Research

Physicochemical properties and health risk assessment of selected heavy metals from soil and borehole water in Ifite-Awka, Anambra State, Nigeria

Maureen N. Okorie[1] · Victor U. Okechukwu[2] · Daniel O. Omokpariola[2,3]

Abstract
Urbanization and industrialization's influence on heavy metal contamination in soil and surface/groundwater resources warrant ongoing attention to protect public health and the environment, especially in Nigeria. Soil samples from different depths (0–10 cm, 15–25 cm, 25–40 cm) and borehole water samples were studied for physicochemical properties and heavy metal content. The result showed that borehole water pH ranged from 5.6 to 6.8, while soil pH ranged from 5.0 to 7.5 which is below WHO limits of 6.5–8.5. Other soil properties such as soil organic matter, cationic exchange capacity, and heavy metals (zinc (Zn), arsenic (As), lead (Pb) and chromium (Cr)) were assessed for fertility and pollution indicators. The concentrations of Zn, Pb and Cr were within WHO standards, but As in Sample C exceeded the limits. Heavy metals concentration order in soil was Zn > Cr > As > Pb. Pearson correlations (r) showed positive and negative relationship between variances in soil and water samples ranging − 0.17–0.99 with diverse chemical interactions across all variables analysed. Risk assessment showed average daily intake dominated through ingestion, with low risks through dermal contact. Hazard quotient and index values for all metals were below one (1), indicating minimal non-carcinogenic risks for adults and children via different pathways (inhalation, ingestion, and dermal pathways). However, cancer risk slightly exceeded USEPA levels, especially for children due to prolonged soil exposure. The analysis further revealed that children are more at risk compared to adults from soil exposure (ingestion and dermal) over a long period. The study highlights the importance of continuous monitoring and environmental regulations to ensure sustainability.

Article Highlights

1. Heavy metal contamination was assessed in Ifite-Awka soil and water.
2. Increasing industrialization and urbanization creates a toll on Ifite-Awka environment.
3. Risk assessment shows children are more vulnerable to long-term soil exposure effects.

✉ Daniel O. Omokpariola, omeodisemi@gmail.com | ¹Department of Industrial Chemistry Chukwuemeka, Odumegwu Ojukwu University, Uli, Nigeria. ²Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Nigeria. ³Department of Production and Technical, Office Chérifien des Phosphates (OCP), Africa Fertilizer Nigeria Limited, Abuja, Nigeria.

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1 Introduction

Environmental contamination arises from human activities like the improper disposal of chemicals and microbiological materials at landfill sites, emissions from vehicles, and the incineration of waste. This issue is a significant concern, particularly due to the rise in economic activities and industrialization, which have led to a notable increase in contamination [1, 2]. Anthropogenic and industrial actions have given rise to environmental hazards. The reckless disposal of their waste has led to contamination, rendering the environment unsuitable and water bodies unsafe for human consumption. Additionally, erosion poses a significant threat to the environment, especially when construction plans are not adequately situated [3]. Soil, a dynamic natural entity shaped by pedogenic processes and rock weathering, is comprised of mineral and organic components. It possesses physical, chemical, and biological attributes that influence various soil processes, making it conducive for agricultural practices and other objectives [4]. Soils play a pivotal role in maintaining ecological stability. However, the presence of contaminants can compromise their quality, leading to potential issues [5].

Contaminants such as heavy metals (lead, arsenic, chromium, cadmium, and mercury) pose risks to human health when consumed in high concentrations due to their toxicity and potential carcinogenic properties [2, 6]. Heavy metals, defined by their density exceeding 5 g/cm^3, adversely affect the environment and living organisms. Even at low concentrations, heavy metal contamination can have detrimental effects on the environment and human health due to its persistence, toxicity, and ability to accumulate [2]. These metals can persist in nature, entering the food chain through plants and animals, as well as water bodies, which poses a considerable risk to human health [6]. The origin of heavy metals in the environment can be both natural and anthropogenic. Anthropogenic sources include the application of manures, sewage sludge, fertilizers, and pesticides. These substances can impact heavy metal dynamics by altering soil physicochemical properties such as pH, organic matter content, organic carbon levels, and the bioavailability of heavy metals in the soil [2, 7]. In the Ifite area, groundwater is the primary water source. However, due to improper waste disposal and various forms of pollution entering water bodies, groundwater contamination has become an issue. Solid waste, soil erosion, and wastewater from residential and industrial zones infiltrate groundwater through leaching [2].

Groundwater contamination arises from chemical leaching from industrial activities, agrochemical discharges, septic tank leakage, leachate seepage from dumpsites, and underground soil erosion, particularly during the rainy season. The extent of contamination depends on factors such as topsoil structure, borehole water depth, percolation rate, and precipitation patterns [8, 9]. Many communities relying on borehole water sources are unaware of its quality and assume it is safe for consumption. However, these contaminants can affect the visual clarity and chemical composition of the water sources. Moreover, they can alter the taste, color, and odor of the water, thus impacting economic activities and influencing consumer perceptions and behavior [10, 11].

In developing countries, around 80% of diseases and over one-third of deaths are attributed to consuming contaminated water. Additionally, approximately one-tenth of a person's productive time is lost due to water-related illnesses [11]. Factors like improper waste disposal, urbanization, industrialization, population growth, and civilization contribute to soil and groundwater quality degradation, resulting in changes to water's physicochemical properties [10].

Human health risk assessment developed by U.S. EPA as a systematic tool to evaluate the potential adverse health effects of exposure to natural and anthropogenic environmental hazards [12, 13]. It involves the integration of scientific data from various key components (hazard identification, exposure assessment, dose–response assessment and risk characterization) to estimate the likelihood of adverse health effects in a given population, as it has been utilized by different studies for cancer and non-cancer risk assessment via different exposure medium (inhalation, dermal and ingestion) and modes (water, soil, air) using different contemporary and novel such as Human Health Risk Assessment (HHRA), HERisk, Monte Carlo Risk simulation and Quantitative Structure–Activity Relationship (QSAR), [14–16], The soil and groundwater resources in Ifite-Awka, Anambra, are substantial but are influenced by complex events, including urban and industrial waste, stormwater, and domestic and commercial waste disposal. While various studies have attempted to describe soil and water quality, these descriptions often lack comprehensiveness [17–19]. Thus, this study aims to assess the physicochemical properties of soil and borehole water and their potential health risks associated with heavy metal contamination in the Ifite-Awka area of Anambra State, Nigeria, while the objectives include: (i) to determine the various soil and water parameters, (ii) to use the physiochemical properties of soil and water quality in tandem with World Health Organization (WHO), (iii) to evaluate the potential health risk assessment for adults and children for exposure medium (inhalation, inhalation and dermal contact.

