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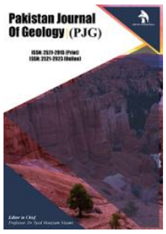

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RESEARCH ARTICLE

ASSESSMENT OF GROUNDWATER QUALITY AND IDENTIFICATION OF GEOCHEMICAL SOURCES IN SELECTED AQUIFERS OF IKPESHI, IYUKU AND ENVIRONS, EDO STATE, NIGERIA

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ABSTRACT

The study investigated and assessed groundwater quality and sources of dissolved geochemical constituents in groundwater within Iyuku and Ikpeshi, Edo State. A total of 32 groundwater samples were obtained from selected boreholes in Ikpeshi and Iyuku and environs. The physico-chemical parameters of the groundwater samples were analyzed using Atomic absorption spectrophometer (AAS) Bulk scientific. The result show that pH ranged from 4.7 to 7.6, EC ranged from 12.24, TDS ranging from 15.40 to 744 mg/l and was classified as fresh water with TDS<1000mg/l. The concentration of the major cation was in the following order $Mg^{2+} > K^{+} > Ca^{2+} > Na^{+}$. The order of anions dominance/ abundance in groundwater was $Cl^{-} > SO_4^{2-} > HCO_3^{-} > NO_3^{-} > PO_4^{-}$. The mean result indicated that the hydrogeochemical constituents in the groundwater were within WHO (2015) standard except $Mg^{2+}$and K^{+}. The result of Results of correlation analysis, principal component analysis (PCA) and hierarchical cluster analysis suggests that the major variations of hydrochemical constituents in the groundwater could be influenced geogenic sources which includes; mineral dissolution of carbonate and silicate rocks, reverse cation exchange and sea water intrusion. However, the presence of NO^{3-}, PO_4^{3-}, and SO_4^{2-} also suggest anthropogenic influences linked to poor well depletion, improper waste disposal and surface run off due to application of fertilizers. The result of spatial distribution of cations, designated the southwestern part of the study area as major hotspots of Mg, K, Ca, and Na. The coliform count ranged from 11-20 cfu/ml and with a mean value of 14.03 cfu/ml, exceeded the Nigerian Standard Drinking Water Quality guideline. This indicates that some of the groundwater wells may have be contaminated with faecal coliform due nitrogenous wastes and poor septic conditions. It is therefore recommended that water, particularly those obtained from hand dug wells should be treated before domestic consumption. Further research on groundwater sources should be carried out by delineation of the prevalent hydrochemical facies using various ionic plots, piper, gibbs and schoeller models. Also health risk assessment studies should be carried out in the study area. Information about geochemical processes responsible for the dominance of some of these cations in groundwater be evaluated.

KEYWORDS

Borehole, geogenic, groundwater sources, domestic uses, spatial maps, contamination

1. INTRODUCTION

Water a precious natural resource that spans about 70% of the Earth's surface. Safe drinking water is of crucial importance for the overall health of humans and other organisms. It represents the largest and most readily accessible freshwater resource on planet and a driver of economic development. Groundwater quality depends on the quality of precipitation and any changes it undergoes from time of infiltration to discharge. The quality of water is proportional to its chemical, physical and biological characteristics which are defined by the amount of dissolved soluble constituents in the water (Zaidi et al., 2015). The compositional and contaminant controlling groundwater quality depend not only on the hydrogeological factors, characteristics of aquifer but also on human activities such as industrialization, urbanization (Emile et al., 2021). Groundwater quality is increasingly under threat by contaminants derived from geogenic and anthropogenic sources. The quality of water might degrade owing to the leaching of geogenic contaminants as a result of weathering in mining operations. Also as water percolates inorganic and organic contaminants might be transferred to infiltrating recharge water. The specific type of contaminants in an environmental media is influence by the activities occurring at the sites. The range of contaminants concentration in groundwater in an area is also usually influenced by the operations carried out in the locality and the waste disposal patterns employed (Zaidi et al., 2015). The presence of industrial minerals such as granite, marble, limestone and quartzite schist in the area and the mine wastes generated from their exploitation during mining might pose serious risk to groundwater quality. In most developing countries, access to clean portable water is often difficult due to inefficiency on the part of water corporations over time to convey water to various homes for domestic application. In order to meet daily water demands, many residents has resorted to developing boreholes (deep well) and hand dug wells which are quite affordable. Lack of care and improper maintenance of Boreholes and Hand dug wells could compromise water quality. Spatial distribution of major ions is influenced by long term geological history of the region, land use and human activities prevalent in the area. These ions are essential in delineation of hydrogeochemical facies and the relationship between dissolved constituents and aquifer matrix (water rock interactions)

