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Quality Evaluation of Soil and Groundwater for Sustainable Application, Niger Delta, Nigeria

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ABSTRACT

The study aimed at evaluating the quality of soil and groundwater for sustainable application. Samples comprising 16 groundwater from existing boreholes (BH) and hand dug wells (HDW), as well as 22 soils from ten sampling points (SS1-SS10) at depth interval of 0-15 cm and 15-30 cm respectively, were collected for the study following standard methods. Physicochemical, bacteriological and heavy metals (Cadmium, Nickel, Vanadium, Chromium (mg/L), were measured. Contamination Factor (CF) and Pollution Load Index (PLI) were determined in the soil samples. Data obtained were subjected to statistical analysis at $P < 0.05$ significance level. The results obtained showed that Turbidity ranged from 1.36 to 11.66 mg/L; pH (2.30-6.20); TDS (248.75-262.50 mg/L); E. coli (1.88-3.75 MPN); Coli count (13.00-43.00 MPN); Cadmium (0.02-0.04 mg/L); Nickel (0.04 – 0.08 mg/L) and Vanadium (0.02 – 0.05 mg/L) in BH and HDW, respectively. Contamination Factor (CF) results ranged from 1.08 -3.22 indicating that the soils were moderately to highly pollute. Pollution load index (PLI) range of 2.0-2.15 and CF values of 1.08 -3.22 confirmed that the soils in and around Osubi dumpsite were moderately to highly contaminate. Cadmium and Lead in sample code SS8 and SS7 respectively were the dominant heavy metal present in the soils. Overall, the results obtained compromised national and international regulatory standard appropriated by World Health Organization (WHO), and the Standard Organization of Nigeria (SON). Stringent policy formulation and enforcement is required to safeguard the quality of soil for agriculture and groundwater protection the study area.

1. Introduction

Soil and water are natural resources that play vital roles in ecosystem sustainability. They interact and facilitate geochemical processes, serving as repositories for anthropogenic and natural environmental stressors (Tonjoh and Omorogieva, 2020; Jire and Imeokparia, 2018; Egai and Imasuen, 2015; Onyeobi and Akujieze, 2014). The qualities of these vital resources determine their application for optimal benefits for humankind and other living resources in an ecosystem. Consequently, regular evaluation is required by scientists to determine its application and support policy makers with vital information that can facilitate regulatory policies for sustainable development (Imasuen and Omorogieva, 2013; Aladin et al., 2024). Environmental media like soil is especially important in ecosystem research due to the role as medium of interactions between minerals, air, water, and biota. Recent studies have shown that soil and groundwater systems have been subjected to physical stress by input of harmful substances through human activities (Ma et al., 2022; Imasuen and Omorogieva, 2013; Shayley et al., 2009), this is attributed to growth in global human population, industries and technology.

In Nigeria and many parts of the world, wastes are usually dumped indiscriminately without precautionary measures to curtail the toxic and hazardous materials resulting from the wastes heap (Imasuen and Omorogieva, 2015; Akujieze and Idehai, 2014; Omorogieva and Igberase, 2021). On the other hand, several governments approved dumpsites are not adequately designed to address the risk of deleterious organic and inorganic pollutants from leaching into soil and subsequently reaching water table to contaminate groundwater (Carla et al., 2023; Adekanmbi et al., 2021; Asuen et al., 2005). Contaminated soil and water can negatively impact human health through food chain (Goswami and Rai, 2023; Omorogieva et al., 2022a; Adimalla et al., 2020; Imasuen and Omorogieva, 2013; Ekwumemgbo et al., 2013; Akujieze and Oteze, 2007). Osubi inNigeria, is an urban town with high human population. The locals within and around depend on the soil for subsistence farming and the groundwater for drinking purposes. Aquifers in Osubi are shallow, and the soil is porous and permeable, compose of fine to medium grain size texture. The soil properties allow the infiltration of fluids including surface derived contaminants, consequently, facilitate the percolation of leachate derived from the heap of wastes dumped indiscriminately in the environment without precautionary measure (Aladin et al., 2024; Efobo et al., 2020; Akujieze, 2004; Akujieze, 2006). Deficiency in soil nutrients and increase in chemical inputs can reduce crop yield and fresh groundwater quality (Medina, 2002; Misra, and Mani, 2009). The gap in knowledge of the current state of soil and groundwater qualities in Osubi motivated the study. The study aimed at assessing the quality of soil and groundwater as well as the ecological risk in and around Osubi main dumpsite in Warri Metropolitan City, Nigeria.

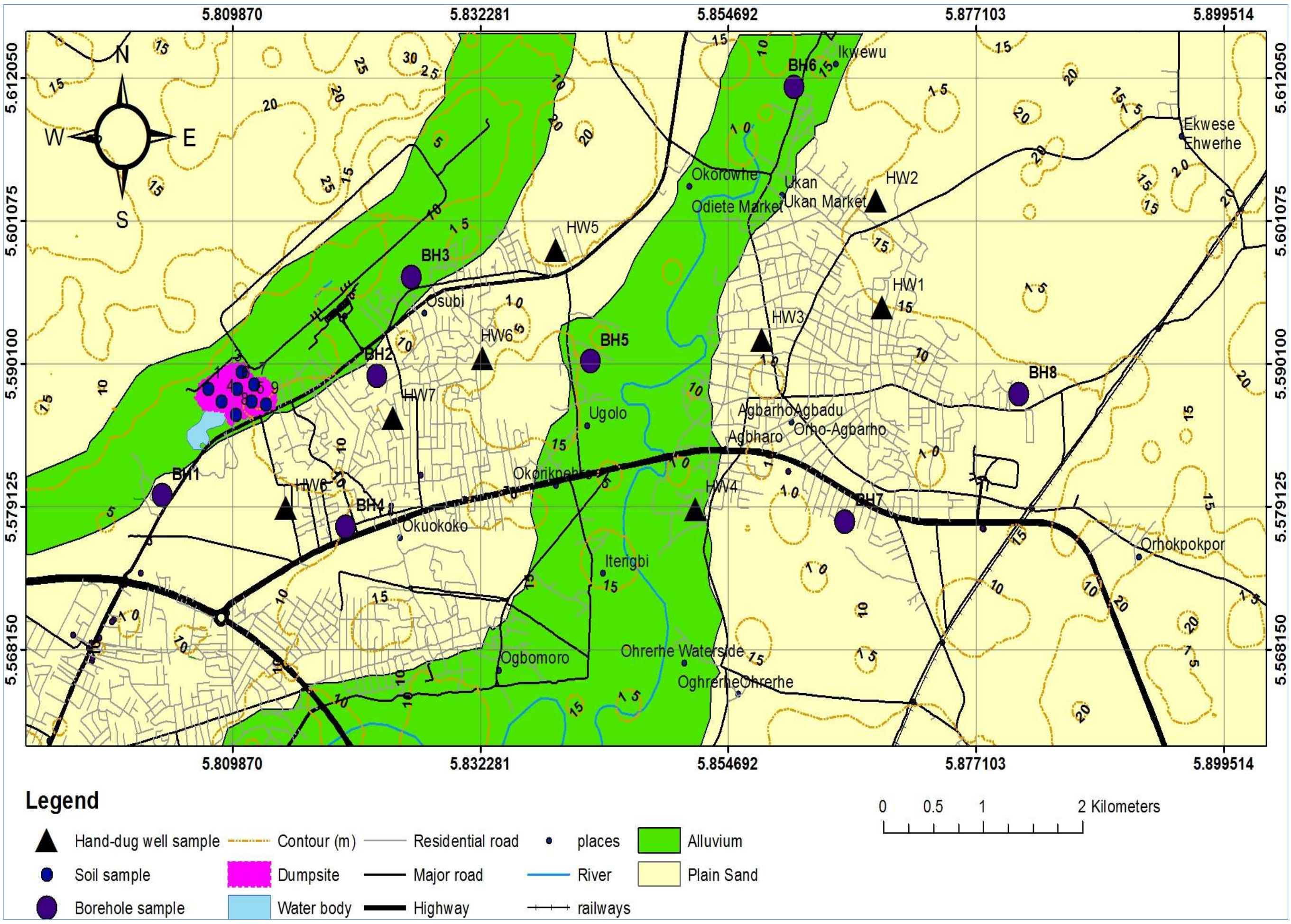

Fig. 1. Geological map of Osubi

The specific objectives are to apply standard procedures to measure the major and trace metal concentration in soil and groundwater; measure the physicochemical and bacteriological components of the collected samples; determine the Pollution Load Index (PLI) and Contamination Factor (CF) in order to ascertain the level of contamination/pollution of the assessed environmental media; compare the results obtained in the study to national and international standard, and evaluate the ecological risks associated with the findings. The expected outcome will serve as baseline study, facilitate policy formulation geared towards environmental management. In addition, it will contribute significantly to the United Nation Sustainable Development Goals (UN-SDGs), agenda 2 (zero hunger), 3 (good health and wellbeing), 6 (access to clean water and sanitation), and 11 (sustainable cities and communities).