2 Materials and experimental method

2.1 Study area

Ifite is located in Anambra State, Nigeria, is a town that houses a university campus, commercial banks, and various business activities. It has a residential population of approximately 65,000. Ifite geographical coordinates span from 6° 12' 21" N to 6° 18' 89" N latitude and from 7° 2' 24" E to 7° 7' 09" E longitude. The average annual rainfall in this area is around 2000 mm [20], which experiences a tropical climate with wet and dry seasons as Fig. 1 shows the map of the location. The temperature remains relatively high (25–31 °C) throughout the year due to the topography of Anambra featuring a mix of plains and undulating landscapes that influence agricultural and drainage patterns in the region. The geology of study area is situated within the Niger delta basin which is known for its sedimentary rock formations such as sandstone, shales and limestone that impacts groundwater availability and soil composition [9, 21].
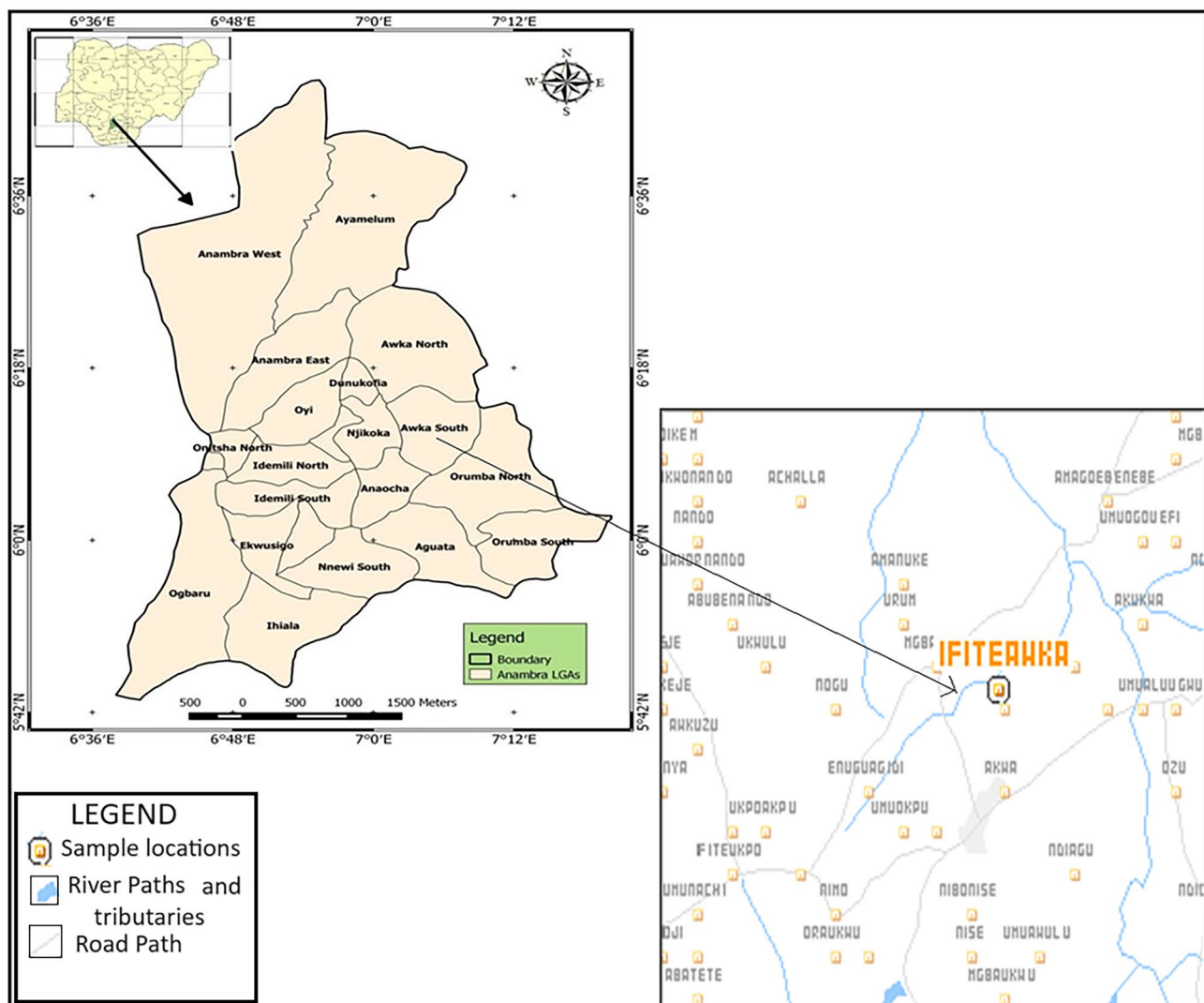

Fig. 1 Map of Ifite Awka and its environs in Anambra, Nigeria. The map was designed using Microsoft Paint 3D Software, released in 2016, version: 6.2310.24037.0, source link: https://www.microsoft.com/en-us/p/paint-3d/9nblggh5fv99)

2.2 Sample collection and preparation

For this study, samples were collected from six communities within Ifite, labeled as Sample A to F: Akpana, Umuchibu, Umukpe, Umuosite, Ezike, and Umuezeafor. A random sampling approach was employed to collect water samples from fifteen different boreholes across various locations within Ifite. The goal was to ensure a comprehensive representation of the study area for a thorough assessment of water quality.

2.3 Water samples

In each community, triplicate groundwater (borehole) samples were collected using sterilized plastic bottles and homogenized into one sample. Before collection, the sampling bottles were rinsed with the water to be collected. The labelled containers were then stored at a temperature of 4 °C in a refrigerator to prevent contamination before analysis. Distilled water and high-purity analytical-grade chemicals were used to prepare solutions for heavy metal analysis.

2.4 Soil samples

Soil samples were gathered randomly using a soil auger at three depths: 0–10 cm (topsoil), 15–25 cm (sub-soil), and 25–40 cm (below subsoil). Samples from each of these three depths were combined to create a composite sample for each community. The composite samples were placed in labelled polythene bags covered with aluminium foil. Afterwards the samples were transported to the laboratory and stored at room temperature. The soil samples were air-dried and passed through a 2-mm stainless steel sieve.

2.5 Methodology

All the reagents used in the analysis were of analytical grade. Standard procedures outlined by APHA [22] were followed for analysing the physicochemical parameters of both water and soil. The analysis was conducted in triplicate using standard methods, and the mean values were recorded. For instance, pH measurements of water samples were taken using a Hanna pH meter. Calcium analysis was performed using a HANNA HI-83200 multi-parameter photometer [23]. Various parameters such as alkalinity, acidity, total hardness, dissolved oxygen (DO), and chemical oxygen demand (COD) were determined using established methods [23, 24]. Chloride levels were assessed using multi-factor water test quality strips. Organic matter content was determined from total organic carbon. Cation exchange capacity (CEC) analysis was carried out using the ammonium acetate digestion method. Soil pH was measured using a digital pH meter in a soil suspension. Blank samples were also analysed to ensure the accuracy and reliability of the laboratory measurements.

2.6 Heavy metal analysis

Samples were digested with concentrated HNO_3 before analysis using (AAS) Varian AA240 Atomic Absorption Spectrophotometer (AAS). Water samples (100 ml) and soil samples (2 g) were measured and transferred into a beaker and concentrated HNO_3 (5 ml) was added. The solution was heated slowly and was allowed to evaporate to 20 ml in a fume cupboard. Additional of 5 ml of Concentrated HNO_3 was added and then heated continuously until a light coloured, clear solution was observed. The beaker wall was then washed with de-ionized water and then filtered with Whatman paper No 42. The filtrate was transferred to a 100 ml volumetric flask, allowed to cool and made-up to mark with distilled water and then shake well [22, 25]. The solution was then transferred into a small plastic bottle for AAS analysis.

2.7 Statistical analysis

The collected data from soil and water samples were analysed using the Statistical Package for Social Science (SPSS) 20.0 and Microsoft Excel 2016. Mean values with standard deviations were reported, and one-way analysis of variance (ANOVA) was employed for analysis. Pearson Correlation test was used for correlation analysis of the parameters studied.

2.8 Human health risk assessment model

A human health risk assessment was conducted to estimate potential adverse health effects resulting from exposure to heavy metals through soil in the study areas. Both adults and children were considered in the assessment. Average daily intake (ADI) was determined, and carcinogenic and non-carcinogenic impacts were evaluated for adults and children through exposure matrices (dermal, inhalation, and ingestion) for soil as shown in Eqs. (1–3) [2, 11].