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Although previous studies have investigated the impact of mining on water quality in the locality, the main sources of dissolved chemical constituents in groundwater remains unresolved (Osiyoku et al., 2023; Nwachukwu et al., 2018; Maju-Oyovihowe). Also the use of kriging interpolation technique to determine the distribution pattern of geochemical constituents in groundwater have not been utilized in the area. Constraining these sources is vital for understanding hydrogeochemical processes and potential contamination pathways affecting groundwater quality. This study aims to fill this gap by employing geochemical spatial variation plots and multivariate statistical techniques to determine the natural and anthropogenic contributors to groundwater composition.

2. Materials and Methods

2.1 The Study Area

The study area is one of the fast rising industrialized towns in Edo State due to the quantum of mineral resources domiciled in Ikpeshi, Iyuku and environs. It falls within latitudes 07 08'N – 070 4'N and longitudes 006 11' E – 006 14' E respectively. The area is accessible through Jattu road while Iyuku is accessed from the Auchi- Abuja express way.

2.2 Geology Of The Study Area

The study area lies beneath the Precambrian Basement Complex rocks that belongs to the southwest basement complex of Nigeria and Cretaceous sediments. The Basement Complex rocks consist of migmatite gneisses, metasedimentary rocks (calc silicate gneisses, quartzite schists, marbles, amphiboles), metaconglomerates and porphyritic granites while the Cretaceous sediments are represented by the Lokoja- Basange formation ((Imeokparia and Emofurieta, 1991; Ocan et al., 2003). The metasedimentary rocks found in the area shows evidence of polyphase deformation that has been changed by the processes of thermo tectonic orogenesis (migmatitic and granitic processes) leading to creation of faults, mineral lineation and foliations, strike-slip, joints. There are some schists foliated in the N-S direction others in the NW-SE orientation within the area of study. Additionally present in the granite body are quartz veins, joints and fractures. There are also presence of quartz veins, joints and fractures in the granite body. The Igarra granites intruded the most easterly schist belts in Southwestern Nigeria (Turner, 1983).

