



AN IN-DEPTH STUDY OF HEAVY METALS IN SOILS AROUND SELECTED WASTE DUMPSITES IN PARTS OF SOUTHERN NIGERIA USING HEAVY METAL INDICES AND MULTIVARIATE STATISTICAL ANALYSIS

OSISANYA OLAJUWON WASIU, AGBALAGBA OGHENENYERHOVWO EZEKIEL, AGHO IFE-OLUFUNMILOLA, EYANKWARE OGHENENYOREME MOSES AND IDUSERI OGIEWWONYI MURPHY
Email: wasiu.osisanya@uniben.edu
ORCID ID: 0000-0001-7280-9771

(Received 28 November 2024; Revision Accepted 8 May 2025)

ABSTRACT

A detailed study was conducted around waste dumpsite in the study area, to evaluate the levels of heavy metals in the soil. Soil samples were collected at twenty (20) different locations within waste dumpsites for the study. The heavy metals (zinc (Zn), chromium (Cr), copper (Cu), lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), arsenic (As), and iron (Fe)) were analyzed using atomic absorption spectrometry (AAS). The resulting data was analysed using principal component analysis (PCA), Pearson correlation, and the heavy metal indices: Potential Ecological Risk (ERI), Geoaccumulation Index (Igeo), Contamination Factor (CF), and Nemerow Pollution Index (PNI). The soil contains the heavy metals: zinc (Zn), chromium (Cr), copper (Cu), Pb, Cd, Hg, Ni, As, and Fe. Their concentrations, in order 9.28 to 60.1 mg/kg for Zn, 4.4 to 14.39 mg/kg for Cr, 5.4 to 21.39 mg/kg for Cu, 6.07 to 17.5 mg/kg for Pb, 0.04 to 1.5 mg/kg for Cd, 0.0001 to 0.003 mg/kg for Hg, 7.28 to 20.38 mg/kg for Ni, 0.0001 to 0.003 mg/kg for As, and 1020 to 16540 mg/kg for Fe. The Igeo data indicated that all samples fell within the range of 0 to 2, implying that the sediment quality was largely unpolluted. The PNI yielded a diverse array of results within the study area, PC1 has a loading percentage of 77.8%, PC2 has a loading percentage of 44.4%, PC3 has a loading percentage of 33.3%, and PC4 has a loading percentage of 11.1%. This loading signifies the element's importance in the contribution of pollution within elements and to the soil. Further deductions from soil samples results that was compared to World Health Organization (WHO), and Department of Petroleum Resource (DPR), permissible limit suggested that all samples were below the permissible limit except for Cd, that its concentration was above WHO limit at some locations namely; DO/ 02, 03, 04, 05, 06, 08, 09, 10, 12, 13, and 18, this could be attributed to anthropogenic activities within the study area. These findings can serve as a valuable resource for those responsible for managing dumpsites, aiding in the prevention of heavy metal soil contamination.

KEYWORDS: Risk Assessment, Index, Solid waste, Ecological risk, Statistical techniques.

INTRODUCTION:

In recent years, all stakeholders, including ecologists and environmentalists, have found the concentration of heavy metals in soils to be a critical issue (Eyankware, et al., 2024; Osisanya, et al., 2024).

Both geogenic and anthropogenic factors, including metal finishing, paint pigment, livestock wastewater, battery manufacturing, leather tanning, mining activities, municipal waste water sludges, urban composts, pesticides, phosphate fertilizers, vehicular exhaust, energy and fuel production,

Osisanya Olajuwon Wasiu, Department of Physics, College of Science, Federal University of Petroleum Resources, Effurun, Delta State

Agbalagba Oghenenyerhovwo Ezekiel, Department of Physics, College of Science, Federal University of Petroleum Resources, Effurun, Delta State

Agho Ife-Olufunmilola, Department of Microbiology, University of Benin, Benin City, Edo state, Nigeria

Eyankware Oghenenyoreme Moses, Department of Geology, Faculty of Science Ebonyi State University, Abakaliki, Ebonyi State, Nigeria

Iduseri Ogiewwonyi Murphy, Department of Physics, University of Benin, Benin City, Edo state, Nigeria

power transmission, automobile mechanic workshops, and chemical lumps from industries and factories, release heavy metals into the environment (Igwe, et al., 2021; Cheng and Zhu, 2007). Heavy metals, such as arsenic (As), iron (Fe), manganese (Mn), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn), particularly contaminate agricultural and industrial soils. Human exposure to certain heavy metals can cause severe ailments such as gastrointestinal, neurological, tumors, head congestion, muscle aches, pharyngeal congestion, eyelid edema, genetic issues, and problems with reproduction (Ogundele, et al., 2020). Currently, soil contamination with heavy metals poses a significant threat to the health of humans, animals, and plants (Omene et al., 2015). It is believed that the heavy metal presence in the soil of the study area primarily stems from garbage dumps (Fig. 1). Globally, human activities generate waste. According to Okoye et al. (2022), waste production is an inevitable aspect of life that must be managed by humans. The rapid urbanization in various regions of Nigeria, including Obiakpo and Imo State, is driven by increasing economic and population growth (Eyankware et al., 2022a). Modern agricultural practices, urban development, industrial activities, and the pursuit of greater crop production have led to substantial releases of heavy metals into the environment (Akinseye, et al., 2023). Soil acts as a primary reservoir for these heavy metals. The extensive application of agrochemicals has heightened the risk of contamination in agricultural areas, significantly affecting the heavy metal levels in the food grown on these lands (Ihedioha, et al., 2019). One of the most difficult tasks facing the government is to provide a healthy and clean environment for the people, particularly in terms of trash management (Eyankware and Ephraim, 2021; Moriasi, et al., 2007). Solid wastes, often referred to as refuse, are discardable materials that outlive their usefulness, while liquid waste, essentially an industrial byproduct, is a major consequence of leachates that contribute to the contamination of water, soil, and air (Awomeso, et al., 2010; Eyankware, et al., 2021a) as shown in Fig. 1a and 1b. The removal of solid waste heaps poses a formidable task for major urban areas, with potential consequences for public health, environmental quality, and the urban landscape (Momodu, et al., 2011; Adedeji and Olayinka, 2013; Walling, et al., 2004; Dimuna, 2004). Waste management is one of those areas that, given the increase in waste output in the urban environment, necessitates additional planning and management. The unprecedented growth of towns and cities has presented numerous obstacles to urban planners, managers, and decision-makers regarding proper urban development and planning. Large cities frequently have open dumps in undesirable sites, which endanger public health through the spread of diseases and odors.

The uncontrolled disposal of waste has heightened the risk of heavy metal contamination in agricultural lands, adversely affecting the ecosystem and significantly influencing the levels of heavy metals in the food cultivated in these areas. The majority of heavy metals have negative health effects on the kidneys and stomach, even causing cancer (WHO, 1993; Zhao, et al., 2018). Unlike organic contaminants, which microbial action converts to carbon (IV) oxide, heavy metals do not undergo microbial or chemical degradation, and their total concentrations in soil persist for an extended period after introduction (Adriano, 2003; Kirpichtchikova, et al., 2006). Most heavy metals disperse throughout the various minerals of soil, potentially altering their mobility and bioavailability. Studies have shown that the particular physicochemical forms of metals in the environment, as opposed to their total concentration, determine their environmental behavior (Bermond, 2001; Landonin, 2002; Eyankware, 2017; Olajire, et al., 2003). This is essential due to the intricate nature of issues like the emergence of new waste streams, contamination by heavy metals and organic pollutants, along with environmental concerns related to waste processing and treatment, among others (Eyankware et al., 2021b; Elaigwu et al., 2007; Eyankware and Obasi, 2021; Zaini, 2011). Waste dumpsites commonly contain toxic metals, a source of concern and a risk to humans who come into contact with contaminated soils and plants. The chemical compositions of solid waste products frequently cause changes in the physical and chemical features of soil due to contamination (Logan, 2002; Akakuru, et al., 2023; Eyankware, et al., 2023a). One of the most harmful categories of pollutants is heavy metals (Ideriah, et al., 2010; Ulakpa and Eyankware, 2021; Odesa, et al., 2024a). Several studies have assessed the impact of solid waste on the environment globally (Eyankware, et al., 2015; Odesa, et al., 2024b; Onwe, et al., 2024; Igwe, et al., 2021). Various primary index methods, including the geoaccumulation index, ecological risk index, and pollutant load index, are employed to evaluate the ecological risk of soil. The evaluation of soil ecological risk is effectively addressed through the use of indices, which facilitate both qualitative and quantitative assessments of environmental and soil ecological risks. These evaluation techniques can directly reflect the spatially changing trend and pollution level of soil pollutants (Ulakpa, et al., 2016). Many urban environmental pollution sources and intricate risk exposure routes exist. Similarly, study conducted by Thelma et al. (2020) examined the levels of heavy metals and the degree of pollution in soils from abandoned dump sites in Kumasi, Ghana. The findings indicated that moderate levels of heavy metals, including arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc, were present in the soils of the dump sites at Amakom and Kronum, with some concentrations surpassing international soil quality standards.