A. Ingestion of heavy metals through soil

$$ADIing = \left(\frac{CS \times IR \times EF \times ED \times CF}{BW \times AT} \right) \tag{1}$$

where ADIing is the average daily intake of heavy metals ingested from soil in mg/kg-day, Cs = concentration of heavy metal in mg/kg for soil. IR is the ingestion rate (100 mg/day—adults and 200 mg/day—children), EF is the exposure frequency (350-day/year), ED is the exposure duration (30 years—adults and 6 years—children) [25, 26], BW is the body weight of the exposed individual (70 kg for adults and 15 kg for children), AT is the time period over which the dose is averaged (non-carcinogens = ED × 365 days; carcinogen = 70 × 365 days), CF is the conversion factor (10^{-6} kg/mg for adults and children) [29, 30].

B. Inhalation of heavy metals through soil particulates

$$ADIinh = \left(\frac{CS \times IRair \times EF \times ED}{BW \times AT \times PEF} \right) \tag{2}$$

where ADIinh is the average daily intake of heavy metals inhaled from soil in mg/kg-day, IRair is the inhalation rate (20 m^3/day—adults and 10 m^3/day—children), PEF, is the particulate emission factor (1.3×10^9 m^3/kg for adults and children) [25, 29]. CS, EF, ED, BW and AT are as defined earlier in Eq. (1) above.

C. Dermal contact with soil

$$ADIder = \left(\frac{CS \times SA \times FE \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \right) \tag{3}$$

where ADIder is the exposure dose via dermal contact in mg/kg/day. SA is exposed skin area (5800cm^2/day—adults and 2100 cm^2/day—children), FE is the fraction of the dermal exposure ratio to soil (unit-less) (0.61 for adults and children), AF is the soil adherence factor (0.07 mg/cm^2—adults and 0.2 mg/cm^2—children), ABS is the fraction of the applied dose absorbed across the skin (unit-less) (0.1 for adults and children) [30]. EF, ED, BW, CF and AT are as defined earlier in Eq. (1) before.

2.9 Non-carcinogenic risk assessment

Non-carcinogenic risk assessment was performed using ADI of dermal, ingestion and inhalation as shown in Eq. (4) [2, 27].

$$THQ = ADI/RfD \tag{4}$$

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Table 1 Reference value for heavy metals

Heavy metals	Dermal		Ingestion		Inhalation	
	CSF	RfD	OSF	RfD	ISF	RfD
Arsenic	1.5	0.0003	1.5	0.0003	1.5	0.0003
Chromium (VI)	NA	NA	0.5	0.003	41	0.00003
Lead	NA	NA	NA	0.0036	NA	NA
Zinc	NA	0.075	NA	0.3	NA	NA

Where CSF: cancer slope factor (mg/kg/day), OSF: oral slope factor (mg/kg/day), IUR: inhalation unit risk (mg/m^3), RfD: reference dose, NA: not available [2, 28]

Table 2 Results of selected portable water samples with WHO Standards for drinking water

Parameter	Units	WHO	Samples					
		Std	A	B	C	D	E	F
Temperature	˚C	–	27.5	27.2	26.9	28	28.3	25.5
Water appearance	Unitless	–	Clear	Clear	Clear	Clear	Clear	Clear
Colour	Hazen	–	Colourless	colourless	colourless	colourless	colourless	colourless
Odor	Unitless	–	odorless	odorless	odorless	odorless	odorless	Odorless
Taste	Unitless	–	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
Dissolved solids	%	–	0.028	0.18	0.022	0.024	0.032	0.19
Suspended solids	%	–	0.12	0.04	0.16	0.08	0.16	0.15
pH	Unitless	6.5–8.5	6.4	5.6	6.5	5.8	6.5	6.8
Dissolved oxygen	mg(O)/l	–	1.6	1.8	1.4	2.4	2.0	1.8
Alkalinity	mg/l(HCO$^-_3$)	30–50	48.90	43.92	44.50	43.93	42.70	48.2
Acidity	mg/l(CaCO$^-_3$)	–	0.14	0.146	0.148	0.144	0.15	0.18
Hardness	mg/l	–	7.214	4.810	6.413	7.214	6.413	6.52
Chloride	mg/l	250	23.43	26.27	20.59	30.53	29.82	30.80
COD	mg/l	–	3200	6400	3200	4800	3200	4850
Manganese	mg/l	0.5	0.38	0.21	0.73	0.05	0.88	0.31
Calcium	mg/l	75	16.03	8.02	18.04	12.02	24.08	15
Magnesium	mg/l	Not > 30	0.2	2.43	4.8	2.48	6.8	5.02

–: No available dataset, A: Akpana, B: Umuchibu, C: Umukpe, D: Umuosite, E: Ezike, F: Umuezeafor, *WHO std* World Health Organization Standards

where ADI is the exposure dose of metals, RFD is the reference dose (mg/kg/day) which is the estimated maximum permissible dose through daily exposure to the human population that is likely to be without an appreciable risk of deleterious (non-cancer) effects during a lifetime. If HQ < 1, indicates no significant risk toxicity, potential non-carcinogenic risk would occur when HQ ≥ 1 [29].

2.10 Hazard index

The hazard index (HI) which evaluates the potential risk of adverse health effects from a mixture of chemical elements was calculated based on the equation as shown in Eq. 5 [26].

$$HI = \Sigma THQ \tag{5}$$

where HI is the sum of THQ (assuming additive effects). If HI < 1, indicates no significant health risk while non-cancer risks are likely to occur if HQ ≥ 1[29].

2.11 Carcinogenic risk assessment

Carcinogenic risk assessment was determined using ADI of dermal, ingestion and inhalation as shown in Eq. (6).

$$Risk_{total} = Risk_{dermal} + Risk_{ingestion} + Risk_{inhalation} = \left(\left[ADI(Dermal) \times CSF\right] + \left[ADI(Ingestion) \times CSF\right] + \left[ADI(Inhalation) \times CSF\right] \right)$$

(6)

where Risk is a unit-less probability of an individual developing cancer over a lifetime, ADI (E) is average daily intake (exposure), CSF is Cancer slope factor of heavy metals (mg/kg/day), Risk $_{total}$ is the total excess lifetime cancer calculated from risk pathway [29, 30]. Both non-carcinogenic and carcinogenic risk assessment of heavy metals are calculated using RfD and CSF values as shown in Table 1.

3 Results and discussions

3.1 Physio-chemical properties of borehole water samples

The findings derived from analysing borehole water samples taken from six locations (denoted as Sample A–F) in Ifite, Anambra State, Nigeria, are presented in Table 2. These samples underwent analysis to assess their physiochemical properties. The examined borehole water exhibited varying concentrations of physicochemical attributes. The mean values of these attributes were compared to the World Health Organization (WHO) standards for drinking water quality [28]. The pH values of the analyzed borehole water samples ranged from 5.6 to 6.8, indicating an acidic to slightly acidic nature. Samples A, C, E, and F were found to align with the WHO standards. Borehole water samples with pH values between 6.4 and 6.8 fell within the WHO's permissible range of 6.5–8.5 for drinking water. These results were consistent with findings reported by previous studies [2, 29]. pH plays a pivotal role in water quality as it can have long-lasting effects on the environment and human health. Notably, pH is linked to the potential for water's corrosiveness, which can be hazardous [28]. Water with a pH below 6.5 can potentially leach metal ions from plumbing systems. The pH level also impacts the physiological and biochemical processes of aquatic organisms, influencing their behaviour, health, and survival.