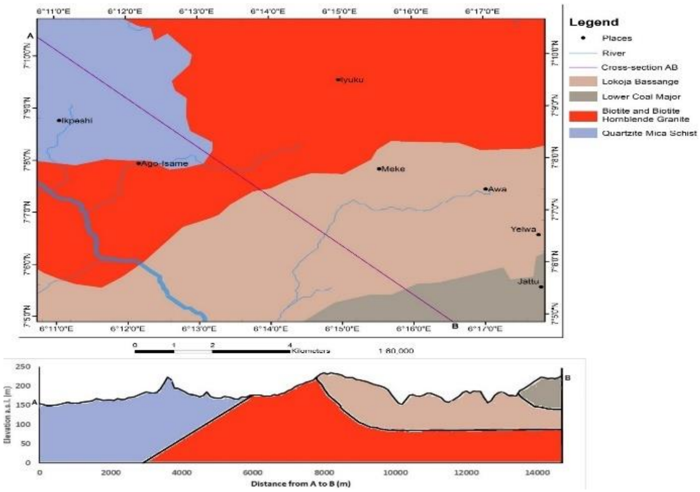

Figure 1: Geological map of the study area

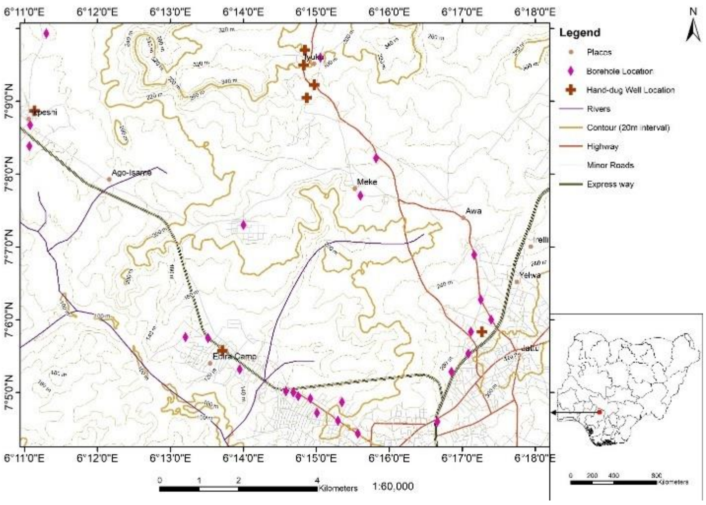

Figure 2: Sampling location map

Thirty-two (32) groundwater samples were randomly collected based on the availability of boreholes and hand dug wells in the area. Twenty-five (25) water samples from borehole and seven (7) water samples from hand dug well (HDW). The water samples were taken in clean plastic bottles that have been treated with 2 ml of concentrated nitric acid and labeled accordingly. The physical chemical parameters of groundwater samples were determined in accordance with the American Public Health Associations recommended standard operating procedures (APHA, 2012). The pH and Electrical conductivity (EC), and TDS, were measured immediately at the point of sampling using pH, EC, and TDS meters respectively. $Ca^{2+}$and Mg^{2+} contents were ascertained using an atomic absorption spectrophotometer (AAS). The flame photometer was used to determine the concentration of Na^{+}, K^{+} while volumetric techniques were used to analyze the bicarbonate (HCO_3^{2-}) and chloride (Cl^{-}) compounds. Microbiological examination of the water samples was done by plate count method using Mac-Conkey agar as growth medium incubated for 24hrs at 37^{o}C (APHA,2012).

2.3 Geospatial Modelling

The spatial distribution of major cations in the groundwater sample within the study area was achieved using the kriging interpolation techniques (Kalu and Iziyon 20).

