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HYDROGEOCHEMICAL ASSESSMENT OF GROUNDWATER QUALITY AT AFE BABALOLA UNIVERSITY, ADO-EKITI, SOUTHWESTERN NIGERIA.

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Abstract
This study evaluates the hydrogeochemical characteristics and groundwater quality of boreholes within Afe Babalola University, Ado-Ekiti (ABUAD), Southwestern Nigeria. Seven groundwater samples were collected randomly and analyzed to determine key physicochemical parameters. Field measurements included pH, electrical conductivity (EC), total dissolved solids (TDS), temperature, and salinity, while laboratory analysis of major ions and trace metals was performed using ICP-OES. Results showed that groundwater in the area was slightly acidic, with pH values ranging from 6.2 to 6.9. EC (239.5–524.9 µS/cm) and TDS (142.7–323.1 mg/L) fall within World Health Organization (WHO) permissible limits, indicating low mineralization and freshwater. Major cations occurred in order of $Ca^{2+} > Na^{+} > K^{+} > Mg^{2+}$, while the anions were in order of $Cl^{-} > SO_4^{2-} > HCO_3^{-}$,. Piper diagram classification revealed the dominance of calcium–chloride water type, suggesting significant rock–water interaction and mineral dissolution processes. Although most major ion concentrations were within the WHO standards, the trace elements—including Cu, Cr, Zn, Mn, and Ni—exceeded the recommended limits of WHO at some locations, indicating localized anthropogenic contamination. These elevated concentrations pose potential health risks and reduce suitability of the groundwater for domestic purpose. Generally, the groundwater within ABUAD fell within freshwater and suitable for domestic use; however, evidence of trace elements enrichment highlights the need for continuous water quality monitoring and the implementation of environmental management strategies to prevent further contamination.
Keywords: Assessment, Groundwater, Water Quality, physicochemical, Ado-Ekiti

Introduction
Water is crucial to many processes and activities in our modern society, providing both environmental and economic advantages. Contaminated groundwater poses a severe threat to humans since it can cause water-borne diseases that can be harmful to health (WHO, 2017). Also, agricultural productivity dependent largely on the appropriateness of groundwater, which increases crop yield. Groundwater is a key natural asset that supports domestic and agricultural needs, and its appropriateness is of major significance for its sustainability and efficient usage (FAO, 2003). Groundwater accounts for a bigger proportion of home, agricultural, and industrial water sources due to its availability and proximity (UNESCO, 2015). Groundwater quality is influenced by natural variables such as aquifer lithology, groundwater velocity, recharge water quality, and interaction with other types of water or aquifers, as well as human activities and the environment (Appelo and Postma, 2005). Contaminants such as leachates and oil pollution, which emanate from various sources and infiltrate into aquifer units via the pores and crevices of rocks or soils after decomposition, become a point source of groundwater pollution (Ganiyu et al., 2015). Rocks and sediments contain pollutants and solutes, and groundwater that flows through them dissolves these chemicals, altering the chemistry of groundwater reservoirs. Groundwater suitability is determined by the hydrogeochemical characteristics and pollution susceptibility of the aquifer layers (Wang et al., 2010). Furthermore, aquifer susceptibility is determined by the porosity, permeability, and overburden thickness of the geologic formation (Aller et al., 1987). Groundwater reservoirs are constantly overstretched by processes such as saltwater intrusion, leachate migration, oil spillage, surface and subsurface leakages, and septic tank leakage (Foster et al., 2002). Discharge-recharge patterns, the composition of the host and related rocks, and polluted activities all have a significant impact on groundwater quality. Groundwater pollution assessment research has helped to accurately measure its vulnerability to pollution and comprehend the hydrogeochemical processes required for evaluating groundwater quality. Groundwater pollution is mostly caused by pluvial water percolation and pollutant infiltration through soil (Ganiyu et al. 2015). Groundwater quality degradation has been a source of concern for human health and agricultural use, and its attendant impact on productivity. When the concentration of dissolved elements exceeds the World Health Organization's (WHO) allowed limits, it has a negative impact on human health as well as plant growth by altering plant absorption power due to complicated changes caused by

osmotic processes. This study was carried out to assess the hydrogeochemical and groundwater quality of boreholes (wells) at Afe Babalola University, Ado-Ekiti (ABUAD), Ekiti state, southwestern Nigeria, to give more relevant information for future studies and research.