Temperature, a critical water quality parameter, quantifies the degree of hotness or coldness of a substance. Table 2 reveals that the temperature concentrations of the sampled borehole water ranged from 26.9 to 28.3 °C, within the WHO's recommended range of 0 to 30 °C [19]. Temperature can affect a range of inorganic constituents and chemical contaminants, which in turn can impact taste. Elevated water temperatures can encourage microorganism growth and exacerbate issues related to taste, odour, colour, and corrosion [28, 30].

Dissolved oxygen (DO) indicates the amount of dissolved oxygen matter in water. The DO values for all samples ranged from 1.4 to 2.4 mg/l, which is lower than 6.5 mg/l acceptable range set by US EPA guidelines, which could be associated to elevated temperature [12, 13]. DO levels are influenced by various factors including temperature, pH, and the presence of organic matter. Low DO levels can stress or even cause mortality in aquatic organisms.

Chemical oxygen demand (COD) gauges the total oxygen required for the chemical oxidation of both biodegradable and non-biodegradable organic matter [13]. High COD values indicate a significant presence of easily degradable and non-degradable organic matter, leading to a decrease in DO due to increased oxygen demand from bacteria consuming the organic material. In Table 2, COD values for the borehole water samples spanned from 3200 to 6400 mg/l, suggesting high pollution levels. These results were consistent with COD values reported by Brima [31]. WHO recommends a COD value below 10 mg/l for drinking water, signifying the presence of substantial organic material that bacteria need to decompose, resulting in insufficient oxygen availability and rendering the water unsuitable for human consumption.

Dissolved solids (DS) in the water samples ranged from 0.022% (2.2 mg/L) to 0.18% (18 mg/L), with a mean value of 0.06% (6 mg/L), aligning with WHO's recommended limit of 0–600 mg/L [19]. These DS values were similar to report by Eboagu et al. [32] and Khan et al., [33]. The presence of dissolved solids can influence water palatability and consumer acceptability, and it can also adversely affect the growth and reproduction of aquatic organisms.

Suspended solids (SS) ranged from 0.04 to 0.16%, with a mean value of 0.11%, within the WHO's permissible limit of 0–30 mg/L [28]. Hardness, measuring dissolved calcium and magnesium in water and its lathering capacity with soap, ranged from 4.810 to 7.214 mg/l. The mean hardness levels of the water samples were in line with WHO's recommended permissible limits of 0–200 mg/L [28]. Elevated hardness levels can result in scaling, distribution system issues, and interference with the effectiveness of soaps and detergents [34].

Chloride concentration spanned from 20.59 to 30.53 mg/l, within the WHO permissible limits of 0–250 mg/L [28]. These chloride concentrations were higher than those reported by Eboagu et al. [32]. Elevated chloride content can lead to pipe corrosion, causing metal leaching and adverse health effects. The acidity of the water samples ranged from 0.14 to 0.18 mg/L ($CaCO_3$), while alkalinity ranged from 42.7 to 48.90 mg/L (HCO_3), both within the WHO's permissible limits [28]. The manganese concentration in the water ranged from 0.00 to 0.88 mg/l, adhering to the WHO's limit of 0.5 mg/l. Exposure to manganese concentrations higher than 0.5 mg/l can lead to nervous system disorders, memory loss, and depression as per WHO guidelines. Calcium concentration ranged from 8.02 to 24.08 mg/l, within the WHO permissible range of 75 mg/l. The magnesium concentration in the water was 3.61 mg/l, within safe limits (not exceeding 30 mg/l) [28].

3.2 Soil physicochemical properties

Table 3 gives the soil physiochemical properties of Ifite-Awka. Soil pH constitutes a crucial chemical parameter as it ensures the availability of essential nutrients for plants. pH measures the degree of alkalinity and acidity in a substance [26]. The average pH of the soil samples was determined to be 7.47, with Sample C exhibiting the highest pH value of 8.05 and Sample E showing the lowest pH value of 6.80. At lower pH levels, toxic metals tend to become more soluble and accessible to plants. pH plays a pivotal role in determining the solubility and accessibility of nutrients and metals in the soil, thereby influencing plant growth and development [2, 11, 35]. All the samples' pH values were within the WHO standard range of 6.50 to 8.50, with Sample E slightly acidic (pH = 6.80) and Sample C slightly alkaline (pH = 8.05). Soil pH significantly affects the availability of certain plant nutrients; the ideal soil pH is close to neutral, falling within a range from slightly acidic (pH 6.5) to slightly alkaline (pH 7.5) [28].

Organic carbon and organic matter measure the organic richness of the soil environment. Organic matter content ranged from 1.37% in Sample B to 6.07% in Sample F, with an average value of 3.45%. The higher organic matter content can be attributed to plant decay, and increased organic matter may enhance soil productivity. Organic carbon presence boosts the soil's cation exchange capacity, facilitating nutrient retention by plants. Organic carbon content in the study soils ranged from 0.68% in Sample B to 2.88% in Sample F, as illustrated in Fig. 1. These values were comparatively lower than those reported by Udeh et al. [36]. The relatively moderate amount of organic carbon in the study soil samples suggests the presence of degradable and compostable waste, indicating a nearly uniform proportion of organic matter across all the studied soils.

Moisture content reflects the soil's water-holding capacity, essential for assessing regional soil water balance. Moisture content across the soil samples ranged from 2.23 to 18.36%, with an average of 7.40%. Sample E exhibited the highest sand content (92.24%), while Sample F displayed the lowest sand content (81.50%). The percentage of clay remained relatively consistent among the samples, averaging 3.88%. Silt content varied considerably, with Sample D

Table 3 Results of selected soil samples

Parameter	WHO Std	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
pH	6.5–8.5	7.81	7.24	8.05	7.23	6.80	7.80
Moisture content (%)	–	7.37	7.17	7.65	8.20	10.02	5.82
Organic carbon (%)	–	0.91	0.68	1.58	2.81	1.50	2.88
Organic matter (%)	–	1.82	1.37	3.16	5.20	3.10	6.07
Clay (%)	–	3.90	3.89	3.89	3.86	3.76	4.01
Silt (%)	–	3.87	3.87	3.88	10.82	9.60	3.85
Sand (%)	–	92.23	92.22	92.24	90.10	85.01	81.50
CEC (cmol/kg soil)	–	58.05	109.24	87.96	75.21	80.91	60.12
Zinc (ppm)	3	0.68	4.08	0.60	5.19	3.21	2.88
Lead (ppm)	0.015	0.52	0.18	0.59	0.21	0.31	0.23
Arsenic (ppm)	0.01	0.00	0.00	2.27	0.02	0.05	0.02
Chromium (ppm)	0.05	1.54	1.86	1.52	0.15	0.18	1.87
Electrical conductivity (µS/cm)	1000	569.7	575.2	620.2	702.5	727.2	672.5
Water holding capacity	–	0.92	2.95	3.18	0.58	8.57	4.75

–: No available dataset, A: Akpana, B: Umuchibu, C: Umukpe, D: Umuosite, E: Ezike, F: Umuezeafor, *WHO std* World Health Organization Standards

recording the highest silt content (10.82%) and Sample F displaying the lowest silt content (3.85%). The percentage composition of these components indicated that Ifite's soils can be classified texturally as sandy loam to loamy sand, with a higher proportion of sand compared to silt and clay. All samples had high silt percentages, and Sample A, B, and C fell within the WHO standard clay percentage range of 0.65 to 9.07%. Soil texture can impact water retention, aeration, and nutrient availability [28].

Cation exchange capacity (CEC) serves as a significant indicator of soil fertility and nutrient availability, influenced by clay and organic matter content. CEC values across all samples fell within the WHO standard limits, ranging from 58.05 to 109.24 mol/kg. Sample B exhibited the highest CEC value (109.24 c.mol/kg soil). Elevated CEC values can enhance nutrient retention in soil and reduce the risk of nutrient leaching [37].