The distribution of these metals was relatively uniform across the study area, although a slightly elevated concentration of lead was observed in the western and northeastern sections of the Kronum and Amakom dump sites, respectively. The index of geoaccumulation and contamination was found to be highest for arsenic at Amakom and for lead at Kronum. Research on heavy metal contamination in soil predominantly emphasizes the quantification of their concentrations in soil samples, often overlooking

their unpredictable nature (Lewandowski et al., 1998; Siepak et al., 1996). While such studies can offer essential insights into the extent of heavy metal pollution, this particular investigation adopts a statistical approach alongside a heavy metal index to assess the impact of solid waste on soil quality. To achieve this, the study set forth several objectives: the evaluation of heavy metals in soil was conducted using various indices, including the potential ecological risk index, the geoaccumulation index (Igeo), the contamination factor, and the Nemerow pollution index.



Fig. 1a. Waste dumpsite around Obiakpu.

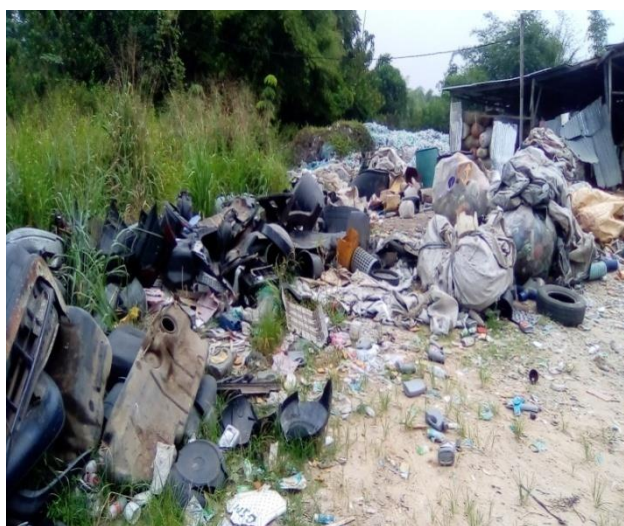


Fig.1b. Waste dumpsite around Obudi.

Description of study area, climate, drainage, and topography

The research area is located between latitudes 5°32' N and 5°47' N, and longitudes 6°38' E and 6°59' E, in the southwestern part of Imo State (see Fig. 2). As per the 2006 census, the population of the Imo state stands at 182,500. However, local inhabitants have recently observed a notable increase in population attributed to urbanization and industrialization (NPC, 2006). Considering the ongoing increase in surface temperatures and fluctuations in rainfall, the study area is probably at risk from the impacts of global warming. The study area is located in the wet tropics. The mean annual rainfall ranges from 2250mm to 2500mm. An annual average temperature exceeding 20 °C (68.0 °F) results in a relative humidity level of 75%. During the rainy season, humidity can rise to as high as 90%. This reaches 90 percent in the rainy season. The dry season is characterized by two months of harmattan (from December to late February). Oguta Lake is fed by four rivers: the Njaba, Awbana, Utu, and Orashi (Ahiarakwem et al., 2012), making their recharge crucial. In the rainy season, the Utu Stream, which is perennial, flows directly into the lake, while the Orashi River runs along the southwest side of the lake.

The Njaba and Awbana Rivers contribute to the lake's water supply throughout the year. According to Mahiarakwem and Onyekuru (2011), the total annual inflow from these rivers and streams is estimated to be 25,801.60 m³. Additionally, the lake is believed to receive 69,000 m³ of return water annually and 138,000 m³ from overland flow (Ifeyinwa and Okorie, 2011). Furthermore, it is estimated that approximately 693,000 m³ of precipitation recharge occurs each year. Ahiarakwem and Onyekuru (2011) also estimate that groundwater contributions to the lake amount to 2,750,400 m³ annually.

Geology of the study area

Short and Stauble (1967) categorized the Niger Delta Formations into three distinct groups: Akata, Agbada, and Benin. Within the delta, the Benin Formation consists of a network of aquifers primarily composed of large, highly porous sands and gravels, interspersed with thin layers of shale and clay. Despite the successful drilling of numerous boreholes into the Benin Formation aquifers, many have been abandoned due to high salinity levels (Oteri and Atolagbe 2003). Weber and Daukoru (1976) noted that the Benin Formation, formed during the continental phase of the Niger Delta, has an approximate sediment thickness of 2100 meters.

Onyeagocha (1980) further described the Benin Formation as predominantly consisting of sandstone, sands, and gravel, with clay appearing in lens-like formations. The sands and sandstones vary in grain size from fine to coarse, are partially unconsolidated, and exhibit differing thicknesses. The Benin Formation is predominantly composed of durable freshwater-bearing continental sand and gravel, with

interlayers of clay and shale (Oteri 1990). The Niger Delta Basin, which features extensive porous sands and gravels, contains a multi-aquifer system. In the unconfined aquifer of the coastal beach ridges, a freshwater lens is present above the seawater. In numerous confined aquifers in the study area, freshwater lies beneath saltwater. Certain zones in the Niger Delta have seen saltwater intrusion into limited aquifers, where saltwater-bearing sands rest atop freshwater-bearing sands, as described by Oteri and Atolagbe (2003).

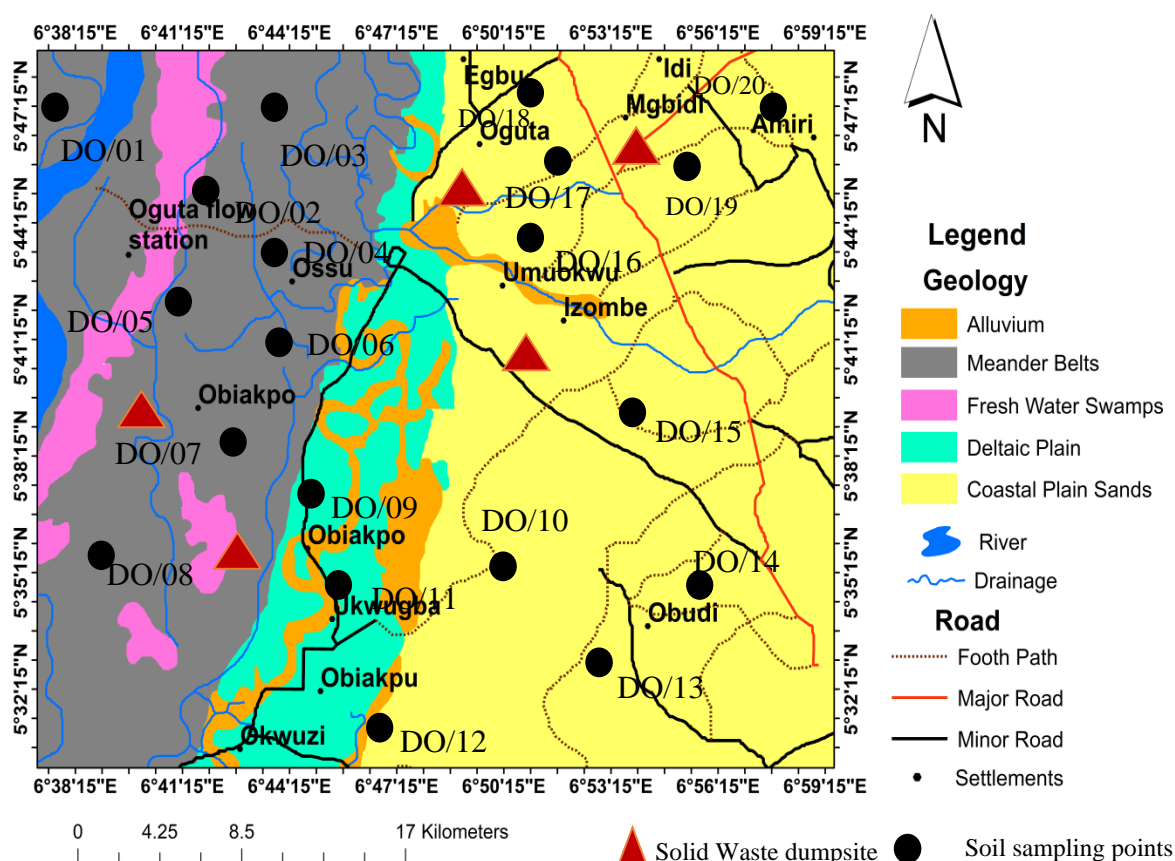


Fig. 2: Geology map of the study area showing soil sample locations

METHODOLOGY

A total of twenty (20), soil samples were collected around dumpsite within the study area, each sampling point yielded a minimum of three composite soil samples. A steel auger was used to collect soil samples from a depth of 0–15 cm into transparent plastic bags. In the laboratory, samples were air-dried for several days by spreading them out on transparent plastic on a bench. The samples were subsequently passed through a 2 mm sieve and stored in transparent plastic bags until analysis could be conducted. A quantity of 10 g of the sieved air-dried soil samples was transferred into 250 cm³ conical flasks that had been meticulously cleaned, followed by the addition of 100 cm³ of 0.5 M nitric acid. The flasks were then subjected to mechanical shaking for a

