

**HEAVY METAL, PHYSICAL AND CHEMICAL INVESTIGATION OF  
GROUNDWATER AT UPPER SAKPONBA COMMUNITY OF BENIN CITY,  
SOUTHERN NIGERIA**

**BY**

**Samuel Aghogho OJANOMARE**

**LSC2009933**

**(GEOLOGY & MINING TECHNIQUES OPTION)**

**DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY**

**FACULTY OF LIFE SCIENCES,**

**UNIVERSITY OF BENIN,**

**BENIN CITY.**

**OCTOBER, 2025**

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**A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF SCIENCE  
LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF  
BENIN, BENIN CITY, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR  
THE AWARD OF BACHELOR OF SCIENCE (B.Sc. IN GEOLOGY & MINING  
TECHNIQUES OPTION) HONOURS IN SCIENCE LABORATORY TECHNOLOGY**

**OCTOBER, 2025**

## CERTIFICATION

This is to certify that this project work was carried out by Samuel Aghogho OJANOMARE with matriculation number, LSC2009933 of the Department of Science Laboratory Technology (Geology and Mining Techniques), Faculty of Life Sciences, University of Benin, Benin City.

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**MR. PETER BASSEY**

**(Project Supervisor)**

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**Date**

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**Dr. P.O. Alonge**

**(Project Coordinator)**

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**Date**

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**PROF. J.O. OSARUNMWENSE**

**(Head of Department)**

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**Date**

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**(External Examiner)**

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**Date**

## **DEDICATION**

I dedicate this work to Almighty God and my beloved parents Mr and Mrs. Ojanomare in appreciation of their inspiration and drive given towards the successful completion of this work.

## ACKNOWLEDGEMENT

I am deeply grateful to God Almighty for granting me the ability to successfully conclude this project.

To my parents (Mr. and Mrs. Ojanomare), I thank you both profoundly for your love, care, and immense support.

To my siblings, Rukevwe, Blessing, Ejiro for always being there for me and for your great support at all times

To my supervisor, Mr. Peter Bassey for his invaluable guidance and mentorship throughout the duration of this project.

I equally appreciate the Head of Department Prof. J .O. Osarunmwense and my Lecturers; Dr. K. Ojeaga and Mrs. A. Janet for their impact in my academic journey and the entire staff of the Department of Science Laboratory Technology

To my friends; Racheal, Doris, Emmmanuel and Favor you guys are the best. Thanks for making school easier and fun. I will always carry our memories

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## ABSTRACT

A groundwater quality assessment was conducted in Ikpoba Okha Local Government Area, Edo State, to evaluate the levels of physicochemical parameters within the region. Fifteen (15) borehole water samples were randomly collected and analyzed to determine their physicochemical characteristics. Both statistical and cluster analyses were applied to interpret the data. The dendrogram, a key output of the cluster analysis, illustrated the Euclidean distance at which different elements and clusters merged. Four distinct clusters were identified, with Cluster 1 comprising mainly heavy metals showing strong correlations and similarities among related parameters.

The study examined parameters such as pH, turbidity, total dissolved solids (TDS), electrical conductivity, salinity, and total suspended solids (TSS). Anions including sulfate, phosphate, nitrate, and carbonate were also analyzed, while heavy metals and cations such as sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) were determined using a flame atomic absorption spectrometer.

Results indicated that the pH of the groundwater samples ranged between 5.28 and 5.98, suggesting slight acidity. TDS values varied from 5.34 to 6.22 mg/L, while nitrate concentrations ranged from 1.54 to 2.12 mg/L within the World Health Organization (WHO) permissible limit of 10 mg/L. Copper concentrations were found between 0.039 mg/L and 0.086 mg/L, with borehole BH9 recording the highest value and BH15 the lowest. Manganese levels ranged from 0.05 mg/L to 0.35 mg/L, exceeding the WHO guideline of 0.1 mg/L in only one sample (BH8).

Overall, the findings suggest that while some boreholes meet WHO standards, others especially well exceed acceptable limits for certain parameters, rendering them unsuitable for human consumption. The deterioration of groundwater quality in the area is likely attributed to anthropogenic activities such as improper waste disposal and sewage discharge.

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of Study

Water pollution has become a major global environmental issue, drawing increasing concern over the years. After decades of neglect, society is beginning to recognize that clean water is a finite and irreplaceable natural resource (Plummer and McGeary, 2016). Access to safe drinking water is vital for public health and economic growth, yet it remains inadequate in many developing nations (Ovrawah and Hymore, 2001). Even naturally occurring water contains varying amounts of dissolved substances. However, poor waste management practices, industrial effluents, and excessive exploitation of limited water resources have led to contamination by harmful agents such as bacteria, viruses, heavy metals, nitrates, and salts (Singh and Mosley, 2003).

In recent years, rapid urbanization has resulted in an increase in borehole drilling across Benin City, as reported by Okhuebor and Izevbuwa (2020). Their findings revealed that nearly every residential building, office complex, and commercial facility in the city possesses at least one borehole. With population growth and expanding human activities such as soil enhancement practices, indiscriminate waste disposal, and the use of septic tanks, soak-away pits, and pit latrines the likelihood of pollutants leaching into groundwater systems has greatly increased. These activities pose a potential threat to the groundwater that serves as a primary water source for residents.

To minimize the risk of groundwater contamination, boreholes must be located far from potential pollution sources, and proper construction techniques should be followed. Effective well design

plays a critical role in preventing subsurface contamination. During drilling, the use of certain fluids, casings, or chemicals can introduce impurities into the well. Moreover, open boreholes created during construction may act as direct pathways for pollutants to infiltrate the aquifer, thereby fostering both chemical and biological contamination (Piper, 1944).

Given these concerns, it is essential to evaluate the quality of borehole water in Evbuobogun Community, Edo State. This study focuses on analyzing the levels of heavy metals, ionic constituents, and key physicochemical parameters such as pH and electrical conductivity to compare them with internationally recognized standards. The outcome of this assessment will help determine the suitability of the groundwater for domestic use.