Heavy metals are metals with a density exceeding 5 g/cm^3, and they can have adverse effects on the environment and living organisms. Zinc, lead, and chromium values in the present study (as depicted in Fig. 1) fell within the WHO standard limit. However, the arsenic value for Sample C exceeded the WHO standard limit of 0.05 ppm. The presence of heavy metals in soil can impact plant growth, soil microbial activity, and pose human health risks [2, 36]. Metal concentrations followed this order: Zn > Cr > As > Pb in the soils. The average lead concentration was 0.34, with Sample B showing the highest lead concentration (0.59 ppm) and Sample A revealing the lowest lead concentration (0.18 ppm). Elevated Pb concentrations could result from factors such as burning fossil fuels, improper disposal of lead-acid battery waste, and leaching of metals from paints and pipes. Lead is toxic even at low concentrations and can cause damage to various body systems, particularly in young children.

The average zinc concentration was 2.77, with Sample D recording the highest zinc concentration (5.19 ppm) and Sample C displaying the lowest zinc concentration (0.60 ppm). Zinc's concentration fell within the WHO standard limit. Zinc, while essential for enzyme reactions, can pose a health threat at high concentrations. The presence of zinc in the soil samples could be attributed to spent battery disposal and the incineration of electronic waste materials [37].

The average chromium concentration was 1.19 ppm, with Sample B showcasing the highest chromium concentration (1.87 ppm) and Sample D displaying the lowest chromium concentration (0.15 ppm). These values exceeded the WHO standard limit (0.05 mg/kg). Chromium sources in the soil may stem from waste containing lead-chromium batteries, coloured polyethene bags, discarded diesel engines using anti-corrosive agents, and discarded plastic materials [34, 35].

Arsenic (As) exhibited the lowest concentration among all the heavy metals analysed, suggesting its lesser contribution compared to other heavy metal sources. Sample C displayed the highest arsenic concentration (2.27 ppm), while Samples A and B had undetectable levels. Agricultural soil contamination from chemical fertilizers, pesticides, and industrial waste materials could contribute to arsenic presence. Arsenic exposure has been linked to skin damage, increased cancer risk, and circulatory system issues [11, 28].
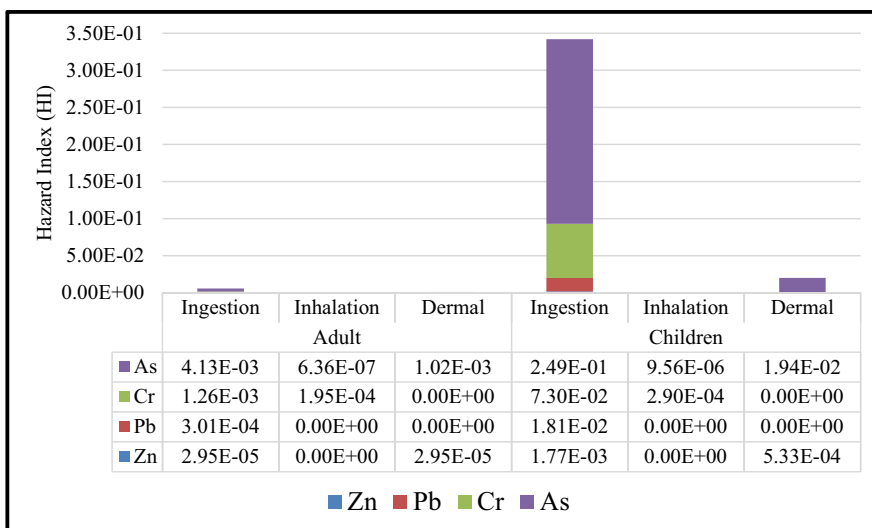
3.3 Human risk assessment

Human health risk assessment involves identifying and evaluating potential adverse health effects that individuals might experience when exposed to toxic substances within a contaminated environment. In this study, the assessment of exposure and associated risks was conducted following the methodology established by the United States Environmental Protection Agency (USEPA). The evaluation of non-carcinogenic risk for both adults and children was predicated on Reference Dose (RfD) values, as outlined in Table 1, and Average Daily Intake (ADI) values provided in Table 4.

Table 4 ADI (mg/kg/day) for heavy metals from soil samples for adults and children

Recipients	Pathways	Zn	Pb	As	Cr	Total
Adult	Ingestion	8.85E−6	1.08E−6	1.24E−6	3.8E−6	1.497E−5
	Inhalation	1.36E−9	1.67E−10	1.91E−10	5.85E−9	7.56E−9
	Dermal	2.19E−6	2.69E−7	3.087E−7	9.4E−7	2.92E−6
	Total	1.104E−5	1.34E−6	1.54E−6	4.74E−6	1.78E−5
Children	Ingestion	531E−4	6.52E−5	7.47E−5	2.2E−4	8.99E−4
	Inhalation	2.04E−8	2.5E−9	2.87E−9	8.77E−9	3.45E−8
	Dermal	4.15E−5	5.09E−6	5.84E−6	1.78E−5	7.023E−5
	Total	5.72E−4	7.02E−5	8.05E−5	2.37E−4	9.6E−4

Fig. 2 Hazard quotient (HQ) and Hazard Index (HI) of heavy metals for adults and children. HI < 1 indicates no adverse health effects, while HI ≥ 1 indicates the likelihood of adverse health effects

	Adult			Children		
	Ingestion	Inhalation	Dermal	Ingestion	Inhalation	Dermal
As	4.13E-03	6.36E-07	1.02E-03	2.49E-01	9.56E-06	1.94E-02
Cr	1.26E-03	1.95E-04	0.00E+00	7.30E-02	2.90E-04	0.00E+00
Pb	3.01E-04	0.00E+00	0.00E+00	1.81E-02	0.00E+00	0.00E+00
Zn	2.95E-05	0.00E+00	2.95E-05	1.77E-03	0.00E+00	5.33E-04

HI<1 indicates no adverse health effects, while HI≥1 indicates the likelihood of adverse health effects.

3.4 Non-carcinogenic risk of heavy metals

The outcomes of this assessment, focusing on ingestion, inhalation, and dermal pathways, are summarized in terms of Hazard Quotients (HQs). When HQ and Hazard Index (HI) values remain below 1 (Fig. 2), there appears to be no evident risk to the population. Conversely, if these values exceed 1, there could be potential concerns regarding non-carcinogenic effects [38]. Across all the investigated metals and for both adult and child populations, the Hazard Quotient (HQ) values remain below one for all three pathways—ingestion, dermal, and inhalation. Likewise, the Hazard Index (HI), calculated from heavy metal intake, remains below one for both adult and child populations. This indicates a limited likelihood of chronic health effects in both demographic groups [38–40].

Furthermore, the findings suggest that the most substantial contributor to non-carcinogenic risk for both adults and children is the ingestion pathway, followed by the dermal pathway. Inhalation is identified as the least influential pathway in terms of risk contribution.