minimum duration of 30 minutes using a mechanical shaker. Soil samples are subjected to drying in an oven at temperatures between 105°C and 110°C to facilitate the evaporation of moisture. The materials were then filtered through ashless Whatman filter paper into 100-cm³ plastic bottles. The percentage recoveries were calculated based on the variations observed between the baseline concentrations and those of the spiked samples. For the formulation of solutions intended for cadmium spiking in samples, cadmium nitrate, a widely used reagent with a minimum purity of 99 percent, was employed. Meanwhile, in creating solutions for spiking samples with lead, copper, and zinc, analytical-grade lead nitrate salt along with analytical-grade granules of copper and zinc were utilized.

A reagent blank for each metal was also prepared and processed entirely prior to its application in the sample analysis. Calibration curves were established using analysis-grade metals and metal salts. Using a Varian Techtron AA6 atomic absorption spectrophotometer and associated metallic hollow cathode lamps, the concentrations of cadmium, copper, lead, and zinc were determined. The fuel was acetylene gas, and the support was air. In each case, an oxidizing flame was used. The concentrations of four metals were calculated using calibration curves. To zero the instrument, a reagent blank was employed. The aspiration of standard solutions was conducted first, followed by the aspiration of extracts from soil samples. Prior to their transport to locations with inadequate road conditions for laboratory testing, the soil samples were stored at a station nearer to these roads, which resulted in a delay in sample transmission. The laboratory analyses were completed 48 hours after the samples were collected. These measures are crucial for maintaining the integrity of the soil samples.

Data analysis

Soil Pollution Index Calculation

The determination of heavy metal levels in the soil was carried out using the potential ecological risk index, the geoaccumulation index (Igeo) outlined in Tables 4 and 5, along with the contamination factor and the potential ecological risk index provided in Tables 6 and 7.

Potential Ecological Risks Assessment

$$E_r^i = C_f^i * T_r^i = T_r^i * C_i / C_b \quad (1)$$

The potential ecological risk index was first proposed by (Hakanson, 1980).

where E_r^i denotes the potential ecological risk index of metal i^{th} ; T_r^i is the toxic response factor of the i^{th} metal. In this study, the T_r^i of Zn, Cr, Pb, Cu, Ni, and Cd are 1, 2, 5, 5, 5 and 30, respectively which helps assess the potential ecological harm caused by heavy metal contamination by quantifying the ecological risk associated with each metal in the environment. The C_f^i values of each heavy metal are obtained from (Eq. 4) by using the quotient of concentration of the heavy metal in the soil with the background/target value. To

quantitatively express E_r^i , five criteria grades were employed: $E_r^i < 40$, $40 \leq E_r^i < 80$, $80 \leq E_r^i < 160$, $160 \leq E_r^i < 320$ and ≥ 320 signifying low, moderate, considerable, high and very high risk, respectively (Hakanson, 1980; Ogunkunle and Fatoba, 2013); Osisanya, et al., 2024). The total of the individual potential ecological risk factors is used to calculate the potential ecological risk index for different heavy metals in soil. The vulnerability of various biological populations is represented, as are any threats posed by heavy metals. All of the detected heavy metals' potential ecological risk indices were calculated using (Equation 2)

$$RI = \sum_i^n E_r^i \quad (2)$$

(ii). The Geo-accumulation index (Igeo)

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5 B_n} \right) \quad (3)$$

As proposed by (Muller, 1979)

Where: B_n is the geochemical background concentration (mg/kg) and C_n is the element n 's measured concentration (gg-1)

iii. Contamination factor (CF)

The CF was calculated using the (Hakanson, 1980) formula

$$CF = \frac{C_n}{B_n} \quad (4)$$

Where: B_n is the background/target value, C_n is the metal concentration (Yahaya, et al., 2021)

STATISTICAL ANALYSIS

The analysis of the data was conducted utilizing the statistical software SPSS, which facilitated the execution of Principal Component Analysis (PCA).

i. Principal Component Analysis (PCA)

PCA is a method for reducing these datasets' dimensionality while enhancing interpretability and reducing information loss (Akakuru et al 2023a). According to Subba Rao et al. (2007), PCA has been a crucial statistical method for figuring out the connections between numerous factors that affect water quality. Component loading in the PCA involved condensing a huge dataset of several variables into a smaller number of linear combinations in the component that accounted for a suitable portion of the total data variance and made it simple to link the variables to the sources or processes using Equation (Eyankware and Akakuru, 2022).

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N (X_{N-N})^2 \quad \text{Eyankware, et al., 2022b(5)}$$

RESULTS AND DISCUSSION

Table 1: Concentration (mg/kg) of heavy metals in soil samples within the study area

Sample site	Zn	Cr	Cu	Pb	Cd	Hg	Ni	As	Fe
DO/01	41.10	8.1	11.1	16	0.6	0.00	14.9	0.00	1025
DO/02	46.20	11.2	16.2	17.5	0.7	0.00	13.1	0.00	13540
DO/03	40.1	10.3	20.1	13.5	1.5	0.00	11.4	0.00	12250
DO/04?	32	7.5	12	12.7	1	0.00	13.8	0.00	16540
DO/05	58.2	12	18.2	16.2	0.7	0.00	12.2	0.00	11280
DO/06	60.1	10.4	20.1	15.3	1.3	0.00	14.5	0.01	12440
DO/07	23.50	9.03	15.22	11.94	0.2	0.00	20.38	0.02	10493
DO/08	14.24	11.39	10.23	9.39	0.8	0.00	9.2	0.01	10401
DO/09	20.11	7.29	9.29	8.2	1.02	0.01	14.19	0.01	10031
DO/10	11.31	5.39	8.39	14.29	0.74	0.01	18.38	0.02	10344
DO/11	10.2	4.4	5.61	9.64	0.06	0.02	10.33	0.01	14441
DO/12?	9.28	10.22	10.21	15.86	0.75	0.001	9.37	0.01	11031
DO/13	27.29	14.39	14.55	6.07	0.69	0.02	7.28	0.01	10001
DO/14	19.82	11.43	9.29	10.54	0.2	0.01	10.96	0.01	10302
DO/15	11.88	6.49	14.2	9.55	0.31	0.01	13.75	0.01	11192
DO/16	18.19	7.08	11.29	12.65	0.4	0.01	15.65	0.12	1023
DO/17?	20.31	6.95	10.11	13.42	0.21	0.01	9.27	0.001	1022
DO/18	19.93	14.31	5.4	16.54	0.68	0.02	10.11	0.02	1020
DO/19	10.88	10.3	19.15	9.06	0.47	0.01	13.38	0.001	10390
DO/20	20.1	9.82	21.39	14.47	0.04	0.03	8.73	0.01	2030
Min	9.28	4.40	5.40	6.07	0.04	0.00	7.28	0.00	1020
Max	60.1	14.39	21.39	17.50	1.50	0.02	20.38	0.12	16540
Aver	25.85	9.40	13.10	12.64	0.62	0.00075	12.54	0.00065	9501.05

Potential Ecological Risks Assessment

A Swedish researcher Hakanson, (1980) developed the potential ecological risk index (Table 2). It provides information on the toxicity and ecological sensitivity of contaminant concentrations and was used to evaluate the harmful impacts of toxins on the environment and humans Hakanson, (1980); Weihua; et al., 2010; Suresh, et al., 2012). The tool's original purpose was to be used for evaluating sediment pollution in aquatic environments. Previously, it was utilized to assess the risks associated with soil, dust, and air pollution. (Qingjie, et al., 2008; Qing, et al., 2015; Ogunkunle

and Fatoba, 2013; Iqbal and Shah, 2014; Osipova, et al., 2016). The ERI results presented in Table 3 indicate that the total sample count exceeded 600, signifying elevated ecological risk. This outcome is expected given that there are numerous garbage disposal stations all around the residential neighborhood. The area's anthropogenic activities such waste disposal, and septic tanks, which have made the soil vulnerable to contamination, may be to blame for this extremely high level of ecological danger (Agidi, et al., 2022; Eyankware, et al., 2021a; Onwe, et al., 2022).