3. Results and Discussion

3.1 Groundwater Suitability to Drinking

The suitability of groundwater for drinking in the area was assessed by comparison of the dissolved physicochemical parameters in the water samples with WHO, 2015 permissible standard.pH is an important water parameter that affects water chemistry including alkalinity, speciation and solubility of elements (Jehan et al., 2019). The result of pH of groundwater samples is presented in Tables 1 and 2. The pH ranged from 5.7 in Ago-Isiame to 7.6 in Iyuku with an average value of 6.18. The pH values of the groundwater signified weak acidity. The mean value is lower than those recorded by (Maju-Oyovwikowhe and Emofurieta 2021). The variation in pH could be attributed to the type of rock or sediment surrounding travel pathway of infiltrating recharge water (Zaidi et al., 2015). The mean value of EC is 235.79 μS/cm and ranged from 22 μS/cm (Meke) - 1063 μS/cm (Ikpeshi) (Tables 4.1 and 4.2). It was found that the average EC value across all sampling locations was less than the recommended threshold of 1400 μS/cm, suggesting that, overall, the groundwater in the study area is suitable for consumption (WHO, 2015). However, the average EC value was lower than those reported by (Maju-Oyovwikowhe and Emofurieta, 2019; Nwachukwu et al., 2018; Egbueri, 2020). They reported that high EC ranging from 250 and 1600 μS/cm can be linked to salt water intrusion and anthropogenic sources (Maju-Oyovwikowhe and Emofurieta, 2019). They reported that the varying concentrations of EC ranging from 99 to 2000 μS/cm in their study area could be attributed to urbanization and industrial wastes (Nwachukwu et al., 2018). They opined that intense mineral exploitation is a major contributor to elevated EC in groundwater (Singh et al., 2017). Therefore, the high value of EC as observed in Ikpeshi could be attributed to the leaching or dissolving of aquifer minerals or mixing of saline water with fresh water (Hounslow, 2018). Total dissolved solids (TDS) in groundwater are influenced by both geogenic and anthropogenic sources. High TDS is responsible for bitter or salty taste of groundwater (Shehzadi et al., 2015). In this study the TDS ranged from 15.40 (Meke) -744 (Ikpeshi) mg/L (Tables 1 and 2). The average total dissolved solids (TDS) concentration was observed to be 165 mg/L. However, the mean TDS value was less than the 500mg/L set by World Health Organization, and the Nigerian Standard for Drinking Water Quality, indicating that the water is generally suitable for domestic consumption in most locations (WHO, 2015; NSDWQ, 2015). However the mean TDS value (165mg/L) was lower than those reported in previous research. They observed a higher TDS values in groundwater samples analyzed from similar geological terrain (Basement complex), suggesting a greater influence of lithological dissolution or anthropogenic inputs in their area of study (Nwachukwu et al., 2018). Similarly, reported that elevated TDS levels in groundwater could be attributed to severe chemical weathering and water-rock interactions (Maju-Oyovwikowhe and Emofurieta, 2021). The low TDS value recorded in the study area might be linked to shorter residence time, slow rate of mineral dissolution and possibly less human impact. The highest TDS value recorded at Ikpeshi (744 mg/L) may be associated with enhanced mineral dissolution, particularly carbonate rocks such as limestone and marbles or increased precipitation rates. Ikpeshi is known for quarrying activities, which may also contribute to elevated TDS through leaching of rock materials into groundwater. In contrast, the significantly lower TDS at Meke (15.40 mg/L) suggests a less mineralized aquifer, possibly recharged by recent precipitation with minimal subsurface interaction. The groundwater in the research area is classified into four groups based on TDS concentrations by (Freeze and Cherry, 1979): fresh (TDS< 1,000 mg/L), brackish (TDS> 1,000 mgL), saline (TDS> 10,000 mg/L) and brine (TDS> 100,000 mg/L). In this study Hardness ranged from 12 (Iyuku) to 24 (Ikpeshi) mg/L with a mean value of 17.15 mg/l that fell below WHO NSDQW standard. They classified water based on its calcium carbonate contents (McGowwan, 2000). The groundwater in the sampling locations in the study area can therefore be classified in the soft water category. The finding is in agreement who classified groundwater in granite dominated terrain of Ikere: Ekiti as soft water (Talabi, 2017).

The abundance of cations in order of arrangement was $Mg^{2+} > K^{+} > Ca^{2+} > Na^{+}$. Tables 1 and 2 revealed that Mg^{2+} was the dominant cation in the groundwater ranging from 2.93 (Ago-Isiame) to 8.25 (Ikpeshi) mg/L with a mean value of 5.08 mg/L and was found below the 150 mg/L benchmark of the (WHO, 2011). These values were higher than those reported by (Osiyoku et al., 2023). The high amount of magnesium in the groundwater could be attributed to rate of weathering of dolomites and silicates minerals (Eyankware, 2019). The mean concentration of K^{+} in the groundwater samples was 2.59 mg/L ranging from 1.28 to 3.87 mg/L and was within the safe drinking water regulations of (WHO, 2015). Although potassium is an essential nutrient, an excessive amount of it can have laxative effects. Sources of potassium in groundwater have been linked to ion exchange processes, orthoclase, microcline and clay minerals (Hem, 1985).

