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Evaluation of Physical and Chemical Properties of Groundwater and Surface Water in Ugbuwangue and Ogunu, Delta State

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Abstract
Groundwater and surface water are important sources of domestic and industrial supply in many developing regions, but increasing human activities threaten their quality. This study evaluates the physicochemical characteristics of groundwater and surface water in Ugbuwangue and Ogunu communities in Delta State, Nigeria. A total of fifteen (15) water samples were collected from boreholes and hand-dug wells. Key parameters analyzed included pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, bicarbonate, major ions, and heavy metals, using standard laboratory methods. Atomic Absorption Spectroscopy (AAS) was used for metal analysis. Results show that pH values ranged from 5.0 to 6.3, indicating slightly acidic conditions below the WHO acceptable limits (6.5–8.5). EC values (52–317 µS/cm) and TDS values (26–157 mg/L) were within permissible limits, suggesting low dissolved ion content. However, elevated levels of iron (Fe), manganese (Mn), chromium (Cr), and lead (Pb) were observed in several samples, exceeding WHO guideline values, indicating potential health risks from long-term consumption. These contaminants may originate from both geogenic processes and anthropogenic inputs, particularly industrial activities. The study recommends appropriate treatment of water before consumption and continuous monitoring to prevent contamination and protect public health.

Keywords
Water quality, heavy metals, groundwater contamination, physicochemical parameters, Ugbuwangue and Ogunu

1. Introduction

Water plays a vital role in sustaining human life, supporting ecological processes, and enabling socio-economic development. In this study, the physical and chemical properties of groundwater and surface water in Ugbuwangue and Ogunu, Delta State, Nigeria, were evaluated. Fifteen (15) water samples were collected from different locations within the communities, consisting of borehole (groundwater) and hand-dug well (surface water) sources.

The collected water samples were assessed for key physicochemical parameters including pH, turbidity, total dissolved solids (TDS), hardness, and selected heavy metals using standard laboratory procedures. Atomic Absorption Spectroscopy (AAS) was employed for the quantification of metal concentrations. The pH of the borehole samples ranged from 5.0 to 6.3, which is below the recommended limits of 6.5–8.5 established by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) and the World Health Organization (WHO, 2011). The slightly acidic nature of the water may be attributed to natural geological influences or anthropogenic contamination, suggesting the need for basic pH adjustment and treatment before consumption.

The presence of these contaminants may be attributed to a combination of geogenic factors, such as the dissolution of metal-bearing minerals, and anthropogenic activities including industrial discharge, poor waste disposal practices, and corrosion of plumbing systems. Appropriate water treatment options such as aeration, activated carbon filtration, ion exchange, or reverse osmosis can be applied to reduce heavy metal concentrations and improve potability prior to domestic use.

2. Description of the Study Area

Ugbuwangue and Ogunu are peri-urban communities located within Warri, a major commercial hub in Delta State, Nigeria. Warri lies in the Niger Delta region, an area recognized for its extensive petroleum exploration and production activities. The region is dominated by a complex network of rivers, creeks, and wetlands that support fishing, transportation, and other human activities, while also serving as important sources of surface and groundwater for domestic, agricultural, and industrial purposes (Nigerian Industrial Standard, 2007).

Ugbuwangue is located along the Warri River, close to the commercial center of Warri. The area has undergone significant population growth and urban expansion in recent years due to its strategic location along the Warri–Sapele axis and its proximity to major economic activities. Most households depend on groundwater from private or community boreholes as their primary source of water, although some residents still utilize surface water from nearby streams and rivers, particularly during periods of water scarcity.

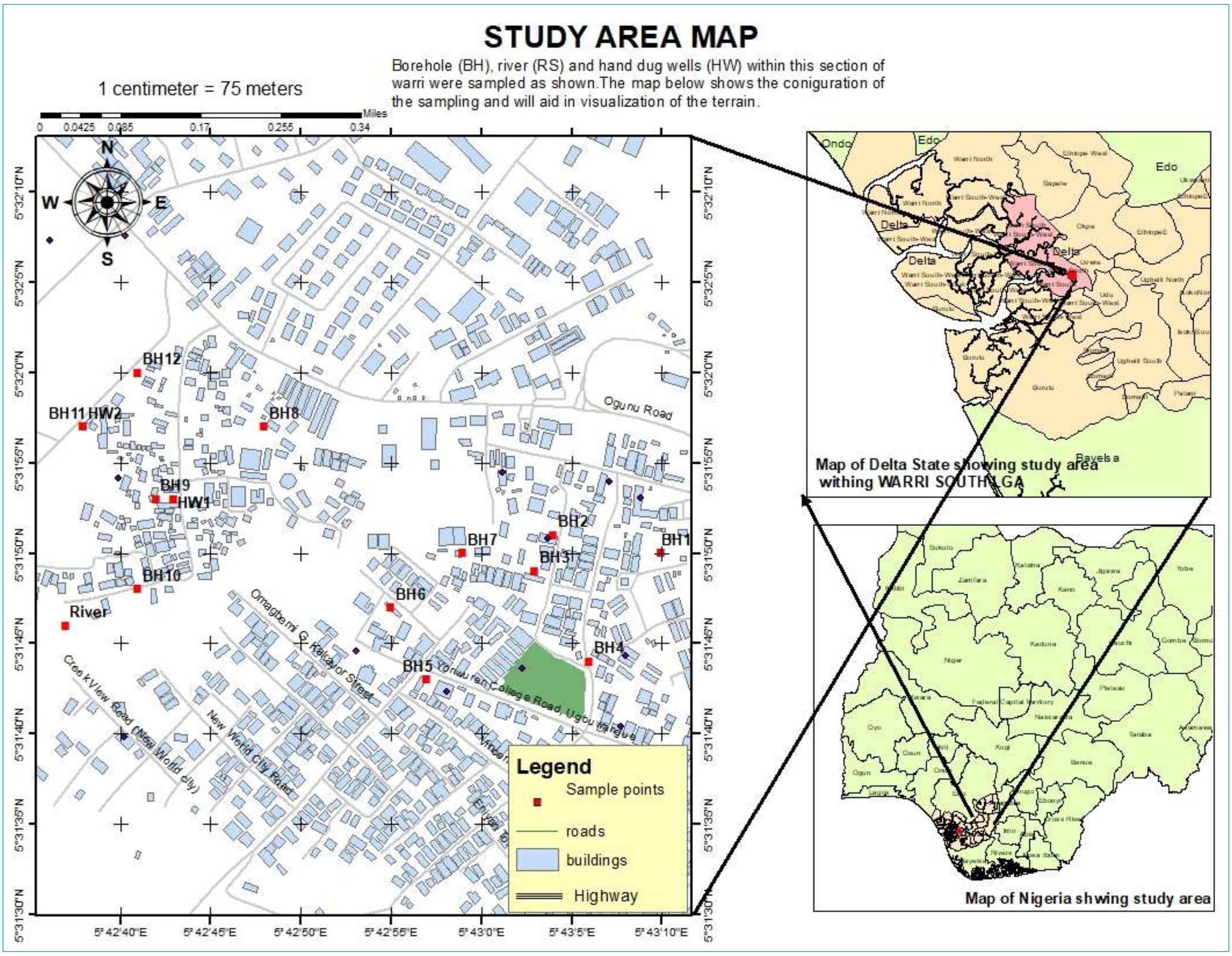


Fig. 1. Based map of the study area

Ogunu, located west of Ugbuwangue, lies within Warri's industrial belt and hosts several petroleum production and storage facilities. The concentration of industrial activity in this area increases the risk of water contamination from oil spills, pipeline leakages, and industrial effluent discharge into surrounding creeks and wetlands.

The primary economic activities in both communities include trading, fishing, agriculture, and industrial employment. In Ugbuwangue, many residents are engaged in small-scale trading and service provision, while fishing remains a vital occupation for those living near the river. The availability of clean surface water is essential for these livelihoods. However, pollution poses a serious threat to fishing activities and overall community well-being.

The industrial dominance of Ogunu has significant implications for water resource sustainability in the region. Large volumes of water are extracted daily to support petroleum refining, cooling systems, and other industrial processes. This often competes with domestic water demand and contributes to periodic shortages. Furthermore, poor waste management practices and the discharge of untreated industrial wastewater threaten both surface and groundwater quality in and around Ogunu.