## **1.2 Aim and Objectives**

The main aim of this study is to assess the physicochemical properties of groundwater within Evbuobogun Community, Edo State, in order to determine the concentration levels of selected

## **1.3 Specific Objectives**

To achieve this aim, the study seeks to:

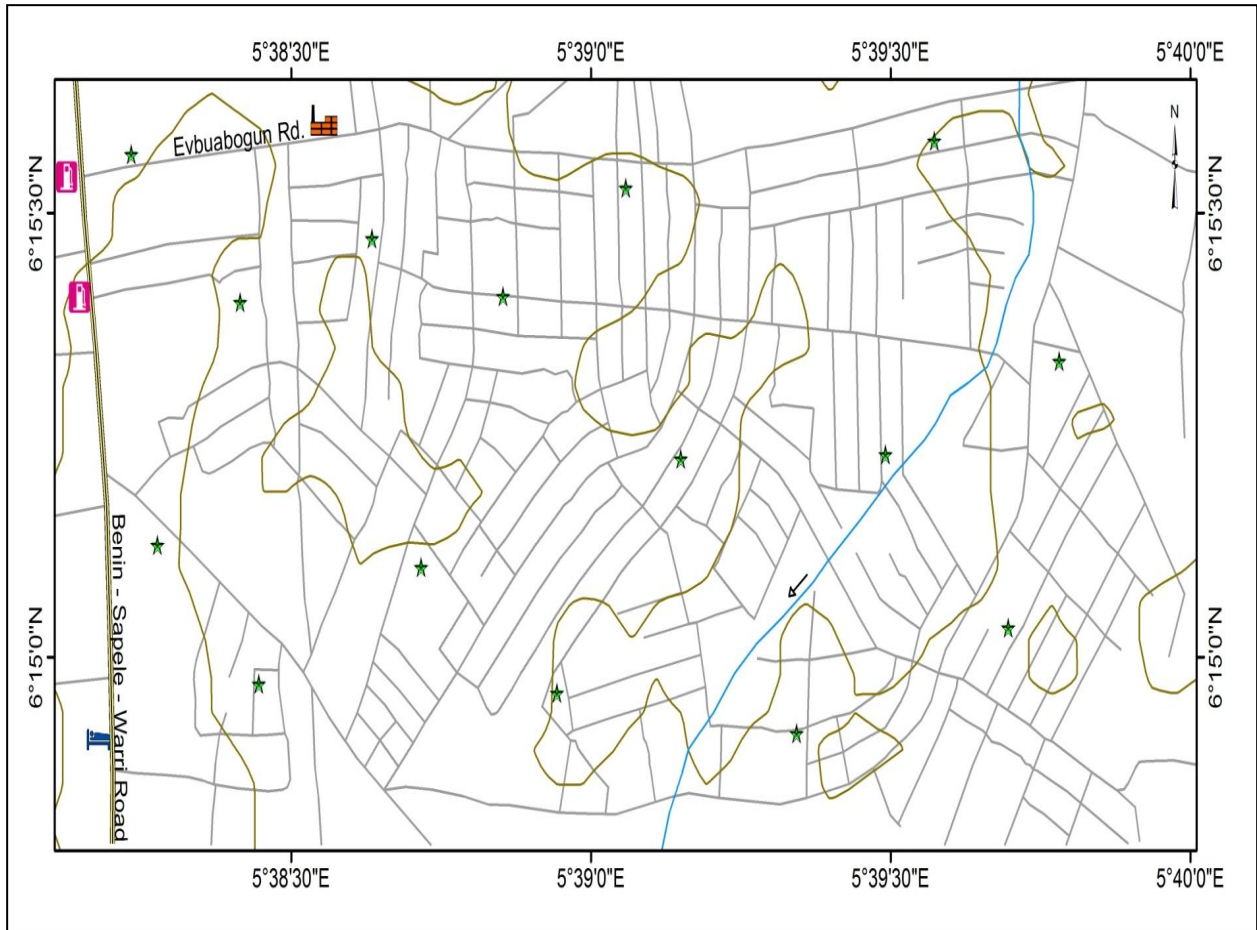
1. Collect groundwater samples systematically from the study area.
2. Conduct laboratory analyses to determine the physical and chemical characteristics, including the concentration of heavy metals.
3. Apply statistical techniques to interpret and evaluate the relationships among the measured parameters.

#### **1.4 Local Geology**

The study was conducted in Ikpoba Okha Local Government Area, located between latitudes  $6^{\circ}15'38.4''\text{N}$  and  $6^{\circ}14'47.7''\text{N}$ , and longitudes  $5^{\circ}38'6.9''\text{E}$  and  $5^{\circ}39'59.7''\text{E}$  (Figure 1). This area lies within Nigeria's South-South geopolitical zone. It is situated approximately 60 meters above sea level and is characterized by relatively flat terrain with poor drainage, leading to waterlogging after rainfall events. Despite this, the area is well connected by an extensive network of residential roads.

#### **1.5 Climate and Vegetation**

The study area lies within the humid tropical climatic region, with an average annual temperature of around  $29^{\circ}\text{C}$ . The highest rainfall occurs between July and September, decreasing gradually toward the dry season, which typically begins in December and extends to January. The mean annual rainfall is approximately 2,500 mm. The vegetation is composed mainly of scattered trees, shrubs, and grasses typical of the tropical environment.



### Legend

- ★ Sample Location
- Contour
- Residential Road
- 🏢 Company
- River
- Express Way
- 🏠 Hotel
- 🛢️ Gas Station



## CHAPTER TWO

### LITERATURE REVIEW

Groundwater possesses several defining parameters that can be identified through various geophysical methods such as electrical resistivity, seismic, magnetic, and gravity surveys. However, this research employed the electrical resistivity survey method due to its proven reliability in groundwater exploration within sedimentary terrains (Emenike, 2001). Key parameters used in characterizing groundwater include porosity, permeability, transmissivity, and conductivity.

According to Ekine and Osobonye (1996), the depth of aquifers varies geographically due to differences in geothermal and geostructural conditions. Geological studies reveal that the study area is underlain entirely by sedimentary rocks, dating from the Paleocene to the Recent period. These rocks predominantly consist of sandstone and shale intercalations (approximately 90%), exhibiting both coarse- and fine-grained textures that are poorly sorted, sub-angular to well-rounded, and contain lignite streaks and fragments of wood (Abdurafiu et al., 2011). The sediments belong to the Benin Formation, which serves as a significant groundwater reservoir capable of supplying large volumes of water, especially around Benin City.

The region lies within the coastal plain of the Niger Delta, characterized by two main climatic seasons wet and dry. Rainfall is heavy and sufficient to support crop production year-round, averaging approximately 2,279 mm annually. The mean annual temperature is about 26.4°C, and relative humidity remains high throughout the year, dropping slightly during the dry months. The dominant soil types in the area are brown loamy and sandy loam soils.