The calcium (Ca) concentration in the groundwater ranged from 0.42 (Ago-Isiame) to 1.87 (Ikpeshi) with mean value of 1.12mg/L. Geogenic sources of Ca includes plagioclase feldspars and carbonate minerals. The sodium content ranged from 0.12 (Ago-Isiame) to 0.32 (Iyuku) with mean of 0.25mg/L. The sources of Na have also been linked to carbonates and feldspar minerals respectively. Out of all the major anions, chloride Cl had the highest mean concentration of 62.54 mg/L. The mean concentration was found greater than those reported and below the WHO recommended guideline value of 500 mg/L (Maju-Oyovwikowhe et al., 2020). A significant anion found in water is chloride. Chloride in groundwater is primarily caused by the erosion and weathering of crystalline rocks. The main minerals responsible for its presence in groundwater include sodalities, apatite, micas and hornblende. High concentration of chloride in water may results from contamination by sewages, seawater and saline residues in soil (Hem,1985). Sulphates and nitrates were among the fewer dominant anions with mean values of 1.36 mg/L and 0.15 mg/L. The order of anions dominance/ abundance in groundwater was $Cl^{-} SO_4^{2-} > HCO_3^{-} > NO_3^{-} > PO_4^{-}$. NO^{-3} is commonly associated with fertilizers and organic wastes. It is quite mobile and soluble and its concentration in groundwater is influenced by leaching through soils by infiltrating recharge water. In this study, the concentration of NO^{-3} ranged from 0.13 to 0.24 with a mean value of 0.15mg/l. It was observed that the concentration of TDS, Hardness, Mg, Ca, and Na in groundwater obtained from borehole samples were higher than those obtained from hand dug wells. The variations could be attributed to longer residence time of water in drill depth of the boreholes, thus, reflecting the long term geological history of the area. However, Nitrates and Chlorides were more concentrated in the groundwater obtained from hand dug wells compared to groundwater collected from boreholes. This possibility could be linked to improper covering of the wells. Nitrate sources in HDW can be linked to its use in production of fertilizers, while chloride sources have been attributed to atmospheric deposition and irrigation return flow (Elemile et al., 2021). The results of bacteriological examination of the groundwater samples revealed that coliforms were present in six (6) groundwater samples; four (4) in hand dug wells and two (2) in borehole water. The values ranged from 11-20 cfu/ml with a mean value of 14.03 cfu/ml that exceeded the acceptable standard in drinking water (WHO, 2004). Since the aquifer in the area is quite shallow, the presence of these coliforms in the samples could be related to potential leaks from adjacent septic tanks, effluents from sewage, and agricultural runoffs (Tijani, 2003).

Table 1: Summary of Univariate Statistical Analysis for Physico chemical parameters and heavy metals in Groundwater Samples obtained from the Study Area.

	Minimum	Maximum	Standard Deviation	Standard Error	Mean	NSDWQ	WHO (2015)
pH	4.7	7.63	0.6639	0.1174	6.1853	6.85-8.5	6.5-8.5
EC(μS/cm)	22	103	270.4099	47.8022	235.7938	1000	900
TDS (mg/l)	15.4	744	189.1990	33.4460	165.0031	500	1000
SO_4 (mg/l)	0.38	1.95	0.3678	0.0650	1.3666	-	-
PO_4 (mg/l)	0.225	0.064	0.0405	0.0072	0.1475	-	-
NO_3 (mg/l)	0.242	0.136	0.0232	0.0041	0.1512	50	5
Cl (mg/l)	5.7	288.38	73.0116	12.9068	62.5447	100	250
Hardness	12	24	2.3295	0.4118	17.1563	150	500
HCO_3 ()	0.1	2.2	0.5531	0.0978	0.8719		
Ca (mg/l)	0.42	1.87	0.3716	0.0657	1.1244	2.49	1.87
Mg (mg/l)	2.93	8.25	1.3644	0.2412	5.0888	2.06	2.06
K (mg/l)	1.28	3.87	0.7299	0.1290	2.5975	1.41	1.41

Table 1 (cont): Summary of Univariate Statistical Analysis for Physico chemical parameters and heavy metals in Groundwater Samples obtained from the Study Area.