2. Materials and Methods

2.1. Geology and Location

The study area is located within the Niger Delta Sedimentary Basin. The Geology consists of unconsolidated sediments of sand, silt and clay derived from the weathering process of Benin Formation and River Niger (Akpoborie et al., 2015). Historically, Osubi is a complex interplay of fluvial, deltaic, and marine processes. It is underlain by the deposits of the Quaternary Sombrero Warri Deltaic Plain Sands (Efobo, 2020; Edegbai et al., 2019). The Sombrero Warri Formation consists of fine to medium, and coarse-grained unconsolidated sands that are often feldspathic, with about 30 - 40 wt% feldspars (Fig. 1). The study area is located along Osubi express road, adjacent Osubi airport (Fig. 1). The area is a flat swampy terrain surrounded by residential buildings, workshops and worship centers, institutions of learning and official buildings.

Geographically, it lies within latitudes 50 35’ 00’N to 50 35’ 30’N of the equator and longitude 50 48’ 30’E to 50 49’ 00’E Greenwich meridian. It can be accessed through interconnected footpaths, minor and main roads. The climatic condition of the area is defined by the tropical rainforest with two distinctive seasons (wet and dry). The month of April marks the beginning of the wet season with July and September as the peak. On the other hand, the month of November mark the commencement of the dry season with January as the peak (Omorogieva et al., 2023). The wet season is associated with heavy downpour, high humidity and cool heavy breeze while the dry season is associated scorching sunshine, harmattan and light cool breeze that blows across the Sahara Desert in the north (Aladin et al., 2024; Tonjoh and Omorogieva, 2020). The soil formation is characterized by weathered sandy-silt to alluvium sediments with fine to medium grain texture, white to milky colouration (Omorogieva et al., 2023; Izeze et al., 2023).

2.2. Sampling Protocol, Quality Assurance and Control Measure

A total of thirty-eight (38) samples were collected randomly for the study. The samples consist of sixteen (16) groundwater derived from existing boreholes and dug wells. The groundwater samples were collected directly from the well head of existing boreholes five minutes after the start of pumping, while the groundwater samples from hand dug wells were collected with water fetcher 0.3 m below the surface of the well following the procedures outlined in Onyeonwu (2000); USEPA (2013) handbook and Ugwuja (2022).

Table 1. Mean values of measured parameters in groundwater (boreholes and hand-dug wells)

Parameters	Mean	Std.E	Min	Max	Mean	Std.E	Min	Max	SON (2015)	WHO (2011, 2017)
pH	5.63	0.07	5.40	5.96	5.64	0.06	5.28	5.78	6.50	8.50
EC (µS/cm)	303.75	53.98	100.00	610.00	461.25	65.59	220.00	850.00	1000.00	1000.00
Turb. (NTU)	1.36	0.34	0.00	2.60	11.66	0.60	9.40	14.80	5.00	5.00
TDS (mg/L)	248.75	65.42	120.00	680.00	262.50	33.37	110.00	420	500.00	60.000
SO4 (mg/L)	83.33	2.48	73.70	93.05	74.60	9.95	46.61	129.30	100.00	260.00
Cl (mg/L)	13.41	1.11	10.90	18.70	53.60	0.81	49.60	56.10	250.00	250.00
Ca (mg/L)	15.47	10.99	0.73	91.60	47.02	8.19	20.12	94.31	260.00	260.00
Mg (mg/L)	1.95	0.67	0.61	6.45	2.96	0.45	1.29	4.84	0.2.00	N/S
Na (mg/L)	9.07	1.79	1.89	15.63	7.43	1.25	3.64	14.67	200.00	200.00
K (mg/L)	6.75	2.50	0.83	21.37	10.36	0.92	7.71	15.62	N/S	260.00
As (mg/L)	0.67	0.04	0.51	0.83	0.77	0.05	0.41	0.90	0.01	0.01
Mn (mg/L)	0.24	0.09	0.03	0.76	0.23	0.05	0.03	0.43	0.20	0.40
Cd (mg/L)	0.02	0.00	0.00	0.03	0.04	0.00	0.03	0.04	0.00	0.00
Cr (mg/L)	0.02	0.01	0.01	0.06	0.14	0.08	0.04	0.71	0.05	0.05
Pb (mg/L)	0.01	0.00	0.00	0.02	0.02	0.00	0.02	0.03	0.01	0.01
Zn (mg/L)	0.16	0.01	0.13	0.19	0.21	0.02	0.15	0.36	3.00	4.00
Cu (mg/L)	0.09	0.02	0.04	0.23	0.08	0.01	0.06	0.11	1.00	2.00
Cn (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.07
Ni (mg/L)	0.040	0.01	0.00	0.06	0.08	0.01	0.06	0.10	0.02	0.07
V (mg/L)	0.02	0.004	0.00	0.03	0.047	0.00	0.04	0.052	N/S	N/S
E.Coli (cfi/100 ml)	1.88	0.64	0.00	6.00	3.75	0.53	2.00	6.00	0.00	N/S
Coliform (MPN/100 ml)	13.00	1.25	8.00	18.00	43.13	1.52	36.00	48.00	0.00	N/S

BDL = Below Detection Limit; N/S = Not Specified; Std.E = Standard Error; Min = Minimum and Max = Maximum

In the study, pH, EC, TDS and temperature were measured in situ during sampling. The portion met for heavy metal analysis was preserved with 30% dilute HNO_3 (Edjah et al., 2023; Rajmohan and Elango, 2005). On the other hand, twenty-two soil samples were collected with soil auger at a depth’s interval of 0-15 cm and 15-30 cm respectively. Control soil sample with same soil characteristics, which was obtained in a pristine environment of about one 1 km from the experimental site, was inclusive of the twenty-two samples collected. The collected soils were stored in a well labelled polythene bags and transported to laboratory for preparation, extraction and analysis.

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At the laboratory premises, soil samples were air dried at room temperature for three (3) days under close monitoring. The samples were mechanically pulverized and sieved through 2 mm screen; thereafter, 0.5 g of the prepared sample was weighed in 250 mL conical flask. Ten (10 mL) of concentrated Nitric acid (HNO_3) was added to the soil content in the conical flask which resulted in effervescence (Adelekan and Abegunde, 2011; Rajmohan and Elango, 2005).

In addition, 5 mL of perchloric acid ($HClO_4$) was added to the mixture and placed on a hot plate for about one hour (1 hour). The content was brought down and allowed to cool for thirty (30) minutes. Subsequently, 20 percent (%) of diluted hydrochloric acid (HCl) was added and filtered through Whiteman paper into 120 mL clean plastic bottle which was made up to mark with distilled water.

2.3. Laboratory and Data Analysis

Method7000B proposed by the United State Environmental Protection Agency (USEPA, 2007) and the America Public Health Association (APHA, 2005), for the analysis of water, wastewater and soil were adopted. Physicochemical parameters were determined by Flame Atomic Absorption Spectrophotometer (FAAS), Perkin Elmer model A3100 with air acetylene**.** On the other hand, anion analysis was done using iron chromatographic method while titrimetric method was used to determine the value of SO_4.

The results were read in triplicate, the values obtained were subjected to statistical analysis of spearman correlation and one way analysis of variance (ANOVA) by using the Software Package for Social Science (SPSS) version 22.0 at $P < 0.05$ (95%) test of significance. On the other hand, spearman's correlation was applied to establish the relationship among the physico-chemical variables in borehole and hand-dug wells respectively. Furthermore, descriptive statistics was also performed to ascertain the measures of dispersion (mean, range, standard error, and standard deviation) of the parameters measured in the study.