Description of the Study Area

The study area, Afe Babalola University, Ado-Ekiti, is situated along Ijan Road, Ado-Ekiti. The university is situated between latitudes $7^0$36'32" N and $7^0$36'55" N and longitudes $5^0$18'05" E and $5^0$18'45" E (Figure 1). It has a relatively low relief with isolated hills and inselbergs that are dome-shaped. The climate is characterized by the tropical type influenced by monsoon winds during the rainy season, with maximum rainfall in October and the dry season. Annual temperature ranges between 28 to 30°C with a mean annual rainfall of 1500 mm. It is located within the Basement Complex of South Western Nigeria. Major lithological units are crystalline basement rocks. These rocks include coarse-grained charnockite, granite, migmatite gneiss, and banded gneiss, with superficial deposits of clay and quartzite (Figure 2). The association of the fine-grained charnockite and the porphyritic biotite-hornblende granite suggests a common age. According to Fetter (2001), crystalline rocks are poor water-bearing aquifers because of their low porosity and low permeability. The hydrogeological characteristics of these rocks depend on the degree of weathering and fracturing of the underlying rock within the tropical rainfall belt. The intense deformational structures of these rocks permit adequate aquifer properties needed to generate the well water.

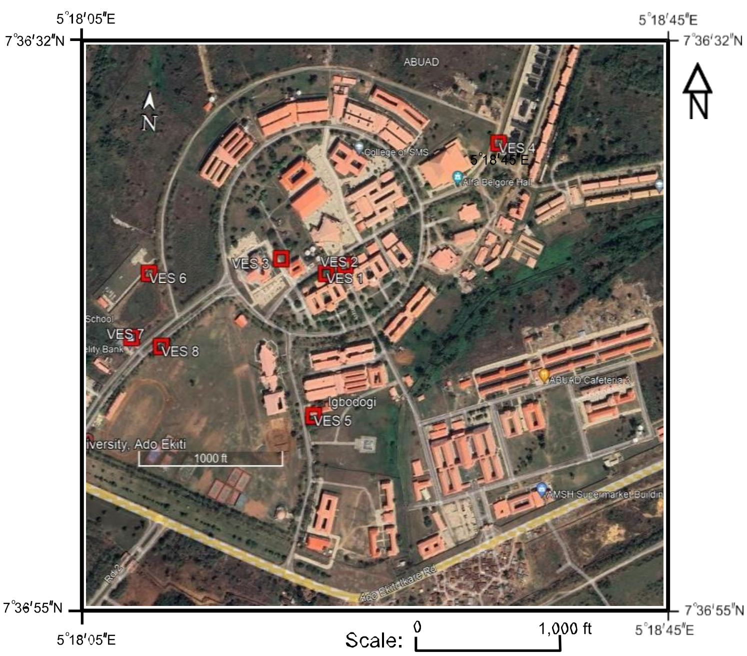

Figure 1: Aerial photograph of the study area showing sample locations.

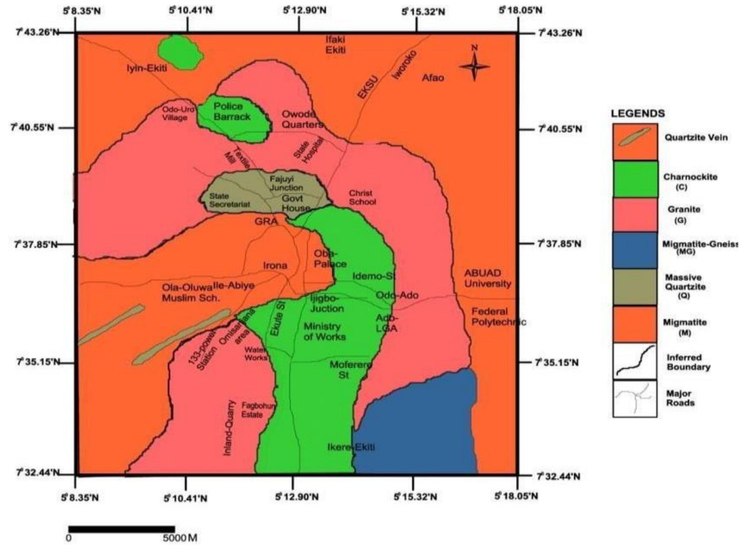

Figure 2: Geological Map of Ado-Ekiti and its Environment.