Table 2: Ecological Risk Index set limit in Soil (Hakason, 1980).

S/No	Range	Remarks
1	$R_i \text{ or } E_r^i$	Ecological Pollution Degree
2	$E_r^i < 40 \text{ or } R_i < 150$	Low Ecological Risk
3	$40 \leq E_r^i < 80 \text{ or } 150 \leq R_i < 300$	Moderate Ecological Risk
4	$80 \leq E_r^i < 600 \text{ or } 300 \leq R_i < 600$	Considerable Ecological Risk
5	$160 \leq E_r^i < 320 \text{ or } 600 \leq R_i$	Very high Ecological Risk

Table 3: Results of Potential Ecological Risk (ERI) in soil samples within the study area

Sample site	Ti * Pi									ERI
	Zn	Cr	Cu	Pb	Cd	Hg	Ni	As	Fe	
DO/01	0.293571	0.081	1.541667	0.8	22.5	0.05	0.532143	0.0006	256250	256275.8
DO/02	0.33	0.112	2.25	0.875	26.25	0.01	0.467857	0.0002	338500	338530.3
DO/03	0.286429	0.103	2.791667	0.675	56.25	0.05	0.407143	0.00002	306250	306310.6
DO/04	0.228571	0.075	1.666667	0.635	37.5	0.05	0.492857	0.00002	413500	413540.6
DO/05	0.415714	0.12	2.527778	0.81	26.25	0.15	0.435714	0.0004	282000	282030.7
DO/06	0.429286	0.104	2.791667	0.765	48.75	0.1	0.517857	0.00002	311000	311053.5
DO/07	0.167857	0.0903	2.113889	0.597	7.5	0.02	0.727857	0.00004	262325	262336.2
DO/08	0.101714	0.1139	1.420833	0.4695	30	0.05	0.328571	0.0002	260025	260057.5
DO/09	0.143643	0.0729	1.290278	0.41	38.25	0.05	0.506786	0.00002	250775	250815.7
DO/10	0.080786	0.0539	1.165278	0.7145	27.75	0.005	0.656429	0.00004	258600	258630.4
DO/11	0.072857	0.044	0.779167	0.482	2.25	0.01	0.368929	0.00002	361025	361029
DO/12	0.066286	0.1022	1.418056	0.793	28.125	0.05	0.334643	0.00002	275775	275805.9
DO/13	0.194929	0.1439	2.020833	0.3035	25.875	0.01	0.26	0.00002	250025	250053.8
DO/14	0.141571	0.1143	1.290278	0.527	7.5	0.005	0.391429	0.00002	257550	257560
DO/15	0.084857	0.0649	1.972222	0.4775	11.625	0.05	0.491071	0.00002	279800	279814.8
DO/16	0.129929	0.0708	1.568056	0.6325	15	0.055	0.558929	0.00024	25575	25593.02
DO/17	0.145071	0.0695	1.404167	0.671	7.875	0.005	0.331071	0.00002	25550	25560.5
DO/18	0.142357	0.1431	0.75	0.827	25.5	0.01	0.361071	0.00024	25500	25527.73
DO/19	0.077714	0.103	2.659722	0.453	17.625	0.005	0.477857	0.00002	259750	259771.4
DO/20	0.143571	0.0982	2.970833	0.7235	1.5	0.015	0.311786	0.00042	50750	50755.76
Min	0.066286	0.044	0.75	0.3035	1.5	0.005	0.26	0.00002	25500	25502.93
Max	0.429286	0.1439	2.970833	0.875	56.25	0.15	0.727857	0.0006	413500	413561.5
Aver	0.183836	0.093995	1.819653	0.63205	23.19375	0.0375	0.448	0.00013	237526.3	237552.7

Geoaccumulation Index

The index of geo-accumulation (I_{geo}), developed by Muller in 1979 to measure the level of contamination of elemental concentrations in sediment, water, dust, and soil, has been widely used to track these pollutants' pollution status globally (Eyankware and Akakuru, 2022). The classifications of (I_{geo}) and their respective interpretations are presented in Table 4. The findings from this study's I_{geo} results (Table 5) reveal that the entire sample is categorized within the range of 0 to 2 (Table 4), suggesting that the soil quality is generally unpolluted, except for iron (Fe), which exhibited significant contamination. Soil

contamination with heavy metals is a significant concern due to its impact on living organisms. Agricultural soils are receiving significant quantities of toxins from various sources. In recent years, rapid urbanization, industrialization, and irresponsible agricultural practices have contributed to the introduction of metal contaminants in farming areas. Heavy metal pollution in agrarian soils might bestow useful issues on soils, impede plant development, and even mischief the strength of people through the defilement of well-established pecking order (Eyankware et al., 2024; Eyankware and Akakuru, 2022).

Table 4: Geoaccumulation Index scale (Igwe, et al., 2020; Igwe, et al., 2022; Hazzeman, et al., 2017).

I_{geo} value	I_{geo} Class	Designation of sediment quality
>5	6	Very highly polluted
4-5	5	Highly polluted
>3-4	4	Moderate to highly polluted
2-3	3	Moderately polluted
>1-2	2	Moderated to unpolluted
0-2	1	Unpolluted
0<	0	Background concentration

Table 5: Results of Igeo soil samples within the study area

	Zn	Cr	Cu	Pb	Cd	Hg	Ni	As	Fe
DO/01	0.058916	0.016256	0.061878	0.03211	0.150515	0.001003	0.021359	1.2E-05	51425.96
DO/02	0.066227	0.022477	0.090309	0.03512	0.175601	0.000201	0.018779	4.01E-06	67932.44
DO/03	0.057482	0.020671	0.11205	0.027093	0.376287	0.001003	0.016342	4.01E-07	61460.29
DO/04	0.045871	0.015051	0.066896	0.025487	0.250858	0.001003	0.019782	4.01E-07	82983.94
DO/05	0.083428	0.024082	0.101458	0.032511	0.175601	0.00301	0.017488	8.03E-06	56593.64
DO/06	0.086152	0.020871	0.11205	0.030705	0.326116	0.002007	0.020785	4.01E-07	62413.55
DO/07	0.033687	0.018122	0.084846	0.023962	0.050172	0.000401	0.029214	8.03E-07	52645.13
DO/08	0.020413	0.022858	0.057028	0.018844	0.200687	0.001003	0.013188	4.01E-06	52183.55
DO/09	0.028827	0.01463	0.051788	0.016456	0.255875	0.001003	0.020341	4.01E-07	50327.2
DO/10	0.016213	0.010817	0.046771	0.028678	0.185635	0.0001	0.026347	8.03E-07	51897.57
DO/11	0.014621	0.00883	0.031274	0.019346	0.015051	0.000201	0.014808	4.01E-07	72452.9
DO/12	0.013303	0.02051	0.056917	0.031829	0.188144	0.001003	0.013432	4.01E-07	55344.36
DO/13	0.03912	0.028879	0.081111	0.012182	0.173092	0.000201	0.010436	4.01E-07	50176.68
DO/14	0.028411	0.022938	0.051788	0.021152	0.050172	0.0001	0.015711	4.01E-07	51686.85
DO/15	0.01703	0.013025	0.07916	0.019166	0.077766	0.001003	0.01971	4.01E-07	56152.13
DO/16	0.026075	0.014209	0.062938	0.025387	0.100343	0.001104	0.022434	4.82E-06	5132.561
DO/17	0.029114	0.013948	0.05636	0.026932	0.05268	0.0001	0.013288	4.01E-07	5127.544
DO/18	0.028569	0.028718	0.030103	0.033194	0.170584	0.000201	0.014492	4.82E-06	5117.51
DO/19	0.015596	0.020671	0.106754	0.018182	0.117903	0.0001	0.01918	4.01E-07	52128.36
DO/20	0.028813	0.019707	0.119241	0.029039	0.010034	0.000301	0.012514	8.43E-06	10184.85

Contamination factor (CF)

In this study, CF was used to calculate the concentration ratio of heavy metals to background values. The values of the contamination factor are described using the following criteria: $CF < 1$ Low contamination

$1 \leq CF \leq 3$ ($CF < 1$), moderate contamination $3 \leq CF \leq 6$, significant contamination $CF > 6$, and very high contamination.