Despite the preference for groundwater abstraction through boreholes in both communities, groundwater quality is increasingly at risk due to human activities. Potential sources of contamination include effluent infiltration from septic tanks, leachates from waste disposal sites, oil pollution, and agricultural runoff. Since both communities rely heavily on groundwater for drinking and domestic purposes, consistent monitoring and protection of water sources are essential to prevent long-term health hazardsthe Nana Sand, known for being friable and unconsolidated.

3. Geology of the Study Area

The Niger Delta Basin extends across parts of Rivers, Bayelsa, Edo, and Delta States in southern Nigeria and occupies an estimated area of about 75,000 km². The basin consists mainly of thick sedimentary successions that were deposited from the Cretaceous to the Recent period, with sediment thickness ranging between 8,000 and 12,000 meters (Orife and Avbovbo, 1982). Located along the Gulf of Guinea at the southern end of the Benue Trough, the Niger Delta is recognized as one of the world's major hydrocarbon provinces (Corredor et al., 2005).

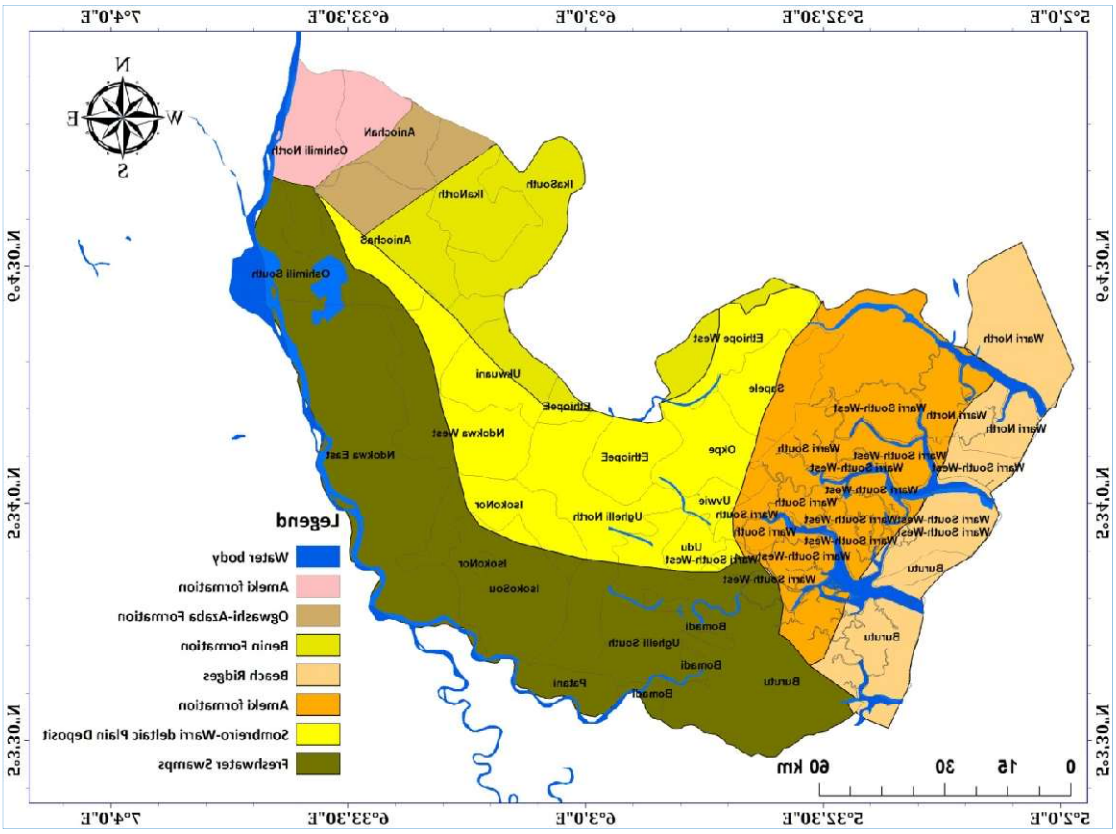


Fig. 2. Geology map of the Delta State (Modified Source: Komolafe and Aladin, 2023)

The region is characterized by a complex network of distributary channels formed by the River Niger, which empties into the Atlantic Ocean, as well as by tidal creeks and low-elevation islands, which rarely exceed 10 meters above sea level (Offodile, 2002).

The Niger Delta is geographically bordered by the Anambra Basin and Abakaliki uplift in the north, the Cameroon Volcanic Line to the east, the Dahomey Embayment to the west, and the Gulf of Guinea along its southern margin. Sediment accumulation in the basin has been dominated by siliciclastic deposits, which began prograding seaward from the Late Eocene period and have continued to build outward over time (Burke abd Dewey, 1972).

The geology of the Niger Delta consists of a thick succession of unconsolidated to poorly consolidated sedimentary formations dominated by sand, silt, and clay. These deposits were transported mainly by the River Niger system and laid down in environments that transitioned from continental fluvial channels to shallow marine settings.

Continuous tectonic subsidence in combination with high sediment input has significantly influenced the stratigraphic evolution of the delta. The subsurface lithostratigraphy of the Niger Delta comprises three principal formations: the Akata, Agbada, and Benin Formations. The Akata Formation forms the deepest sequence and is made up predominantly of marine shales with minor siltstone interbeds. Overlying this unit is the Agbada Formation, which consists of interbedded sandstones and shales deposited in delta-front to delta-plain environments. The uppermost unit, the Benin Formation, is composed mainly of continental sands and gravels and serves as the principal groundwater aquifer in the region (Short and Stauble, 1967).

The Benin Formation, commonly known as the Coastal Plain Sands, was deposited from the Miocene to Recent epochs. The formation is dominated by coarse to medium-grained sands with occasional clay lenses and peat layers. Its high porosity and permeability make it the most productive aquifer unit in the Niger Delta and the primary source of groundwater for domestic and industrial use in many communities (Offodile, 2002).

Table 1. Physiochemical parameters of water samples collected at Ugbuwange Community

S/N	Code	BH 1 GB	BH 2 GB	BH 3 GB	BH 4 GB	BH 5 GB	BH 6 GB	BH 7 GB	Average	Min	Max
1	pH	5.3	5.5	5.9	5	6.3	5.7	5.3	5.57	5.0	6.3
2	EC µS/cm	130	52	154	317	100	78	237	152.57	52	317
3	Sal.g/l	0.06	0.024	0.07	0.143	0.045	0.035	0.107	0.069	0.024	0.143
4	TDS	66	26	58	157	50	40	119	73.714	26	157
5	COD	8	5.1	9.7	14.2	7.6	7.2	10.3	8.8714	5.1	14.2
6	HCO3	50.3	12.8	51.1	80.2	44.5	38.2	61.6	48.356	12.8	80.2
7	Na	2	1	2.2	4	1.8	1.7	3.1	2.257	1	4
8	K	0.73	0.36	0.82	1.5	0.68	0.62	1.15	0.837	0.36	1.5
9	Ca	6.5	3.2	7.3	13.3	6.1	5.5	10.3	7.457	3.2	13.3
10	Mg	4.1	2	4.6	8.4	3.8	3.5	6.5	4.70	2	8.4
11	Cl	187	56.6	210	287.4	101.2	75.6	223	162.971	56.6	287.4
12	P	0.051	0.021	0.063	0.116	0.048	0.033	0.088	0.06	0.021	0.116
13	NH4N	1.74	0.53	1.82	2.61	0.93	0.73	2.09	1.493	0.53	2.61
14	NO2	0.4	0.12	0.42	0.6	0.17	0.21	0.48	0.343	0.12	0.6
15	NO3	5.87	1.8	6.12	8.77	3.12	2.44	7.02	5.02	1.8	8.77
16	SO4	3.87	1.19	4.04	5.8	2.06	1.61	4.63	3.314	1.19	5.8

Table 2. Comparison of physiochemical parameters with NSWDQ (2007) and WHO (2011)