2.4. Quantification of Heavy Metal Load in Soil

The degree of soil pollution was determined by comparing the data obtained with the background/control values. The background value of an element is the maximum concentration of the element in environment beyond which the environment is said to be contaminate and or pollute (Puyate et al., 2007; Parry et al., 1981). In this regard, Pollution Load Index (PLI) was performed to quantify the enrichment of heavy metals in soils with respect to the background value. For each sampling site, the PLI was calculated to determine the degree of heavy metal pollution in soils. The calculation was based on Hankinson (1980) and Wang et al. (2010) as demonstrated forthwith.

$$PLI=(C_F1\times C_F2\times C_F3.........C_{Fn}) \quad \text{(Hankinson, 1980)} \qquad (1)$$

where; n = number of metals and C_F = contamination factor.

Values of the PLI are interpreted as follows.

PI < 1, low contamination,
1 ≤ PI < 3, moderate contamination,
3 ≤ PI < 6, considerable contamination, and
6 ≥ 6PI, very high contamination.

Similarly, contamination factor (CF) was also performed. According to Tijani et al. (2004), CF is the quantification of the degree of contamination relative to either average crustal composition of respective metal or to the measured background values from geologically similar and uncontaminated area. Contamination Factor (CF) is classified into four categories thus;

CF < 1 - Low contamination factor,
1 < CF < 3 –Moderately contaminated,
3< CF < 6 – Considerably contaminated
6≥ 6 CF- Very high contamination factor.

It is expressed as;

$$CF = C_m/B_m \quad \text{(Tijani et al., 2004; Lar and Shehu, 2014)} \qquad (2)$$

where; C_m is the mean concentration, while B_m is the background concentration of metal directly determined from a geologically similar area (control sample) (Lar and Shehu, 2014).

2.5. Microbial Characterization in Groundwater

Total and Faecal coliforms counts were analyzed using the Most Probable Number (MPN) method. Serial dilutions of10^{-1} . 10^{-8} were prepared by serially diluting 1 mL of the water sample. One-milliliter aliquots from each of the dilutions were inoculated into 5 mL of MacConkey Broth with inverted Durham tubes and incubated at 37°C for total coliforms and 44°C for faecal coliforms for 18-24 hours (Omorogieva and Ogieriakhi, 2021). Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours (hrs.) were identified as positive for both total and faecal coliforms; counts per 100 mL were calculated from MPN Tables (Anna and Piotr, 2014). From each of the positive tubes identified, a drop of trypton water was transferred into a 5 mL test tube and incubated at 44°C for 24 hours. Kova's reagent was then added to the tube containing trypton water. All tubes identified with red ring colour development after gentle agitation signified the presence of indole and recorded as presumptive for thermotolerant coliform (*E. coli*) which is measured in counts per 100 mL.

3. Results

The results obtained in triplicates both in groundwater and soil were recorded as mean values and are represented in Tables 1, 2, 3, 4 and 5, respectively. The parameters measured and the results obtained for the assessments of groundwater and soils in the study area are also represented in Appendix 1 and 2 respectively.

3.1. Groundwater Results

The hydrogen potential (pH) recorded for groundwater (boreholes and hand-dug wells) in the study area ranged from 5.40 to 5.96. Borehole coded with OSBH4 and the hand-dug well coded OSHW3 has the highest and lowest values of 5.96 and 5.28 respectively. These values are below the minimum permissible limits appropriated by World Health Organization and the Nigeria Standard for Drinking Water Quality (WHO, 2011; WHO, 2017; SON, 2015).

Similarly, the mean values of electrical conductivity (EC) recorded range from 313.75-461.25 µS/cm. The lowest value of 100 µS/cm was recorded in sample code OSBH8 and the highest value of 850 µS/cm was recorded in hand-dug well coded OSHW3 (Table 1 and Appendix 1), the values were within the specified limit by local and international regulatory agencies. For turbidity, the values recorded in the study range from 0.00 - 14.80 NTU with a mean value of 1.36 and 11.66 NTU for borehole and hand-dug wells respectively. The values obtained for turbidity in borehole water were below the recommended value of 5 NTUS, except those obtained from hand-dug wells. Total dissolved solid (TDS) for boreholes and hand-dug wells were also measured. The measured values in and around the study area ranged from 110-680 mg/L. The highest and lowest values of 680.00 mg/Land 110.00 mg/L were recorded in samples coded OSHW3 and OSHW2 respectively (Table 1).

Sulphate value for groundwater recorded in the study area ranged from 46.61-129.3 mg/L. Samples OSHW3 and OSHW8 had the highest and lowest values respectively. A mean of 83.33 and 74.60 mg/L was also recorded in borehole and hand-dug wells sample locations in the study area. The concentration of chloride (Cl) in the study ranged from 10.9 - 18.8 mg/L in borehole and 49.60 to 56.10 mg/L in hand-dug wells. The lowest value was recorded in OSBH8 while the highest was recorded in sample OSHW5 (Table 1).

These values are within minimum, and the maximum limit of 200 mg/L approved for Cl concentration in drinking water by national and international regulatory agencies (WHO, 2017; Orobosa et al., 2023). Calcium (Ca) was among the major elements measured in the groundwater of Osubi. The values recorded for calcium in groundwater samples collected in and around Osubi dumpsite (Fig. 1) ranged from 0.73 to 91.6 mg/L in borehole samples and 20.12 to 94.31mg/L in hand-dug wells. The mean values recorded for Ca in borehole and hand-dug wells were 15.47 mg/L and 2.96 mg/L, respectively.

The highest value of Ca concentration in the study was recorded in OSHW3 while the lowest value was recorded in sample code OSBH2 (Table 1). The values recorded were within the safety limit of 250 mg/L approved by the Nigeria Standard for Drinking Water Quality and WHO (Omorogieva and Igberase, 2021; WHO, 2017; Ajibade et al., 2011).

Similarly, Magnesium (Mg) values recorded ranged from 0.61-6.45 mg/L in borehole and 1.29-4.84 mg/L in hand-dug wells. The mean recorded in borehole was 1.95mg/L and 2.96 mg/L in hand-dug wells. In the study, the highest value of Mg concentration was recorded in sample OSBH5 while the lowest value was recorded in sample code OSBH1 (Table 1 and Appendix 1). By comparing the values obtained in the study to the approved regulatory standard of 0.20 mg/L dissolved Mg in drinking water, it was noted that groundwater in and around Osubi exceeded the set limit.

Table 2. Mean concentration of parameters measured in soil and control point (CP)

Parameters	Soil Mean	Std.E	Min	Max	CP Mean
pH $_{(0-15cm)}$	4.70	0.26	2.60	5.70	4.65
pH $_{(15-30cm)}$	4.48	0.34	2.30	6.20	3.90
EC (us/cm) $_{0-15cm}$	1354.55	290.65	270	3010	2050
EC (us/cm) $_{15-30cm}$	1379.09	277.83	510	2990	2100
O.M (%) $_{0-15cm}$	2.75	0.45	0.93	5.83	3.50
O.M (%) $_{15-30cm}$	2.35	0.42	0.52	5.44	2.49
Na (mg/kg) $_{0-15cm}$	11.79	0.53	9.40	15.60	9.90
Na (mg/kg) $_{15-30cm}$	10.76	0.45	7.70	13.10	9.60
K (mg/kg) $_{0-15cm}$	8.05	0.43	4.70	9.40	8.70
K (mg/kg) $_{15-30cm}$	6.80	0.60	3.90	9.30	4.40
Mg (mg/kg) $_{0-15cm}$	10.57	0.65	8.10	14.9	10.8
Mg (mg/kg) $_{30-15cm}$	10.03	0.58	6.30	13.2	6.30
Ca (mg/kg) $_{0-15cm}$	13.57	0.59	10.5	17.3	13.30
Ca (mg/kg) $_{15-30cm}$	12.22	0.70	8.60	15.2	8.60
As (mg/kg) $_{0-15cm}$	18.23	1.01	11.56	23.4	11.56
As (mg/kg) $_{15-30cm}$	16.32	0.92	10.58	21.2	10.58
Mn (mg/kg) $_{0-15cm}$	3.27	0.18	1.46	3.58	1.46
Mn (mg/kg) $_{15-30cm}$	3.27	0.19	1.42	3.52	1.42
Cd (mg/kg) $_{0-15cm}$	2.26	0.19	1.08	3.46	1.08
Cd (mg/kg) $_{15-30cm}$	2.24	0.19	1.06	3.43	1.06
Cr (mg/kg) $_{0-15cm}$	3.53	0.22	1.64	4.52	1.64
Cr (mg/kg) $_{15-30cm}$	3.50	0.23	1.61	4.55	1.61
Pb (mg/kg) $_{0-15cm}$	2.80	0.13	2.14	3.69	2.14
Pb (mg/kg) $_{15-30cm}$	2.80	0.14	2.11	3.71	2.11
Zn (mg/kg) $_{0-15cm}$	9.99	0.63	5.79	14.21	5.79
Zn (mg/kg) $_{15-30cm}$	10.27	0.78	5.77	15.5	5.77
Cu (mg/kg) $_{0-15cm}$	2.48	0.15	1.86	3.23	1.86
Cu (mg/kg) $_{15-30cm}$	2.20	0.13	1.69	3.17	1.69
Cn (mg/kg) $_{0-15cm}$	0.00	0.00	0.00	0.01	0.00
Cn (mg/kg) $_{15-30cm}$	0.00	0.00	0.00	0.01	0.00
Ni (mg/kg) $_{0-15cm}$	2.94	0.24	1.35	4.59	1.35
Ni (mg/kg) $_{15-30cm}$	2.77	0.25	1.31	4.51	1.31
V (mg/kg) $_{0-15cm}$	2.81	0.21	1.24	3.81	1.24
V (mg/kg) $_{15-30cm}$	2.83	0.24	1.26	3.95	1.26