(Igwe, et al., 2021; Bhutian, et al., 2017; Eyankware, et al., 2024).

Table 6: Result of the Contamination factor (CF) in soil samples within the study area

Sample site	Zn	Cr	Cu	Pb	Cd	Hg	Ni	As	Fe
DO/01	2.56	0.21	3.17	0.29	0.78	0.01	5.73	0.00	256.25
DO/02	2.88	0.29	4.62	0.31	0.92	0.01	5.03	0.00	338.5
DO/03	2.50	0.27	5.74	0.24	1.97	0.01	4.38	0.22	306.25
DO/04	2	0.19	3.42	0.23	1.31	0.01	5.30	0.22	413.5
DO/05	3.63	0.31	5.2	0.29	0.92	0.01	4.69	0.00	282
DO/06	3.75	0.27	5.74	0.27	1.71	0.01	5.57	0.22	311
DO/07	0.05	0.23	4.34	0.21	0.26	0.00	7.83	0.44	262.325
DO/08	0.89	0.29	2.92	0.17	1.05	0.01	3.53	0.01	260.025
DO/09	1.25	0.19	2.65	0.14	1.34	0.01	5.45	0.22	250.775
DO/10	0.70	0.14	2.39	0.25	0.97	0.05	7.06	0.44	258.6
DO/11	0.63	0.11	1.60	0.17	0.07	0.01	3.97	0.22	361.025
DO/12	0.58	0.26	2.91	0.28	0.98	0.00	3.60	0.22	275.775
DO/13	1.705	0.37	4.15	0.11	0.90	0.00	2.80	0.22	250.025
DO/14	1.23	0.30	2.65	0.19	0.26	5.26	4.21	0.22	257.55
DO/15	0.74	0.17	4.05	0.17	0.40	0.01	5.28	0.22	279.8
DO/16	1.136	0.18	3.22	0.23	0.52	0.01	6.01	0.01	25.575
DO/17	1.269	0.18	2.88	0.244	0.27	0.05	3.56	0.222	25.55
DO/18	1.245	0.37	1.54	0.30	0.89	0.01	3.8	0.01	25.5
DO/19	0.68	0.27	5.47	0.16	0.61	0.02	5.14	0.22	259.75
DO/20	1.25	0.25	6.11	0.26	0.05	0.01	3.35	0.01	50.75
Min	0.05	0.11	1.54	0.11	0.05	0.00	2.8	0.00	25.5
Max	3.75	0.37	6.11	0.31	1.97	5.26	7.83	0.44	413.5
Aver	1.25	0.24	3.74	0.22	0.82	0.48	4.86	0.17	235.88

The sample locations DO/01, 02, 03, 04, 09, 13, 14, 16, and 17 displayed moderate levels of contamination in 55% of instances. Conversely, 30% of the samples (DO/08, 10, 11, 12, 15, and 19) were identified as having "significant contamination," a classification that also applied to moderate zinc contamination at the same rate. Regarding all samples, 55% (DO/01, 02, 03, 05, 06, 07, 13, 15, 16, and 19) were noted for "significant contamination" concerning copper, while 40% (DO/08, 09, 10, 11, 12, 14, 17, and 18) fell into the "moderate contamination" category, and 5% were recorded under "very high contamination." Regarding cadmium, 25% of the analyzed samples fell into the category of "moderate contamination," while a larger proportion, 75%, was identified as having "low contamination." In the case of nickel, a significant 80% of the samples were deemed to have "significant contamination," with 15% categorized as "very high contamination," and 5% as "moderate contamination." For chromium, lead, mercury, and arsenic, every sample was classified as exhibiting "low contamination," whereas all samples

pertaining to iron received a designation of "very high contamination."

Pearson correlation

The correlation matrix is a handy tool for determining how two variables are related. Typically, the correlation coefficient ranges from -1 to +1. The link is referred to as having a negative slope or being anti-correlated if the r-value is close to -1. The relationship is referred to as having a positive slope or being correlated when the value of r is near +1. The points are regarded as uncorrelated if the value is zero (Eyankware and Akakuru, 2022). The findings indicate correlations between the following pairs: Zn and Cu (0.464), Zn and Pb (0.473), Zn and Cd (0.557), and Zn and Hg (0.633). Additionally, correlations were observed between Cr and Ni (-0.449), Pb and As (0.494), and Cd and Hg (0.454), as illustrated in Table 7. These results suggest a weak correlation among the elements, implying that they are largely independent of one another (Akakuru et al., 2021a; Akakuru et al., 2021b).

Table 8: Results of Pearson correlation

	Zn	Cr	Cu	Pb	Cd	Hg	Ni	As	Fe
Zn	1.000								
Cr	.325	1.000							
Cu	.464	.283	1.000						
Pb	.473	.107	.126	1.000					
Cd	.557	.247	.229	.173	1.000				
Hg	.633	.097	.343	.276	.454	1.000			
Ni	-.069	-.449	.045	.147	.064	.115	1.000		
As	.358	.176	.125	.494	-.158	.290	-.034	1.000	
Fe	.240	-.119	.127	-.152	.389	.232	.206	-.316	1.000

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was applied to determine the underlying structure among the heavy metals. A categorization method known as Principal Component Analysis (PCA) seeks to elucidate the variance among numerous interrelated variables (Eyankware and Akakuru, 2022; Akakuru et al., 2021b). This technique demonstrates the relationships between variables, thereby reducing the complexity of the dataset. The covariance matrix of the initial data is used by PCA to extract the eigenvalues and eigenvectors. The uncorrelated (orthogonal) variables known as principal components (PCs) are created by multiplying the initial correlated variables by the eigenvectors (loadings). The transformed observations are referred to as scores; the eigenvalues of the PCs measure their associated variance; and the loadings show the original variables' involvement in the PCs. Each principal component represents a latent factor influencing metal concentrations across soil samples. PC1 explains the highest variance, indicating it captures the most significant combination of metals. Each principal component represents a latent factor influencing metal concentrations across soil samples. In order to determine the most likely sources of groundwater contamination, it explains the relationship between the variables. Four important principal components were identified. All loadings larger than 0.4 (+ or -) are regarded as important contributors in the analysis interpretation. Zn (0.911), Cr (0.420), Cu (0.585), Pb

(0.553), Cd (0.644), Hg (0.764), and As (0.418) all had positive high loadings in principal component 1 (PC1, 77.7%), according to the results shown in Table 9. This could point to man-made factors like urban or industrial activity, agricultural activities etc. High loading for Cd (0.461), Ni (0.443), As (-0.672), and Fe (0.789) is seen in PC2 (44.4%). could be a reflection of geogenic or anthropogenic sources, such as urban activity and the natural background soil composition. Industrial sources may contribute high concentrations of certain metals like Cd and Ni (positive loadings), while agricultural runoff may reduce others like As (negative loading). PC3 (33.3%): Significant contributions from Cr (-0.656), Pb (0.472), and Ni (0.443) imply localized contamination or an additional source of pollution. PC4 (11.1%): Moderate contributions from various sources and a prominent loading on Cu (0.755) may suggest site-specific or mixed sources. Communalities reflect how much of each variable's variance is explained by the extracted PCs: Higher values (>0.7) suggest that most variance is captured by the PCs. For example, **Cu (0.936)** and **Zn (0.837)** are well-represented in the PCA model. In summary, according to Table 8's PCA results, PC1 has a loading percentage of 77.8%, PC2 has a loading percentage of 44.4%, PC3 has a loading percentage of 33.3%, and PC4 has a loading percentage of 11.1%. This loading signifies the element's importance in the contribution of pollution within elements and to the soil (Table 9).