S/N	Parameters	BH 1 GB	BH 2 UGB	BH 3 UGB	BH4 UGB	BH 5 UGB	BH 6 UGB	BH 7 UGB	NSWDQ, 2007	WHO, 2011
1	pH	5.3	5.5	5.9	5	6.3	5.7	5.3	6.5-8.5	6.5-8.5
2	EC µS/cm	130	52	154	317	100	78	237	1000	900
3	Sal.g/l	0.06	0.024	0.07	0.143	0.045	0.035	0.107		
4	TDS	66	26	58	157	50	40	119		
5	COD	8	5.1	9.7	14.2	7.6	7.2	10.3	500	1000
6	HCO_3	50.3	12.8	51.1	80.2	44.5	38.2	61.6	250	250
7	Na	2	1	2.2	4	1.8	1.7	3.1	200	200
8	K	0.73	0.36	0.82	1.5	0.68	0.62	1.15		
9	Ca	6.5	3.2	7.3	13.3	6.1	5.5	10.3	75	200
10	Mg	4.1	2	4.6	8.4	3.8	3.5	6.5	50	100
11	Cl	187	56.6	210	287.4	101.2	75.6	223	250	250
12	P	0.051	0.021	0.063	0.116	0.048	0.033	0.088		
13	NH4N	1.74	0.53	1.82	2.61	0.93	0.73	2.09	35	35
14	NO_2	0.4	0.12	0.42	0.6	0.17	0.21	0.48	3.0	3.0
15	NO_3	5.87	1.8	6.12	8.77	3.12	2.44	7.02	50	50
16	SO_4	3.87	1.19	4.04	5.8	2.06	1.61	4.63	100	250

3. Materials and Methods

3.1. Materials

A total of fifteen (15) water samples were collected from the Ugbuwangue-Ogunu Community. These included groundwater samples obtained from drilled boreholes and surface water samples from hand-dug wells. Each sample was collected in sterilized plastic bottles, stored in a cooler containing ice to preserve sample integrity, and transported promptly to Martlet Environmental Research Laboratory Limited for physicochemical and heavy metal analyses. The materials used during sampling included: Sterilized plastic bottles, Ice-filled cooler, Masking tape for labelling, Global Positioning System (GPS) device for coordinate logging, Bacon bags for safe sample handling.

The following parameters were analyzed to assess water quality and potential contamination levels: Physicochemical Parameters: pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity, Colour (Pt-Co), Turbidity, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD), Nutrients and Major Ions: Bicarbonate (HCO_3^-), Phosphorus (P), Ammonium (NH_4-N), Nitrite (NO_2^-), Nitrate (NO_3^-), Calcium (Ca^{2+}), Potassium (K^+), Sodium (Na^+), Carbonate (CO_3^{2-}), Chloride (Cl^-), Sulphate (SO_4^{2-}), and Magnesium (Mg^{2+}), Heavy Metals: Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), Nickel (Ni), and Vanadium (V).

3.2. Methods

3.2.1. Analytical Technique: Atomic Absorption Spectroscopy

The concentration of heavy metals in the water samples was determined using Atomic Absorption Spectroscopy (AAS).

This technique measures the absorption of specific wavelengths of light by atoms in the ground state and is widely used for detecting trace metal ions in environmental and drinking water samples. The apparatus used included:

250 mL digestion tubes, Hot plate, Funnels, 25 mL and 50 mL, volumetric flasks, Filter paper, Beakers.

3.2.2. Sample Preparation for AAS

The following procedure was adopted for sample digestion and preparation:

Acidification: 25 mL of the water sample was transferred into a PTFE (polytetrafluoroethylene) beaker. It was acidified with 2.0 mL of concentrated nitric acid (HNO_3) and 6.0 mL of concentrated hydrochloric acid (HCl), both trace-metal grade.

Heating: The sample was heated on a hot plate under a fume hood until the mixture neared boiling and turned clear, indicating the digestion was complete.

Cooling and Dilution: After cooling, the contents were transferred into a 50 mL volumetric flask. The beaker walls were rinsed with ultrapure water (resistivity: 18.2 MΩ·cm), and the rinsate was added to the flask. The volume was adjusted with ultrapure water.

Filtration (if necessary): If solids or silicates were present, the solution was filtered or centrifuged to prevent clogging of the AAS nebulizer. All filtration equipment was cleaned with dilute HNO_3 before use to prevent contamination.

Final Adjustment: The final solution was diluted to 100 mL, ensuring an overall acid concentration of 10%. The sample was then ready for AAS analysis.

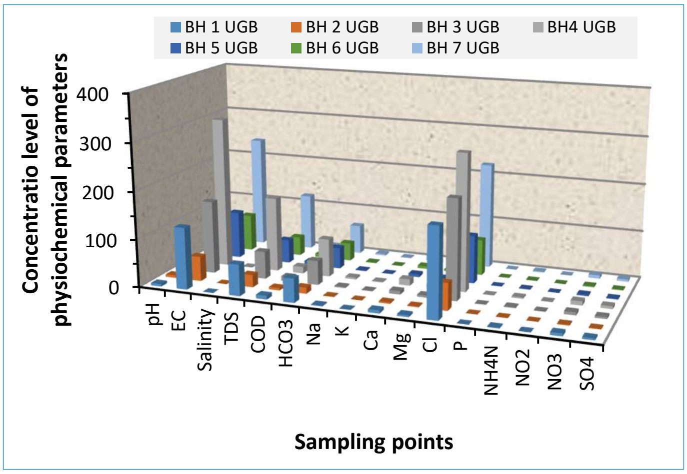


Fig. 3. Concentration level of physicochemical parameters against sampling points

3.2.3. AAS Operational Procedure

Sample Introduction: The prepared sample was aspirated into the flame of the AAS instrument, where its constituents were vaporized into free atoms.

Atomization: The high temperature of the flame generated atomic vapors of the target elements, primarily in their ground state.

Radiation Absorption: A hollow cathode lamp specific to the element of interest emitted light at a characteristic wavelength. Ground-state atoms in the sample absorbed this radiation.

Measurement: The instrument measured the degree of light absorption, which is proportional to the element's concentration in the sample.

Quantification: Concentrations were determined using a calibration curve constructed from standard solutions of known concentrations for each element.

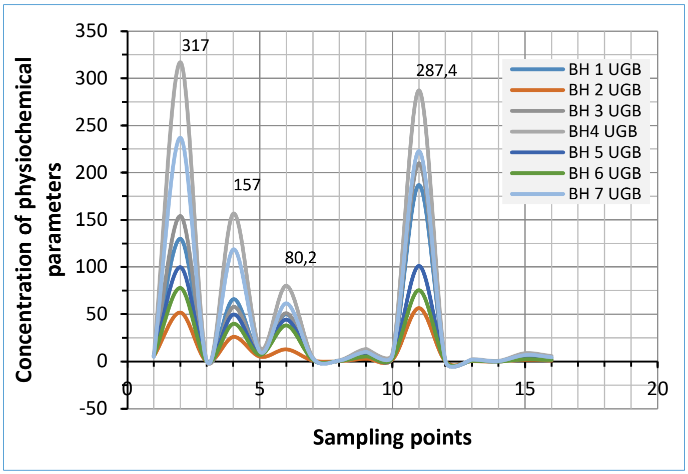


Fig. 4. Scatter diagram showing the concentration level of sampling points

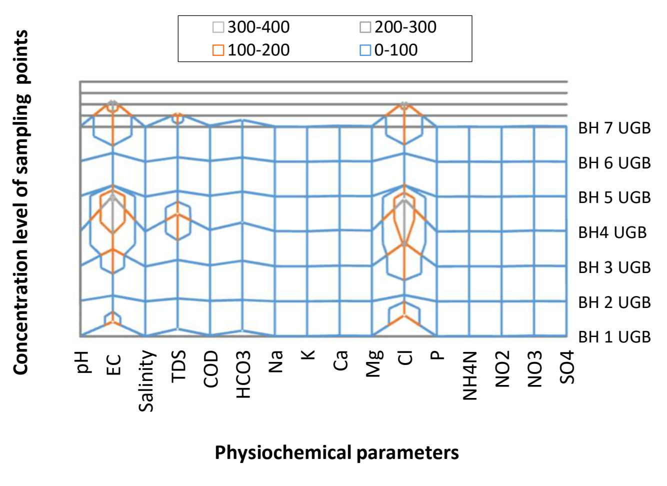


Fig. 5. Surface contour showing the concentration level of the sampling points of the study area

3.3. Statistical Software

The statistical software used to analysis the dataset is Microsoft Xcel and SPSS. PCA is packaged in SPSS software. PCA is a statistical technique used to reduce the dimensionality of data while preserving as much variance as possible.