Materials and Methods of Studies

Materials

Specific equipment was used for the field exercise which included a Global Positioning System (GPS), pH meter, Temperature meter, Electrical conductivity meter, HI-8733 EC/TDS Multimeter (TDS), Salinity meter, containers (fetcher), and a sample bottles of about 1 lt. size, sample bags, polythene bags, permanent markers, masking tape, field notebook and concentrated nitric acid HNO_3 for sample digestion.

Field physicochemical measurement

Well-inventories were carried out on a total of 7 wells used for this study. The physicochemical parameters were measured in the field using a Model 99720 Multimeter capable of measuring total dissolved solids (TDS), Salinity, and Temperature, while the coordinates of each sampled well were recorded using GPS.

The following physicochemical parameters were measured at each sampling well:

- **pH:** Represents the concentration of hydrogen ions in the water, indicating its acidity or alkalinity.
- **Total Dissolved Solids (TDS):** Describes the total concentration of dissolved organic and inorganic substances. It is typically measured in parts per million (ppm) or parts per billion (ppb).
- **Electrical Conductivity (EC):** Reflects the capacity of the water to conduct an electric current, which is directly related to the concentration of dissolved ions. It is expressed in microsiemens per centimeter (µS/cm).
- **Temperature:** Indicates the average kinetic energy of the water molecules, expressing the degree of thermal intensity. This was recorded in degrees Celsius (°C).
- **Salinity:** Refers to the total concentration of all dissolved salts in the water sample.

Sampling and Preservation

Water samples were collected from motorized boreholes at seven locations in Afe Babalola University, Ado-Ekiti (ABUAD), Ekiti State, Nigeria, and acidified with two drops of concentrated HNO_3. The samples were collected directly from the wellhead into two separate clean plastic bottles. The samples were all kept at a low temperature of about 4°C in a cooler box and transferred to a refrigerator before being transferred to the Laboratory.

Laboratory Analysis

The chemical analyses were done for ions and trace metals. Inductively coupled plasma optical emission spectroscopy (ICP-OES) was used for the analysis. The water samples were first shaken a few times, and then roughly 15 ml were filtered through a 0.45 µm acetate cellulose syringe filter (VWR International LLC) and collected in clean centrifuge tubes. Matrix matching (2% HNO_3) standards were prepared by dilution of certified standards for all the elements of interest and used to obtain a four-point calibration curve. Yttrium (Y^{3+}) at a concentration of 5 ppm was used as an internal standard. Element carry-over effect was assessed by running samples containing only acid mix (no elements) and blank samples immediately after the highest standard was used for calibration purposes. Quality control (QC) samples containing the analytes of interest at known concentrations were prepared, and all samples were analyzed to check instrument performance throughout the sample analysis. Samples whose concentration exceeded the highest standard were adequately diluted to fit in the linear range of the calibration curve. Method quantification limit (MQL) for all the elements ranged from 0.0001 to 0.1194 mg/L.

Results and Discussion

The results of the water analysis and physical parameters were presented in Table 2 (a – c). The range and means of the different parameters in the water samples were also compared to the WHO standard (2008) (Table 2).