## Groundwater Chemistry in Nigeria

A comprehensive review by Eni et al. (2011) examined groundwater chemistry across Nigeria's major geological units, including the Benin, Benue, Niger Delta, and Sokoto sedimentary basins, as well as crystalline basement complexes. The study found that total dissolved solids (TDS) concentrations in most groundwater sources were below 250 mg/L, except in saline aquifers where values reached up to 15,700 mg/L due to salt deposits and seawater intrusion. Elevated nitrate levels, particularly in the Sokoto Basin, were attributed to anthropogenic pollution. Multivariate statistical analyses showed that chloride dissolution, silicate and carbonate weathering, and ion exchange were the main processes influencing groundwater chemistry.

In sedimentary regions, higher levels of electrical conductivity (EC) and ions such as Na, K, Mg, and Cl were recorded compared to basement terrains. The general ionic composition followed the order:

- Sedimentary areas:  $\text{Na} > \text{Ca} > \text{K} > \text{Mg} / \text{HCO}_3 > \text{Cl} > \text{SO}_4$
- Basement complex:  $\text{Ca} > \text{Na} > \text{Mg} > \text{K} / \text{HCO}_3 > \text{SO}_4 > \text{Cl}$

The spatial distribution of ions reflected the lithological composition of each area. Except for saline conditions found in parts of the Benue Basin and coastal aquifers, the groundwater in these basins was generally suitable for agriculture and irrigation purposes.

Further research by Ocheri et al. (2014) in Lagos revealed that the local geology significantly influenced how contaminants moved and were naturally attenuated within groundwater systems. The city's hydrogeological setting encouraged adsorption and retention of contaminants, resulting in irregular leachate migration. Landfills were identified as one of the key sources of groundwater pollution.

Similarly, Adebo and Adetoyinbo (2009) investigated a coastal aquifer in Lagos and found chloride concentrations exceeding WHO permissible limits, attributing this to saltwater intrusion.

They classified groundwater types in the area as Fe-Ca-Mg-SO<sub>4</sub>, Fe-Cl-HCO<sub>3</sub>, and Mg-Cl.

In Ibadan, Ajibade et al. (2010) studied groundwater contamination and flow characteristics, identifying the predominant ions as Na, Ca, K, Mg, Al, P, and Fe, with trace elements such as Mn, Zn, Ni, Co, Pb, Cu, Cr, Sb, and Sr. High contamination factors were recorded for lead, chromium, and strontium, and the dominant water types were classified as earth-alkaline and earth-alkaline with alkali compounds.

## **2.1 Urbanization and Groundwater Pollution**

African cities have long depended on both surface and subsurface water for domestic and industrial supply. However, urbanization, industrial growth, and the high costs of dam construction have led to declining surface water quality and quantity, shifting attention toward groundwater as a more reliable source (Adelana et al., 2008). Urban expansion has significant implications for water demand, waste disposal, and particularly for the protection and management of groundwater systems (Eni et al., 2011).

Research by Adelana et al. (2003, 2004, 2005) on the southeastern Lagos region (1999–2001) found that nearly all groundwater samples contained objectionable concentrations of sulphate, nitrate, and chloride. Nitrate contamination, in particular, was traced to human activities. The study attributed groundwater vulnerability to its shallow depth and unconsolidated sand and gravel aquifers, which allow easy infiltration of contaminants.

In Calabar, Eni et al. (2011) discovered that urbanization contributed to high acidity, nitrate, and faecal coliform levels in well water. Regression analyses revealed strong correlations between

urban expansion and increases in faecal coliform, pH, and chlorine, suggesting poor sanitation as a key factor.

A similar study by Amadi et al. (2010) in Makurdi Metropolis found that wells near dumpsites had low pH, elevated concentrations of iron, manganese, calcium, total dissolved solids, and total coliform bacteria indicating contamination by leachates. The dominant groundwater type in this region was identified as Ca-SO<sub>4</sub>. Tse and Adamu (2012) further confirmed that hand-dug wells in Makurdi contained trace amounts of heavy metals (iron, zinc, copper, lead, cadmium) and high bacterial counts, with the water being slightly acidic, moderately hard, and of low TDS.

## **2.2 Geology of the Study Area**

Geologically, the research area represents a typical Niger Delta environment, specifically underlain by the Benin Formation, also known as the Coastal Plain Sands (Abdurafiu et al., 2011). The formation comprises massive, highly porous, freshwater-bearing sandstones with occasional clay intercalations and is characterized by high permeability. According to Abimbola et al. (2002), this formation serves as the primary aquifer system providing potable groundwater to surrounding communities.

The sedimentary sequence consists largely of sandstone and shale approximately 90% sandstone interbedded with shale layers with grain sizes ranging from coarse to fine, poorly sorted, and containing lignite streaks and wood fragments (Abdurafiu et al., 2011). The Benin Formation therefore represents an important groundwater reservoir, accounting for the substantial volume of water available in Benin City and its environs.

## CHAPTER THREE

### MATERIALS AND METHOD

#### 3.1 Sample Collection and Preservation

A total of fifteen (15) borehole water samples were randomly collected using 0.75 L plastic containers with tightly sealed lids. The samples were drawn from active boreholes located across different parts of the study area. Before filling each container, it was rinsed with a small portion of the sample water to minimize contamination.

For metal analysis, 1 mL of nitric acid ( $\text{HNO}_3$ ) was added to each sample immediately after collection to prevent metal precipitation. All samples were then refrigerated prior to laboratory testing to maintain stability. The physicochemical and heavy metal analyses were performed at the Chemistry Department Laboratory, University of Benin, Benin City.

#### 3.2 Materials Used

The following laboratory materials and equipment were utilized during the analysis: Test tubes, Petri dishes, inoculating lamp, syringe pipettes, aluminum foil, test tube rack, cotton wool, glass slides, matches, microscope, incubator, refrigerator, autoclave, and Mettler balance.

#### 3.3 Methods

The conductivity and temperature of the water samples were measured using a HANNA EC/TDS conductivity and temperature meter. Turbidity was analyzed using a Wagtech waterproof turbidity meter (WT 3020, Serial No. 197619). Chemical parameters such as  $\text{NO}_3^-$ ,  $\text{Fe}^{2+}$ ,  $\text{Na}^+$ ,  $\text{Mg}^{2+}$ , and  $\text{Ca}^{2+}$  were determined with a spectrophotometer, while a Wagtech photometer (wavelength range: 410–640 nm; Serial No. 3400-008) was used for other chemical

measurements.

Physical parameters including odor, taste, and color were noted at the collection sites.

### **3.3.1 Determination of pH**

The pH value, which expresses the acidity or alkalinity of a water sample, is defined as the negative logarithm of the hydrogen ion concentration. It significantly affects the solubility and behavior of ions in water.