Furthermore, Sodium (Na) concentration was determined. The values recorded in the study showed that Na ranged from 1.89-15.63 mg/L in borehole samples and 3.64 to 14.67 mg/L in hand-dug wells. The mean values for borehole and hand-dug wells were 9.07 mg/L and 7.43mg/L, respectively. On the other hand, the highest value of Na concentration in the study area was noted in sample code OSBH7 while the lowest concentration was recorded in sample code OSBH3; these values were within the acceptable limit for drinking water quality (WHO, 2017).

The values of K recorded in groundwater in the study ranged from 0.83 to 21.37 mg/L in borehole samples and 7.71-15.62 mg/L in hand-dug wells. The mean values for K in Osubi groundwater was 6.75 mg/L for borehole and 10.36 mg/L for hand-dug wells. The highest value of K concentration was recorded in sample code OSHW6 and the lowest was recorded in sample coded OSBH1; these values were within the acceptable limit of 260 mg/L for drinking water application (WHO, 2017).

To ensure holistic knowledge of Osubi drinking water condition, metals of known health implication were also measured. These include Arsenic (As), Manganese (Mn), Cadmium (Cd), Chromium (Cr), Lead (Pb), Zinc (Zn), Copper (Cu) and Nickel (Ni). In the study, the values of Arsenic recorded in groundwater samples collected ranged from 0.51-0.83 mg/L in borehole and 0.41-0.9 mg/L in hand-dug wells.

The mean values for borehole and hand-dug wells were 0.67 mg/L and 0.77 mg/L respectively (Appendix 1). The highest value of arsenic concentration was recorded in sample code OSHW5 and the lowest in sample code OSHW1. The concentration of arsenic in Osubi groundwater exceeds the maximum value of 0.01 mg/L for health intervention (Krishna and Achari, 2024; WHO, 2017).

Manganese (Mn) is a micronutrient for plants and animals and mostly in association with iron compounds. The values recorded for Mn in groundwater samples within the study area ranged from 0.03 - 0.76 mg/L in borehole and 0.03 - 0.43 mg/L in hand-dug wells. The highest value of manganese concentration was recorded in sample code OSBH5 while the lowest value was recorded in sample code OSBH2 (Table 1).

It was noted that OSBH1-4, OSBH6, OSBH8, and OSHW2 exceeded the maximum guideline of 0.2-0.4 mg/L for drinking purposes. Similarly, Cadmium concentration in groundwater in the study area ranged from 0.03-0.76 mg/L in borehole and 0.00-0.03mg/L in hand-dug wells. The mean values of Cd concentration in Osubi drinking groundwater were 0.24 mg/L for boreholes and 0.03 mg/L for hand-dug wells, respectively. The highest concentration of Cd was measured in sample code OSHW1 and the lowest in sample code OSBH2 (Appendix 1).

Based on regulatory guidelines, Cd concentration in the drinking groundwater exceeded the maximum tolerable limit of 0.005 mg/L for health intervention (WHO, 2017; SON, 2015). In addition to the earlier measured metals, Chromium (Cr) was also considered. In this study, the concentration of Cr in the drinking groundwater obtained from Osubi ranged from 0.013-0.06 mg/L in borehole samples and 0.04-0.71 mg/L in hand-dug wells. The highest value of Cr recorded was observed in sample code OSBH7and the lowest was recorded in sample code OSHW2.

It was noted that sample code OSBH2 - 8, OSHW7 and OSHW8 were within the acceptable 0.05 mg/L for health intervention. Other metals measured in the study are Lead (Pb), Zinc (Zn), Copper (Cu) and Nickel (Ni). The values recorded for lead in groundwater samples within the study area ranged from 0.00- 0.02 mg/L in borehole samples and 0.02- 0.03 mg/L in hand-dug wells; the mean values recorded for Pb in boreholes was 0.01 and 0.02 mg/L in hand-dug wells.

The highest value of Pb concentration was recorded in sample code OSHW2 and the lowest was measured in sample code OSBH2. Other boreholes and hand-dug wells in the study area compromised the standard of 0.05 mg/L Pb set as guideline for drinking water except OSBH1, OSBH2, OSBH7 and OSBH8.In this study, values recorded in groundwater samples for Zinc (Zn) ranged from 0.13 - 0.19 mg/L in borehole samples and 0.15- 0.36 mg/L in hand-dug wells.

The mean values of 0.16 mg/L and 0.21 mg/L were recorded in boreholes and hand-dug wells, respectively. The highest value of zinc concentration recorded was observed in sample code OSHW1and the lowest was measured in sample code OSBH5 (Appendix 1). These values do not compromise the limit of 5 mg/L health intervention in drinking water. For Copper (Cu), the mean values recorded for boreholes and hand-dug wells were 0.09 mg/L and 0.08 mg/L. On the other, the highest value of copper concentration was recorded in sample code OSBH6 and the lowest value was observed in sample code OSBH8.

Overall, the values recorded in groundwater evaluated ranged from 0.04-0.23 mg/L in borehole and 0.06- 0.11 mg/L in hand-dug wells, respectively. Nickel was also reported in this study due to its carcinogenic attributes. The values of Ni concentration recorded in borehole samples ranged from 0-0.06 mg/Land 0.06-0.10 mg/L in hand-dug wells. The highest value was recorded in sample code OSHW8 while the lowest concentration was recorded in sample code OSBH8.Statistical input revealed that the mean concentration of Ni in boreholes was 0.39 mg/L and 0.08 mg/L. The groundwater samples except OSBH8 exceed the NSDWQ limit of 0.02 mg/L but falls within the WHO drinking water standard limit of 0.07mg/L.

3.2. Biological Composition of Osubi Groundwater

Coliform is a sub-group of coliform bacteria that is found in large great quantities in the intestines of humans and animals. In this study, the value of Coliform recorded in groundwater obtained from existing boreholes and hand dug wells ranged from 8-18 cfu/100 mL and 36-48 cfu/100 mL in hand-dug wells. The value of Coliform measured in Osubi groundwater exceeded the limit of 10 cfu/ml recommended by the NSDWQ except OSBH7 and OSBH8. However, the World Health Organization (WHO, 2017) set a zero (0) limit of coliform in drinking water.