Table 9: PCA matrix

	Communalities	Components			
		PC1	PC2	PC3	PC4
Zn	.837	.911	.001	-.030	-.079
Cr	.754	.420	-.384	-.656	.005
Cu	.936	.585	.052	-.145	.755
Pb	.740	.553	-.372	.472	-.272
Cd	.796	.644	.461	-.224	-.343
Hg	.636	.764	.161	.162	-.012
Ni	.783	.011	.443	.741	.195
As	.772	.418	-.672	.380	.041
Fe	.690	.242	.789	-.081	-.047
Eigenvalues		4.55	0.48	0.62	0.24
Variance (%)		22.14	17.61	10.04	7.35
Cumulative var. (%)		22.14	39.75	49.79	57.140

Comaprism of soil result of the study area to International standard

Results from Table 10, revealed all sampled parameters where below WHO, (1981) permissible limit except for Cd. The concentration of Cd soil samples results were below, WHO, (1981) maximum permissible limit except for sample location; DO/ 02, 03, 04, 05, 06, 08, 09, 10, 12, 13, and 18.

According to Agidi et al. (2022) and Li et al. (2015), the concentration of cadmium (Cd) is influenced by the geological parent materials. Cadmium present in the soil arises from a combination of natural processes and human activities. The natural contributors encompass the weathering of geological formations, volcanic eruptions, and the atmospheric deposition of soil particles carried by wind, as well as residues from forest fires (Eyankware, et al., 2024).

On the other hand, human-induced factors, including mining operations, the application of fertilizers—especially those containing phosphates—and various industrial practices such as combustion and waste management, play a substantial role in elevating cadmium concentrations in the soil (Osisanya, et al., 2024).

Table 10: show soil results obtained from the study area that is compared to WHO, 1981 heavy metal standard for soil, Maximum Permissible Addition (MPA).

S/No	Heavy metal	Target value of soil	Comaprism
1	Zn	50	Below set standard
2	Cr	100	Below set standard
3	Cu	36	Below set standard
4	Pb	85	Below set standard
5	Ni	35	Below set standard
6	As	4.5	Below set standard
7	Co	24	Below set standard
8	Cd	0.8	Above set standard for samples location DO/ 02, 03, 04, 05, 06, 08, 09, 10, 12, 13, and 18

Comaprism of soil result of the study area to (Department of Petroleum Resources) DPR permissible limit. Findings from Table 11, suggested that soil samples within the study area when compared DPR, (1991) revealed that analyzed soil samples of the study area were below DPR, (1991) set limit, except for Cd, where sample locations DO/03, 04, and 09 where slightly above the set limit. The presence of cadmium

in soil is predominantly due to both natural and human-induced sources. In its natural state, cadmium is present in the Earth's crust as a result of geological weathering and volcanic activity (Eyankware, et al., 2024). In contrast, human activities contributing to cadmium levels include mining, smelting, the irrigation of crops with sewage, as well as the application of phosphate fertilizers and various agricultural practices.

Table 11, show soil results obtained from the study area that is compared to DPR, (199)

S/No	Heavy metal	Target value of soil	Comaprism
1	Zn	140	Below set limit
2	Cr	100	Below set limit
3	Cu	36	Below set limit
4	Pb	85	Below set limit
5	Ni	35	Below set limit
6	Cd	0.8	slightly above set limit DO/ DO/ 02, 03, 04, 05, 06, 08, 09, 10, 12, 13, and 18
7	Fe	47000.0	Below set limit

Source: DPR, (1991)

CONCLUSION

Establishing a suitable theoretical framework for analyzing soil conditions across industrial sites, residential neighborhoods, and waste disposal areas is enhanced by calculating indices with diverse attributes. The soil samples were analyzed for the presence of elements such as Zn, Cr, Cu, Pb, Cd, Hg, Ni, As, and Fe. Results from the Igeo test indicated that, apart from Fe, which exhibited significant pollution, all other samples scored between 0 and 2, suggesting that the overall soil quality remains unpolluted. The finding from Pearson correlation reveals a weak association between the elements. Weak correlation also implies that the elements are

generally unrelated to one another. According to the PCA results, PC1 has 77.8% loading, PC2 has 44.4 percent loading, PC3 has 33.3 percent loading, and PC4 has 11.1 percent loading. The primary source of heavy metals in soil within the study area can be attributed to uncontrolled anthropogenic activities, trash dumps, and unsanitary processing environments. Additional analysis of soil sample results, when compared to the permissible limits set by the WHO, indicated that all samples fell below the acceptable threshold, with the exception of cadmium (Cd). The concentration of Cd exceeded the WHO limit at specific locations, namely: DO/02, 03, 04, 05, 06, 08, 09, 10, 12, 13, and 18.

This anomaly may be linked to human activities within the study area. This study would help alert the inhabitants of the study area to the concentration of heavy metals in the soil within the study area, thereby averting several health-related issues linked to heavy metal contamination. The occurrence of heavy metals in soil could be attributed to anthropogenic sources. It is also advised to conduct regular monitoring of the area for its quality standards be ensured to avoid further declines in soil quality.

Competing interest: This manuscript's development got no financial support.

Compliance with ethical standards

Conflict of interest: The corresponding author certifies that there are no conflicts of interest on behalf of all authors. There are no actual or potential conflicts involving the work.

Data availability statement:

Data related to the article are stored in a data repository.

REFERENCE

- Adededeji, O. H., Olayinka, O. O., 2013. Heavy metal concentrations in urban stormwater runoff and receiving stream. *Journal of Environment and Earth*, 3(7):141-150.
- Adriano, D. C., 2003. Trace elements in terrestrial environments: bio-geochemistry, bio availability and risks of metals (2nded.). New York City: Springer.
- Agidi B.M., Akakuru O.C., Aigbadon G.O., Schoeneich K., Isreal H., Ofoh I., Njoku J., Esomonu I., 2022. Water quality index, hydrogeochemical facies and pollution index of groundwater around Middle Benue Trough, Nigeria. *Int J Energ Water Res.* <https://doi.org/10.1007/s42108-022-00187-z>
- Ahiarakwem C.A., Onyekuru S.O., 2011. A Comparative Assessment of the Physico-Chemical and Microbial Trends in Njaba River, Niger Delta Basin, Southeastern Nigeria. *J Water Resour Prot.* 2011;03(09):686–93.
- Ahiarakwem C.A., Nwankwor G.I., Onyekuru S.O., 2012. An Assessment of the Physical and Environmental Aspects of a Tropical Lake: A Case Study of the Oguta Lake Watershed, Niger Delta Basin, Nigeria. *Am Int J Contemp Res.* 2(7):53–60.
- Akakuru, O. C., Akudinobi, B. E., Nwankwoala, H. O., Akakuru, O. U., and Onyekuru, S. O., 2021a. Compendious evaluation of groundwater in parts of Asaba Nigeria for agricultural sustainability. *Geosciences Journal.* <https://doi.org/10.1007/s12303-021-0010-x>
- Akakuru, O. C., Akudinobi, B., Opara, A. I., Onyekuru, S. O., and Akakuru, O. U., 2021b. Hydrogeochemical facies and pollution status of groundwater resources of Owerri and environs, Southeastern Nigeria. *Environmental Monitoring and Assessment*, 193, 623. <https://doi.org/10.1007/s10661-021-09364-9>.
- Akakuru, O. C., M. O. Eyankware., Akakuru, O. U., Nkwoada, A. U., Agunanne, V. C., 2023. Quantification of contamination, ecological risk index, and health risk assessment of groundwater using artificial neural network and multi-linear regression modeling approaches within Egbema, Nigeria. *Arab J Geosci* 16(9):507. <https://doi.org/10.1007/s12517-023-11600-0>
- Akinseye, V.O., · Osisanya, W.O., Eyankware, M.O., Korode, I.A., Ibitoye, A.T., 2023. Application of second-order geoelectric indices in determination of groundwater vulnerability in hard rock terrain in SW. Nigeria. *Sustainable Water Resources Management.* 9:169, <https://doi.org/10.1007/s40899-023-00936-w>
- Akakuru OC, Adakwa CB, Ikoro DO, Eyankware MO, Opara AI, Njoku AO, IHEME KO, Usman AO., 2023a Application of artificial neural network and multi-linear regression techniques in groundwater quality and health risk assessment around Egbema, Southeastern Nigeria. *Environ Earth Sci.* <https://doi.org/10.1007/s12665-023-10753-1>
- Akakuru, O. C., Ray, P. A., Reza, S. H., Temgoua, E., Eyankware, M. O., Aigbadon, G.O., Obite, C.P., Algeo, T.J., Akingboye, S.A., 2025. Leveraging Novel Machine Learning Models in Predicting Groundwater Irrigation Suitability in Southeastern Nigeria: A Hydrogeochemical Approach, *Scientific African*, doi: <https://doi.org/10.1016/j.sciaf.2025.e02646>
- Ananaba, S.E., Onu, N.N., and Iwuagwu, C.J., 1993. Geophysical study of the gravel deposits in Ihiagwa, Owerri, Nigeria. *Journal of Mining Geology*, Vol.29 (2), pp.95-100.
- Awomeso, J. A., Taiwo, A. M., Gbadebo and Arimoro, A.O., 2010. Waste disposal and pollution management in urban areas: A workable remedy for the environment in developing countries. *Am. J. Environ. Sci.*, 6: 26-32