### **3.3.2 Determination of Conductivity**

Conductivity was measured directly from the samples using a conductivity meter. This parameter reflects the ability of water to conduct electricity, which depends on the concentration and mobility of dissolved ions as well as temperature. It is a standard indicator of water purity.

Procedure:

The conductivity cell was detached and cleaned thoroughly using a bottle brush, followed by rinsing with distilled water to remove residues. It was then rinsed with a small portion of the sample before measurement. The meter's dial was adjusted until the indicator stabilized at the center position, and the readings were recorded in  $\mu\text{S}/\text{cm}$ .

### **3.3.3 Determination of Total Dissolved Solids (TDS)**

Procedure:

A 100 mL sample was filtered through a pre-weighed filter paper into a graduated cylinder and topped up to the mark with distilled water. The filtrate was transferred into a pre-weighed

crucible and evaporated to dryness using a steam bath, then oven-dried at 180°C for 1.5 hours. After cooling in a desiccator, the crucible was weighed.

Let:

- $W_1$  = weight of empty crucible
- $W_2$  = weight of crucible + residue

The difference ( $W_2 - W_1$ ) represents the total dissolved solids.

### **Total Suspended Solids (TSS)**

TSS represents the portion of solids retained on the filter. The same pre-weighed filter paper used in the TDS test was dried at 105°C for 30 minutes, cooled in a desiccator, and weighed again.

Calculation:

$$\left[ \begin{array}{l} \text{TSS (ppm)} = (W_2 - W_1) \times 10^3 \end{array} \right]$$

### **3.3.4 Determination of Chloride**

The Mohr titration method was used, employing silver nitrate ( $\text{AgNO}_3$ ) as the titrant and potassium chromate ( $\text{K}_2\text{CrO}_4$ ) as the indicator. The chloride ions in the sample reacted to form a white silver chloride ( $\text{AgCl}$ ) precipitate.

#### **Procedure:**

50 mL of the water sample was placed in a conical flask, and 10 drops of potassium chromate

were added to produce a yellow color. The sample was titrated against **0.05 M AgNO<sub>3</sub>** until the color changed from yellow to reddish-brown, indicating the endpoint.

### 3.3.5 Determination of Nitrate

Nitrate concentration was determined colorimetrically using hydrazine sulfate ( $\text{N}_2\text{H}_2 \cdot \text{H}_2\text{SO}_4$ ) and copper sulfate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ) as a catalyst. A reddish color developed, and its intensity was compared against the Aqua Merck nitrate color scale to obtain the concentration in ppm. Similar colorimetric methods were employed to determine **nitrite**, **silicate**, and **phosphate** using the **Aqua Merck water analysis reagent kit** (Merck, 1982).

### 3.3.6 Determination of Metals

Heavy metal concentrations were analyzed using a Buck Model Flame Atomic Absorption Spectrophotometer (AAS). This method involves aspirating the sample into a flame where it is atomized, and the absorbance of each element is measured.

#### **Procedure:**

Standard metal solutions were prepared in ppm concentrations from pure metal salts. The AAS instrument was powered on for about 15 minutes to ensure stability. Each element's respective lamp was installed, and both standard solutions and samples were aspirated sequentially. The absorbance values were recorded under identical conditions as outlined in the Buck Scientific Operations Manual for AAS.

## CHAPTER FOUR

### RESULT AND DISCUSSION

#### 4.1 RESULT

Fifteen (15) groundwater samples from the study area were collected for physicochemical examination. The following variables were analyzed: hydrogen potential, electrical conductivity, turbidity, total suspended solids, total solids, alkalinity, carbonate, sulphate, chloride, and nitrate levels, as well as calcium, magnesium, iron, zinc, lead, cadmium, copper, and manganese concentrations.

Statistical, Correlation and Cluster analysis were carried out and the outcome displayed in tables and figures below:

Table 1: Summary of the Physical and Chemical Analyses of Groundwater Samples from the Study Area

Parameters	Mean	S.E.	Std.	Min	Max	WHO
			Dev.			LIMIT
<i>PH</i>	4.75	0.055	0.212	4.51	5.22	6.5 - 8.5
<i>TURBIDITY (NTU)</i>	0.05	0.004	0.017	0.03	0.09	5
<i>CONDUCTIVITY</i>	12.42	0.218	0.843	11.38	13.81	1000
<i>TDS (mg/l)</i>	5.75	0.077	0.298	5.34	6.22	500
<i>TSS (mg/l)</i>	6.87	0.524	2.031	4	10	N/S
<i>TOTAL SOLID (mg/l)</i>	12.99	0.573	2.221	9.3	15.3	N/S
<i>ALKALINITY (mg/l)</i>	6.76	0.293	1.135	4	8	N/S
<i>CARBONATE (mg/l)</i>	5.20	0.296	1.146	4	7	N/S

<i>SULPHATE (mg/l)</i>	1.68	0.041	0.157	1.21	1.84	250
<i>CHLORIDE (mg/l)</i>	13.91	0.092	0.358	13.03	14.13	200
<i>NITRATE (mg/l)</i>	1.85	0.050	0.193	1.54	2.12	10
<i>CALCIUM (mg/l)</i>	0.92	0.107	0.416	0.39	1.73	200
<i>MAGNESIUM (mg/l)</i>	0.48	0.011	0.042	0.36	0.53	20
<i>IRON (mg/l)</i>	0.57	0.053	0.204	0.263	0.891	0.3
<i>ZINC (mg/l)</i>	0.17	0.013	0.050	0.116	0.269	0.01
<i>COPPER (mg/l)</i>	0.06	0.004	0.014	0.039	0.086	0.5
<i>MANGANESE (mg/l)</i>	0.05	0.021	0.083	0.021	0.35	0.1
<i>CADMIUM (mg/l)</i>	0	0	0	0	0	0.003
<i>LEAD (mg/l)</i>	0	0	0	0	0	0.05

---

Table 2: Correlation coefficient matrix of ground water quality parameters in the study area

	PH	Turb	EC	TDS	TSS	TS	ALK	CO <sub>3</sub> <sup>2-</sup>	SO <sub>4</sub> <sup>2-</sup>	Cl <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Cu <sup>2+</sup>	Mn <sup>2+</sup>
PH	1																
Turb	.143	1															
EC	.154	<b>.855*</b>	1														
TDS	.384	<b>.770*</b>	<b>.861*</b>	1													
TSS	.052	-.312	-.182	-.080	1												
TS	.140	-.270	-.220	.016	<b>.921*</b>	1											
ALK	.364	.190	.299	.340	.010	-.031	1										
CO <sub>3</sub> <sup>2-</sup>	.045	-.332	-.300	-.241	<b>.933*</b>	<b>.846**</b>	.045	1									
SO <sub>4</sub> <sup>2-</sup>	.297	.188	.265	.315	-.136	-.126	<b>.966*</b>	-.095	1								