3.3. Characteristics of Osubi Soils

The hydrogen potential (pH) concentration of the soils collected range 2.60-5.70 at topsoil of depth 0-15cm whereas at the subsoil of depth 15-30 cm, the pH values ranged from 2.30-6.20. The mean values of pH for topsoil of depth 0-15 cm and subsoil of depth 15-30 cm were 4.36 and 4.32 respectively. Conversely, the mean values of 4.70 and 3.90 were recorded at the control site (Table 2). The mean values recorded for Electrical Conductivity (EC) in soil was 1354.55μS/cm at the topsoil of depth range 0-15 cm and 1379.09 μS/cm at subsoil of depth range 15-30 cm. On the other hand, the mean values of 2050 μS/cm and 2100 μS/cm were recorded at the topsoil and subsoil at the control site. Soil organic matter (OM) is an essential component of crops production with characteristics of living organisms, crops residue, decomposing organic matter and humus content (Mosaic, 2021). Osubi soil OM range from 0.93-5.83 % at topsoil and 0.52-5.44 % at subsoil respectively. The highest value was recorded in sample the coded SS5 while the lowest value was recorded in sample code SS3. At the control site, the mean values recorded for topsoil and subsoil were 3.50 and 2.49 % respectively. Furthermore, the concentration of major elements was measured, in this study, the values of Sodium (Na) concentration ranged from 9.40-15.6 mg/kg at topsoil of depth range 0.00-15.00 cm and 7.70-13.10 mg/kg at subsoil of depth range 15.00-30.00 cm.

Table 3. Spearman's correlation matrix of groundwater parameters

Parameters	pHBH	EC (us/cm) BH	Turb. (mg/L) BH	TDS (mg/L) BH	SO4 (mg/L BH	Cl (mg/L BH	Ca (mg/L BH	Mg (mg/L BH	Na (mg/L BH	K (mg/L BH	As (mg/L BH	Mn (mg/L BH	Cd (mg/L BH	Cr (mg/L BH	Pb (mg/L BH	Zn (mg/L BH	Cu (mg/L BH	Ni (mg/L BH	V (mg/L BH	E. Coli (NTU) BH	Coliform (NTU) BH
pH HW	.333	-.323	**-.850****	-.359	.071	.190	-.548	.167	.333	0.000	-.072	-.500	-.299	-.310	-.263	-.398	**-.714***	-.132	-.429	-.250	-.371
EC (us/cm) HW	.119	.311	.575	.132	-.024	-.071	.095	-.429	-.429	-.405	.217	.190	-.144	-.167	.084	.205	.286	-.156	-.048	-.225	.108
Turb. (mg/L) HW	-.095	.359	0.000	-.275	-.286	.238	-.071	-.690	-.643	-.548	.410	-.310	-.323	.571	-.383	**.771***	.262	-.096	.595	-.050	.012
TDS (mg/L) HW	-.084	.301	.325	.247	.216	-.323	.323	-.156	-.036	0.000	-.455	.467	-.060	-.515	-.301	.224	.527	-.398	-.455	-.504	-.367
SO4 (mg/L) HW	.214	.395	.036	-.563	.119	-.024	-.095	**-.905****	**-.881****	**-.714***	.699	-.429	-.108	.262	.144	**.759***	.381	.012	.452	.125	.395
Cl (mg/L) HW	.619	-.359	-.048	-.012	.524	-.571	.238	.500	.119	.476	-.060	.310	.575	-.238	.611	-.615	-.143	.012	-.095	.300	.563
Ca (mg/L) HW	.333	.551	.192	.024	.595	-.333	.595	-.214	-.119	.071	.012	.405	.503	-.476	.371	.048	.429	.252	-.048	.225	.527
Mg (mg/L) HW	-.381	.347	.299	.407	.119	-.238	.500	.024	.190	.238	-.675	.595	.036	-.357	-.455	.277	.619	-.275	-.333	-.401	-.467
Na (mg/L) HW	.167	-.036	-.060	-.407	**.810***	-.690	.357	0.000	-.167	.262	.096	.048	**.778***	-.214	**.838****	.145	.571	.275	.024	.601	.671
K (mg/L) HW	.190	-.084	-.587	**-.743***	**.762***	-.619	-.048	-.286	-.262	-.024	-.060	-.333	.252	-.357	.180	.446	.476	-.216	-.286	.025	.012
As (mg/L) HW	.347	-.343	.090	.072	.491	-.707	.419	.515	.072	.587	-.242	.467	.639	-.060	.482	-.345	.204	-.090	.024	.290	.458
Mn (mg/L) HW	.071	.587	.180	-.036	.119	.310	.286	-.333	-.119	-.190	.530	-.048	.347	.024	.527	.060	.048	**.778***	.405	.626	**.731***
Cd (mg/L) HW	**-.786***	**.719***	.455	.419	-.357	.548	.524	-.190	.143	.024	.048	.238	.192	.405	-.060	.446	.429	**.731***	.571	.476	.180
Cr (mg/L) HW	.095	.311	.120	-.275	-.405	.429	-.167	-.667	**-.714***	-.643	**.819***	-.429	-.240	**.762***	0.000	.518	-.048	.216	**.857****	.275	.443
Pb (mg/L) HW	.060	.267	-.097	-.624	-.133	.301	-.349	**-.843****	**-.771***	**-.771***	**.890****	**-.723***	-.212	.506	.194	.677	.084	.242	.602	.304	.400
Zn (mg/L) HW	-.072	.145	-.060	-.500	-.132	.335	-.252	-.527	-.503	-.491	**.855****	-.647	.048	.587	.470	.436	0.000	.542	.683	.630	.590
Cu (mg/L) HW	-.238	.156	-.156	-.455	-.262	.476	-.310	-.500	-.381	-.476	**.735***	-.690	-.084	.619	.240	.482	-.048	.515	.643	.526	.359
Ni (mg/L) HW	.095	.299	.036	-.455	-.286	.429	-.286	**-.762***	**-.738***	**-.738***	**.952****	-.619	-.204	.643	.204	.542	-.048	.335	**.762***	.375	.515
V (mg/L) HW	.156	.259	-.042	-.488	-.275	.419	-.323	**-.743***	**-.731***	**-.731***	**.939****	-.647	-.229	.635	.163	.509	-.108	.289	**.743***	.340	.488
E. Coli (mg/L) HW	.267	.146	-.073	-.543	-.242	.242	-.364	**-.764***	**-.861****	**-.752***	**.859****	-.618	-.317	.643	.018	.577	-.048	-.006	.691	.140	.366
Coliform (mg/L) HW	.238	0.000	-.048	-.707	.262	-.190	-.238	-.619	**-.762***	-.524	**.783***	-.571	.132	.286	.611	.506	.262	.156	.405	.426	.611

*Note: *Correlation is significant at the 0.05 level (2-tailed) and highly significant at (P< 0.05) ** HW = Hand Dug Well, BH = Borehole*

At subsoil, the highest value recorded was observed in sample code SS8 while the lowest value recorded was observed in the sample code SS3. The control site mean values for Na were 9.90 and 9.60 mg/kg for topsoil and subsoil respectively. Potassium mean concentration in topsoil and subsoil samples were 8.05 mg/kg and 6.80 mg/kg while the mean concentration recorded at the control site were 8.70 mg/kg and 4.40 mg/kg for topsoil and subsoil of depth range 0-15 cm and 15-30 cm respectively. The highest value recorded was in sample code SS4 and the lowest in sample code SS3. Similarly, Magnesium was measured, and the result obtained showed a mean concentration of 10.57 mg/kg and 10.03 mg/kg for topsoil and subsoil, respectively.

The maximum and minimum values recorded in topsoil and subsoil were recorded in sample codes SS8 and SS3. For the control site, the mean value recorded for topsoil and subsoil were 10.80 mg/kg and 6.30 mg/kg respectively. Calcium concentration in this study range from 10.50 -17.30 mg/kg at topsoil and subsoil respectively (Table 2 and Appendix 2).

On the other hand, the mean concentration of Ca for topsoil and subsoil in the study site were 13.57 mg/kg and 12.22 mg/kg while the control site value was 13.33 mg/kg for topsoil and 12.22 mg/kg for subsoil respectively.

3.4. Heavy Metal Concentration.

The heavy metals measured in the study include Arsenic (As), Manganese (Mn), Cadmium (Cd), Chromium (Cr), Lead (Pb), Zinc (Zn), Copper (Cu), Cyanide (Cn), Nickel (Ni) and Vanadium (V). The results obtained showed that As concentration ranged from 11.56-23.4 mg/kg at the topsoil and 10.58-21.2 mg/kg at the subsoil. The highest value measured in subsoil was recorded in sample code SS2 while the lowest value was recorded in sample code SS6. The result for the control point showed that the mean values for topsoil was 11.56 mg/kg and10.58 mg/kg for subsoil respectively. For Mn, the concentration ranged from1.46 - 3.58 mg/kg for the topsoil and 1.42 - 3.52 mg/kg for subsoil respectively. The highest value for the subsoil was recorded in sample code SS4 while the lowest value recorded was in sample code SS2. Conversely, the highest value recorded in the topsoil was in sample code SS4 while the lowest value was in sample code SS2.