Groundwater chemistry

The pH has a range of 6.2 – 6.9 with a mean of 6.7 and this compare favorably with the WHO standard for drinking water (WHO, 2004). The mean pH value suggests that the water quality is close to the neutrality level (Olofinlade et al. 2018). pH controls the solubility and biological availability of chemical constituents of nutrients and metals. The EC ranged from 239.5 – 524.9 µS/cm with an average of 341.8 µS/cm. The lowest concentration of EC was recorded in sample FD2 collected around the Founders Lodge, while the highest concentration was observed in sample S17AH from Animal House. EC is directly linked to the concentration of ionized substances in water and, may be linked directly to excessive hardness and other mineral contamination. The EC of water is an indication of the amount of dissolved substances present in the water. This range of values was within the WHO standard recommended for safe water. TDS has values ranging from 142.7 – 323.1 mg/L with an average of 205.9 mg/L, which fell below the WHO standard, and these values fell within the excellent and palatable class (Rahman et al. 2015). According to Yetiş et al. (2019) and Akakuru et al. (2021), variation of TDS is greatly controlled by the anthropogenic activities and geochemical processes taking place within the groundwater repositories, and also the residence time of groundwater in a hydrogeologic unit (Alsuhaimi et al. 2019). Chloride ranged from 8.3 – 17.52 mg/L with a mean concentration of 13.11 mg/l (Table 1). Chloride has been described as the most common anion in natural water, and it occurs naturally in all types of water (WHO, 2017). The highest concentration of chloride in the study area was observed in sample S12A collected from Bogoro Research Center, while sample IPP obtained at the back of Fidelity Bank had the lowest Cl^-. All water samples have their chloride concentrations below the desirable limit of 250 mg/L. The concentration of HCO_3^- ranges from 1.61 to 3.30 mg/L, with a mean value of 2.5 mg/L in all water samples analyzed, below the typical global average for river water ($\approx 10-20$ mg/L) and the WHO threshold for palatability (250 mg/L). These values were below the WHO standard, which may be due to a lower concentration of dissolved solutes in water. The values of SO_4^{-2} ranged from 6.2 to 13.1 mg/L with a mean of 9.0 mg/L, which was within the WHO standard for drinking water. Elevated SO_4^{-2} concentrations can increase groundwater hardness and corrode copper plumbing; furthermore, excessive levels may lead to respiratory irritation and potential lung disease. The sodium (Na^+) concentration ranged from 10.6 – 21.3 mg/L, and its average value of 16.7 mg/L was within the WHO permissible limit of 200 mg/L. Calcium concentration ranged from 25.9 to 43.60 mg/L and had an average concentration of 31.60 mg/L. The highest concentration of calcium was found in sample S23 (at Fidelity Bank, ABUAD), while the lowest concentration was observed in location PAV2 at the School Sport Pavilion. Potassium (K^+) ranged from 17.7 to 34.3 mg/L with an average of 23.1 mg/L. The highest concentration of potassium in water samples in the study area was observed in sample S23 (Fidelity Bank), while sample S17AH (Animal House) had the lowest concentration. Fe^{2+} ranged from 0.5 to 1.2 mg/L, and its average value of 0.8 mg/L was within the WHO permissible limit for drinking water. The high concentration of Fe^{3+} in sample FDL1 (the Founder's Lodge). Mg concentrations generally ranged from 2.6 to 8.9 mg/L with an average concentration of 5.0 mg/L. The highest concentration of Mg was observed in sample CS1, collected in one of the wells located at the back of the College of Sciences, while the lowest concentration was observed in sample S15AH (Animal House). The presence of magnesium in natural water is primarily attributed to ion exchange processes occurring between groundwater and the minerals found in surrounding rocks and soils. The concentration of Mn^{2+} ranged from 0.16 to 0.5 mg/L with a mean of 0.3 mg/L. These were within the WHO standard for drinking water. Iron and manganese occur naturally in groundwater as a result of weathering of iron- and manganese-bearing minerals and rocks. The highest concentration was obtained sample CS2 from a well at the back of College of Sciences while the lowest concentration was from sample S1A BG. The concentration of Arsenic within the study area ranged from 0.003 to 0.1 mg/L, with a mean value of 0.009 mg/L, which was within the WHO permissible limit for drinking water. Cu concentration (0.097 mg/L) was lowest in sample S15 and highest (0.34 mg/L) in sample CS1 located at the back of the College of Sciences. This value was well above the WHO permissible limit for drinking water. Lead has a concentration (0.01 mg/L) higher than the WHO permissible limit in a sample taken from a well around S12. Another sample taken at location S23 (in Fidelity Bank) has the highest concentration of Zinc (0.32 mg/L), although all values obtained from this study area were within the WHO permissible limits for drinking water.

Table 1a: Results of the chemical composition of groundwater samples from the study area.