---

$r(0.05)(\infty 2) \text{ df}(13)=0.514$

$r(0.01)(\infty 2) \text{ df}(13)=0.641$

**Bold values = Significant ( $P < 0.05$ )**

**Bold values with underline = Highly Significant ( $P < 0.01$ )**

## Chart Representation

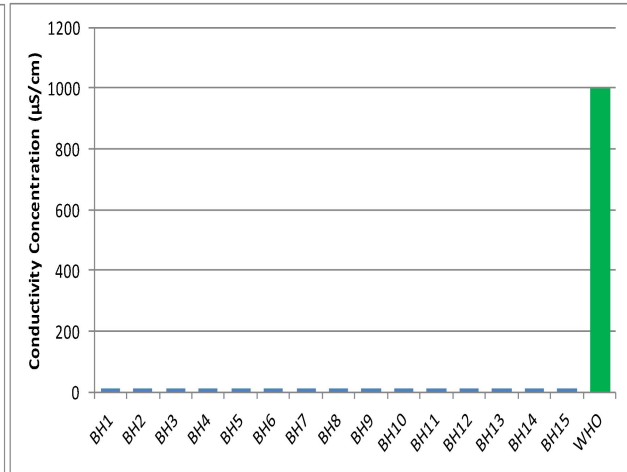
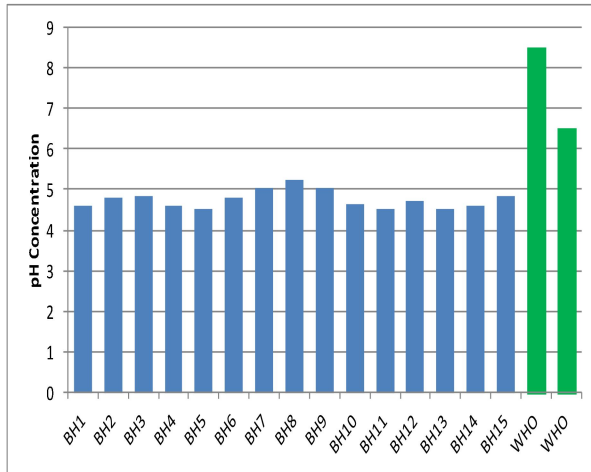


Fig. 2: Comparative pH values and WHO minimum and maximum limit concentration values and WHO limit

Fig. 3: Comparative EC

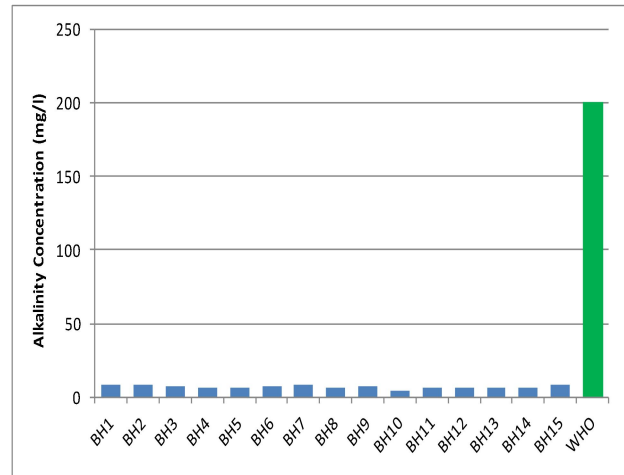
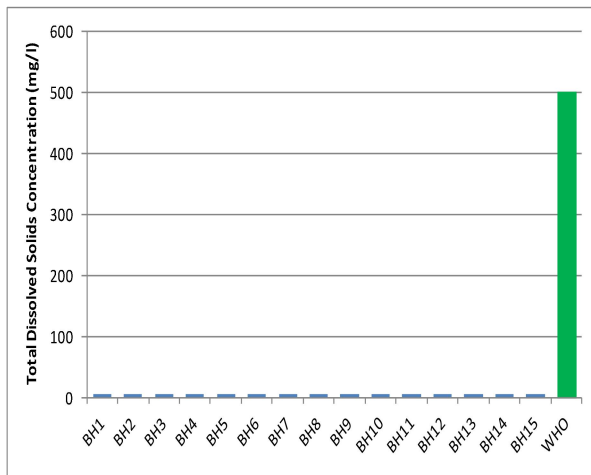


