of analysis for better comprehension.

**3.1 Major Elements Geochemistry of Asoro, Otofure, and Ikhueni Dumpsites**

Table 1 presents the concentrations of major elements in soil samples collected from the Asoro, Ikhueni, and Otofure communities. For Asoro community, analysis of the samples revealed that the concentration values of potassium (K) ranged from 25 - 3910 mg/L (at 15 - 30 and 0 - 15 cm respectively), calcium ranged from 25 - 13,545 mg/L (at 15 - 30 cm for both lowest and highest concentrations), manganese ranged from 84 - 405

mg/L (at 0 - 15 for both lowest and highest concentrations), iron ranged from 6448 - 38,588 mg/L with both the highest and lowest values at the depth of 0 - 15 cm and titanium ranged from 1951 - 13,972 mg/L (at a depth of 0 - 15 cm for both lowest and highest concentrations). The average concentrations of these elements in the Asoro community are 777 mg/L, 2742 mg/L, 214 mg/L, 26149 mg/L and 6583 mg/L for K, Ca, Mn, Fe and Ti respectively. The concentration trend followed the order: Fe > Ti > Ca > K > Mn.

In Otofure community, analysis of the soil samples revealed that the concentration values of potassium ranged from 25 - 19,353 mg/L with the lowest concentration at a depth of 15 - 30 cm, calcium ranged from 25 - 14,202 mg/L with a depth of 15 - 30 cm and 0 - 15 cm for the lowest and highest concentration respectively, manganese ranged from 3 - 410 mg/L with the highest concentration at a depth of 0 - 15 cm, iron ranged from 50 - 35,006 mg/L with highest concentration at 15 - 30 cm and titanium ranged from 20 - 7015 mg/L with the highest concentration at 15- 30 cm. The average concentrations in Otofure were 3129 mg/L, 1877 mg/L, 161 mg/L, 16,475 mg/L and 3,995 mg/L for K, Ca, Mn, Fe and Ti respectively, (Table 1). The concentration trend followed: Fe > Ti > K > Ca > Mn.

While in Ikhueni community, potassium ranged from 25 - 8714 mg/L (with the lowest concentration at 15 - 30 cm), calcium ranged from 25 - 46220 mg/L (with the lowest and highest concentrations at a depth of 15 - 30 cm and 0 - 15 cm respectively), manganese ranged from 15 - 362 mg/L (with the highest concentration at a depth of 0 - 15 cm), iron ranged from 50 - 44,455 mg/L (with its highest value at a depth of 15 - 30 cm) and titanium ranged from 20 - 9343 mg/L also having its highest value at a depth of 15 - 30 cm. The average concentrations were 1397 mg/L, 3830 mg/L, 152 mg/L, 19874 mg/L and 4487 mg/L for K, Ca, Mn, Fe and Ti respectively, (Table 1) and it increased in the order: Fe > Ti > Ca > K > Mn.

**Table 1: Major Elements of Soil Samples in Asoro, Otofure, Ikhueni Communities (in mg/L)**

Sample	Depth	K	Ca	Mn	Fe	Ti
<b>Asoro</b>						
ASR1	0-15	195	1581	114	26019	6048
ASR2	15-30	25	25	130	33787	8255
ASR3	15-30	25	25	128	28088	7609
ASR4	0-15	469	3259	164	27373	7366
ASR5	0-15	25	25	86	23126	5616
ASR6	15-30	509	423	125	29390	6888
ASR7	0-15	1892	8619	349	38588	13972
ASR8	15-30	1627	3146	321	36748	9955
ASR9	15-30	403	25	132	12387	3770
ASR10	0-15	515	25	84	6448	1951
ASR11	0-15	378	1537	405	23488	5550
ASR12	15-30	25	67	330	30552	6528
ASR13	0-15	3910	6858	361	29901	6081
ASR14	15-30	1292	13545	356	29366	5114
ASR15	0-15	359	1971	122	16969	4047
<i>AVERAGE</i>		777	2742	214	26149	6583
<b>Ikhueni</b>						
IKH1	15-30	25	25	140	28912	7296
IKH2	0-15	380	323	87	12331	3291
IKH3	0-15	470	4012	111	10010	3174

**Table 1 (cont): Major Elements of Soil Samples in Asoro, Otofure, Ikhueniro Communities (in mg/L)**

IKH4	0-15	390	368	186	19354	4034
IKH5	15-30	25	25	149	30536	6081
IKH6	0-15	4527	685	15	50	20
IKH7	15-30	386	25	189	44455	9343
IKH8	0-15	1881	637	156	29050	5401
IKH9	15-30	437	653	83	12921	3579
IKH10	0-15	8714	252	27	50	3518
IKH11	15-30	720	3021	167	33095	6232
IKH12	0-15	1871	46220	362	29214	5913
IKH13	15-30	297	25	127	17194	4151
IKH14	0-15	444	527	172	13888	3415
IKH15	15-30	395	649	308	17048	5429
<i>AVERAGE</i>		1397	3830	152	19874	4487
<i>Otofure</i>						
OTF1	15-30	472	2468	136	14953	4073
OTF2	15-30	594	25	155	33892	6389
OTF3	0-15	2144	14202	136	14065	3498
OTF4	0-30	317	108	112	21847	5434
OTF5	15-30	354	778	79	11032	3668
OTF6	0-15	9854	944	9	50	20
OTF7	0-30	19353	1472	18	50	20
OTF8	0-15	485	1530	323	21068	4774
OTF9	15-30	293	208	145	19433	4236
OTF10	0-30	11281	582	3	50	20
OTF11	0-15	396	1231	294	16071	4311
OTF12	15-30	381	444	289	17048	5910
OTF13	0-15	425	2416	410	28088	6747
OTF14	15-30	25	25	170	35006	7015
OTF15	0-15	562	1724	129	14468	3807
<i>AVERAGE</i>		3129	1877	161	16475	3995