S/N	Sample Codes	Parameters					
		pH	EC (µS/cm)	TDS (mg/L)	Cl^- (mg/L)	HCO_3^{2-} (mg/L)	SO_4^{2-} (mg/L)
1	IPP1	6.820	285.620	161.280	10.195	1.612	6.717
2	IPP2	6.590	302.510	169.350	8.262	1.708	8.252
3	PAV 1	6.660	266.905	157.235	12.078	2.162	6.198
4	PAV 2	6.910	250.642	155.314	10.314	2.528	9.067
5	CS 1	6.530	402.150	279.610	12.272	2.713	7.150
6	CS 2	6.720	396.718	262.308	13.852	2.904	7.946
7	FDL 1	6.910	239.612	142.714	10.620	1.975	8.905
8	FDL 2	6.830	246.509	145.262	13.916	2.182	8.602
9	S11A FB	6.760	376.804	205.308	15.196	2.372	9.512
10	S23A FB	6.480	285.726	191.570	16.542	3.078	12.652
11	S15AH	6.940	524.916	323.160	12.908	2.618	10.906
12	S12A BG	6.280	385.230	204.520	17.524	3.279	13.185
13	S17AH	6.810	516.802	310.184	13.902	2.528	9.756
14	S1A BG	6.380	306.218	175.650	15.282	2.702	7.313

Table 1b: Results of the chemical composition of groundwater samples from the study area (Cont'd)

S/N	Sample Codes	Parameters					
		Na (mg/L)	Ca (mg/L)	K (mg/L)	Fe (mg/L)	Mg (mg/L)	Mn (mg/L)
1	IPP1	12.600	33.500	20.500	0.713	2.943	0.392
2	IPP2	10.900	29.800	18.700	0.652	2.658	0.517
3	PAV 1	17.300	26.500	25.100	1.066	6.133	0.310
4	PAV 2	19.200	25.900	22.400	0.914	4.642	0.362
5	CS 1	21.300	37.100	28.500	0.558	8.990	0.484
6	CS 2	18.600	35.300	26.900	0.795	6.574	0.517
7	FDL 1	13.200	28.400	22.500	0.942	3.728	0.193
8	FDL 2	15.700	30.300	18.600	1.215	4.263	0.208
9	S11A FB	10.600	36.800	20.700	0.847	6.135	0.375
10	S23A FB	20.900	43.600	34.300	0.686	5.943	0.320
11	S15AH	16.400	29.300	24.500	0.814	2.632	0.426
12	S12A BG	19.800	32.900	19.300	0.787	4.181	0.363
13	S17AH	15.600	26.500	17.700	0.658	5.366	0.211
14	S1A BG	17.200	31.300	21.500	0.902	4.190	0.167

Table 1c: Results of the chemical composition of groundwater samples from the study area (Cont'd)

S/N	Sample Codes	Parameters					
		As (mg/L)	Cu (mg/L)	Cr (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
1	IPP1	0.010	0.312	0.151	0.011	0.014	0.313
2	IPP2	0.015	0.195	0.110	0.009	0.009	0.276
3	PAV 1	0.007	0.208	0.093	0.003	0.018	0.191
4	PAV 2	0.003	0.185	0.107	0.007	0.012	0.156
5	CoS 1	0.011	0.343	0.190	0.009	0.007	0.214
6	CoS 2	0.008	0.298	0.132	0.005	0.003	0.203
7	FDL 1	0.010	0.202	0.063	0.002	0.002	0.176
8	FDL 2	0.013	0.244	0.090	0.010	0.005	0.159
9	S11A FBK	0.017	0.183	0.113	0.008	0.006	0.325
10	S23A FBK	0.010	0.196	0.098	0.003	0.012	0.188
11	S15AH	0.005	0.097	0.077	0.007	0.007	0.173
12	S12A BGC	0.008	0.130	0.102	0.011	0.010	0.106
13	S17AH	0.013	0.118	0.094	0.006	0.008	0.132
14	S1A BGC	0.009	0.165	0.173	0.008	0.005	0.110

Table 2: Summary of the geochemical results of water samples in the study area.