Total Eigenvalues: This represents the amount of variance explained by each principal component (PC), *% of Variance:* This indicates the percentage of the total variance that each component accounts for; *Cumulative %:* This shows the cumulative variance explained by the components up to that point; *Rotation Sums of Squared Loadings:* Similar to the initial eigenvalues but reflects the variance explained after rotation (which makes the output easier to interpret).

4. Presentation of Results and Discussion

4.1. Physicochemical Characteristics of Water Samples from Ugbuwangue–Ogunu Community

The physicochemical assessment of borehole water samples from the Ugbuwangue–Ogunu Community revealed spatial variations in the water quality parameters (Table 2 and Figs. 3–5). The pH values ranged between 5.0 and 6.3, with a mean of 5.57, indicating that all samples were slightly acidic. These values are below the permissible range (6.5–8.5) set by the (NSDWQ, 2007) and (WHO, 2011), suggesting influences from natural geochemical processes or anthropogenic contamination. Electrical Conductivity (EC) ranged from 52 to 317 µS/cm (mean: 152.57 µS/cm), remaining well below the limits of 1000 µS/cm (NSDWQ, 2007) and 900 µS/cm (WHO, 2011). This reflects low ionic concentration and generally good water quality. Similarly, salinity values ranged from 0.024 to 0.143 g/L (mean: 0.069 g/L), confirming the water's fresh nature with negligible salt content. Total Dissolved Solids (TDS) ranged from 26 to 157 mg/L (mean: 73.71 mg/L), well below the 500 mg/L (NSDWQ) and 1000 mg/L (WHO) thresholds, indicating minimal dissolved substances and good potability. Chemical Oxygen Demand (COD) values (5.1–14.2 mg/L) were moderate, implying limited organic pollution, with slightly higher levels observed in BH 6 UGB and BH 7 UGB. Bicarbonate (HCO_3^-) ranged from 12.8 to 80.2 mg/L (mean: 48.36 mg/L), below the 250 mg/L guideline, indicating an adequate buffering capacity. Major cations showed low concentrations: Na^+: 1–4 mg/L (mean: 2.26 mg/L); K^+: 0.36–1.5 mg/L (mean: 0.84 mg/L); Ca^{2+}: 3.2–13.3 mg/L; Mg^{2+}: 2–8.4 mg/L (mean: 4.7 mg/L).

Table 3. physiochemical parameters of water samples collected at Ogunu Community

S/N	Parameters	BH 8 OGU	HDW 9 OGU	BH 10 OGU	BH 11 OGU	RW 12 OGU	HDW 13 OGU	BH 14 OGU	BH 15 OGU	Average	Min	Max
1	pH	5.5	6.5	5.9	5.9	6.6	6.3	6	5.9	6.075	5.5	6.6
2	EC µS/cm	365	645	472	474	166	269	26	464	360.125	26	645
3	Sal.g/l	0.165	0.291	0.213	0.214	0.075	0.122	0.012	0.21	0.16275	0.012	0.291
4	TDS	163	325	235	236	62	134	13	232	175	13	325
5	COD	16.6	33.1	22	28.1	9.8	11.8	3.3	18.7	17.925	3.3	33.1
6	Turb.	ND	ND	ND	ND	1	ND	ND	ND	1	1	1
7	TSS	ND	ND	ND	ND	1.7	ND	ND	ND	1.7	1.7	1.7
8	TDS	ND	ND	ND	ND	62	ND	ND	ND	62	62	62
9	HCO_3	95.5	123.6	102.5	111	54.3	74.4	11	102.2	84.3125	11	123.6
10	Na	4.2	6.3	4.6	5.6	2.6	3.3	0.6	4.3	3.9375	0.6	6.3
11	K	1.57	2.33	1.71	2.08	0.96	1.23	0.23	1.58	1.46125	0.23	2.33
12	Ca	14	20.8	15.3	18.6	8.6	11	2.1	14.1	13.0625	2.1	20.8
13	Mg	8.8	13.1	9.6	11.7	5.4	6.9	1.3	8.9	8.2125	1.3	13.1
14	Cl	317.7	599.1	444	456.2	217.2	271	36.6	347.2	336.125	36.6	599.1
15	P	0.16	0.28	0.187	0.215	0.084	0.102	0.008	0.177	0.151625	0.008	0.28
16	NH_4N	3.04	5.17	3.92	3.97	1.98	2.5	0.28	3.4	3.0325	0.28	5.17
17	NO_2	0.7	1.2	0.9	0.91	0.45	0.56	0.06	0.78	0.695	0.06	1.2
18	NO_3	10.23	17.41	13.2	13.36	6.65	8.42	0.94	11.4	10.20125	0.94	17.41
19	SO_4	6.75	11.49	8.71	8.81	4.4	5.56	0.62	7.52	6.7325	0.62	11.49

Table 4. Comparison of physiochemical parameters and NSDWQ (2007) and WHO (2011)

S/N	Parameters	BH 8 OGU	HDW 9 OGU	BH 10 OGU	BH 11 OGU	RW 12 OGU	HDW 13 OGU	BH 14 OGU	BH 15 OGU	NSWDQ, 2007	WHO, 2011
1	pH	5.5	6.5	5.9	5.9	6.6	6.3	6	5.9	6.5-8.5	6.5-8.5
2	EC µS/cm	365	645	472	474	166	269	26	464	1000	900
3	Sal.g/l	0.165	0.291	0.213	0.214	0.075	0.122	0.012	0.21		
4	TDS	163	325	235	236	62	134	13	232		
5	COD	16.6	33.1	22	28.1	9.8	11.8	3.3	18.7	500	1000
6	Turb.	ND	ND	ND	ND	1	ND	ND	ND		
7	TSS	ND	ND	ND	ND	1.7	ND	ND	ND		
8	TDS	ND	ND	ND	ND	62	ND	ND	ND		
9	HCO3	95.5	123.6	102.5	111	54.3	74.4	11	102.2	250	250
10	Na	4.2	6.3	4.6	5.6	2.6	3.3	0.6	4.3	200	200
11	K	1.57	2.33	1.71	2.08	0.96	1.23	0.23	1.58		
12	Ca	14	20.8	15.3	18.6	8.6	11	2.1	14.1	75	200
13	Mg	8.8	13.1	9.6	11.7	5.4	6.9	1.3	8.9	100	100
14	Cl	317.7	599.1	444	456.2	217.2	271	36.6	347.2	250	250
15	P	0.16	0.28	0.187	0.215	0.084	0.102	0.008	0.177		
16	NH4N	3.04	5.17	3.92	3.97	1.98	2.5	0.28	3.4	35	35
17	NO_2	0.7	1.2	0.9	0.91	0.45	0.56	0.06	0.78	3	3
18	NO_3	10.23	17.41	13.2	13.36	6.65	8.42	0.94	11.4	50	50
19	SO_4	6.75	11.49	8.71	8.81	4.4	5.56	0.62	7.52	100	250

Chloride (Cl^-) ranged between 56.6 and 287.4 mg/L (mean:

162.97 mg/L). Elevated concentrations in BH 4 UGB and BH 7 UGB approached or exceeded the 250 mg/L limit, suggesting possible contamination from wastewater, dumpsites, or saltwater intrusion. Phosphorus (P) levels (0.021–0.116 mg/L, mean: 0.06 mg/L) were low and pose no health risk. Ammonium (NH_4–N) ranged from 0.53 to 2.61 mg/L (mean: 1.49 mg/L), far below the 35 mg/L limit, indicating minimal organic or agricultural impact. Nitrite (NO_2^-) (0.12–0.6 mg/L) and Nitrate (NO_3^-) (1.8–8.77 mg/L, mean: 5.02 mg/L) were also within safe limits (<3 mg/L and <50 mg/L, respectively), suggesting limited fertilizer or sewage influence. Sulphate (SO_4^{2-}) values (1.19–5.8 mg/L, mean: 3.31 mg/L) were far below permissible limits (100–250 mg/L), confirming low sulphate content.

Figs. 3–5 show colour-coded bar charts illustrating parameter concentrations: Blue (0–100) represents minimal levels, Light Orange (100–200) low, Orange (200–300) moderate, and Yellow (300–400) high concentrations.