According to Table 1 above, Iron was detected in high concentrations in all the dumpsites, it had the highest average concentration amongst all elements analysed within the study location. This can be attributed to the availability of iron containing waste at the dumpsites which are eventually leached into the underlying soils. It appears to be the highest amongst the major elements in all dumpsites followed by titanium. Also, the Asoro dumpsite soil sample had higher average concentration of iron, titanium and manganese than all other dumpsites which indicates the clayey nature of the soil found there (EPA, 2003). One of the most prevalent elements on Earth is iron, and soils typically have concentrations of iron ranging from 0.2% to 55% (20,000 to 550,000 mg/kg). Although it accomplishes crucial functions in the human body, including as transferring oxygen, synthesising DNA, and exchanging electrons, it may also accumulate and become toxic and dangerous. It is significant to remember that there is no suggested iron guideline value based on health. Despite not being harmful in and of itself, iron interacts with toxic metals to have severe environmental effects (EPA, 2003). It is well known that soil with high

concentrations of iron compounds absorbs trace metals much less slowly. The ratio of iron and manganese in growth medium and plant tissue appears to be more significant to plant metabolism than their quantities (WHO, 2003). In humans, acute iron toxicosis results in both cellular damages brought on by circulating free iron and a direct corrosive effect on the gastrointestinal system. In addition, it results in post-arteriolar dilatation, increased capillary permeability, necrosis of the myocardium, and decreased cardiac output (Yousif, 2009).

Titanium is utilized in a variety of products including cosmetics, paints, food, pharmaceuticals, and medical implant materials, including dental implants. TiO<sub>2</sub> powder is currently the most widely utilized type of titanium. Concern over the impact of TiO<sub>2</sub> powder on people and the surrounding ecosystem has grown as production of it expands. Reports of metal fragments from titanium prosthesis wear have been made in response to the possible dangers of TiO<sub>2</sub> buildup in the body. Research shows that two patients who had implanted joints, experienced a buildup of metal fragments such titanium, aluminum, and vanadium in their bone

marrow (Winkler et al., 2018).

A close look at the results shows that in Ikhueni community, the major element with the highest range of concentration was calcium (46220 mg/L) at a depth of 0 - 15 cm as found in Table 1. The mean levels of Ca in soil were above the WHO acceptable limit of ≤100ppm. Leaching of the burnt waste as well as the agro utilization of lime in the surrounding location could account for the high concentration of calcium in the dumpsite located in Ikhueni community. Also, the presence of an abattoir few kilometers from the dumpsite, whose waste products (bones and husks) may have a considerable impact on the increased calcium level in the particular sample cannot be overlooked (Wanjala et al., 2019).

The highest average potassium concentration was found in Otofure dumpsite (Table 1). According to previous research, potassium has the following toxicities: 150 mg/L, 150 - 250 mg/L, > 250 mg/L, and 800 mg/L as low, medium, high, and toxic levels, respectively. Few samples had concentration values that were significantly below the high optimum for potassium in soils, which is where potassium concentration levels from most depths in all of the study sites fall. Humans require potassium, which is rarely or never present in drinking water at quantities that would be dangerous for healthy people. Over 3000 mg is the recommended daily intake for people. Only people in high-risk groups will be affected by health issues, which are largely related to the consumption of drinking water treated by potassium-based treatment procedures (Kalala et al., 2017).

Manganese had the lowest concentration range (3 mg/L) as well as the lowest average concentration amongst the major elements in all the study sites. Natural and anthropogenic activities contribute to human exposure to manganese, a prevalent element in nature occurring naturally in over a hundred minerals. Ambient values in soil range from 40 to 900 mg/kg, with an approximate average environmental concentration of 330 mg/kg (USEPA, 2018). Industrial emissions, the burning of fossil fuels, and soil erosion from manganese-rich soils all release manganese into the surroundings. Studies highlighted manganese to have a critical value of

about 425 ppm in plant leaves (mangosteen), compared to 22 to 24 ppm in soil. One of the most significant barriers to plant growth in acidic soils is manganese toxicity. In addition to inhibiting chlorophyll biosynthesis, too much manganese can hinder the uptake and translocation of other vital elements like Ca, Mg, Fe, and P (Martias et al., 2021).

**3.2 Trace Elements Geochemistry of Asoro Dumpsite**

Table 2 displays the concentration of the trace elements found in Asoro, Ikhueni and Otofure communities. For trace elements in Asoro community, Zirconium ranked highest with an average concentration of 625 ppm, followed by Barium (81 ppm), Zinc (79 ppm), Vanadium (49 ppm), Nickel (47 ppm), Niobium and Strontium averaged the same (29 ppm), Yttrium (16 ppm), Thorium (13 ppm), Copper (12 ppm), Tantalum (9 ppm), Chromium (7 ppm), Rubidium (6 ppm), Uranium (4 ppm) and Molybdenum (2 ppm).