- Bhutian R., Dipali-Bhaskar, K., and Khanna, D. R., and Gautam, A., 2017. Geochemical distribution and environmental risk assessment of heavy metals in groundwater of an industrial area and its surroundings, Haridwar, India. *Energy, Ecology and Environment*, 2(2), 155–167. <https://doi.org/10.1007/s40974-016-0019-6>.
- Bermond, A., 2001. Limits of sequential extraction procedures reexamined with emphasis on the role of H⁺ ion reactivity. *Analytica Chimica Acta*, 445, 79–88.
- Cheng, J. L., and Zhu, Z. Y., 2007. Assessment and mapping of environmental quality in agricultural soils of Zhejiang Province, China. *Journal of Environmental Sciences*, 19, 50–56.
- Dimuna K.O., 2004. The problem with the management of environmental pollution in Nigeria. *Journal of Applied and Basic Sciences*. 2(1 and 2):5-9.
- DPR., 1991. DPR Environmental Guidelines and standard for the petroleum industry in Nigeria
- Duru, P.N, and Chibo, C.N., 2014. Flooding in Imo State Nigeria: The Socio-Economic Implication for Sustainable Development” in *Humanities and Social Sciences Letters* Retrieved from [http://pakinsight.com/?ic=journal and journal=73; 10/01/2017](http://pakinsight.com/?ic=journal&journal=73; 10/01/2017)
- Elaigwu S.E., Ajibola V.O., and Folaranmi F.M., 2007. Studies on the impact of municipal waste dump on surroundings soil and air quality of two cities in northern Nigeria. *Journal of Applied Sciences*. 7(3):421-425. Available: www.aseanenvironment.info
- Eyankware. M. O., Eyankware, R. O., and Effam, S. C., 2015. Soil erodibility assessment in selected part of Ekwusigo Local Government Area Anambra State, South-Eastern Nigeria. *International Intern. Jour. of Innovational and Scientific Research*, 13(1):50-62.
- Eyankware, M. O., 2017. Hydrogeochemical evaluation of groundwater for irrigation purposes in mining areas of Umuoghara near, Abakaliki, SE. Nigeria. *Science and Technology Vol. 3(9)*:1-19.
- Eyankware, M. O., and Ephraim, B. E., 2021. A comprehensive review of water quality monitoring and assessment in Delta State, Southern Part of Nigeria. *Journal of Environmental and Earth Sciences*. 3(1); 16-28. DOI: <https://doi.org/10.30564/jees.v3i1.2900>
- Eyankware, M. O., and Obasi, P. N., 2021. A holistic review of heavy metals in water and soil in Ebonyi SE. Nigeria; with emphasis on its effects on human, aquatic organisms and plants. *World News of Natural Science*, 38; 1-19.
- Eyankware, M. O., Igwe, E. O., and Onwe, M. O., 2021a. Geochemical study using geochemical modelling approach in Ojekwe region of southern Benue Trough, Nigeria. *International Journal of Energy and Water Resources*. <https://doi.org/10.1007/s42108-021-00163-z>.
- Eyankware. M. O., Ogwah, C., and Ike, J.C., 2021b. A synoptic review of mineralogical and chemical characteristics of clays in the southern part of Nigeria. *Research in Ecology*, DOI: <https://doi.org/10.30564/re.v3i2.3057>.
- Eyankware M.O., and Akakuru C.O., 2022. Appraisal of groundwater to risk contamination near an abandoned limestone quarry pit in Nkalagu, Nigeria, using enrichment factor and statistical approaches. *J Energy Water Resour*. <https://doi.org/10.1007/s42108-022-00186-0>
- Eyankware, M.O., Akakuru, C. O., Ulakpa, R. O., and Eyankware, E.O., 2022a. Hydro geochemical approach in the assessment of coastal aquifer for domestic, industrial, and agricultural utilities in Port Harcourt urban, southern Nigeria. *International Journal of Energy and Water Resources*. <https://doi.org/10.1007/s42108-022-00184-2>
- Eyankware M.O., Akakuru, O.C., and Eyankware E.O., 2022b. Interpretation of hydrochemical data using various geochemical models: a case study of Enyigba mining district of Abakaliki, Ebonyi State, SE Nigeria. *Sustainable Water Resources Management*. <https://doi.org/10.1007/s40899-022-00613-4>
- Eyankware. M. O., and Umayah, S.O., 2022. 1D modeling of aquifer vulnerability and soil corrosivity within the sedimentary terrain in southern Nigeria, using resistivity method. *World News of Natural Science*, 41; 33-50.

- Eyankware, M.O., Akakuru, O. C., Osisanya, W. O., Umayah, S. O., and Ukor, K. P., 2023a. Assessment of heavy metal pollution on groundwater quality in the Niger Delta Region of Nigeria. *Sustainable Water Resources Management*, 2023. 9:189. <https://doi.org/10.1007/s40899-023-00955-7>
- Eyankware, M. O., Akakuru, O. C., Igwe, E. O., Olajuwon, W. O., and Ukor. K. P., 2024. Pollution Indices, Potential Ecological Risks and Spatialdistribution of Heavy Metals in soils around Delta State, Nigeria. *Water, air, and soil Pollution*. <https://doi.org/10.1007/s11270-024-07209-yl>.
- Grzebisz, W, L. Cieřla, J., Komisarek, J., and Potarzycki, 2002. Geochemical Assessment of Heavy Metals Pollution of Urban Soils *Polish Journal of Environmental Studies* Vol. 11, No. 5, 493-499.
- Hakanson L., 1980. An ecological risk index for aquatic pollution control, a sedimentological approach. *Water Res* 14:975–1001
- Hazzeman, H., Ley J. L., Ahmad Z. A., Nor F. M., Nur, A. A. A., Fatimah, M., Yusoff, A. B. S., and Sarva, M. P., 2017. Geo-accumulation index and contamination factors of heavy metals, Zn and Pb. in urban river sediment. *Environ Geochem Health*, 39:1259–1271, <https://doi.org/10.1007/s10653-017-9971-0>
- Ideriah T. J. K., Harry, F. O., Stanley, H. O., Igbara, J. K., 2010. Heavy metal contamination of soils and vegetation around solid waste dumps in port-Harcourt, Nigeria. *J. Appl. Sci. Environ. Manage.* 14(1):101-109.
- Igwe, E. O., Ede, C. O., Eyankware, M. O. 2021. Heavy metals concentration and distribution in soils around Oshiri and Ishiagu lead – zinc mining areas, southeastern Nigeria. *World Scientific News*, 158, 22–58.
- Igwe, O., Ngwoke, M., and Ukah, B.U., 2021b. Assessment of the physicochemical qualities of groundwater and soils around oil-producing communities in Afam, area of Porthacourt, Niger Delta Nigeria. *Appl Water Sci*11, 74. <https://doi.org/10.1007/s13201-021-01393-6>
- Igwe, E. O., Ede, C. O., Eyankware, M. O., Nwachukwu, C. M., and Onyekachi, B. W., 2022. Assessment of potentially toxic metals from mine tailings and waste rocks aroundmining areas of Oshiri-Ishiagu region, southeastern Nigeria. *Earth Systems and Environment*, 6(2), 597–615. <https://doi.org/10.1007/s41748-022-00306-0>
- Kirpichtchikova, T. A., Manceau, A., Spadini, L., Panfili, F., Marcus, M. A., and Jacquet, T. 2006. Speciation and solubility of heavy metals in contaminated soil using X-ray microfluorescence, EXAFS spectroscopy, chemical extraction, and thermodynamic modeling. *Journal of Geochemicaet Cosmochimica Acta*, 70(9), 2163–2190.
- Landonin, D. V., 2002. Heavy metal compounds in soils: problems and methods of study. *Eurasian Soil Science*, 35(6), 605–613.
- Lewandowski P., Burghardt W., and Ilnicki P.,1998. Heavy Metals in Soils of the River Warta Valley in Poznan. (in Polish). *Roczn.Glebozn.*49, (3/4) 19.
- Logan T.J., 2002. Soil and environmental quality in: Anikwe MAN, MAFF (Ministry of Agriculture, Fisheries and Food) and Welch office agriculture department, 1992. Code of good agriculture practice for the protection of soil. Draft Consultation Document, MAFF, London.
- Odesa, G. E., Elozona, O. E., and Eyankware. M.O., 2024a. A Review Study on Ecological Equity and Modern Remediation Techniques in Management of Soil. *Journal of Pure and Applied Sciences*.24.
- Odesa, G. E., Ozulu, G. U., M. O. Eyankware., Mba-Otike, M. N., and Okudibie, E. J. 2024b. A holistic review three-decade oil spillage across the Niger Delta Region, with emphasis on its impact on soil and water. *World News of Science*. 190(2); 119-139.
- Ogunkunle C.O., Fatoba P.O., 2013. Pollution loads and the ecological risk assessment of soil heavy metals around a mega cement factory in Southwest Nigeria. *Polish J Environ Std* 22(2):487–493.