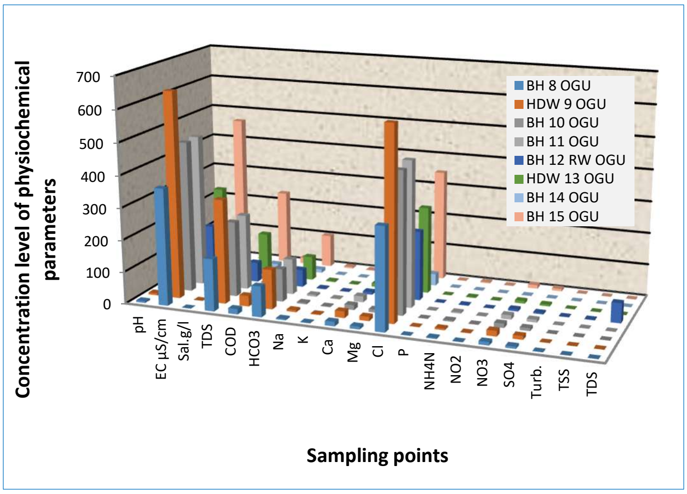


Fig. 6. Concentration level of physiochemical parameters against sampling points

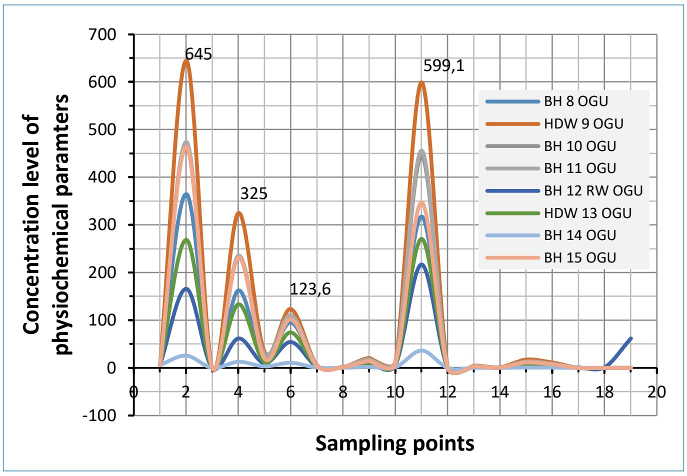


Fig. 7. Scatter diagram showing the concentration level of sampling points

Most boreholes fall within the blue range, confirming low contaminant levels and good overall water quality. However, BH 6 UGB and BH 7 UGB display elevated EC, TDS, salinity, chloride, COD, and magnesium, suggesting possible influence from waste leachate or nearby pollution sources. Conversely, BH 1 UGB and BH 2 UGB exhibited the lowest contaminant concentrations, indicating minimal external interference.

This spatial trend indicates localized contamination, emphasizing the need for targeted monitoring and remediation at vulnerable boreholes, particularly BH 6 UGB and BH 7 UGB, to safeguard community water resources.

4.2. Physiochemical Parameters of Water Samples Collected in Ogunu Community

The physicochemical assessment of water samples from the study area revealed variations in quality across sampling points (Table 2 and Figs. 3–6). The pH values ranged from 5.0 to 6.6, with a mean of 6.1, indicating that the water is acidic to slightly acidic. Since water with a pH below 7 is considered acidic, the observed values may be attributed to the area's geological characteristics or anthropogenic contamination.

Electrical Conductivity (EC) ranged from 26 to 645 µS/cm, with a mean of 360 µS/cm, reflecting the concentration of dissolved ions and the water's ability to conduct electricity. These values are within permissible limits set by NSDWQ (1000 µS/cm) and WHO (900 µS/cm). Salinity ranged from 0.012 to 0.291 g/L, with a mean of 0.16 g/L. Although no specific standards exist for salinity in drinking water, elevated levels in some boreholes could affect taste and reduce suitability for irrigation, particularly for salt-sensitive crops.

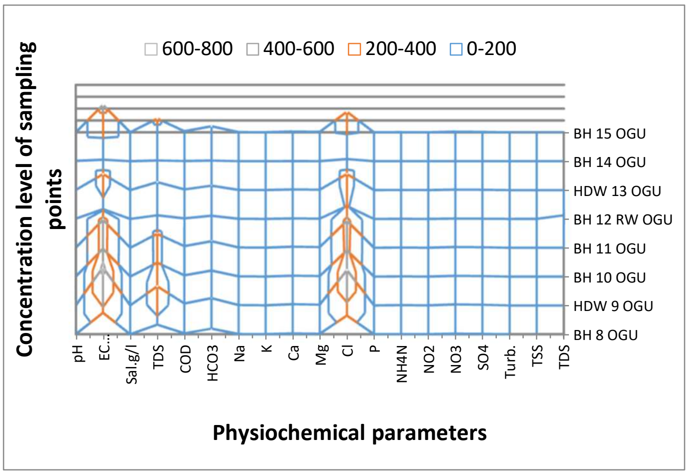


Fig. 8. Surface contour of concentration level of sampling points of the study area

Total Dissolved Solids (TDS) ranged from 13 to 325 mg/L, with a mean of 175 mg/L, remaining well below the acceptable limits (NSDWQ: 500 mg/L; WHO: 1000 mg/L), indicating good water quality in terms of dissolved substances. Chemical Oxygen Demand (COD) ranged from 3.3 to 33.1 mg/L, with a mean of 17.9 mg/L, reflecting the amount of organic matter in the water. Elevated COD levels suggest possible organic contamination from wastewater or surface runoff. Bicarbonate (HCO_3^-) concentrations varied from 11 to 123.6 mg/L, with a mean of 84.3 mg/L, well below the NSDWQ limit of 250 mg/L. Bicarbonates play an important role in buffering and stabilizing pH. Sodium (Na) concentrations ranged from 0.6 to 6.3 mg/L (mean: 3.9 mg/L), while Potassium (K) ranged from 0.23 to 2.33 mg/L (mean: 1.46 mg/L). These low concentrations pose no health risk.

Calcium (Ca) values ranged from 2.1 to 20.8 mg/L, and Magnesium (Mg) from 1.3 to 13.1 mg/L (mean: 13 mg/L), both well below permissible limits (Ca: 75 mg/L; Mg: 50 mg/L), indicating low hardness and suitability for domestic use. Chloride (Cl^-) concentrations showed significant variability, ranging from 36.6 to 599.1 mg/L (mean: 336 mg/L). Most samples exceeded the NSDWQ and WHO limits of 250 mg/L, except RW 12 OGU and BH 14 OGU. High chloride levels likely result from leachate infiltration, seawater intrusion, or wastewater contamination, which can increase corrosiveness and affect taste. Phosphorus (P) values ranged from 0.008 to 0.28 mg/L (mean: 0.15 mg/L).

Although phosphorus is not regulated in drinking water, elevated concentrations may promote eutrophication in nearby surface water bodies. Ammonium (NH_4^+-N) ranged from 0.28 to 5.17 mg/L (mean: 3.03 mg/L), Nitrite (NO_2^-) from 0.06 to 1.2 mg/L (mean: 0.695 mg/L), and Nitrate (NO_3^-) from 0.94 to 17.41 mg/L (mean: 10.2 mg/L). Although all are below NSDWQ limits (NH_4-N: 35 mg/L; NO_2: 3 mg/L; NO_3: 50 mg/L), their presence indicates possible contamination from fertilizers, sewage, or agricultural runoff. Sulphate (SO_4^{2-}) concentrations ranged from 0.62 to 11.49 mg/L, with a mean of 6.7 mg/L, well below NSDWQ (100 mg/L) and WHO (250 mg/L) standards. Low sulphate concentrations are not a health concern but may influence taste and contribute to scaling in distribution systems.

The colour-coded bar chart in Fig. 6 classifies concentration levels as follows:

Yellow (600–800) – Highest concentrations
Gray (400–600) – Moderate concentrations
Orange (200–400) – Low concentrations
Blue (0–200) – Lowest concentrations

Most sampling points fall within the blue to orange ranges, suggesting mild contamination, except RW 12 OGU and HDW 9 OGU, which show elevated TDS, EC, salinity, and COD, likely due to leachate migration or runoff from nearby dumpsites. Chloride concentrations exceeded acceptable limits in HDW 9 OGU, BH 8 OGU, BH 10 OGU, BH 11 OGU, HDW 13 OGU, and BH 15 OGU, indicating potential saltwater intrusion or wastewater influence.