Fig. 4: Comparative TDS values and WHO standard values and WHO standard

Fig. 5: Comparative Alkalinity

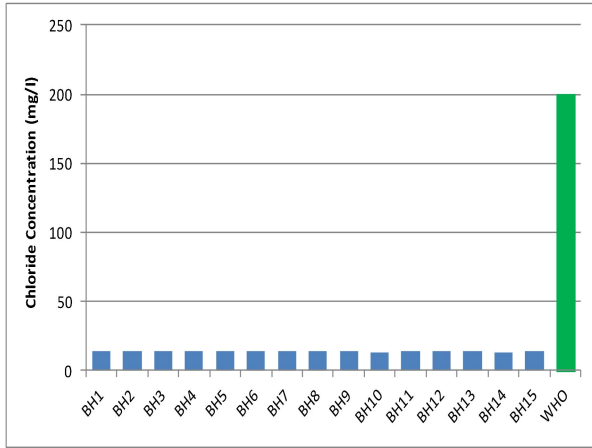


Fig. 6: Comparative Cl<sup>-</sup> values and WHO standard

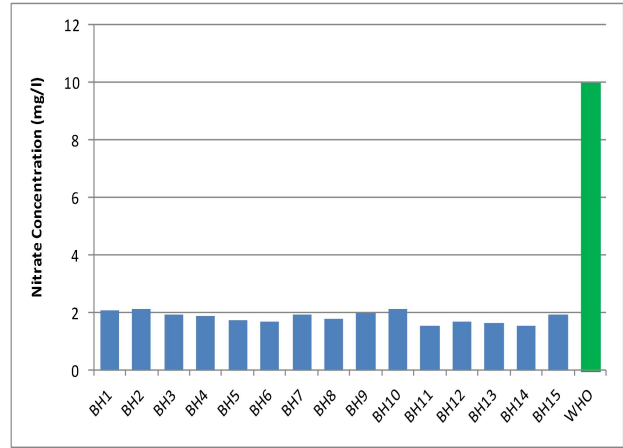


Fig. 7: Comparative NO<sub>3</sub><sup>-</sup> values and WHO standard

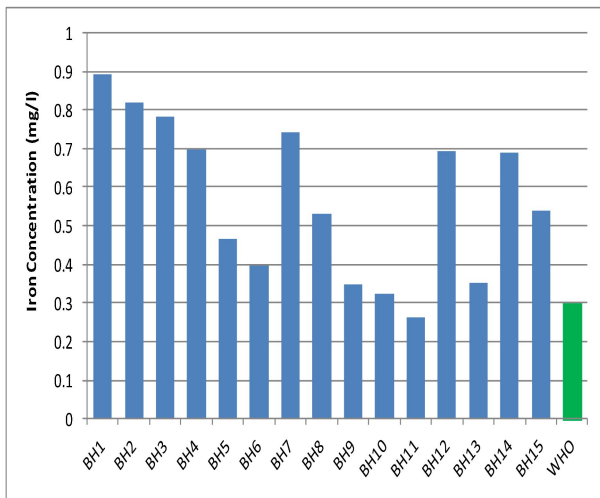


Fig. 8: Comparative Fe concentration values and WHO limit

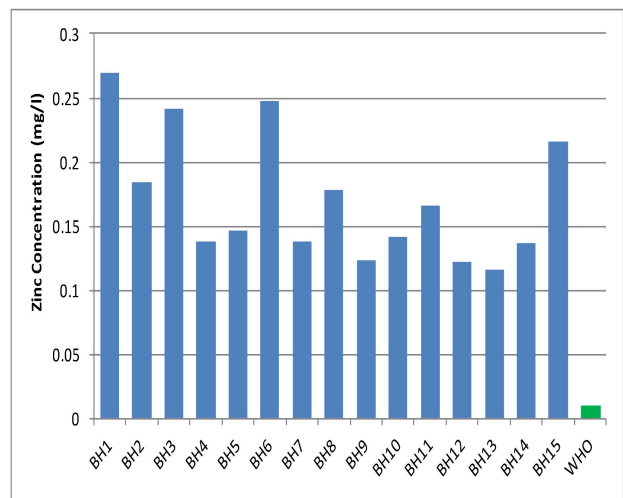


Fig. 9: Comparative Zn concentration values and WHO limit

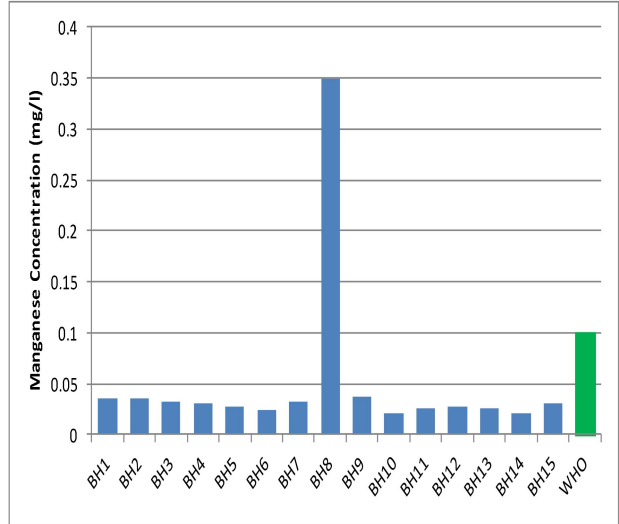
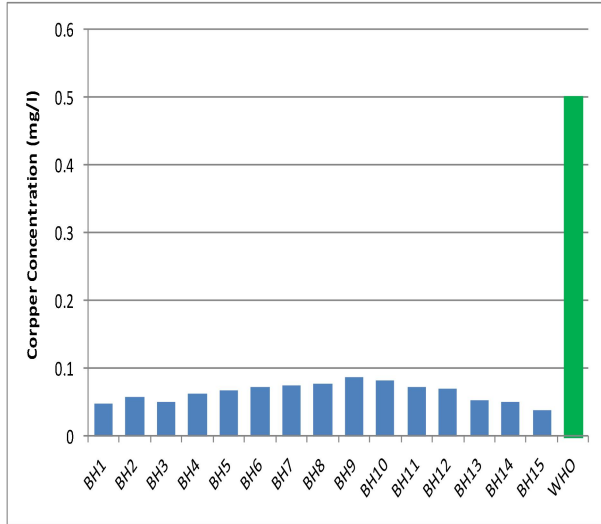