Fig. 3 Cancer risk values for heavy metals for adults and children in soil
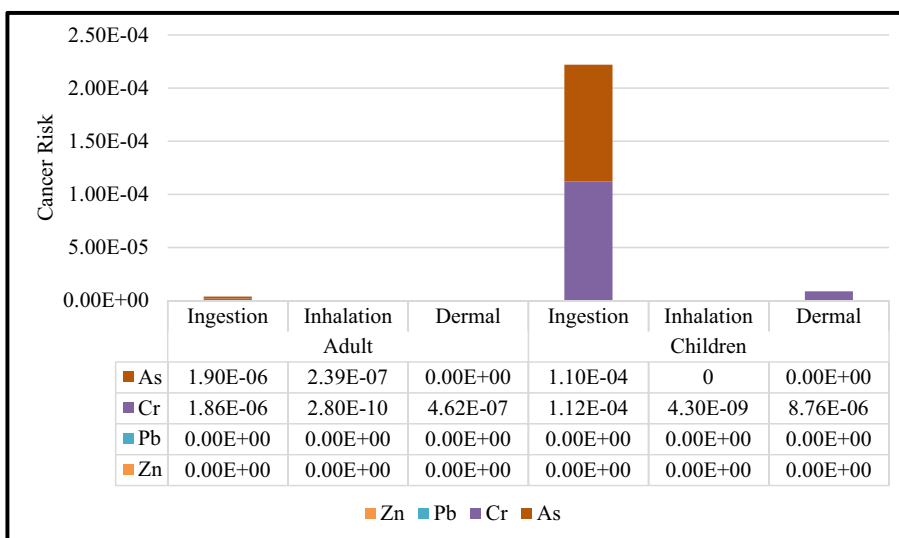

	Adult			Children		
	Ingestion	Inhalation	Dermal	Ingestion	Inhalation	Dermal
As	1.90E-06	2.39E-07	0.00E+00	1.10E-04	0	0.00E+00
Cr	1.86E-06	2.80E-10	4.62E-07	1.12E-04	4.30E-09	8.76E-06
Pb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 5 Correlation analysis of borehole water and soil samples

	Borehole water													Soil										
	Temp. (°C)	DS (%)	SS (%)	pH	DO (mg/l)	Alkalinity	Acidity	Hardness	Cl (mg/l)	COD	Mn	Ca	Mg	pH	MC	OC (%)	OM (%)	Clay (%)	Silt (%)	Sand (%)	CEC	Zn	Pb	As	Cr
Temp. (°C)	1.00																								
DS (%)	−0.33	1.00																							
SS (%)	0.13	−0.76	1.00																						
pH	0.06	−0.72	**0.97***	1.00																					
DO (mg/l)	**0.78***	−0.05	−0.38	−0.50	1.00																				
Alkalinity	−0.30	−0.21	0.02	0.24	−0.45	1.00																			
Acidity	0.13	0.07	0.38	0.20	0.01	−0.87	1.00																		
Hardness	0.39	−0.91	**0.47***	**0.48***	0.21	**0.43***	−0.42	1.00																	
Cl (mg/l)	**0.88***	0.04	−0.30	−0.41	**0.95***	−0.52	0.17	0.07	1.00																
COD	−0.17	**0.86***	**−0.94***	**−0.97***	0.35	−0.30	−0.06	−0.68	0.31	1.00															
Mn	0.03	−0.33	**0.86***	**0.84***	−0.50	−0.19	**0.64***	−0.02	−0.29	−0.69	1.00														
Ca	**0.42***	−0.67	**0.94***	**0.90***	−0.16	−0.12	**0.46***	**0.40***	0.00	**−0.87***	**0.87***	1.00													
Mg	0.30	−0.18	**0.58***	**0.41***	0.05	−0.78	**0.96***	−0.18	0.21	−0.30	**0.75***	**0.68***	1.00												
pH	−0.92*	0.32	−0.08	0.08	−0.88*	**0.58***	−0.33	−0.32	−0.91*	0.04	0.03	−0.32	−0.45	1.00											
MC	−0.92*	0.36	−0.11	0.05	−0.87*	**0.56***	−0.32	−0.35	−0.90*	0.07	0.02	−0.34	−0.45	**1.00***	1.00										
OC (%)	−0.92*	0.01	0.24	0.33	−0.92	0.42	−0.10	−0.14	−0.99*	−0.22	0.25	−0.07	−0.17	**0.90***	**0.89***	1.00									
OM (%)	−0.92*	0.01	0.24	0.33	−0.92	0.42	−0.10	−0.14	−0.99*	−0.22	0.25	−0.07	−0.17	**0.90***	**0.89***	**1.00***	1.00								
Clay (%)	−0.91*	0.39	−0.14	0.02	−0.85*	0.57	−0.33	−0.37	−0.88*	0.10	0.00	−0.36	−0.46	**1.00***	**1.00***	**0.87***	**0.87***	1.00							
Silt (%)	−0.91*	0.39	−0.14	0.02	−0.85*	0.56	−0.33	−0.37	−0.88*	0.10	0.00	−0.36	−0.46	**1.00***	**1.00***	**0.87***	**0.87***	**1.00***	1.00						
Sand (%)	−0.91*	0.39	−0.14	0.02	−0.85*	0.56	−0.33	−0.37	−0.88*	0.10	0.00	−0.36	−0.46	**1.00***	**1.00***	**0.87***	**0.87***	**1.00***	**1.00***	1.00					
CEC	−0.93*	−0.30	−0.30	−0.20	−0.74*	0.25	−0.09	−0.65	−0.75*	0.37	−0.04	−0.49	−0.30	**0.91***	**0.93***	**0.78***	**0.78***	**0.93***	**0.93***	**0.93***	1.00				
Zn	−0.51*	**0.98***	**−0.73***	**−0.65***	−0.22	−0.06	−0.03	−0.89	−0.16	**0.81**	−0.32	−0.70	−0.28	**0.51***	**0.54***	0.21	0.21	**0.57***	**0.57***	**0.57***	**0.77***	1.00			
Pb	−0.80*	−0.17	0.33	**0.46***	−0.90*	**0.67**	−0.33	0.11	−0.98*	−0.40	0.24	0.03	−0.33	**0.87***	**0.86***	**0.95***	**0.95***	**0.84***	**0.84***	**0.84***	**0.64***	0.04	1.00		
As	−0.66*	−0.29	**0.51***	0.44	−0.64*	−0.07	0.35	0.00	−0.73*	−0.38	0.45	0.22	0.32	0.45	0.44	**0.79***	**0.79***	**0.41***	**0.41***	**0.41***	**0.41***	−0.15	**0.66***	1.00	
Cr	−0.90*	**0.52***	−0.26	−0.10	−0.80*	0.49	−0.30	−0.49	−0.80*	0.24	−0.06	−0.45	−0.46	**0.98***	**0.98***	**0.81***	**0.81***	**0.99***	**0.99***	**0.99***	**0.96***	**0.69***	**0.75***	0.33	1.00

Bold significance >0.05 confidence level

*Significant correlation at the 0.05 confidence level

3.5 Carcinogenic risk assessment of heavy metals from soil for adults and children

The assessment of cancer risks for adults and children is carried out independently by calculating the collective impact of individual heavy metals within the soil for all available pathways, utilizing Eqs. (6) and (7). The results of the calculated cancer risks are illustrated in Fig. 3, drawing from the carcinogenic risk values obtained from the ADI values outlined in Table 3. Notably, the evaluation of cancer risks focuses on the presence of Arsenic (As) and Chromium (Cr) in particular, which emerged as the primary contributors to the cancer risk profile. To establish a benchmark for regulatory purposes, the US Environmental Protection Agency deems an acceptable range for cancer risk to fall between 1×10^{-6} and 1×10^{-4} [2, 30, 33]. In the context of this study, the calculated cancer risk (R_{total}) for adults was determined to be 4.461×10^{-6}, while for children, it was found to be 2.31×10^{-4}. These calculated values surpass the acceptable threshold, indicating that both adults and children within the study area face an elevated risk. Moreover, within this context, children are notably more susceptible to this risk than adults. The primary route for cancer risk, as observed, is through the ingestion pathway, followed by the dermal pathway [41].