- Ogundele, L. T., Ayeku, P. O., Adebayo, A. S., Olufemi, A. P., and Adejoro, A. I. 2020. Pollution indices and potential ecological risks of heavy metals in the soil: a case study of municipal wastes site in Ondo State, Southwestern, Nigeria. *Polytechnica*, 3, 78–86. <https://doi.org/10.1007/s41050-020-00022-6>
- Olajire, A. A., Ayodele, E. T., Oyedirdan, G. O., and Oluyemi, E. A. 2003.. Levels and speciation of heavy metals in soils of industrial southern Nigeria. *Environmental Pollution*, 113, 135–144.
- Omene, M. E., Chokor, J. U., and Eyankware, M. O., 2015. The effects of land use on soil physiochemical properties in Ughelli and its environs, Nigeria. *International Journal of Research and Review*, 2(11), 656–671
- Onwe, I. M., M. O. Eyankware., Obasi, P. N., Ifeanyichukwu, K. A., 2022. Hydrochemical and statistical approaches in the evaluation of groundwater quality for drinking and irrigation uses around Ezzangbo–Ngbo area, Southeastern Nigeria. *Modeling Earth Systems and Environment*, <https://doi.org/10.1007/s40808-022-01503-6>.
- Onwe, I. M., Obasi, I. A., Eyankware, M. O., Uchenna, O. L., 2024. An integration of hydrochemical data and stable isotopes in groundwater evaluation in Ngboejogu, Southern Benue Trough, Nigeria. *Modeling Earth Systems and Environment*, <https://doi.org/10.1007/s40808-024-02166-1>
- Okoye, E. A., Anthonet, E., Ify, L. N., Chiara, F., Orish, E. O., 2022. Heavy metals and arsenic in soil and vegetation of Niger Delta, Nigeria: Ecological risk assessment. *Case Studies in Chemical and Environmental Engineering*. <https://doi.org/10.1016/j.cscee.2022.100222>
- Osisanaya, W.O., Agho, I.F., Ovri, A.A., M.O Eyankware, 2024. Studies of heavy metal in soil at Omoku, River State, Nigeria, using Pollution Indices and Potential Ecological Risk. *Anchor University Journal of Science and Technology (AUJST)*. Vol. 5 (2): Pp. 240-257
- Osipova, N. A., Kate, A. F., Anna, V. T., Egor, G. Y., 2016. Geochemical approach to human health risk assessment of inhaled trace elements in the vicinity of industrial Enterprises in Tomsk, Russia. *Human Ecol. Risk Assess, An Interna J* 21(6):1664–1685
- Ifeyinwa, O., Okorie, F., 2011. Impacts of Climate Variability and Change on Environment: A Case Study of Imo State of Nigeria. Conference: The 1st World Sustainability Forum. DOI: 10.3390/wsf-00722
- Ihedioha, J. N., Ogili, E. O., Ekere, N. R., Ezeofor, C.C., 2019. Risk assessment of heavy metal contamination of paddy soil and rice (*Oryza sativa*) from Abakaliki, Nigeria. *Environ Monit Assess* (2019) 191: 350, <https://doi.org/10.1007/s10661-019-7491-3>
- Iqbal J, Shah HM, 2014. Occurrence, risk assessment, and source apportionment of heavy metals in surface sediments from Khanpur Lake. *Pakistan, J Anal Sci Techn* 5:28–40
- Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., Veith. T. L., 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *Transactions of the ASABE*, 50(3), 885–900. doi:10.13031/2013.23153
- Momodu, N. S., Dimuna, K. O., Dimuna, J. E. (2011). Mitigating the impact of solid wastes in urban centres in Nigeria. *J. Hum. Ecol.* ;34(2):125-133.
- Muller G., 1979) Index of Geoaccumulation in sediments of Rhine River. *Geojournal* 2:108–118
- National Population Commission (2006). Population distribution by sex, State, LGA's, Senatorial District
- Nemerow NL., 1974. Scientific stream pollution analysis. McGraw-Hill
- Siepak J, Elbanowska H., Kozacki L., 1996. Arrangement contamination of soil by heavy metals near public main roads in the city of Poznan. *Polish J. Env. Studies*, 2, 45.

- Short K.C, Stauble A.J., 1967. Outline of Geology of Niger Delta. Am Assoc Pet Geol Bull. 51.
- Suresh G, Sutharsan P, Ramasamy V, Venkatachalapath R., 2012 Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of veeranam lake sediments India. Ecotoxicol Environ Saf 84:117–124
- Subba Rao N, Prakasa RaoJ, Subrahmanyam A., 2007. Principal component analysis in groundwater quality in a developing urban area of Andhra Pradesh. J Geol Soc Ind 69:959–969
- Thelma A., Sandra B., Lawrence S. B., Matt D., Godfred D., 2020. Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghana. Scientific African. <https://doi.org/10.1016/j.sciaf.2020.e00614>
- Qingjie G, Jun D, Yunchuan X, Qingfei W, Liqiang Y., 2008. Calculating pollution indices by heavy metals in ecological Geochemistry assessment: A case study in parks of Beijing. J China University Geosci, 19(3):230–24.
- Qing X, Yuton XZ, Shenggao L., 2015. Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China, Ecotox environ. Safety 120: 377–385
- Ulakpa, R.O.E., Eyankware, M. O., 2021. Contamination assessment of water resources around waste dumpsites in Abakaliki, Nigeria. A Mini Review Journal Clean WAS, 5(1): 13-16.
- Ulakpa, W. C., Eyankware. M. O., Eyankware, E.O., Eyankware, R. O. U., 2016. Evaluation of radionuclides in Elioza dumpsite, Obio-Akpor L.G.A. South-South Nigeria. International Journal of Science and Healthcare Research India. 1(2): 15-22
- Walling E, Walston A, Warren E, Warshay B, Wilhelm E., 2004. Municipal solid waste management in developing countries, Nigeria, a case study, Group 9, NTRES. 314.
- Weihua G, Liu X, Liu Z, Li G., 2010. Pollution and potential ecological risk evaluation of heavy metals in the sediments around Dongjiangharbour, Tianjin. International Society for Environmental Information Sciences Annual conference (ISEIS). Procedia Environ Sci 2:729–736.
- WHO., 1981. Arsenic environmental health criteria. In World Health Organization (Vol. 18, p. 174). Geneva
- WHO., 1993. Evaluation of certain foods additives and contaminants. Forty-first report of the Joint FAO/WHO Expert Committee on Foods Additives (JECFA), p. 53. Geneva, Technical Report Series 837: WHO.
- Yahaya SM, Abubakar F, Abdu NU., 2021. Ecological risk assessment of heavy metal-contaminated soils M of selected villages in Zamfara State, Nigeria. SN Appl Sci 3:168. <https://doi.org/10.1007/s42452-021-04175-6>
- Zaini S., 2011. Municipal solid waste management in Malaysia. Journal of Applied Sciences in Environmental Sanitation.. 6(1):29-38.
- Zhao Y, Xu M, Liu Q, Wang Z, Zhao L, Chen Y., 2018. Study of HMPollution, ecological risk and source apportionment in the surface water and sediments of the Jiangsu coastal region, China: a case study of the Sheyang Estuary. Marine Pollut Bull. 137:601–609. <https://doi.org/10.1016/j.marpolbul.2018.10.044>