The results from Ikhueni dumpsite, further showed that amongst the trace elements, Zirconium had the highest average concentration value (430 ppm) followed by Copper (74 ppm), Zinc (71 ppm), Nickel (45 ppm), Vanadium (39 ppm), Strontium and Barium having the same average concentration (24 ppm), Niobium (22 ppm), Thorium and Yttrium having the same average concentration (10 ppm), Rubidium (9 ppm), Chromium and Tantalum both having the same average concentration (7 ppm), Uranium (3 ppm) and Molybdenum (2 ppm).

Analysis of the trace elements found in the Otofure soil sample, also showed Zirconium to have the highest average concentration of (430 ppm) followed by Zinc (47 ppm), Nickel (38 ppm), Vanadium (37 ppm), Strontium (24 ppm), Barium and Niobium both having same average composition (20 ppm), Rubidium (12 ppm), Copper (10 ppm), Yttrium and Thorium both having same average concentration of 9 ppm, Tantalum and Chromium having same average concentration of 6 ppm, Uranium (3 ppm) and Molybdenum (1 ppm).

**Table 2: Trace Elements of Soil Samples in Asoro community (in ppm)**

Sample	Depth	Y	Nb	Ba	Ta	Ni	Rb	Sr	Zr	Th	Mo	U	V	Cu	Zn	Cr
<b>Asoro</b>																
ASR1	0-15	18.8	34.2	27	11.9	42	3.5	28.9	834	13.8	4.1	5.0	47	8.0	34.8	8.1
ASR2	15-30	22.9	42.1	10	12.8	54	3.9	30.8	1091	21.0	1.0	5.6	60	3.0	25.8	10.3
ASR3	15-30	12.0	30.1	10	10.3	61	5.6	19.1	529	13.2	1.0	4.2	54	3.0	18.6	8.8
ASR4	0-15	30.2	29.7	695	9.3	61	4.5	39.0	821	11.9	1.0	6.7	93	9.0	57.0	8.3
ASR5	0-15	11.3	28.7	10	8.2	45	3.7	18.8	500	13.0	6.0	4.8	39	3.0	12.9	7.6
ASR6	15-30	13.6	34.8	235	13.2	43	4.7	28.3	962	16.2	5.6	7.1	60	3.0	28.6	9.0
ASR7	0-15	32.8	34.2	31	14.2	70	11.2	39.7	719	13.0	1.0	2.6	82	46.0	77.0	12.0
ASR8	15-30	17.0	32.3	10	10.9	65	9.2	26.4	545	16.9	2.6	5.2	65	24.0	52.0	12.1
ASR9	15-30	5.8	14.1	10	4.9	40	1.9	9.4	344	6.8	1.0	3.0	21	3.0	10.6	4.1
ASR10	0-15	5.1	10.4	10	2.9	36	2.1	8.8	199	7.5	1.0	1.0	13	3.0	13.0	2.3
ASR11	0-15	15.3	26.8	10	6.2	42	6.7	22.0	514	10.7	3.2	4.6	37	21.0	22.3	6.6
ASR12	15-30	14.0	34.3	10	11.3	48	4.6	21.6	471	14.9	3.2	1.0	50	3.0	25.4	9.2
ASR13	0-15	20.6	21.8	95	8.9	37	14.6	53.6	915	10.5	1.0	6.7	46	23.0	204.0	8.2
ASR14	15-30	8.5	19.3	35	6.0	33	13.3	64.9	348	10.8	1.0	2.7	45	22.0	505.0	8.4
ASR15	0-15	10.5	24.9	10	4.4	28	3.4	18.7	582	10.2	1.0	3.8	30	7.0	60.0	4.2
AVERAGE		16	29	81	9	47	6	29	625	13	2	4	49	12	76	7
<b>Ikhueni</b>																
IKH1	15-30	56	4.8	19.8	13.1	801	15.3	31.1	10	1.0	11.8	3.0	23.2	4.5	54	9.8