Chemical Parameters	Minimum	Maximum	Mean	W.H.O. Standard
pH	6.2	6.9	6.7	6.5 - 8.5
EC ($\mu S/cm$)	239.6	524.9	341.8	500
TDS (mg/L)	142.7	323.1	205.9	1000
Cl^- (mg/L)	8.3	17.5	13.1	250
HCO_3^{2-} (mg/L)	1.6	3.3	2.5	250
SO_4^{2-} (mg/L)	6.2	13.2	9.0	250
Na (mg/L)	10.6	21.3	16.7	200
Ca (mg/L)	25.9	43.6	31.6	300
K (mg/L)	17.7	34.3	23.1	12
Fe (mg/L)	0.5	1.2	0.8	1.0
Mg (mg/L)	2.6	8.9	5.0	50
Mn (mg/L)	0.16	0.5	0.34	0.02
As (mg/L)	0.003	0.01	0.009	0.01
Cu (mg/L)	0.097	0.34	0.21	0.05
Cr (mg/L)	0.06	0.17	0.11	0.1
Ni (mg/L)	0.002	0.01	0.007	0.1
Pb (mg/L)	0.002	0.01	0.008	0.01
Zn (mg/L)	0.11	0.3	0.19	0.04

Comparative study of groundwater quality with WHO standards

From Table 2, the mean values of the major cations were compared with one another and with the WHO standards. Among the cations, calcium showed the highest value (31.6 mg/l), this was followed by sodium (25.7 mg/l), then calcium (23.1 mg/l), while Fe (5.0 mg/l) has the lowest value (Figure 3). The dominance of Ca^{2+} and Na^+ is typically attributed to the breakdown of plagioclase feldspar (common in silicate rocks like granite) or the dissolution of calcite and dolomite (in sedimentary rocks) (Meybeck, 1987).

This demonstrates an interaction between the groundwater and the underlying bedrock weathering. It could be concluded that the origin of these cations is geogenic in nature. Ca and Na have their mean values below the WHO permissible limit for drinking water. The values of anions and dissolved solids measured in the water samples are within the WHO permissible limit for drinking water (Figure 4). Conversely, considering and comparing the mean of all the analyzed trace elements that are far greater than the WHO standard (0.01 mg/l) is recommended for safe drinking water. Cu has the highest mean value, then Zn, and this is closely followed by Cr, while Pb has the least mean value (Figure 5). The mean values of Ar, Cu, Cr, Ni, Pb, and Zn were compared with the WHO standards for safe drinking water, and it was discovered that Cu, Cr, and Zn recorded values above the WHO permissible limit.

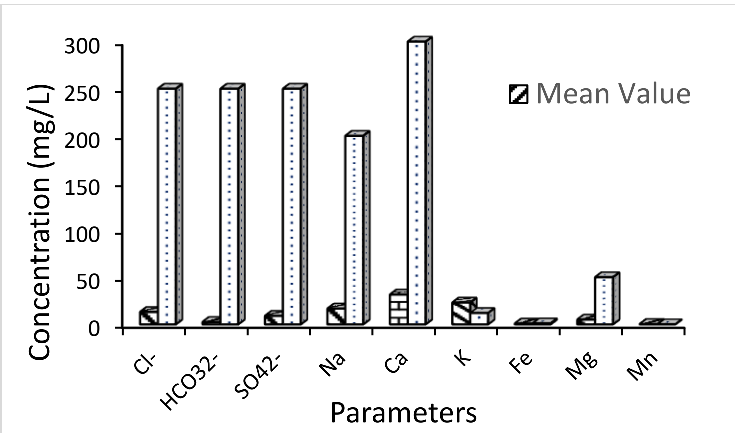

Figure 3: Comparison of the concentration of the mean values of with their WHO standard.