3.6 Correlation matrix

To establish comparative relationships between soil and borehole water samples across various locations, correlation analyses were performed. The outcomes of these analyses, demonstrating the strength and direction of linear connections between different variables, are presented in Table 5. This cumulative Pearson correlation matrix reveals significant associations at a significance level of $p \geq 0.05$. The findings from Table 5 highlight both positive and negative relationships between variables in the context of soil and borehole water. Notably, temperature exhibits a robust positive correlation with chloride (0.88) and dissolved oxygen (0.78). Furthermore, the pH of the borehole water demonstrates a negative correlation with soil pH (− 0.92) and a positive correlation with dissolved oxygen (0.50). Soil pH, in turn, exhibits a potent negative correlation with moisture content (− 0.92), as well as with organic carbon, organic matter, and clay/silt/sand content (0.39), indicative of intricate pH variations and interactions between soil and borehole water. Chloride showcases a strong positive correlation with temperature (0.88) and dissolved oxygen (0.95), while manifesting a negative correlation with COD (− 0.31). COD, in contrast, displays a robust positive correlation with dissolved solids (0.86) and a substantial negative correlation with suspended solids (− 0.97). Moisture content, as observed, exhibits a pronounced negative correlation with pH, organic carbon, organic matter, and clay/silt/sand content (0.39). Organic carbon and organic matter similarly exhibit a strong negative correlation with pH (− 0.92), as well as with moisture content (0.01) and clay/silt/sand content. CEC (cation exchange capacity) reveals notably positive correlations with organic carbon (0.90), organic matter (0.90), and clay (0.87), alongside a negative correlation with pH (− 0.45). On the other hand, correlations between zinc, lead, arsenic, chromium and other variables are relatively weak. The positive correlations denote that as one variable increases, the other variable decreases, suggesting a robust relationship between similar waste components discharged into the soil, subsequently infiltrating groundwater [30, 41, 42]. Conversely, negative correlations signify a diverse array of chemical interactions consistently occurring within both borehole and soil constituents [43, 44].

4 Conclusion

The soil and water samples analysed in this study were found to be within the WHO standard limits for most parameters. However, arsenic was detected in one of the soil samples at a concentration above the WHO standard, indicating possible contamination. The water samples had acceptable levels of pH, colour, odour, taste, turbidity, dissolved solids, dissolved oxygen, alkalinity, acidity, hardness, and chloride. The high values of COD obtained in the water samples indicate that the water from the borehole contains high levels of inorganic and organic matter, is unsafe for drinking, and thus amounts to a health hazard. These parameters can have adverse effects on human health and the environment. However, other parameters such as soil pH, moisture content, organic carbon, and CEC are within the standard limits. Correlation analysis indicates strong significant positive and negative correlations among the studied metals. The results of the health risk of soil samples indicated that the ingestion pathway was the greatest

contributor to the chronic daily intake followed by dermal contact and inhalation. Hazard index (HI) values were less than one (1) for soil samples. Cancer risk for adults was found to be 4.461×10^{-6} and 2.31×10^{-4} for children, which were both higher than USEPA-acceptable limits. This shows that prolonged exposure to soil from contaminants can lead to detrimental health impacts for children compared to adults. Therefore, it is important to take measures to improve the quality of both soil and water samples such as:

1. Regular testing of soil and water samples should be carried out to monitor the levels of different parameters.
2. Immediate measures should be taken to reduce the levels of lead and arsenic in the soil samples.
3. Proper disposal of hazardous waste should be ensured to prevent contamination of soil and water resources.
4. Adequate wastewater treatment plants should be established to treat and reduce the levels of pollutants in water.
5. Farmers should adopt sustainable agriculture practices to reduce the use of fertilizers and pesticides that can contribute to soil and water pollution.
6. Awareness campaigns should be conducted to educate the public on the importance of proper waste disposal and water conservation.
7. Efforts should be made to identify and address the sources of pollution in the study area.

Government authorities should enforce regulations and laws to ensure the protection and conservation of soil and water resources.

Data availability All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Pitt R, Clark S, Field R. Groundwater contamination potential from stormwater infiltration practices. Urban Water. 1999;1:217–36. https://doi.org/10.1016/S1462-0758(99)00014-X.
2. Onwukeme VI, Okechukwu VU. Leaching matrix of selected heavy metals from soil to ground water sources in active dumpsites: a case study of Southern Nigeria. IOSR J Environ Sci Toxicol Food Technol. 2021;15(4):1–18. https://doi.org/10.9790/2402-1504020118.
3. Ubuoh EA, Nwawuike MN, Obeta MC, Osujieke MD. Environmental risk assessment of heavy metal concentrations in road runoff with absorption atomic spectrophotometer (AAS), Imo State, Nigeria. J Environ Earth Sci. 2014;4(5):2224–3216.
4. Rakesh K, Rakesh KUS, Brijesh Y. Vertical distribution of physico-chemical properties under different toposequence in soils of Jharkhand. J Agric Phys. 2012;12(1):63–9.
5. Brady NC, Weil RR. The nature and properties of soils. 13th ed. Upper Saddle River, New Jersey: Pearson Education Inc.; 2002. p. 960.
6. Doan NH, Lo VT, Duong KV, Ta TB, Ha LP, Nguyen DT, Nguyen DS, Hoang TG, Nguen MH, Pham MK. Lead environmental pollution and childhood lead poisoning at Ban Thi Commune, Bac Kan Province, Vietnam. BioMed Res Int. 2018;1:1–7.
7. Lu Y, Yin W, Huang LB, Zhang GL, Zhao YG. Assessment of bioaccessibility and exposure risk of arsenic and lead in urban soils of Guangzhou City, China. Environ Geochem Health. 2011;33:93–102. https://doi.org/10.1155/2018/5156812.

8. Badmus BS, Ozebo VC, Idowu OA, Ganiyu SA, Olurin OT. Physicochemical properties of soil samples and dumpsite of environmental impact on ground water quality in south-western Nigeria. Afr Rev Phys. 2014;9(15):103–13.

9. Omokpariola ECO, Omokpariola DO. Weathering profile of schistose rock from geotechnical and geochemical parameters at Okpe, Igarra Schist Belt in Edo State, Nigeria. World Sci News. 2021;154:89–100.

10. Taruna J, Alankrita C. Assessment of water quality and its effects on the health of residents of Jhunjhunu district, Rajasthan: a cross sectional study. J Public Health Epidemiol. 2013;5(4):186–91. https://doi.org/10.5897/JPHE12.096.

11. WHO. Guidelines for Drinking-water Quality. Fourth Edition. World Health Organization, Geneva, Switzerland. 2011. https://apps.who.int/iris/bitstream/handle/10665/44584/9789241548151_eng.pdf.

12. USEPA. U.S. Environmental Protection Agency. Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors; USEPA: Washington, DC, USA, 1991.

13. USEPA. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment); USEPA: Washington, DC, USA, 2004.

14. Egbueri JC, Enyigwe MT, Ayejoto DA. Modeling the impact of potentially harmful elements on the groundwater quality of a mining area (Nigeria) by integrating NSFWQI, HERisk code, and HCs. Environ Monit Assess. 2022;194(150):1–10. https://doi.org/10.1007/s10661-022-09789-w.

15. Aswal RS, Prasad M, Patel NK, et al. Occurrences, sources and health hazard estimation of potentially toxic elements in the groundwater of Garhwal Himalaya, India. Sci Rep. 2023. https://doi.org/10.1038/s41598-023-40266-7.