**Table 2 (cont):** Trace Elements of Soil Samples in Asoro community (in ppm)

IKH2	0-15	43	3.1	15.3	11.4	447	8.0	19.6	28	1.0	4.0	8.0	12.5	1.0	15	3.9
IKH3	0-15	38	2.5	16.4	8.1	575	6.0	13.3	10	1.0	5.3	3.0	17.3	3.1	21	3.5
IKH4	0-15	40	2.9	15.8	8.6	396	9.1	19.6	10	1.0	6.4	3.0	16.4	3.3	26	6.3
IKH5	15-30	45	4.5	25.6	12.1	437	14.1	31.8	10	3.5	8.6	3.0	22.4	1.0	48	8.0
IKH6	0-15	20	29.4	26.2	3.0	5	2.0	1.0	10	1.3	1.5	10.6	13.0	1.0	62	13.1
IKH7	15-30	81	6.9	28.7	16.2	566	15.2	45.9	10	1.0	15.4	3.0	34.7	5.3	80	13.0
IKH8	0-15	46	6.7	23.2	10.8	496	13.7	30.7	23	1.0	10.5	3.0	27.7	3.5	41	7.6
IKH9	15-30	36	3.3	12.2	10.5	538	9.4	17.7	29	4.1	4.3	3.0	32.7	5.1	27	4.1
IKH10		20	43.8	8.6	3.0	5	2.0	1.0	40	1.9	1.5	16.9	13.9	1.0	28	2.0
IKH11	15-30	56	7.6	34.1	12.8	465	14.6	31.9	24	1.0	11.4	23.0	163.0	5.2	55	9.9
IKH12	0-15	72	10.9	91.9	13.0	509	12.5	24.2	125	1.0	5.7	1021.0	638.0	3.4	46	10.9
IKH13	15-30	42	2.9	13.5	8.7	306	9.5	17.7	10	3.5	5.5	3.0	11.2	3.4	27	5.4
IKH14	0-15	34	4.4	12.2	7.0	256	6.0	13.6	10	1.0	2.9	7.0	14.6	3.1	19	4.3
IKH15	15-30	47	3.5	15.2	12.0	733	6.7	26.0	10	1.0	7.3	3.0	18.2	6.3	30	4.9
<i>AVERAGE</i>		45	9	24	10	436	10	22	24	2	7	74	71	3	39	7
<b>Otofure</b>																
OTF1	15-30	40	6.0	71.0	4.6	20.6	7.8	3.8	24	480	7.7	19.3	10	1.0	5.8	4.4
OTF2	15-30	44	3.0	25.5	5.4	23.6	11.8	4.2	54	564	14.9	34.7	28	1.0	10.7	8.7
OTF3	0-15	38	31.0	165.0	7.8	41.5	9.0	1.0	28	541	7.3	16.3	58	2.6	4.6	7.5
OTF4	0-30	35	6.0	30.2	6.3	27.4	14.2	2.8	45	557	12.5	30.3	28	1.0	7.9	6.8
OTF5	15-30	36	3.0	15.4	2.5	11.3	8.4	3.1	13	403	9.1	16.1	10	3.1	2.4	4.2
OTF6	0-30	20	13.6	21.9	33.6	20.0	3.0	1.0	45	5	2.0	1.0	10	1.0	1.5	5.3
OTF7	15-30	20	27.0	49.6	43.3	17.8	3.0	1.0	34	5	2.0	1.0	10	1.0	1.5	2.0
OTF8	0-15	47	3.0	31.6	4.9	26.6	11.7	6.2	31	515	12.1	23.0	10	1.0	7.3	7.2
OTF9	15-30	38	3.0	21.9	3.9	20.1	8.4	3.3	27	317	9.8	24.1	24	1.0	6.3	5.9
OTF10	0-30	20	10.3	9.6	44.9	27.6	3.0	1.0	55	5	2.0	1.0	10	1.0	1.5	8.2
OTF11	0-15	37	11.0	16.6	3.3	20.2	11.7	3.3	27	438	9.1	20.5	10	1.0	2.7	5.5
OTF12	15-30	47	3.0	20.2	3.0	18.6	10.5	2.7	32	484	11.0	22.3	10	1.0	8.7	5.5
OTF13	0-15	60	19.0	83.0	6.4	36.8	14.2	4.1	53	970	9.8	31.3	40	1.0	11.3	9.1
OTF14	15-30	56	3.0	34.4	4.2	29.3	12.0	3.6	57	597	15.8	40.3	35	1.0	14.6	9.5
OTF15	0-15	38	3.0	115.0	4.5	15.4	11.2	2.8	26	565	9.1	19.7	10	2.9	4.1	4.1
<i>AVERAGE</i>		38	10	47	12	24	9	3	37	430	9	20	20	1	6	6

Trace elements studied showed zirconium to be of highest concentration than the rest elements, with the mean concentration values within all 3 communities as high as 497ppm, followed by zinc (65.67ppm), nickel (43.3ppm), barium (41.67ppm), vanadium (41.67ppm), copper (32ppm),

strontium (25.67ppm), niobium (23.67ppm), yttrium (11.67ppm), thorium (10.67ppm), tantalum (7.3ppm), chromium (6.67ppm), uranium (3.33), rubidium (3ppm) and molybdenum (1.67ppm).

Table 2 also shows zirconium to be highest in Asoro dumpsite sample (625

ppm) followed by Ikhueniro (436 ppm) and Otofure (430 ppm). All of these data were below the critical level of Zirconium in soils which varies from 32 to 850 mg/kg. There has been relatively few report on human oral contact with zirconium however, no dosing details were offered. Symptoms from acute ingestion included sensational burning in the mouth and throat, seizures, vomiting, liver damage with jaundice, watery or bloody diarrhea, tenesmus, retching, hemolysis, anuria, hypotension, collapse, and hematuria. According to a collection of studies published over the years, prolonged inhalation exposure to zirconium can lead to health issues like pulmonary granuloma, respiratory tract irritation and dermatitis, acute allergic alveolitis-like hypersensitivity reaction, pulmonary fibrosis, and interstitial lung granuloma (Hichem et al., 2022 ; Maxim and Utell, 2018).

Average copper concentration was higher in Ikhueniro sample (74 ppm) followed by in Asoro sample (12 ppm) and finally Otofure (10 ppm). The amount found in this study falls within the acceptable range of Cu availability in the soil. Cu occurs naturally in soils with contents ranging from 60 to 125 mg/L. It is a crucial micronutrient for the growth of plants. Industrial, mining, and agricultural activities by humans play a major role in soil pollution with copper. The primary source of Cu entry into agricultural soils is the intensive application of Cu-containing agrochemicals or pig dung (Kumar et al., 2021). Global human population is projected to reach nine billion people in 2050 (FAO, 2021) and this prediction raises concerns that more agricultural crops will need to be grown to meet the global demand for plant and animal foods, which will lead to a boost in the utilization of agrochemicals comprising copper for phytosanitary goals. Cu lowers plant growth and production when present in soil at dangerous levels by inhibiting the uptake of water and mineral nutrients, promoting oxidative stress, and interfering with photosynthesis (Shabbir et al., 2020).