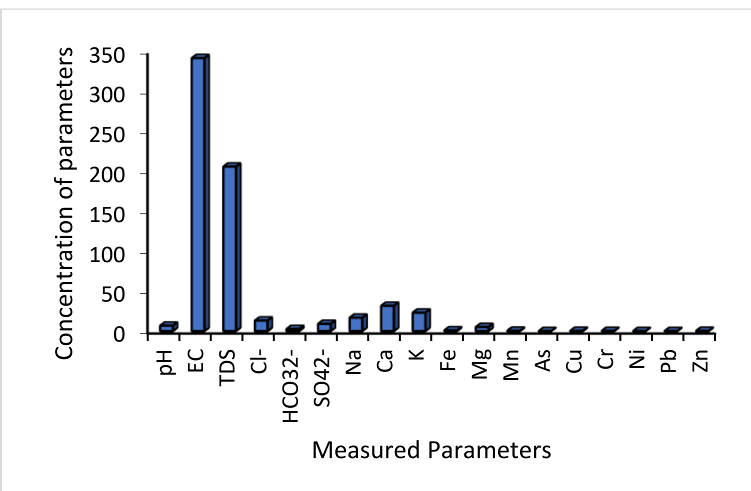

Figure 4: Comparison among the mean values of major elements.

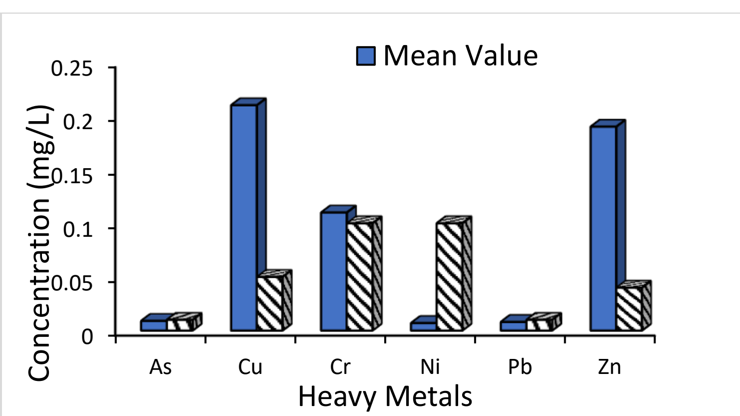

Figure 5: Comparison of the concentration of the mean values of heavy metals with their WHO standard.

Schoeller representation

Figure 6 depicts the chemical composition of groundwater collected from the research area. The left and right sides of the image show the mean concentrations of cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (SO_4^{-2}, Cl^{-}, and HCO^{-}), respectively. The plot shows that Ca^{2+} concentrations exceed those of other cations, while Cl^{-} concentrations exceed those of other anions. The most abundant ions in sequence are Ca2+> Na+ > K+ > Mg2+ for cations and $Cl^{-} > SO_4^{-2} > HCO^{-3}$ for anions, showing that inorganic salts are dominant in the research site.

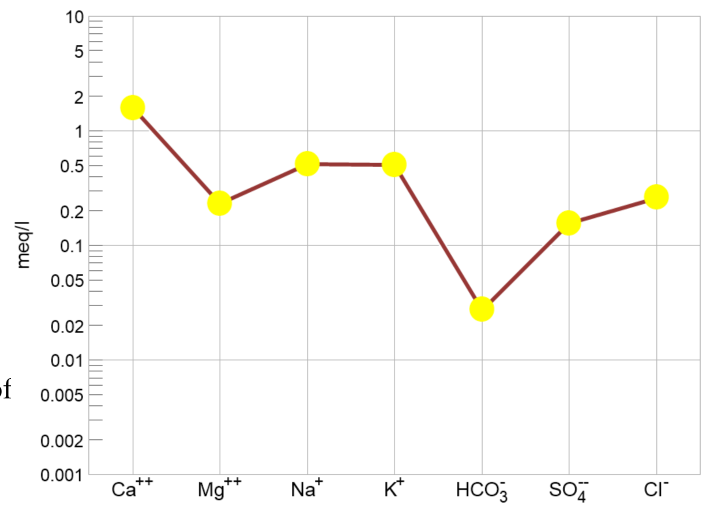

Figure 6: Schoeller representation of the mean concentrations of major ions in groundwater samples.