Overall, all parameters comply with NSDWQ (2007) and WHO (2011) standards, except pH and chloride in some locations. The slightly acidic pH may corrode plumbing systems, while elevated chloride levels could reduce portability and necessitate treatment or blending before consumption.

Table 5. Heavy metal concentration levels of study area (Ugbuwange-Ogunu Community)

Parameters	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Cu (mg/L)	Cr (mg/L)	Cd (mg/L)	Pb (mg/L)
BH 1 UGB	0.845	0.35	0.625	0.158	0.088	0.006	0.029
BH 2 UGB	0.89	0.369	0.659	0.166	0.093	0.006	0.031
BH 3 UGB	0.812	0.336	0.601	0.151	0.085	0.006	0.028
BH4 UGB	0.668	0.277	0.494	0.125	0.07	0.005	0.023
BH 5 UGB	0.866	0.359	0.641	0.161	0.09	0.006	0.03
BH 6 UGB	0.871	0.361	0.65	0.162	0.091	0.006	0.03
BH 7 UGB	0.701	0.29	0.519	0.131	0.073	0.005	0.024
BH 8 OGU	0.51	0.211	0.377	0.095	0.053	0.004	0.018
HDW 9 OGU	0.33	0.137	0.244	0.062	0.034	0.002	0.011
BH 10 OGU	0.41	0.17	0.303	0.076	0.043	0.003	0.014
BH 11 OGU	0.389	0.161	0.288	0.073	0.041	0.003	0.013
RW 12 OGU	0.807	0.334	0.597	0.15	0.084	0.006	0.028
HDW 13 OGU	0.68	0.282	0.503	0.127	0.071	0.005	0.023
BH 14 OGU	0.911	0.378	0.674	0.17	0.095	0.007	0.031
BH 15 OGU	0.457	0.189	0.338	0.085	0.048	0.003	0.016
AVERAGE	0.676	0.280	23.012	0.126	0.071	0.005	0.023
MIN	0.33	0.137	0.244	0.062	0.034	0.002	0.011
MAX	0.911	0.378	338	0.17	0.095	0.007	0.031

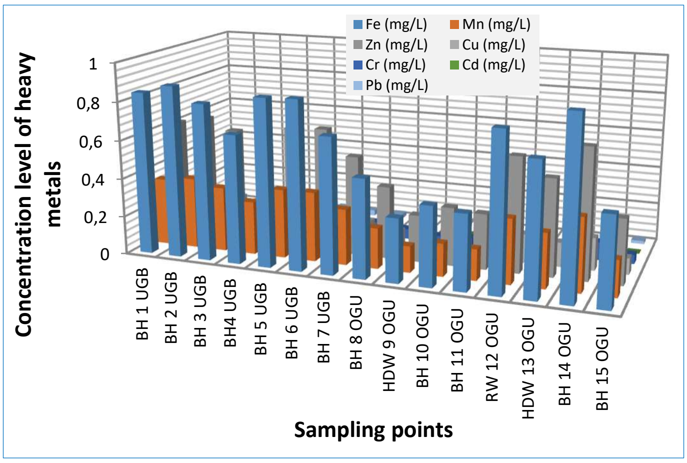
4.3. Heavy Metals Concentration of Water Samples Collected at the Study Area (Ugbuwange-Ogunu Community)

The concentrations of heavy metals in the analyzed water samples show varying degrees of compliance with international drinking water standards (Tables 5–6 and Figs. 9–11). Iron (Fe) concentrations range from 0.33 to 0.911 mg/L, with a mean value of 0.676 mg/L. The lowest concentration (0.33 mg/L) was recorded at HDW 9 OGU, while the highest (0.911 mg/L) occurred at BH 14 OGU.

These values exceed the WHO (2011) guideline limit of 0.3 mg/L, suggesting possible iron contamination from natural geological formations or corrosion of iron pipes. Elevated iron levels may impart an unpleasant taste, cause reddish-brown staining, and affect laundry and plumbing fixtures.

Manganese (Mn) concentrations range between 0.137 and 0.378 mg/L, with a mean of 0.280 mg/L, exceeding the WHO standard of 0.1 mg/L in all samples. High manganese levels may contribute to metallic taste, water discoloration, and potential neurological health effects upon long-term exposure. Zinc (Zn) concentrations exhibit a wide variability, ranging from 0.244 to 338 mg/L, with a mean of 23.012 mg/L. The unusually high maximum value greatly skews the average, indicating localized contamination at specific sampling points. Given the WHO permissible limit of 3 mg/L, this elevated value suggests possible corrosion of galvanized materials or natural mineral enrichment. Copper (Cu) concentrations vary from 0.062 to 0.17 mg/L, with a mean of 0.126 mg/L, remaining well below the WHO limit of 2 mg/L. Thus, copper levels are within safe limits and pose no significant health risk in the study area. Chromium (Cr) concentrations range between 0.034 and 0.095 mg/L, with an average of 0.071 mg/L. The WHO standard for chromium is 0.05 mg/L, indicating that some samples exceed permissible limits. Elevated chromium levels may result from industrial discharges, waste leachate, or natural mineral dissolution, and prolonged exposure can lead to toxic or carcinogenic effects. Cadmium (Cd) concentrations are relatively low, ranging from 0.002 to 0.007 mg/L, with a mean of 0.005 mg/L. Despite the low absolute values, the WHO limit (0.003 mg/L) is exceeded in several samples, raising concerns about potential toxic effects. Cadmium presence is often associated with industrial pollution, wastewater infiltration, or agricultural runoff containing phosphate fertilizers. Lead (Pb) concentrations range from 0.011 to 0.031 mg/L, with a mean of 0.023 mg/L, exceeding the WHO guideline value of 0.01 mg/L in all samples. The elevated levels of lead suggest contamination from old plumbing materials, industrial effluents, or leaching from contaminated soils. Chronic lead exposure poses serious health risks, especially to children, affecting neurological development and overall wellbeing.

Overall, most samples show elevated concentrations of Fe, Mn, Zn, Cr, Cd, and Pb, indicating varying degrees of metal contamination, likely influenced by both natural geological factors and anthropogenic activities such as industrial discharge, corrosion of metallic pipes, and waste leachate infiltration.



4.3.1. Heavy Metal Concentration Level in Ugbuwange Community

The concentration levels of most heavy metals conform to the permissible standards set by NSDWQ (2007) and WHO (2011), as shown in Table 6, except for iron, which ranges from 0.668 to 0.89 mg/L, with an average concentration of 0.3 mg/L. These values exceed the recommended limit of 0.3 mg/L set by both NSDWQ (2007) and WHO (2011). Elevated iron levels can lead to a metallic taste, staining of laundry and plumbing fixtures, and may indicate corrosion in the water system. Such high concentrations of iron may require treatment before the water is suitable for drinking.