The highest average barium concentration was found in Asoro dumpsite sample (81 ppm) followed by Ikhueniro (24 ppm) and then Otofure (20 ppm). All of these values were within the range of barium in soils (15 – 3500ppm) as shown in the table of soil quality standards (EPA, 2018). Both igneous and sedimentary rocks contain trace amounts of barium, and barium compounds can be utilized for the manufacture of soap, explosives, fire extinguishers, drilling fluids, pesticides, and other products (Kumar et al., 2021). Although there is no proof that barium is mutagenic or carcinogenic, high levels of barium exposure in humans have been linked to acute hypertension, diarrhea, cardiac arrhythmia, vomiting, and hypokalemia. Although barium has been found to cause nephropathy in test animals, it appears that barium's potential to cause hypertension at a toxic level is a major source of concern to humans. (Hu et al., 2019).

The highest average concentration for zinc was found in Asoro dumpsite sample (76 ppm) followed by Ikhueniro (71 ppm) before Otofure (47 ppm). In the form of salts or organic complexes, zinc is a crucial trace element that is present in almost all foods and drinkable water. It is a micronutrient that is crucial for enzymatic activities and whose presence in the soil may prevent plants from assimilating much Cadmium (Wanjala et al., 2019). All of the study soils' total zinc concentrations fell within the permissible range for zinc in soil. Based to the geological makeup and weathering of the parent material, zinc concentrations in soils can range from 10 to 300 parts per million (ppm), with an average concentration of 50 ppm. Most plants typically contain 20 to 100 ppm of Zn (IPNI, 2019). A joint FAO/WHO Expert Committee on Food Additives suggested in 1982 that the provisional daily maximum intake for zinc be set at 1 mg/kg body weight. Adults must consume between 15-20 milligrams every day. Abdominal pain, vomiting, and diarrhea can occur when significant doses of zinc are accidentally ingested. The effects (sideroblastic anemia, leukopenia, and hypochromic microcytic anemia) of long-term high doses of zinc at pharmacological doses (150–2000 mg/day) are reversible upon stopping zinc therapy and/or restoring copper status, and are primarily attributed to zinc-induced deficits in copper (WHO, 2020).

A close look at Table 5 and 6 shows that uranium, molybdenum, tantalum, thorium, yttrium and chromium were relatively lower in all the sample sites with very insignificant differences between their concentration values.

In granites and other types of mineral formations, uranium, thorium, and their decay series are examples of naturally occurring radioactive materials (NORM) (IAEA, 2020). Nevertheless, human activities including mining and enriching uranium or thorium, burning coal and other fuels, agriculture activities, and nuclear energy generation could increase the concentrations of uranium and thorium in soils. In accordance with the levels discovered by (United States Environmental Protection Agency, 2018), the average uranium concentration in Ikhueniro and Otofure sample soil was found to be around 3 ppm. The Asoro sample exceeded

the standard by 1 ppm. Children are more likely than adults to unintentionally swallow soil via hand-to-mouth activities, and they may do so up to 100 mg per day. Nephrotoxic, hematotoxic, and a high risk of cancer have all been associated to incidental ingestion of soils with high amounts of uranium and thorium. Human uranium intake through the air is minimal, and it daily uranium intake through food ranges from 1 to 4 µg/day. Drinking water intake is often quite modest, however in situations when uranium is available in a source of drinking water, it may account for the majority of ingestion. The main uranium-related chemical consequence in people is nephritis. Human exposure to ambient uranium may have long-term negative impacts on one's health (ATSDR, 2019).

Because of the toxicity, resilience, and biological accumulation of chromium which is widely distributed in the Earth's crust, significant research has been conducted as it poses a severe threat to the surroundings and human health via the food chain. Based on an upper-limit concentration that exhibits no unfavorable or detrimental impacts, soil quality parameters are developed. The chromium concentration in the study sites were within the acceptable standards found in soil. The average amount of total chromium in soil is 37.0 mg/kg, with ranges between 1 and 2,000 mg/kg (EPA, 2018). Roots and tubers typically absorb higher amounts of chromium and other trace metals since chromium has a limited mobility for translocation from roots to aboveground sections of plants. Root inhibition rate and soil chromium concentration are linearly associated, according to current research on species response diversity (Liu et al., 2021).

Nickel is a common trace metal found in soil, water, and air samples across the biosphere and it is released into the environment by both natural and anthropogenic causes. The rising amount of nickel that airborne nickel particles are depositing into agricultural soils is especially alarming. Nickel mining, steel production, oil and coal combustion for heat or power generation, and other atypical sources, including cement production, are the main sources of nickel emissions into the atmosphere. In addition to being an integral part of the enzyme urease, which is necessary for nitrogen metabolism in higher plants, nickel is a crucial element for plant growth. As shown in Table 2, the nickel concentration found in all sites were above the WHO Target values (35 ppm) for desirable maximum levels for nickel in unpolluted soils, although the range of nickel in soils has been reported to be 3 – 1000mg/kg. Diseases of the respiratory system, nasal cavities and sinuses, the immunological system, and the skin can arise from environmental and occupational exposure to dangerous amounts of nickel (Ibrahim et al., 2020).