Piper plot for hydrochemical facies

The hydrochemical properties of groundwater are often determined by major ions and can be visualized on a Piper diagram (He & Li, 2020; Jayathunga et al., 2020; Ma et al., 2022; Zhang et al., 2020). The Piper diagram presents two separate trilinear plots sandwiched with a diamond-shaped central plot (Figure 7). The anions and cations were plotted on the right and left sides of the diamond, respectively. In this study, all samples fell into Chloride anion facie type. While no single cation dominates the entire dataset, the Ca^{2+} facies type is the most prevalent, representing 40% of the analyzed groundwater samples. The remaining 60% of the samples fell into the no-dominant type zone. This indicates that the hydrochemistry of the studied samples is characterized by alkali, suggesting that weathering and mineral dissolutions are the predominant conditions in the study site (Gugulothu et al., 2022). The Piper diagram reveals that the majority of samples plot within the Calcium-Chloride water type (Zone 6), with a single sample falling into the Mixed water type (Zone 9). This hydrochemical signature indicates that alkaline earths exceed alkalies, and strong acids predominate over weak acids across the study area.

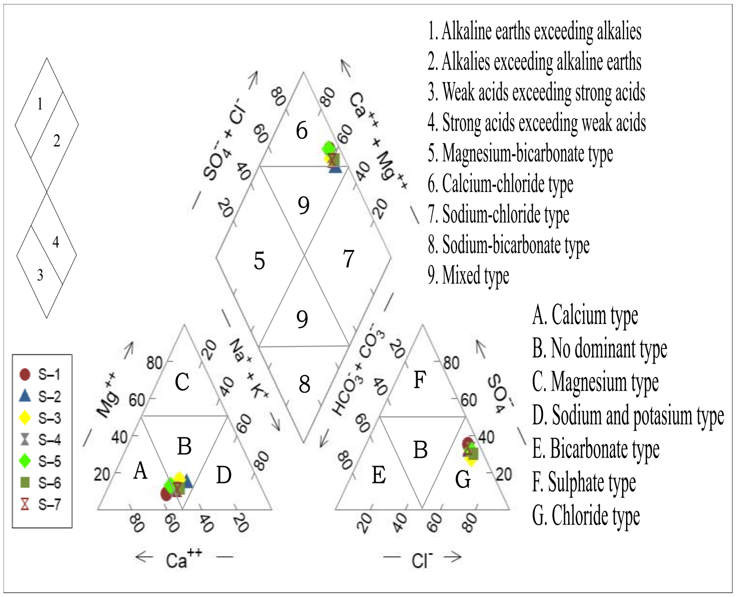

Figure 7: Piper representation of the hydrochemical facies of the studied samples

Regarding drinking water quality, the groundwater samples were generally classified as fresh based on electrical conductivity and Total Dissolved Solids (TDS) values obtained. Most samples were found to be suitable for domestic consumption. However, elevated concentrations of some of the metals, such as Manganese (Mn), Zinc (Zn), Copper (Cu), Chromium (Cr), and Nickel (Ni), as evident from the concentration values which exceeded the (WHO) standards in certain locations, render the water unfit for drinking.

Conclusion

This study made use of in-situ and laboratory analysis of seven (7) water samples obtained from boreholes within Afe Babalola University, Ado-Ekiti (ABUAD), Ekiti State, Southwestern Nigeria. The suitability of groundwater for various applications was evaluated by comparing physicochemical and hydrochemical analytical data against the World Health Organization (2004) guidelines. The resulting hydrochemical facies suggest that groundwater chemistry in the study area is primarily governed by a combination of meteoric precipitation—reflected in low chloride and bicarbonate levels—and anthropogenic inputs, evidenced by localized heavy metal enrichment. Based on the electrical conductivity (EC) and Total Dissolved Solids (TDS), the groundwater from the study area fell within the fresh water categories. While the general physicochemical parameters suggest that most groundwater samples are suitable for consumption, elevated concentrations of Zinc (Zn), Manganese (Mn), Copper (Cu), Chromium (Cr), and Nickel (Ni) at specific locations exceed WHO drinking water standards. Consequently, these localized heavy metal enrichments render the water at those sites unfit for human consumption. While the groundwater in the study area remains generally potable, it exhibits evidence of heavy metal enrichment derived from anthropogenic activities. Consequently, a comprehensive Environmental Impact Assessment (EIA) is recommended to quantify the extent of this contamination and implement mitigation strategies to prevent further environmental degradation.

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