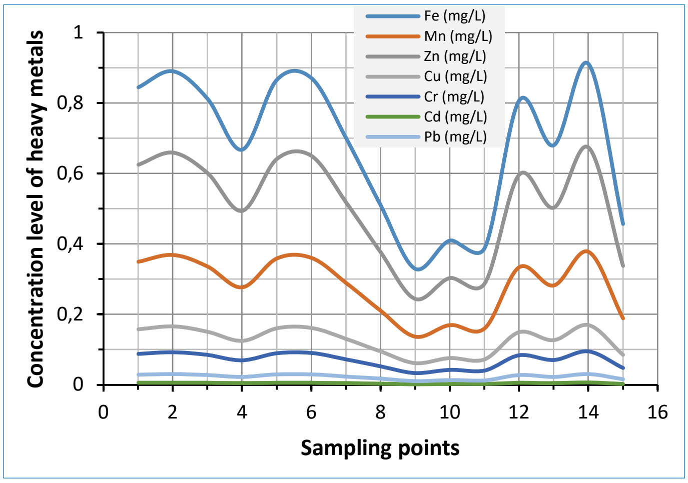


Fig. 10. Scatter diagram showing the concentration level of heavy metals

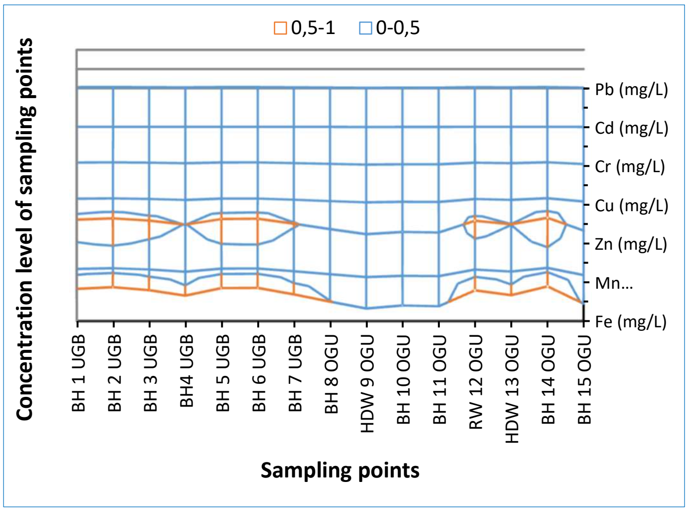


Fig. 11. Surface contour showing the concentration level of the sampling points

Manganese levels range from 0.277 to 0.369 mg/L, with an average concentration of 0.334 mg/L. While these values surpass the NSDWQ (2007) limit of 0.2 mg/L, they remain within the WHO (2011) guideline of 0.4 mg/L. Elevated manganese can result in a brownish colour in water, staining, and altered taste. Chromium concentrations range from 0.07 mg/L to 0.093 mg/L, with an average of 0.084 mg/L, all exceeding the NSDWQ and WHO permissible limit of 0.05 mg/L. High chromium levels are concerning, as chromium, especially in its hexavalent form, is toxic and a known carcinogen. Immediate investigation and treatment are recommended. Cadmium concentrations range from 0.005 mg/L to 0.006 mg/L with an average value of 0.006 mg/L, exceeding the 0.003 mg/L limit set by both NSDWQ (2007) and WHO (2011). Lead concentrations range from 0.023 to 0.031 mg/L, with an average of 0.028 mg/L, exceeding the 0.01 mg/L limit set by both NSDWQ (2007) and WHO (2011). Elevated lead levels pose serious health risks, particularly for children, as lead exposure can cause neurological damage, developmental issues, and other severe health problems. Urgent remediation is necessary to reduce lead contamination as shown in Table 6.

4.3.2. Heavy Metal Concentration Level in Ogunu Community

The concentrations of zinc (Zn), copper (Cu), and cadmium (Cd) in the analyzed water samples are below the permissible limits set by NSDWQ (2007) and WHO (2011). However, notable variations were observed in the concentrations of other metals across sampling points. Iron (Fe) concentrations range from 0.33 to 0.911 mg/L, with a mean value of 0.562 mg/L, exceeding the recommended limit of 0.3 mg/L. Elevated iron levels can cause reddish-brown staining of clothes and plumbing fixtures and impart a metallic taste to water. Such concentrations may result from natural geological sources or corrosion of iron pipes. To improve water quality, filtration or aeration treatment methods are recommended to reduce iron concentrations. Manganese (Mn) concentrations range from 0.137 to 0.378 mg/L, with a mean value of 0.233 mg/L. Manganese levels in BH 8 OGU, BH 10 OGU, BH 11 OGU, and HDW 9 OGU exceed the NSDWQ (2007) limit of 0.2 mg/L but remain within the WHO (2011) permissible limit of 0.4 mg/L.

Table 6. Comparison of heavy metal concentration level with NSWDQ (2007) and WHO (2011)

Parameters	BH 1 UGB	BH 2 UGB	BH 3 UGB	BH 4 UGB	BH 5 UGB	BH 6 UGB	BH 7 UGB	Average	NSWDQ, 2007	WHO, 2011
Fe (mg/L)	0.845	0.89	0.812	0.668	0.866	0.871	0.701	0.807	0.3	0.3
Mn (mg/L)	0.35	0.369	0.336	0.277	0.359	0.361	0.29	0.334	0.2	0.4
Zn (mg/L)	0.625	0.659	0.601	0.494	0.641	0.65	0.519	0.598	3	5
Cu (mg/L)	0.158	0.166	0.151	0.125	0.161	0.162	0.131	0.150	1	2
Cr (mg/L)	0.088	0.093	0.085	0.07	0.09	0.091	0.073	0.084	0.05	0.05
Cd (mg/L)	0.006	0.006	0.006	0.005	0.006	0.006	0.005	0.006	0.003	0.003
Pb (mg/L)	0.029	0.031	0.028	0.023	0.03	0.03	0.024	0.028	0.01	0.01

Table 7. Comparison of Heavy metal concentration level with NSDWQ (2007) and WHO (2011)

Parameters	BH 8 OGU	HDW 9 OGU	BH 10 OGU	BH 11 OGU	BH 12 RW OGU	HDW 13 OGU	BH 14 OGU	BH 15 OGU	Average	NSWD, Q 2007	WHO, 2011
Fe (mg/L)	0.51	0.33	0.41	0.389	0.807	0.68	0.911	0.457	0.562	0.3	0.3
Mn (mg/L)	0.211	0.137	0.17	0.161	0.334	0.282	0.378	0.189	0.233	0.2	0.4
Zn (mg/L)	0.377	0.244	0.303	0.288	0.597	0.503	0.674	0.338	0.426	3	5
Cu (mg/L)	0.095	0.062	0.076	0.073	0.15	0.127	0.17	0.085	0.105	1	2
Cr (mg/L)	0.053	0.034	0.043	0.041	0.084	0.071	0.095	0.048	0.059	0.05	0.05
Cd (mg/L)	0.004	0.002	0.003	0.003	0.006	0.005	0.007	0.003	0.004	0.003	0.003
Pb (mg/L)	0.018	0.011	0.014	0.013	0.028	0.023	0.031	0.016	0.019	0.01	0.01

Elevated manganese levels can cause discoloration, staining, and taste problems in water, often associated with geogenic sources or oxidation of manganese-bearing minerals. Chromium (Cr) concentrations range from 0.034 to 0.095 mg/L, with an average value of 0.059 mg/L. Samples from BH 12 RW OGU, HDW 13 OGU, and BH 14 OGU exceed both the NSDWQ (2007) and WHO (2011) limits of 0.05 mg/L.

Chromium contamination, particularly in its hexavalent form (Cr^{6+}), is of serious concern due to its carcinogenic and toxic effects. These elevated concentrations may be linked to industrial discharge, metal plating, or waste leachate, necessitating further hydrochemical investigation and appropriate treatment interventions. Lead (Pb) concentrations range from 0.011 to 0.031 mg/L, with a mean value of 0.019 mg/L, exceeding the recommended limit of 0.01 mg/L set by both NSDWQ (2007) and WHO (2011).

The elevated lead levels indicate possible leaching from old plumbing materials, industrial waste, or urban runoff. Chronic exposure to lead poses serious health risks, especially to infants and young children, including neurological and developmental impairments. Immediate remediation measures, such as lead-removal filtration systems or replacement of corroded pipes, are strongly recommended.

Cadmium (Cd) concentrations range from 0.005 to 0.006 mg/L, with an average value of 0.006 mg/L, exceeding the 0.003 mg/L limit specified by both NSDWQ (2007) and WHO (2011). Although detected at relatively low concentrations, cadmium is highly toxic even at trace levels. Its presence may result from industrial activities, battery waste, or agricultural inputs such as phosphate fertilizers.

Overall, the elevated levels of iron, manganese, chromium, lead, and cadmium in certain sampling points indicate localized contamination influenced by both geogenic and anthropogenic sources. These findings, as summarized in Table 7, underscore the need for continuous monitoring, source identification, and the implementation of appropriate water treatment technologies to safeguard public health.

4.4. Heavy Metals Correlation Matrix and Hierarch Cluster

Table 8 presents the correlation matrix among the analyzed heavy metals (Fe, Mn, Zn, Cu, Cr, Cd, and Pb). The correlation coefficients range from –1 to +1, where +1 represents a perfect positive correlation (indicating that as one variable increases, the other also increases), –1 denotes a perfect negative correlation (as one variable increases, the other decreases), and 0 signifies no correlation between the variables.