16. Ayejoto DA, Egbueri JC. Human health risk assessment of nitrate and heavy metals in urban groundwater in Southeast Nigeria. Acta Ecol Sin. 2023. https://doi.org/10.1016/j.chnaes.2023.06.008.

17. Nnabuihe EC, Madueke CO, Osujieke DN, Chukwu ED, Obasi SN, Okafor MJ, et al. Mineralogical composition and distribution in selected floodplain soils of southeastern Nigeria: implications for arable crop production. Int J Agric Food Biodivers. 2023;2(1):16–23.

18. Ben-Owope OA, Okoyeh EI, Anaekwe MU. Assessment of the influence of groundwater level and chemistry on concrete foundations around Ifite Awka, Anambra State, Nigeria. Int J Earth Sci Knowl Appl. 2021;3(2):89–97.

19. Okafor UC, Anastasia ON, Dike UN. Microbiological quality and physico-chemical properties of bore-hole water from stored water tanks in selected hostels in Ifite-Awka, Nigeria. Trop Aqua Soil Pollut. 2023;3(2):144–52. https://doi.org/10.53623/tasp.v3i2.267.

20. Obeta MC. Industrial water supply in Nnewi Urban Area of Anambra State, South Eastern Nigeria. J Geo Environ Earth SciInt. 2015;2(1):12–23. https://doi.org/10.9734/JGEESI/2015/14538.

21. Omokpariola EC, Anakwuba EK. Delineation of geothermal energy potentials in parts of Calabar Flank, Southeastern Nigeria using aeromagnetic data. World Sci News. 2022;164:77–107.

22. APHA. Standard Methods for the Examination of Water and Waste Water. 22nd Edition, American Public Health Association, American Water Works Association, Water Environment Federation. 2012.

23. Asagba EU, Okiemen FE, Osokpor J. Screening and speciation of heavy metal contaminated soil from an automobile spare parts market. Chem Speciat Bioavailab. 2015;19(1):9–15. https://doi.org/10.3184/095422907X198022.

24. Elfaki J, Gafer M, Suliemanand M, Ali M. Comparison and evaluation of two analytical Methods for cation exchange capacity and exchangeable sodium percentage of five soil types in Central Sudan. J Soil Sci. 2015;5:311–8. https://doi.org/10.4236/ojss.2015.512029.

25. American Public Health analysis. Standard procedures and guidelines for heavy metal analysis.2000; 25: 161–169.

26. Akpoveta OV, Okoh BE, Osakwe SA. Quality assessment of borehole water used in the vicinities of Benin, Edo State and Agbor, Delta State of Nigeria. Curr Res Chem. 2011;3:62–9.

27. USEPA. Screening for environmental hazards at sites with contaminated soil and groundwater, hazard evaluation and emergency response. US. Environmental Protection Agency Washington D.C. 2012. http://hawaii.gov/health/environmental/hazard/index.html.

28. World Health Organization (WHO). Guidelines for Drinking Water Quality, 4th ed. incorporating the first Addendum Geneva, pp 1–631. 2017. https://apps.who.int/iris/bitstream/handle/10665/254636/9789241550017-eng.pdf.

29. Charity LK, Wirnkor VA, Emeka AC, Isioma AA, Ebere CE. Health risks of consuming untreated borehole water from Uzoubi Umuna Orlu, Imo State Nigeria. J Environ Anal Chem. 2018;5:250. https://doi.org/10.4172/2380-2391.1000250.

30. Ojaniyi OF, Okoye PA, Omokpariola DO. Heavy metals analysis and health risk assessment of three fish species, surface water and sediment samples in Ogbaru Axis of River Niger, Anambra State, Nigeria. Asian J Appl Chem Res. 2021;9(1):64–81. https://doi.org/10.9734/AJACR/2021/v9i130205.

31. Brima EI. Physicochemical properties and the concentration of anions, major and trace elements in groundwater, treated drinking water and bottled drinking water in Najran area, KSA. Appl Water Sci. 2017;7:401–10. https://doi.org/10.1007/s13201-014-0255-x.

32. Eboagu NC, Ajiwe VIE, Aralu CC, Ochiagha KE, Morah EJ. Assessment of physicochemical parameters of water from selected boreholes around Nnewi Industrial Area, Anambra State, Nigeria. Am J Environ Sci Eng. 2023;7(1):23–33. https://doi.org/10.11648/j.ajese.20230701.14.

33. Khan S, Shahnaz M, Jehan N, Rehman S, Shah MT, Din I. Drinking water quality and human health risk in Charsadda district, Pakistan. J Clean Prod. 2013;60:93–101. https://doi.org/10.1016/j.jclepro.2012.02.016.

34. Shigut DA, Liknew G, Irge DD, Ahmad T. Assessment of physicochemical quality of borehole and spring water sources supplied to Robe Town, Oromia Region, Ethiopia. Appl Water Sci. 2017;7:155–64. https://doi.org/10.1007/s13201-016-0502-4.

35. Dordas C. Role of nutrients in controlling plant diseases in sustainable agriculture. A review. Agron Sustain Dev. 2008;28:33–46. https://doi.org/10.1051/agro:2007051.

36. Udeh NP, Ikegwuonu AC, Okeke OA, Obudulu C, Okafor KP, Egwuagu CC. Physicochemical characteristics and heavy metals contents in soils and cassava plants from farmlands within Nnamdi Azikiwe University, Awka, Anambra State. Asian J Res Zool. 2021;4(3):37–43. https://doi.org/10.9734/AJRIZ/2021/v4i330118.

37. Brady NC, Weil RR. The nature and properties of soils. 15th Edition, Pearson Education, Inc. 2010. https://epsc413.wustl.edu/TOC_Textbook.pdf.

38. Awokunmi EE, Asaolu SS, Ipinmoroti KO. Effect of leaching on heavy metals concentration of soil in some dumpsites. Afr J Environ Sci Technol. 2010;4(8):495–9.

39. Nduka JK, Omokpariola DO, Kelle HI, Mgbemena NM, Iduseri EO. Chemometrics and health risk assessment of nitrogen composition of atmospheric rainwater from diverse surfaces in Rivers State, Nigeria. Environ Monit Assess. 2022;194(807):18. https://doi.org/10.1007/s10661-022-10459-0.

40. Omokpariola PL, Omokpariola DO. Institutional framework for the sound management of chemicals and chemical industries in Nigeria. ACS Chem Health Saf. 2021;28(6):457–67. https://doi.org/10.1021/acs.chas.1c00045.

41. Omokpariola DO, Omokpariola PL. Health and exposure risk assessment of heavy metals in rainwater samples from selected locations in Rivers State, Nigeria. Phys Sci Rev. 2021. https://doi.org/10.1515/psr-2020-0090.

42. Okechukwu VU, Omokpariola DO, Onwukeme VI, Nweke EN, Omokpariola PL. Pollution investigation and risk assessment of polycyclic aromatic hydrocarbons in soil and water from selected dumpsite locations in Rivers and Bayelsa State, Nigeria. Environ Anal Health Toxicol. 2021;36(4): e2021023. https://doi.org/10.5620/eaht.2021023.

43. Environmental Protection Agency. Factsheet on water quality parameter: dissolved oxygen. Document No.: EPA 841F21007B. 2021. https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_do.pdf.

44. Umeh CT, Nduka JK, Omokpariola DO, Morah JE, Mmaduakor EC, Okoye NH, Lilian EEI, Kalu IF. Ecological pollution and health risk monitoring assessment of polycyclic aromatic hydrocarbons and heavy metals in surface water, southeastern Nigeria. Environ Anal Health Toxicol. 2023;38(2): e2023007. https://doi.org/10.5620/eaht.2023007.