Fig. 10: Comparative Cu concentration values and WHO limit

Fig. 11: Comparative Mn

concentration values and WHO limit

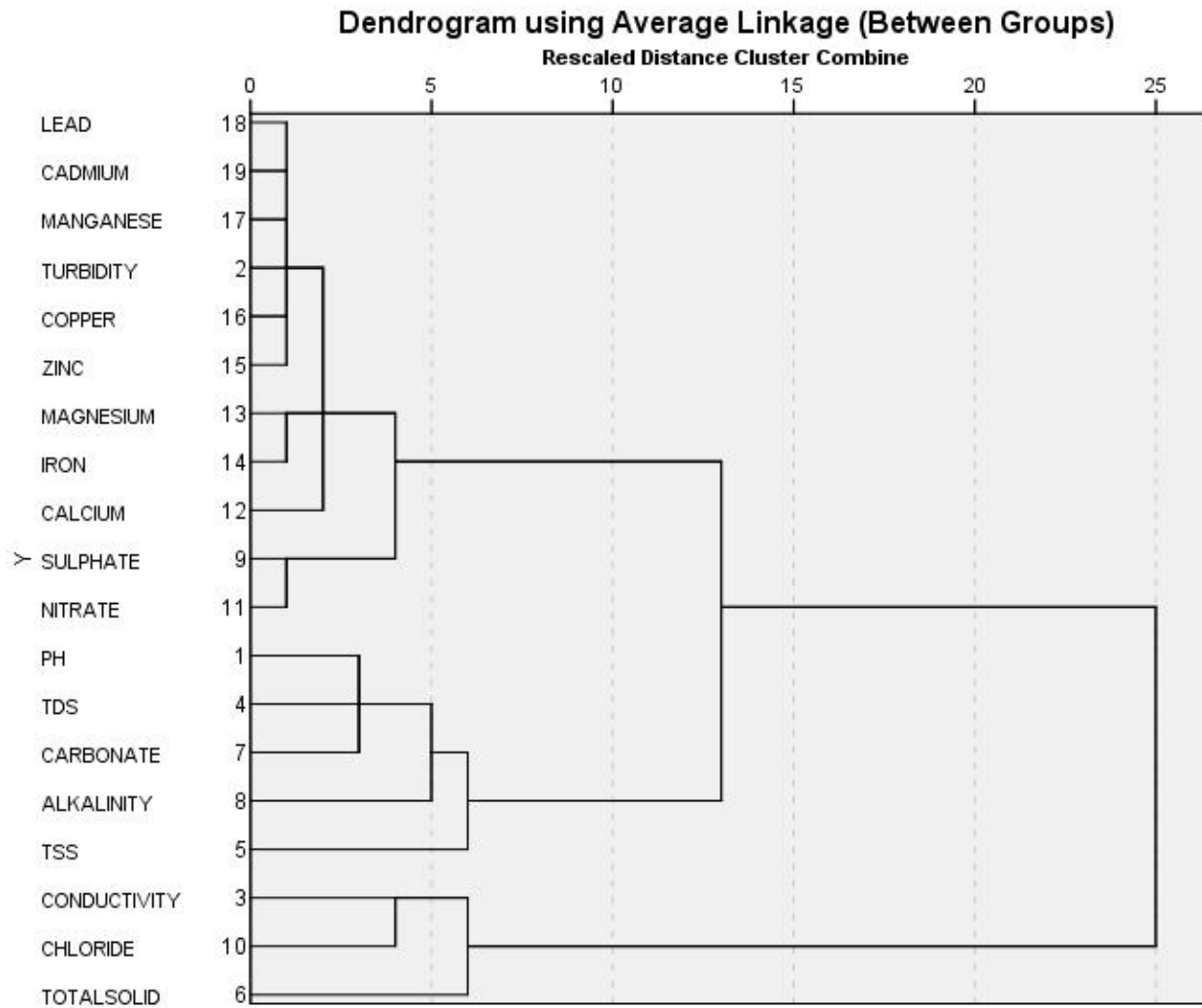


Figure 12: Dendrogram (R – mode)

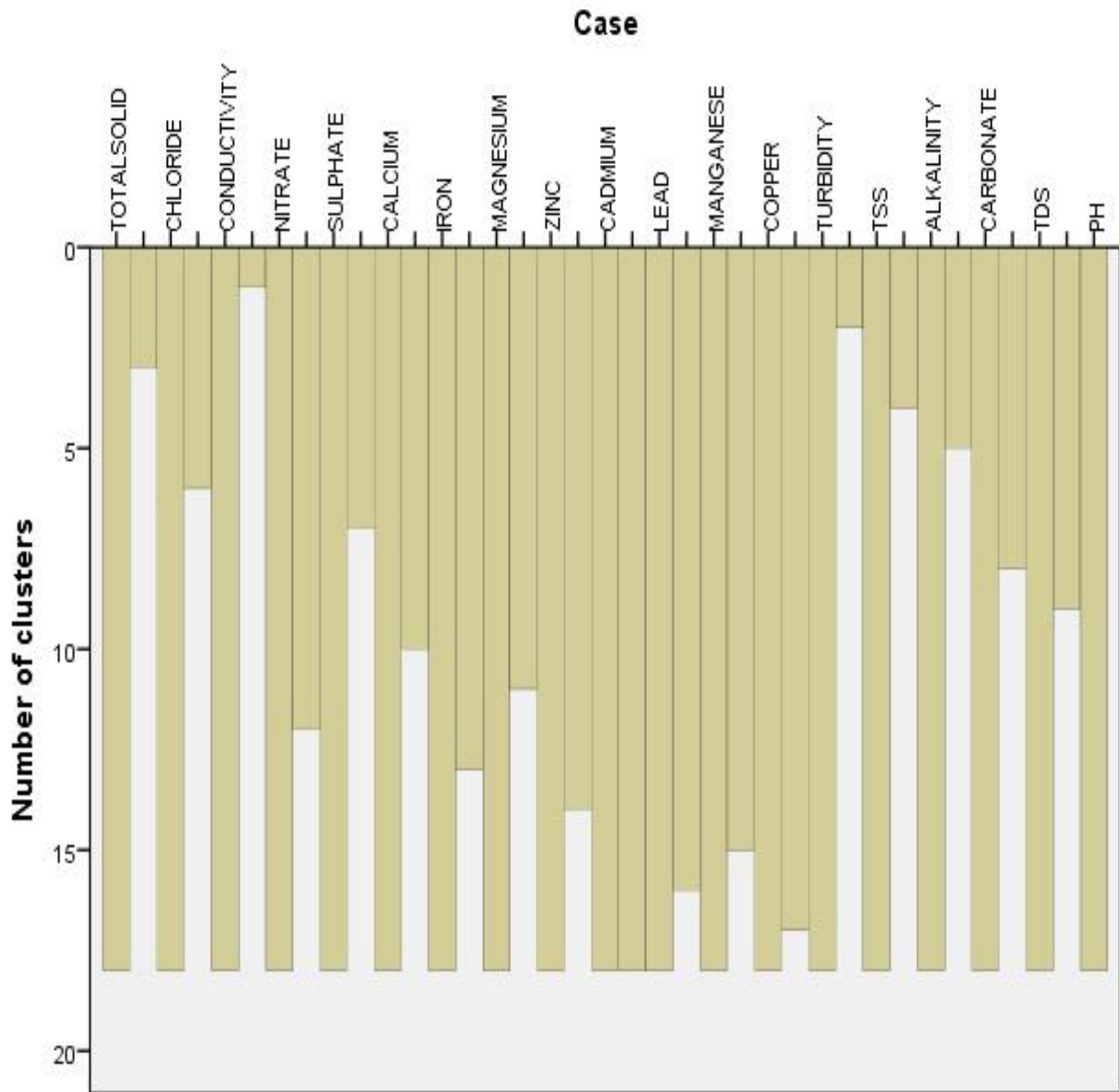


Figure 13: Icicle diagram (R-Mode)

## 4.2 Discussion

### Physicochemical Parameters

According to Todd (1980), pH represents the negative logarithm of hydrogen ion activity, indicating the concentration of hydrogen ions ( $H^+$ ) in water. In this study area, pH values ranged between 4.51 and 5.22, with BH8 showing the highest and BH11 the lowest readings. None of the samples met the WHO recommended pH range (6.5–8.5) (Table 1). The relatively low pH could enhance the leaching of metallic ions such as iron, manganese, copper, lead, and zinc from pipelines and plumbing fixtures, which may cause undesirable taste, staining of laundry and sinks, and other aesthetic issues (Rajappa et al., 2011).