The control means values recorded for topsoil and subsoil were1.46 and 1.42 mg/kg respectively. Cadmium value in topsoil sample ranged from 1.08-3.46 mg/kg and 1.06-3.43 mg/kg in subsoil (Table 2). The mean values of Cd for topsoil, subsoil and control point were 2.26 mg/kg, 2.24 mg/kg and 1.06 mg/kg, respectively. The highest and lowest values for topsoil and subsoil were recorded in samples code SS9 and SS8 respectively. The concentration of Cr in the study ranged from 1.64-4.52 mg/kg for the topsoil of depth 0-15 cm while the range for subsoil was 1.61-4.55 mg/kg. The mean value recorded for topsoil, subsoil and control point in the study were 3.53 mg/kg, 3.50 mg/kg, 1.64 mg/kg and 1.61 mg/kg respectively. In this study, the values of Pb recorded in topsoil and subsoil ranged from 2.14-3.69 mg/kg and 2.11-3.71 mg/kg. The highest value was recorded in sample code SS4 and the lowest value was recorded in sample code SS7.

The mean values of 2.14 and 2.11 mg/kg recorded for topsoil and subsoil in the control site indicate a decrease in concentration of Pb. For Zinc (Zn), the mean concentration measured in topsoil samples was 9.99 mg/kg and 10.27 mg/kg in the subsoil. The control site mean value for topsoil and subsoil were 5.79 mg/kg and 5.77 mg/kg respectively. Copper concentration was also measured, the values obtained range from 1.86 -3.23 mg/kg for topsoil and 1.69-3.17 mg/kg for subsoil. The mean concentration for topsoil was 2.48 mg/kg while the value for subsoil was 2.20 mg/kg, respectively.

There was significant reduction in concentration at the control site, given a value of 1.86 mg/kg and 1.69 mg/kg for topsoil and subsoil respectively. In addition, Nickel (Ni) mean concentration in Osubi soil samples was 2.94 mg/kg for topsoil and 2.77 mg/kg for subsoil. At the control site, the means value for topsoil was 1.35 mg/kg and 1.31 mg/kg for subsoil. Concentration of Vanadium (V) in soil samples of Osubi dumpsite ranges 1.24 - 3.81 mg/kg in topsoil of depth 0-15 cm and 1.26-3.95 mg/kg in subsoil of depth 15-30 cm. The mean values recorded for Cd were 2.81 mg/kg in subsoil and 2.83 mg/kg in topsoil. The minimum and maximum values were recorded in sample code SS8 and SS7, respectively.

3.5. Particle Size Distribution of Osubi Dumpsite Soil

The particle size distribution of Osubi dumpsite soil and the control site is presented in Appendix 2. Soil particle size distribution was observed to be a combination of sand, clay and silt in all the sites investigated. The sandy component ranged from 76.2-88.4% in the topsoil of 0-15 cm whereas the subsoil particle size of depth 15-30 cm ranged from 72.1- 85.2 %. The silt fraction of the soil samples collected were low, the values ranged from 5.6 – 15.0% in the topsoil and 3.4 – 13.8% in the subsoil. The clay percentage ranged from 7.0 – 9.1% in topsoil and 4.3 – 8.6% in subsoil. Similarly, the control site result for particle size distribution indicated that 88.4% was made up of sand, 6 % clay and 5.6% silt. Sandy soils are permeable and could allow enormous quantities of fluid like leachates, crude and refined hydrocarbon fractions to percolate into the subsurface.

4. Discussions

4.1. Groundwater Quality

The quality of water determines its application. Potable water must meet the required standard, otherwise the health status of the consumers may be at risk. The physical properties of groundwater consumed by Osubi locals' shows a variability in acceptance. For example, the pH value for acceptable drinking water is in the range of 6.50-8.50. Water quality with values below or above the recommended standard is not fit for human consumption (WHO, 2017). Although pH does not necessarily indicate that water quality is poor but can influence several chemical processes and facilitate the dissolution of materials in water; this can compromise the quality of drinking water (Adimalla et al 2020; Islam et al., 2023; Orobosa et al., 2023).

In the study area, the values of pH measured indicated that the drinking water quality is moderately acidic, falling below the required standard. Moderate pH values recorded in the study could be attributed to industrial input, Osubi dumpsite, acid rainfall and other anthropogenic activities associated with the study area. Similarly, the turbidity measured in the study area exceeded 5NTU recommended by national and international regulatory agencies; this may have been influenced by the low pH recorded in the study area. On the other hand, the values of electrical conductivity (EC) and the total dissolved solid in the drinking water source in Osubi were within the recommendation of the Nigeria Standard for drinking water quality and world health organization (WHO, 2017). Chlorine and Sulphate as the main anion were also measured in Osubi groundwater. The results obtained revealed that both parameters were within the acceptable limit appropriated by national and international regulatory agencies. There are several sources of chlorine and sulphate in groundwater, however, in Osubi, the sources of Cl^- and SO^{2-}_4 could be attributed to wastewater from neighborhood, percolating leachate from Osubi dumpsite, weathering rock and the dissolution of minerals rich in sulphate and chlorine. Although Cl^- and SO^{2-}_4 are essential constituents of drinking water but excess of it can be detrimental to human health (Aladin et al., 2024). Similarly, the cations measured in the study (Ca, Mg and K) show variability in values and acceptance for drinking water purpose. The values of Ca and K were within the acceptable limit for drinking water. However, the result of Mg indicated high value above the acceptable limit of 0.2 mg/L by WHO and the Standard Organization of Nigeria (SON).

The presence of Mg in Osubi groundwater is likely to be from minerals that have been eroded from local rocks and dissolve in groundwater. Magnesium in drinking water may be recommended for people with heart disease because soft water contain Sodium which is added in the process of softening and may be challenging for people with circulatory or heart disease to consume (Balamurali and Sivanandan, 2024).

Heavy metal results obtained in the study revealed that groundwater for drinking purpose in Osubi was inconsistence with regulatory standard, this may be attributed to gas flaring, vehicular and industrial emissions, leachate from waste heap, household activities, weathering processes and percolation of dissolved minerals in water are the main sources of heavy metal is soil and groundwater in the study area. The concentration of these metals was observed around samples collected in OSBH2-5 and OSHW3 and 5, respectively (Fig.1).

The areas where the concentration of the heavy metal was high was characterized by heavy population, proximity to dumpsite and soil with textural properties that facilitated fluids flow. Concentration of Arsenic, Cadmium and Chromium above background levels in environmental media can lead to chronic or acute cancer and or arsenicosis (Zhou et al., 2020; Selinus et al., 2013).

Drinking water containing substantial amount of these metals in water supply sources can accumulate and biomagnified to impact human health through food chain. Juxtaposing correlation with laboratory analyses at $p < 0.05$, the results obtained showed a negative correlation in some aspects and a positive strong collection in some other aspects between the measured variables in borehole water (BH) and hand dug wells (HW) as indicated in Table 3.

It was observed that pH, K, Cr, Pb, Zn, Cu and Ni in hang dug well showed a positive strong correlation at two tailed with a correlation coefficient range of 0.515-0.939; this indicates that the contaminants/pollutants are mainly from the same source possibly from percolating leachate from the wastes heap. In addition, biological characteristics of E.coli and coliform counts indicated that Osubi drinking groundwater was modernly to well contaminate when compared to regulatory standard.

It was observed that the hand-dug wells were more impacted than the boreholes. This could be attributed to the absorption and dissolution of atmospheric gases from flaring, industrial emission and acid rain. This can be enhanced by the high percentage of sand. Sandy soils are permeable and could allow large quantities of leachates from the wastes to infiltrate into the subsurface and consequently impact the quality of groundwater resources (Omorogieva and Tonjoh, 2020).