Na (mg/l)	0.12	0.37	0.0671	0.0119	0.2463	8.70	8.70
Coliform Cfu/ml	11	20	3.48	0.2118	14.03	10	0

Table 2: Groundwater classification and categorization

Groundwater $CaCo_3$ content	**Classification**
< 60 mg/L	Soft
(60-120 mg/L)	moderately hard
(>180 mgL)	very hard

Source: (McGowwan, 2000)

3.2 Spatial Distribution of Major Cations in the Groundwater

The kriging and interpolation techniques was used to provide a better prediction and fitting of strong variability and anomalous conditions of dominant cation in the groundwater. The results of geospatial modelling of magnesium ion (Mg^{2+}) as shown in Figure indicates that the south-western region of the study area comprising of Ebira camp and Ikpeshi is a hotspot for magnesium enrichment. The highest magnesium concentration in the groundwater, represented by the red color on the map, exceeds 7.01mg/L. The magnesium concentration may be associated with both geogenic contributions such as weathering; gradual replacement of calcium by magnesium in the formation of dolomite ($CaMg(CO_3)^2$); leaching of magnesium rich sediments and agricultural practices prevalent in the area (Tiwari et al., 2010). Mg^{2+} is an essential activator of enzymes, it is however cathartic and diuretic (Jehan et al., 2019).

The spatial map of Potassium (K^+) in Figure indicates that the Southern region comprising mainly of Ebira camp in the study area is the major hotspot for K^+ (Potassium) contribution as indicated by the pink coloration in the spatial map. The high concentration of potassium concentration in this area could be due to ion exchange process, weathering of orthoclase, microcline and clay minerals (Hem, 1985).

As depicted in Figure the predicted groundwater Calcium concentration could exceed 1.60mg/l., with the Southwestern region depicted by dark brown color emerging as the primary hotspot for calcium enrichment. The high calcium content in this area could be linked to the weathering of carbonate rocks (dolomite and marbles) present in Ikpeshi and plagioclase feldspars found in Iyuku and environs. High calcium concentration impairs the quality of groundwater and may cause kidney stones in the bladder (Keesari et al., 2016). These values were lower than those reported

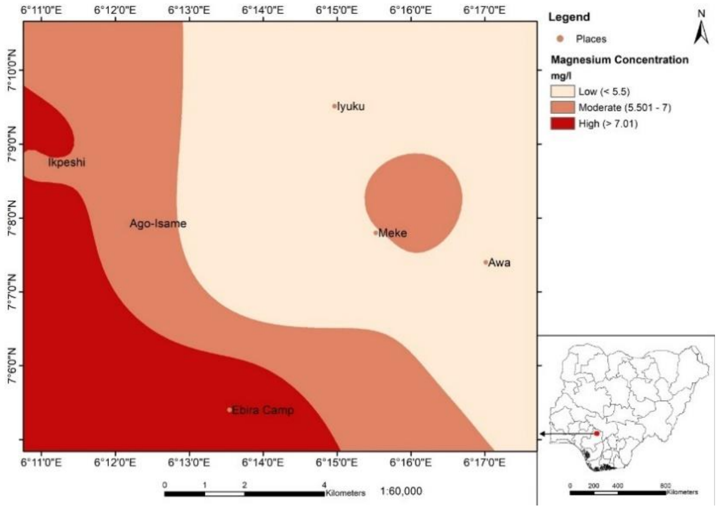

Figure 3: Spatial distribution of Magnesium (Mg)

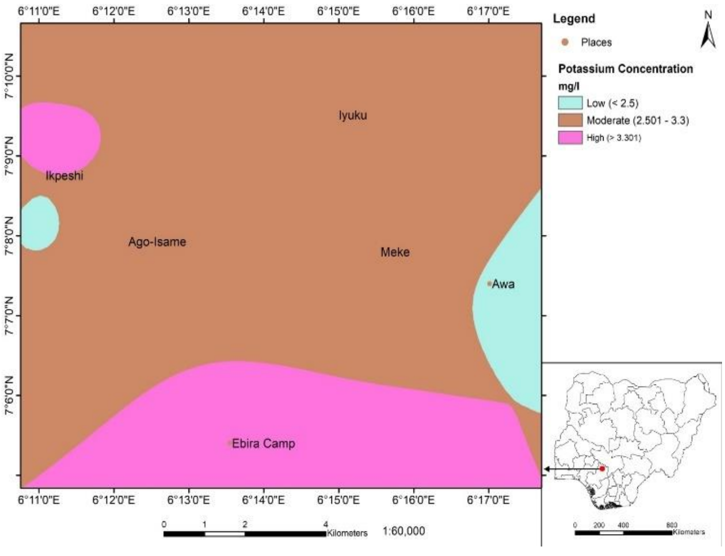

Figure 4: Spatial distribution of Potassium (K)