Total Dissolved Solids (TDS), primarily composed of inorganic salts (e.g., calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates) along with trace organic matter, ranged from 5.34 to 6.22 mg/l (Table 1). BH6 had the highest value (6.22 mg/l), while BH1 recorded the lowest (5.34 mg/l). All TDS results were far below the WHO permissible limit of 500 mg/l, indicating excellent water quality in this regard.

The alkalinity of the water samples ranged between 1.135 mg/l and 8 mg/l, with an average of 6.76 mg/l, also within the WHO limit of 200 mg/l. Adequate alkalinity provides buffering capacity, reducing the water's susceptibility to acidification (Olobaniyi & Owoyemi, 2004).

Chloride, a common constituent of both surface and groundwater (Olobaniyi & Owoyemi, 2004), is often used as an indicator of sewage contamination because it is resistant to oxidation and other removal processes (Nwankwoala et al., 2009). The mean chloride concentration was 13.91 mg/l, ranging from 13.03 mg/l (BH10) to 14.13 mg/l (BH1) (Table 1), well within the WHO guideline of 200 mg/l. This also suggests the water is relatively soft and free from significant sewage influence.

Nitrate levels in the study area varied between 1.54 mg/l and 2.12 mg/l, remaining below the WHO threshold of 10 mg/l. The presence of nitrate likely results from microbial oxidation of organic nitrogen by nitrifying bacteria, as well as infiltration of sewage effluents. Although current concentrations are safe, elevated levels can cause methemoglobinemia (“blue baby syndrome”) in infants under six months (Ovrawah & Hymore, 2001; Olobaniyi & Owoyemi, 2004).

### **Heavy Metal Parameters**

Iron (Fe) concentrations ranged from 0.26 mg/l to 0.891 mg/l, with an average of 0.57 mg/l. About 93% of the samples exceeded the WHO permissible limit of 0.3 mg/l. The elevated iron content is likely due to dissolution of iron minerals during groundwater percolation. This is consistent with the iron-rich Benin Formation, which naturally contributes to high iron levels in groundwater. Excess iron imparts a metallic taste and can cause dark precipitates and staining when the water is exposed to air (Iyaka & Kakulu, 2012).

Zinc (Zn) concentrations ranged from 0.116 mg/l to 0.269 mg/l (Table 1), exceeding the WHO limit of 0.01 mg/l. The elevated zinc could originate from industrial waste, landfill leachates, or agrochemical residues such as fungicides and pesticides. High zinc concentrations pose health risks, including nausea, vomiting, diarrhea, and dizziness (Iyaka & Kakulu, 2012).

Copper (Cu) levels ranged from 0.039 mg/l to 0.086 mg/l, all below the WHO standard of 0.5 mg/l. The highest and lowest values were observed in BH9 and BH15, respectively. Although copper is an essential trace element, excessive intake can cause gastrointestinal irritation, nausea, and a metallic taste (Klaassen, 2001).

Manganese (Mn) concentrations averaged 0.05 mg/l, ranging between 0.021 mg/l and 0.35 mg/l (Table 1). Only BH8 exceeded the WHO limit of 0.1 mg/l. Elevated manganese levels can cause aesthetic issues such as staining and metallic taste and, with long-term exposure, may affect the nervous system, leading to Parkinson-like symptoms, especially in vulnerable groups such as children and pregnant women (Nwankwoala et al., 2009).

Cadmium (Cd) and Lead (Pb) were not detected in all samples, but both are known toxic elements posing serious health hazards (Anon, 1970). According to Nagendra and Ramkrishna (2011), cadmium contamination may result from industrial effluents, fertilizers, and atmospheric deposition, while lead exposure, even at low concentrations, can impair neurological and hematological functions, especially in infants and children, leading to learning deficits, developmental delays, and increased blood pressure in adults (Erah et al., 2002).

### 4.3 Cluster Analysis

The **dendrogram (Figure 12)** illustrates the Euclidean distance levels at which various water quality parameters cluster together. Six clusters were identified:

- **Cluster 1** – Pb, Cd, Mn, Cu, Zn, Fe, and NO<sub>3</sub> (distance ≈ 1), primarily representing **heavy metals** with strong interrelationships.
- **Cluster 2** – Turbidity and Ca (distance ≈ 2)
- **Cluster 3** – pH and CO<sub>3</sub> (distance ≈ 3)
- **Cluster 4** – Mg, SO<sub>4</sub>, and Cl<sup>-</sup> (distance ≈ 4)
- **Cluster 5** – TDS and Alkalinity (distance ≈ 5)
- **Cluster 6** – TSS, Electrical Conductivity, and Total Solids (distance ≈ 6)

These groupings indicate varying degrees of association among parameters, with **Cluster 1** showing the strongest similarity among the heavy metals. The corresponding **icicle diagram** is presented in **Figure 13**.

#### 4.4 Correlation Analysis

The correlation matrix of the physicochemical data revealed significant positive correlations at  $p < 0.01$  between several parameters, including:

- Turbidity & Electrical Conductivity / TDS
- Electrical Conductivity & TDS
- TSS & Total Solids / Carbonate / Nitrate / Calcium
- Total Solids & Carbonate / Nitrate
- Alkalinity & Sulphate / Chloride
- Carbonate & Nitrate / Calcium

At  $p < 0.05$ , positive correlations were observed between:

- Total Solids & Calcium
- Alkalinity & Iron / Manganese
- Calcium & Magnesium / Iron / Zinc

No correlation was found between Copper and pH, TDS, Mg, Fe, Zn, or Mn. The strongest correlation was observed between Alkalinity and Sulphate ( $R^2 = 0.966$ ).

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

This study assessed the physicochemical and heavy metal composition of borehole water samples from Ikpoba-Okha LGA, Benin City. Results indicate that the water is slightly acidic and shows varying degrees of inter-parameter correlation. Turbidity, Electrical Conductivity, TSS, Total Solids, Alkalinity, Carbonate, and Calcium displayed significant positive relationships, while Copper showed no correlation with several other parameters.

When compared with WHO drinking water standards, parameters such as pH, Fe, Zn, and Mn exceeded acceptable limits. The findings suggest localized contamination by iron and zinc, indicating a need for improved water management and monitoring.

#### 5.2 Recommendations

1. Regular groundwater quality monitoring should be conducted by environmental geologists at defined intervals.
2. Public environmental education programs should be implemented to raise awareness among residents of the area.
3. Deeper borehole drilling is recommended to access cleaner aquifers with lower iron content.
4. Water treatment should include aeration/oxidation and filtration, and lime or calcium carbonate may be added to adjust pH and remove excess iron and magnesium.
5. Future studies should include microbiological assessments to provide a more comprehensive understanding of groundwater safety and contamination levels.

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