The results reveal very strong positive correlations among several heavy metals, indicating that they may have common geochemical or anthropogenic sources. Specifically, the correlations between Fe–Mn (0.99999), Fe–Cu (0.99995), Fe–Cr (0.99992), Mn–Cu (0.99995), Mn–Cr (0.99991), Mn–Pb (0.99920), Cu–Cr (0.99987), Fe–Pb (0.99926), Cd–Fe (0.98443), Cd–Mn (0.98437), Cd–Cu (0.98451), and Cd–Cr (0.98471) show strong positive relationships. These strong associations imply that the metals are likely derived from similar contamination sources, such as industrial discharge, waste leachate, corroded metallic materials, or natural mineral dissolution, and are influenced by comparable geochemical processes in the subsurface environment.

Table 8. Correlation of heavy metals concentration level of water samples collected from Ogunu Community

	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Cu (mg/L)	Cr (mg/L)	Cd (mg/L)	Pb (mg/L)
Fe (mg/L)	1						
Mn (mg/L)	0.99999	1					
Zn(mg/L)	-0.29455	-0.29545	1				
Cu(mg/L)	0.99995	0.99995	-0.2968	1			
Cr(mg/L)	0.99992	0.99991	-0.2912	0.99987	1		
Cd(mg/L)	0.98443	0.98437	-0.34146	0.98451	0.98471	1	
Pb(mg/L)	0.99926	0.99920	-0.2805	0.99903	0.99918	0.98224	1

Conversely, zinc (Zn) exhibits negative correlations with most other metals, with Zn–Fe (–0.29455), Zn–Mn (–0.9545), Zn–Cu (–0.2968), Zn–Cr (–0.2912), and Zn–Cd (–0.34146). This inverse relationship suggests that zinc behaves differently in the hydrogeochemical environment compared to the other metals.

The negative correlations indicate that zinc concentrations decrease when other metal concentrations increase, possibly due to differences in solubility, adsorption behavior, or redox stability.

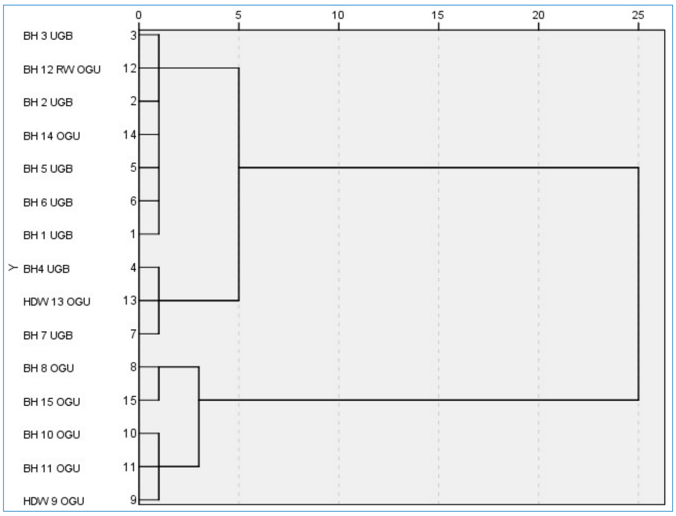


Fig. 12. Dendrogram using average linkage (between groups) to show the relationship between sampling points

Overall, the correlation analysis shows that iron, manganese, copper, chromium, cadmium, and lead are strongly interrelated, suggesting they may originate from common geogenic or anthropogenic sources such as industrial effluents, corrosion of metallic components, or weathering of metal-bearing rocks. The distinct behavior of zinc implies that it may be controlled by different geochemical mechanisms or localized environmental conditions, as illustrated in Table 8.

The dendrogram grouped the sampling points into two distinct clusters. Cluster 1 comprises (BH 1, BH 2, BH 5, BH 6, BH 13, BH 14, RW 12, and HDW 13), which exhibit strong correlations and close relationships among them, suggesting that they share a common source of contamination. Cluster 2 includes (BH 8, BH 10, BH 11, BH 15, and HDW 9), which also show strong interrelationships, indicating a similar contamination origin within this group, as illustrated in Fig. 12.

Similarly, the dendrogram classified the heavy metals into two clusters. Cluster 1 consists of (Cd, Pb, Cr, Cu, and Mn), which demonstrate strong positive correlations, implying that these metals likely originate from the same contamination source. Cluster 2 includes (Fe and Zn), which also show a strong correlation with each other, suggesting a shared source or similar geochemical behavior, as presented in Fig. 13.

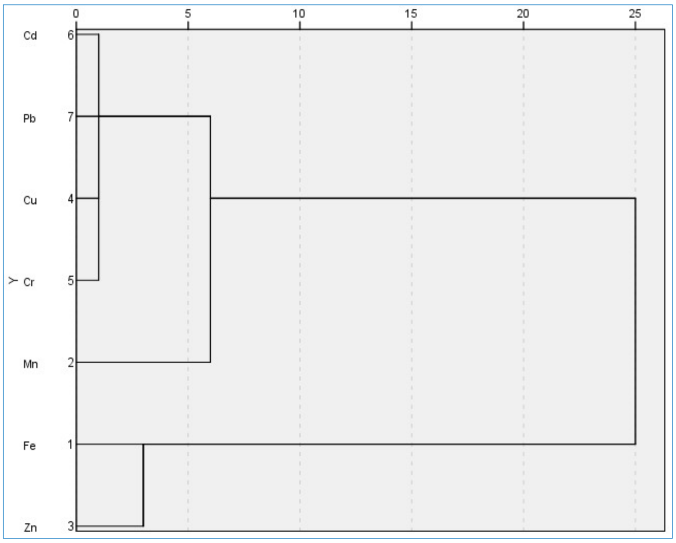


Fig. 13. Dendrogram using average linkage (between groups) to show the relationship between heavy metal

5. Conclusion

The pH values of all borehole samples, ranging from 5.0 to 6.3, fall below the acceptable limits prescribed by NSDWQ (2007) and WHO (2011) standards (6.5–8.5), indicating slightly acidic water conditions. This mild acidity may result from natural geochemical processes, atmospheric carbon dioxide dissolution, or anthropogenic contamination. Appropriate treatment methods such as filtration or aeration are therefore recommended to improve the pH balance before consumption.

Electrical Conductivity (EC) values, which range from 52 µS/cm to 317 µS/cm, are well below the permissible limits of 1000 µS/cm (NSDWQ) and 900 µS/cm (WHO, 2011). These low EC readings suggest minimal ionic concentration, implying that the water generally exhibits good quality in terms of salinity and dissolved solids.

Chloride concentrations vary between 56.6 mg/L and 287.4 mg/L, with BH 4 UGB and BH 7 UGB showing levels close to or exceeding the 250 mg/L threshold set by both NSDWQ and WHO. Elevated chloride levels could indicate contamination from domestic wastewater, leachates, or seawater intrusion, and may impart a slightly salty taste to the water.

The concentrations of Fe, Mn, Zn, Cr, Cd, and Pb exceed WHO permissible limits in several locations, suggesting varying degrees of heavy metal contamination. The most concerning elements are lead (Pb) and manganese (Mn), which consistently exceed allowable limits across all samples and pose significant public health risks. Possible contamination pathways include leaching from corroded plumbing materials, industrial or agricultural runoff, and natural mineral dissolution within the aquifer system.

In contrast, zinc (Zn) and copper (Cu) remain within acceptable limits, presenting no immediate health hazards. However, chromium (Cr) and lead (Pb) contamination require urgent attention, as hexavalent chromium (Cr^{6+}) in particular is toxic and carcinogenic, often associated with industrial pollution or rock-water interactions.

The observed metal concentrations indicate that both natural geological factors and anthropogenic activities are influencing groundwater quality in the study area. Continuous monitoring, source identification, and remediation efforts are essential to safeguard public health and ensure sustainable groundwater use.

6. Recommendations

Water Treatment: Employ appropriate treatment technologies such as filtration, reverse osmosis, or chemical precipitation to reduce harmful metal concentrations, particularly for lead, chromium, and manganese.

Source Investigation: Conduct further geochemical and hydrogeological studies to determine the sources and pathways of contamination, especially in boreholes with elevated iron, zinc, manganese, and lead levels.

Regular Monitoring: Establish a routine groundwater quality monitoring program to track changes in physicochemical and heavy metal parameters over time.

Public Awareness: Educate residents on the potential health risks of contaminated groundwater and promote safe water management practices.

Policy and Regulation: Encourage local authorities to enforce groundwater protection regulations and control industrial discharges, waste disposal, and agricultural runoff within the study area.

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