Although the quantity of strontium naturally present in soil can fluctuate widely, the normal concentration is 0.2 mg/kg. Strontium levels in soil may rise as a result of the dumping of coal ash, incinerator ash, and industrial wastes (Wang et al., 2021). By inhaling air, ingesting food or beverages, drinking water, or accidentally ingesting dirt or dust that includes strontium, humans can be exposed to low levels of this element. The main sources of exposure to strontium are food and water. Due to the bio-accumulating nature of strontium, some of it ends up in seafood, plants, and animals. According to the main sources of dietary strontium for people are grains, green vegetables, and dairy products (El-Kady and Abdel-Wahhab, 2018). Less than 64 mg of strontium (64 ppm) per kilogram of fresh vegetables can be found in leafy vegetables like cabbage. The most dangerous isotope of strontium, strontium 90 (<sup>90</sup>Sr), is a radioactive form of the element that exists. When eating food that was grown on a hazardous waste site contaminated with radioactive strontium, there is an increased risk of ingesting <sup>90</sup>Sr. Due to the destruction of cells' genetic material (DNA), radioactive strontium may result in cancer. People in one foreign population who ingested rather substantial levels of <sup>90</sup>Sr (and other radioactive materials) in river water contaminated by a nuclear weapons factory have been documented to develop leukemia over time. Animal investigations through breathing exposures have revealed leukemia, bone, nose, and lung cancers. Animals that were exposed to large levels of radiation through the skin have also been reported to have developed skin and bone cancer. Radioactive strontium deposits inside the body and emits beta radiation, thus the International Agency for Research on Cancer (IARC) has established that it is carcinogenic to humans. Radioactive strontium is a known human carcinogen (Essien et al., 2022).

A transition metal that is hard, silvery-white or dark grey, molybdenum is necessary for plants, animals, including humans, as a micronutrient (Smedley and Kinniburgh, 2017). In all three sites, the molybdenum concentration was well below the WHO standards of 45 ppm. According to the knowledge at hand, molybdenum rarely ever bioaccumulates and biomagnifies in flora and fauna (Ogbe et al., 2020).

Vanadium in all the soil samples from various locations (s) were within the

acceptable range of vanadium in soils. With a natural occurrence rate of 0.01%, vanadium is one of the five transition elements with the highest abundance. It is present in the crust of the earth at 159 g t<sup>-1</sup> and 0.14 mg kg<sup>-1</sup>. It only occurs in limestone soils that contain about 65 distinct types of minerals, primarily iron oxide, argillaceous minerals, carnotite, chileite, bravoite, roscoelite, patronite, vanadinite, and davidite, as well as organic fractions (Aihemaitia et al., 2019). It has a mean content of 150 mg kg<sup>-1</sup> in soil in metropolitan areas and is dispersed across the lithosphere in the range of 10- 220 mg kg<sup>-1</sup>. Vanadium toxicity is not widely known. It is primarily deposited in the roots and prevents plants from nitrifying and mineralizing nitrogen. Utilizing five distinct plant species grown in an artificial soil with varying nutrient inputs the biomass of plants was shown to be reduced by 50% at soil vanadium concentrations ranging from 21 to 180 mg kg<sup>-1</sup> (Roychoudhury, 2020).

Niobium and tantalum are lithophile elements that occur solely as oxides and hydroxides forming complexes with several oxidation states of which the +5 oxidation state is the most stable state and the only one found in nature. They are usually given off as by-products of tin mining. The average concentration of niobium and tantalum found in the three sample locations were moderately above the conventional soil concentration values of 20ppm and 0.68ppm for niobium and tantalum respectively (Sutliff-Johansson et al., 2021).

Reports show that niobium appears to be innocuous to humans while tantalum tends to cause mild eye and skin irritations, although in animal, niobium tends to have higher toxicity than tantalum and some of the rare earth elements (USEPA, 2018).

Rubidium in all three sites were 6ppm, 9ppm and 12ppm in Asoro, Ikhueniro and Otofure community respectively and this was well within the acceptable range of 2 – 390 ppm usually found in soils. However, very minimal toxic effects have been found for rubidium and rubidium compound. It readily reacts with the skin moisture forming rubidium hydroxides thereby causing skin irritation (USEPA, 2016).

The primary source of yttrium pollution in the environment is the petroleum industry. Additionally, it gets into the environment when domestic items are thrown away. As yttrium builds up in soils, water, and plants, its concentrations in humans, animals, and soil particles will also rise. Except for the Asoro dumpsite, where it was somewhat higher than the typical range of yttrium in soils (2.9ppm - 10ppm), the average concentration level in all examined locations was within the acceptable limit (USEPA, 2018). Lung embolisms are brought on by yttrium poisoning, especially after prolonged exposure. Yttrium can potentially cause cancer in people since it increases the risk of developing lung cancer when breathed in. The accumulation of it in the human body can also be harmful to the liver (Nkwunonwo et al., 2020).

This study disagrees with findings in Etueffont landfill (France), who observed the values of iron, zinc, copper and nickel to be 2630µg/L, 300 – 1850µg/L, 0 – 1770µg/L and 170 – 8640µg/L (Khattabi, 2002). In Yemen, a similar study also gave a deviation from the concentration values observed in this current study (Al-sabahi et al., 2009). The observed range for iron, zinc, copper and nickel were 46000 – 47700µg/L, 56000 – 85500µg/L, 21500µg/L and 1700 – 1800µg/L respectively as compared to our current study of 50 – 44455 mg/L, 9.6 – 638ppm, 3 – 1021ppm and 20 – 80ppm for iron, zinc, copper and nickel respectively.

The heavy metal contamination in soil around hazardous waste disposal sites in Hyderabad city (India), discovered the range of elements such as chromium, copper, nickel and zinc in waste disposal sites to be 12.2 – 480.5mg/L, 11 – 186.6mg/L, 12.5 – 131.9mg/L and 26.9 – 882.1mg/L, which were higher than the range of natural background metallic values of Hyderabad city (14 – 33mg/L, 35 – 93 mg/L, 19 – 57mg/L, 34 – 64mg/L for chromium, copper, nickel and zinc respectively) (Partha et al., 2011). The heavy metal concentration by Partha et al. was higher than the range values obtained in this present study for chromium (2 – 13.1ppm), nickel (20 – 80ppm) and zinc (9.6 – 638ppm), but not for copper (3 – 1021ppm).