Table 4. Test of difference between control and soil samples

Parameters	Control Mean ± SE	Soil Mean ± SE	Test of Significance (P-value)
pH	4.50 ± 0.20	4.36 ± 0.20	**P< 0.05
EC (us/cm)	219.00 ± 4.00	1576.80 ± 749.10	P <0.05
O.M (%)	3.44 ± 0.31	3.31 ± 0.34	P<0.05
Na (mg/kg)	6.27 ± 0.25	4.10 ± 1.00	**P<0.05
K (mg/kg)	6.32 ± 0.08	2.77 ± 0.57	P <0.05
Mg (mg/kg)	7.30 ± 0.10	4.65 ± 0.18	P <0.05
Ca (mg/kg)	10.30 ± 0.40	8.46 ± 1.38	*P<0.05
As (mg/kg)	19.20 ± 0.60	17.89 ± 1.07	**P< 0.05
Mn (mg/kg)	3.64 ± 0.03	3.45 ± 0.25	P <0.05
Cd (mg/kg)	2.37 ± 0.56	1.07 ± 0.56	P <0.05
Cr (mg/kg)	3.71 ± 0.37	1.60 ± 0.37	P <0.05
Pb (mg/kg)	2.9 ± 0.15	2.10 ± 0.38	P <0.05
Zn (mg/kg)	9.09 ± 0.08	5.21 ± 0.14	P <0.05
Cu (mg/kg)	5.39 ± 0.12	4.97 ± 0.31	**P<0.01
Cn (mg/kg)	2.63 ± 0.06	1.18 ± 0.65	**P<0.01
Ni (mg/kg)	3.64 ± 0.03	2.76 ± 0.33	P <0.05
V (mg/kg)	2.87 ± 0.15	1.50 ± 0.07	P < 0.05

**Bold values indicate significant difference and*
***Bold indicate highly significant difference*

4.2. Soil Quality Evaluation

In this study, the quality of soil for agricultural application was screened for physicochemical, particle size distribution, organic matter and heavy metal parameters. The results obtained in the study area was compared to the values obtained from control site (Appendix 2 and Table 4). The P-Values of the analysis of variance (ANOVA) revealed a significant difference in the pH, Na, As, Ca and Cu values between the study area and control site. Conversely, there was significant difference between the study area and the control site in the EC, OM, K, Mg, Mn, Cd, Cr, Pb, Zn, Ni and V.

Although there was a significant difference in some aspect of the soil chemistry in around the dumpsite and the control site, however, the values obtained shows that the soil was heavy metal loaded. Soil with high concentration of heavy metal above threshold values and high percentage of sand cannot adequately support crops production. Ideally, crops do better in soil with pH range from 6.5-7.5 and 6.0-7.0, respectively. If the pH of soil becomes too acidic or alkaline, crops production will be disadvantaged. The soil pH in this study and the control site shows moderate to highly acidic soil within the range of 2.0-5.5; this is detrimental to crop production, hence the uncultivated landmass in Osubi. When available land cannot be harnessed for crops production or related agricultural activities, this may result in food scarcity (Ugwuja, 2022; Omorogieva and Tonjoh, 2020).

It was also observed that OM, major and minor soil nutrients were very low couple with high percentage of sand (Appendix 2). Omorogieva and Tonjoh (2020), Asuka and Hyginus (2023) demonstrated that soil with low nutrients and poor silty-clay cannot support crops production; this is because the loose interconnected pore space allow nutrients to percolate into deeper subsoil which crops may not be able to access.

The CF values of Mn, V, Cr, Ni, Cd, Zn, As, Pb, and Cu in the study area revealed that Osubi soil is moderately contaminated to highly polluted, CF <3 -> 6 (Hankinson, 1980). The heavy metal load in the soil was attributed to anthropogenic activities especially industrial, vehicular and the use of hydrocarbon driven machines emitted fume. Other factors may include percolation of leachate from septic tank due to high population and mineral mixing in soil due to dissolution of eroded sediments.

The values of PLI (Fig. 2) also buttress the influence of human activities. The CF revealed the order soil pollution in the various work station; thus, SS8 > SS5 > SS9 > SS4 = SS7 and SS10 > SS2 > SS3 > SS6. Similarly, the PLI in the study revealed the order of heavy metal pollutant in Osubi soil as follows; Mn> V > Cr > Ni > Cd > Zn > As >Pb> Cu. Based on these findings, there was a progressive level of soil deterioration in workstations SS8, SS5, SS9, SS2, SS3, and SS6 whereas SS4, SS7 and SS10 had only baseline level of pollution. Overall, the quality of soil in the study area is moderately contaminated with respect to the control site which acts as a normalizer.

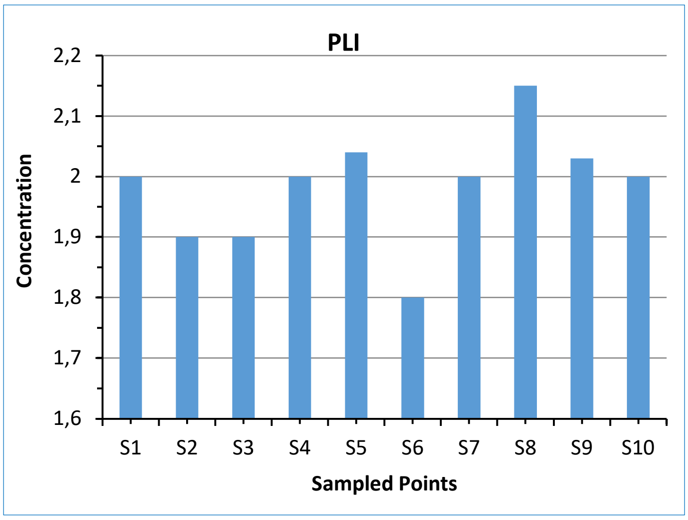

Fig. 2. Pollution load index classification for soils in the study area

4.3. Treatment/Remediation of Poor Drinking Water Quality and Soil

There are several approaches to improving the quality of drinking water depending on the severity. Omorogieva et al. (2022b); Wolowiec et al. (2019) and Lenntech (2020) demonstrated that groundwater laden with metalloids and heavy metals can be treated by the application of chemical oxidation or aeration just before swift sand filtration. Similarly, Cr (VI), Pb, and Ni in drinking water can be disinterested by adsorption–reduction mechanism, reverse osmosis, adsorbents and ion exchange resin (Sharma et al., 2005; Liu et al., 2018).

The process is highly dependable and cost effective. Introduction of Ca and Mg rich powdered to groundwater source can clog the impurity in the water system to form slag which can be filtered off during routing water treatment. On the other hand, soil deficient with required supplements for crops to grow can be improved by agricultural waste products like cow dung, poultry dropping and goat excreta and the addition of quick lime. These materials can be locally sourced with low coast (Asuka and Hyginus, 2023).

If soil becomes too acidic with a pH < or > 6, crops production will be impacted; to fix soil pH for optimal crop production, it is imperative to apply lime and fertilizer materials. This practice will enable the soil to regain it natural Ca and Mg supply, consequently neutralizing the soil acidity. The addition of soil organic matter supplements and the practice of crop rotation to allow the soil to regain its lost nutrients and adequate irrigation practice can help restore soil acidity and improves its quality for agricultural practice.

5. Conclusion

This study has provided invaluable information on the soil and groundwater status of Osubi. The results obtained from the combination of field study and hydrogeochemical appraisal of groundwater and soil revealed that Osubi groundwater and soil for agricultural activities and drinking purposes compromise the approved regulatory national and international standards for water and soil quality assessment. However, by the application of common and affordable remedial methods, the soil and groundwater quality can be improved for optimal benefit. This will eventually contribute to sustainable environmental management that will support sustainable development.

Declarations of Competing Interest

No conflict of interest was reported in this study.

Authors Contribution

The study was designed by Mr. Samuel E. Oseji in collaboration with Dr Osakpolor M. Omorogieva and Osazuwa E. Ogieriakhi. Authors contributed equally to all aspects of the research work. The manuscript was written by Dr Osakpolor M. Omorogieva and was read by all the contributing authors for publication in the International Journal Earth Science, Knowledge and Application.

Declaration of generative AI

This work's composition, including manuscript report, does not involve artificial intelligence (AI) generative assistance.

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Appendix 1. Physical, chemical and biological parameters measured in groundwater

Parameters	OSBH1	OSBH2	OSBH3	OSBH4	OSBH5	OSBH6	OSBH7	OSBH8	OSHW1	OSHW2	OSHW3	OSHW4	OSHW5	OSHW6	OSHW7	OSHW8
pH	5.4	5.69	5.89	5.96	5.55	5.44	5.49	5.63	5.59	5.78	5.28	5.76	5.6	5.67	5.73	5.69
EC (µS/cm)	400	250	350	250	260	210	610	100	550	220	850	460	370	350	410	480
Turb *(mg/L)*)	2.6	BDL	1.9	BDL	2.2	1.1	1.5	1.6	12.4	14.8	12.5	10.3	10.4	12.1	11.4	9.4
TDS *(mg/L)*	210	130	180	120	180	130	300	240	270	110	420	230	180	270	340	280
SO_4 *(mg/L)*	73.7	76.15	87.22	93.05	83.7	89.6	86.3	76.9	103.5	69.3	129.3	75.35	53.72	61.62	57.38	46.61
Cl *(mg/L)*	18.7	18.2	11.4	11.6	12.1	10.9	12.6	11.8	49.6	52.2	55.3	55.5	56.1	53.4	51.6	55.1
Ca *(mg/L)*	1.04	0.73	8.29	0.93	91.6	7.82	12.55	0.81	37.65	20.12	94.31	61.91	39.3	35.1	55.38	32.4
Mg *(mg/L)*	0.61	0.92	0.75	1.16	6.45	1.83	1.63	2.24	2.74	1.47	4.53	1.29	2.54	3.18	4.84	3.08
Na *(mg/L)*	4.04	4.54	1.89	8.66	13.17	11.6	15.63	13.03	6.38	3.64	8.54	14.67	6.51	9.68	5.76	4.26
K *(mg/L)*	0.83	0.9	1.33	2.42	21.37	10.29	8.89	7.94	8.62	9.29	11.19	11.76	7.71	15.62	10.69	8.03
As *(mg/L)*	0.08	0.07	0.03	0.03	0.02	0.05	0.04	0.07	0.04	0.09	0.08	0.08	0.09	0.08	0.07	0.06
Mn *(mg/L)*	0.1	BDL	0.2	0.1	0.3	0.1	0.3	0.1	0.3	0.2	0.2	0.4	0.3	0.23	0.3	0.30
Cd *(mg/L)*	0.02	BDL	0.02	0.02	0.03	0.02	0.02	0.01	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.03
Cr *(mg/L)*	0.06	0.03	0.02	0.01	0.03	0.02	0.01	0.02	0.07	0.7	0.07	0.06	0.06	0.05	0.04	0.04
Pb *(mg/L)*	0.01	BDL	0.01	0.02	0.02	0.01	BDL	0.01	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02
Zn *(mg/L)*	0.19	0.16	0.17	0.14	0.13	0.17	0.15	0.13	0.36	0.23	0.17	0.24	0.19	0.19	0.16	0.15
Cu *(mg/L)*	0.11	0.04	0.12	0.06	0.07	0.23	0.09	0.04	0.11	0.10	0.06	0.09	0.07	0.08	0.06	0.06
Ni *(mg/L)*	0.05	0.03	0.03	0.04	0.05	0.04	0.03	0	0.05	0.09	0.08	0.08	0.07	0.1	0.11	0.13
V *(mg/L)*)	0.03	0.03	0.02	0.01	0.03	0.01	0.01	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04
E.Coli (NTU)	2	1	1	2	6	2	1	BDL	5	6	5	4	3	3	2	2
Coliform (NTU)	14	11	14	17	18	13	9	8	47	43	46	48	42	45	36	38

Appendix 2. Physicochemical parameters of Osubi soils and control samples

Parameters	Depth (cm)	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	Control
pH	0–15	5.5	4.4	4.7	4.1	2.6	5.6	5.7	4.8	4.8	4.3	4.0
	15–30	5.4	3.6	6.2	4.8	2.3	5.1	5.2	5.3	3.8	3.7	3.0
EC (μS/cm)	0–15	700	610	770	780	3010	270	370	2670	2030	1640	150
	15–30	500	600	730	610	2990	510	520	2630	1900	1750	140
O.M (%)	0–15	1.53	3.74	0.93	3.74	5.83	1.46	1.51	1.56	3.13	3.37	1.3
	15–30	1.44	2.96	0.52	3.68	5.44	1.34	1.44	1.08	2.45	2.98	0.3
Na (mg/kg)	0–15	12.8	11.8	9.4	13.2	10.2	11.7	11.9	15.6	10.7	12.5	9.1
	15–30	11.5	11.0	7.7	12	10.1	9.6	11.4	13.1	10.3	11.4	9.0
K (mg/kg)	0–15	9.1	8.5	4.7	9.4	9.4	8.2	9.1	7.2	7.1	7.1	4.0
	15–30	8.2	8.4	3.9	8.5	7.4	3.9	8.3	9.3	5.9	6.6	3.4
Mg (mg/kg)	0–15	13.1	9.4	8.1	12	9	8.7	8.3	14.9	11.4	10.6	10.8
	15–30	12.6	9	8.8	10.5	8.5	9.8	13.2	10.8	9.9	10.9	6.3
Ca (mg/kg)	0–15	15.5	13.1	10.5	15.5	12.1	13	12.1	17.3	12.2	14.7	9.1
	15–30	14.1	12.5	9.1	14.4	11.2	10.3	15.2	15.1	11.7	12.2	8.6
Sand %	0–15	76.9	80.0	76.2	78.6	88.4	84.2	76.8	70.8	83.6	79.7	87.3
	15–30	80.4	78.5	82.0	74.9	86.7	80.3	84.5	78.9	74.2	85.4	78.8
Silt %	0–15	5.60	6.80	4.80	5.80	6.40	5.40	7.40	6.90	5.70	6.60	5.70
	15–30	6.20	5.85	6.50	4.75	6.20	6.70	4.50	6.20	4.90	6.40	6.30
Clay %	0–15	15.5	12.2	18.5	14.5	4.6	8.2	14.8	18.9	10.0	13.5	5.6
	15–30	13.4	14.7	13.2	18.7	3.2	12.1	10.5	13.8	18.2	8.4	14.5
As (mg/kg)	0–15	19.2	23.4	21.6	19.1	18.03	14.36	15.34	19.6	19.28	19.06	11.56
	15–30	16.4	21.2	19.16	17.6	16.8	12.63	13.32	17.28	18.06	16.47	10.58
Mn (mg/kg)	0–15	3.58	3.42	3.49	3.58	3.26	3.37	3.48	3.54	3.4	3.44	1.46
	15–30	3.51	3.37	3.47	3.42	3.52	3.43	3.51	3.52	3.39	3.42	1.42
Cd (mg/kg)	0–15	2.08	2.13	2.14	2.22	3.25	2.13	2.12	3.46	2.07	2.21	1.08
	15–30	2.07	2.11	2.11	2.18	3.19	2.09	2.12	3.43	2.05	2.24	1.06
Cr (mg/kg)	0–15	3.51	3.51	3.52	3.57	4.49	3.48	3.54	4.52	3.53	3.54	1.64
	15–30	3.54	3.49	3.53	3.56	4.55	3.49	3.51	4.55	3.38	3.32	1.61
Pb (mg/kg)	0–15	2.72	2.54	2.56	3.69	2.87	2.81	2.32	3.42	2.89	2.85	2.14
	15–30	2.71	2.51	2.55	3.71	2.87	2.83	2.3	3.40	2.92	2.83	2.11
Zn (mg/kg)	0–15	8.54	10.21	10	10.2	9.97	10.8	11.5	14.21	8.18	10.46	5.79
	15–30	8.46	9.66	9.6	9.81	10.3	8.0	9.50	13.5	8.09	10.44	5.77
Cu (mg/kg)	0–15	2.02	2.54	2.06	2.17	2.86	2.21	2.95	2.16	3.23	3.2	1.86
	15–30	1.98	2.34	1.76	2.04	1.99	2.06	2.51	2.08	3.17	2.57	1.69
Ni (mg/kg)	0–15	3.18	2.64	3.36	2.29	3.24	2.81	2.95	3.41	4.59	2.49	1.35
	15–30	3.21	2.54	3.21	2.03	3.13	2.02	2.26	3.32	4.51	2.38	1.31
V (mg/kg)	0–15	2.83	2.54	2.87	2.87	2.79	3.71	3.81	2.34	3.18	2.76	1.24
	15–30	2.80	2.41	2.84	2.13	2.81	3.91	3.95	2.27	3.55	2.21	1.20