The concentration ranges of elements such as iron (50 – 44455 mg/L), zinc (9.6 – 638ppm), copper (3 – 1021ppm) and nickel (20 – 80ppm) in this present study disagrees with the ranges obtained from the metal concentration of leachates from the Akouédo landfill (72 – 34100µg/L, 197 – 1015µg/L, 83 – 1117µg/L and 95 – 412µg/L for iron, zinc, copper and nickel respectively) in Abidjan (Cote d'Ivoire) by (Naminata et al., 2018). All of these were above the WHO standard (3 – 5500µg/L, 0.03 – 1000µg/L, 0.005 – 10µg/L and 0.015 – 13µg/L for iron, zinc, copper and

nickel respectively). Further studies showed increased cancer cases amongst residents of the Akouédo landfill area (Adjiri, et al., 2019).

Similar study in Ilokun waste dumpsite, located in Ado-Ekiti local government area, Ekiti state, Southern Western Nigeria had higher concentration values for zinc, manganese, nickel, chromium, copper, yttrium, niobium, barium, rubidium, strontium, zirconium, thorium and uranium which ranged from 166 – 1257ppm, 496 – 4166ppm, 441 – 2444ppm, 425 – 3341ppm, 126 – 1041ppm, 10 – 219ppm, 40 – 514ppm, 11 – 590107ppm, 113 – 1094ppm, 25 – 891ppm, 1500 – 12914ppm, 441 – 1034ppm and 153 – 605ppm respectively as compared to the ranges obtained from our present study (9.6 – 638ppm, 9 – 410mg/L, 20 – 80ppm, 2 – 13.1ppm, 3 – 1021ppm, 3 – 32.8ppm, 1 – 45.9ppm, 10 – 695ppm, 1.9 – 44.9ppm, 8.6 – 91.9ppm, 5 – 1091ppm, 2 – 21ppm and 1 – 7.1ppm respectively). However, it gave lesser values for iron (6.343 – 74.5ppm), calcium (1325 – 6581ppm), potassium (542 – 1065ppm) and titanium (0.408 – 0.906ppm), compared to the ranges obtained from Tables 1 – 6 of this present study (50 – 44455mg/L, 25 – 46220mg/L, 25 – 19353 mg/L, and 20 – 13972 mg/L respectively) (Olagunju et al., 2018). Iron, zinc, manganese, calcium, nickel, chromium and copper were above the WHO permissible value in drinking water of 0.2ppm, 3ppm, 0.05ppm, 200ppm, 0.07ppm, 0.1ppm and 1ppm. Continuous exposure to nickel contamination affects the soil, as well as humans by causing cardiovascular damages, respiratory tract cancer, allergies and kidney damages. In general, toxic concentrations of these elements inhibits the natural development and life processes of plants and invariably damages different tissues, organs, and system of humans and animals when exposed (Ogundele et al., 2020).

An analysis of soil from an abandoned municipal waste dumpsite in Owerri, Imo state, Nigeria gave the ranges of elements such as iron (116.5 – 203mg/L), zinc (0.8 – 1.4mg/L) to be less than those observed in this study (50 – 44455mg/L, and 9.6 – 638ppm for iron and zinc respectively) while chromium (150 – 450mg/L) was above the range observed in this present study (2 – 13.1ppm). Manganese (20) and copper (12.4 – 18.8mg/L) were well within the range of those observed in this study (9 – 410mg/L and 3 – 1021ppm for manganese and copper respectively) (Chizoruo et al., 2017).

A study carried out in a dumpsite in Ekenwan, Benin city presented the range of nickel, copper, zinc, manganese and iron to be 28.42 – 42.67mg/l, 40.45 – 51.50 mg/l, 138.35 – 145.20mg/l, 89.62 – 104.32mg/l and 420.17 – 425.62mg/l, respectively and all of these were lower than the ranges observed within our study sites for the said elements as shown in Tables 1 - 6 (20 – 80 mg/l, 3 – 1021mg/l, 9.6 – 638mg/l, 9 – 410mg/l, and 50 – 44455mg/l respectively). The same dumpsite had higher concentration range of chromium (15.11 – 18.30mg/l) as compared to our current study (2 – 13.1mg/l) (Agho et al., 2021).

All of these fluctuations in concentrations as compared to the values obtained in the present study could be due to the nature of waste generated in the locality which invariably ends up in the waste sites.

### 3.3 Mineralogy of the Dumpsite Soils

The diffraction analysis for three study locations (Asoro, Ikhueniro and Otofure) is presented as X-ray diffractograms (Fig. 4 - 6). For simple mineral identification at each study site, labels are placed on each peak of the diffractogram and are organized in the legend. The mineralogical composition of the dumpsite soils reveals a dominance of quartz, along with varying proportions of kaolinite, halloysite, zircon, anatase, hematite, calcite, and albite. Quartz was consistently identified as the predominant mineral across all three locations, likely due to its high crystallinity and resistance to weathering. The mineral profiles of Asoro and Otofure were similar, comprising quartz, kaolinite, halloysite, zircon, anatase, and hematite. However, Ikhueniro exhibited a more diverse composition with additional minerals such as calcite and albite, which are known for their roles in enhancing soil fertility. Calcite, in particular, contributes to soil organic matter retention, making the Ikhueniro site potentially more suitable for agricultural activities. The composite mineral distribution at Otofure highlights the predominance of quartz (38%), followed by kaolinite and halloysite (25%), hematite (16%), zircon (12%), and anatase (9%). These findings provide valuable insights into the mineralogical characteristics of the studied dumpsites, which could influence soil properties, land use planning, and potential remediation strategies.

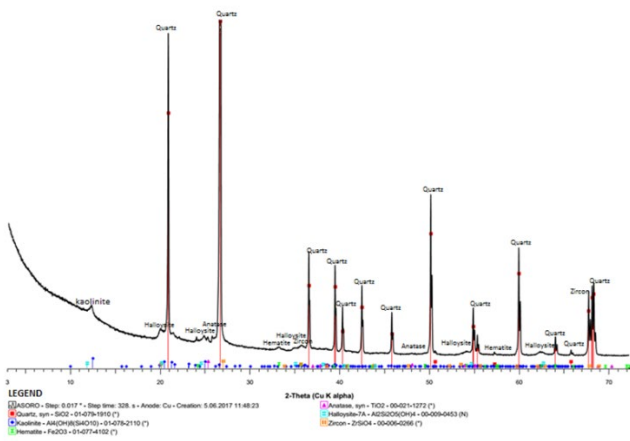


Figure 4: X-Ray diffractogram indicating the minerals present in Asoro dumpsite

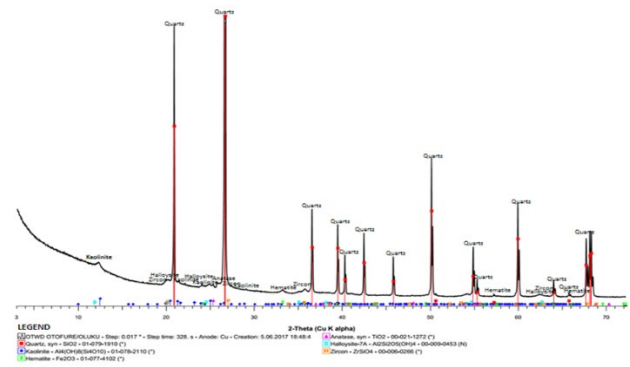


Figure 5: X-Ray diffractogram indicating the minerals present in Otofure dumpsite

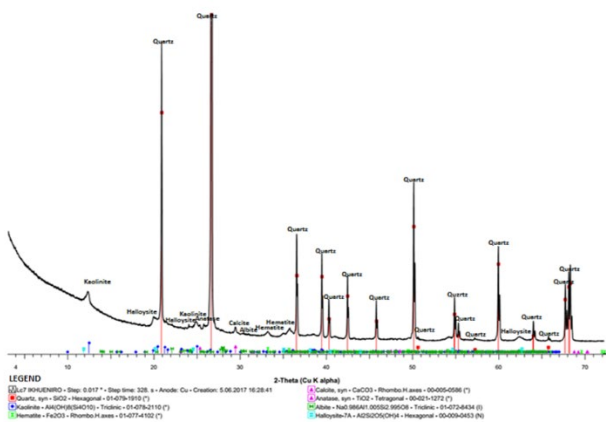


Figure 6: X-Ray diffractogram indicating the minerals present in Ikhueniro dumpsite

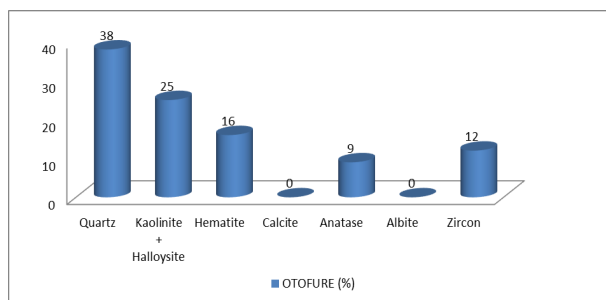


Figure 7: Percentage distribution of the minerals present in Otofure

4. CONCLUSION

The geochemical and mineralogical analyses of soil samples from Asoro, Ikhueniro, and Otofure dumpsites provide critical insights into the influence of anthropogenic activities on soil composition and potential

environmental implications. The geochemical assessment revealed significant variations in major and trace element concentrations, with iron (Fe) consistently exhibiting the highest levels across all locations, likely due to iron-containing waste materials. High concentrations of titanium (Ti) suggest industrial contributions, while the elevated calcium (Ca) levels in Ikhueniro highlight potential agricultural and abattoir influences. Potassium (K) concentrations in Otofure approached the high-to-toxic threshold, indicating potential impacts on soil fertility. Among trace elements, zirconium was predominant, though within acceptable limits, while nickel and uranium exceeded WHO standards, posing contamination risks.

The mineralogical characterization identified quartz as the dominant mineral across all sites, with kaolinite, halloysite, zircon, anatase, and hematite present in varying proportions. The presence of calcite and albite in Ikhueniro suggests enhanced soil fertility potential, making it suitable for agricultural use. These findings underscore the interplay between waste disposal, industrial activities, and soil chemistry, influencing element mobility, bioavailability, and environmental risks. While most elements remained within regulatory limits, elevated levels of nickel, uranium, and barium highlight the need for continuous monitoring and proper waste management strategies to mitigate potential health and ecological risks.

STATEMENT OF INTEREST

The authors declare there are no competing financial, professional or personal interest that might have influenced the performance/presentation of work described in the manuscript.

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