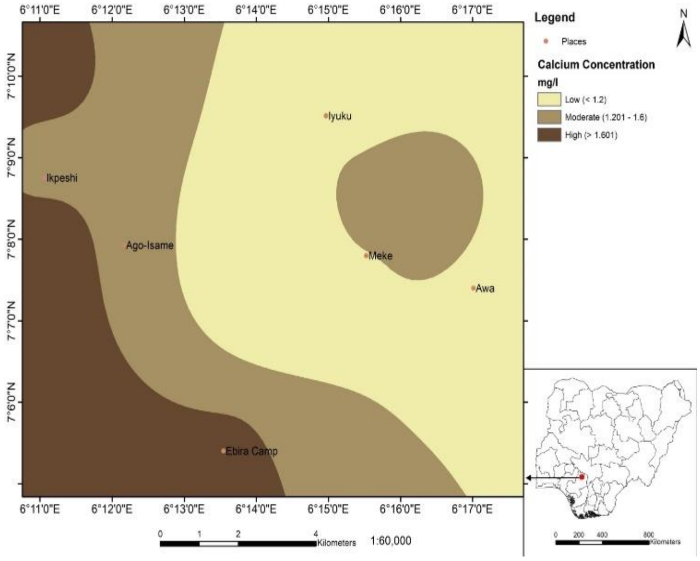

Figure 5: Spatial distribution of Calcium (Ca)

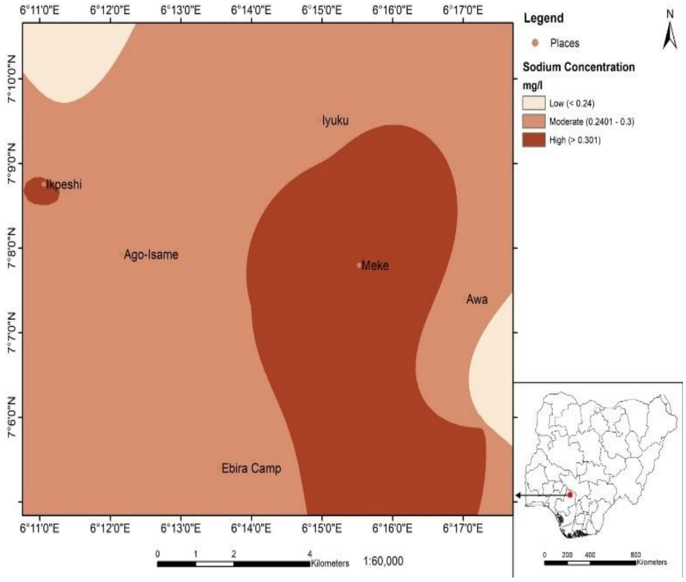

Figure 6: Spatial distribution of Sodium (Na)

The spatial map of sodium (Na) presented in Figure 6 suggests that the highest sodium concentration were observed in Meke, Iyuku and parts of Ebira camp in the study area. These areas depicted by reddish brown colour forms a contiguous zone which extends from central part to the Southeastern parts and it indicates that the concentration of sodium > 0.30mg/l. Previous research has shown that the most common sources of sodium (Na) in drinking water are geogenically linked to erosion of salt deposits, ion exchange processes, evaporation of salt enriched groundwater and mineral dissolution. While anthropogenic sources of Na in water may be attributed to water treatment chemicals, poor sewage treatment (Jehan I 2019; WHO 2011).

3.3 Sources of Dissolved Constituents in Groundwater samples

3.3.1 Correlation

Pearson correlation analysis was used to evaluate and established the sources of dissolved hydrochemical constituents in the groundwater as presented in Table 3. Correlation coefficient < 0.5 was considered weak, (0.5-0.75) as moderate and (> 0.75) as strong.

In this study, it was observed that EC had positive significant correlation with TDS, Cl^-, HCO_3^-. This result indicated they mainly originate from similar sources such as water rock interactions and sea water intrusion influenced by residence time (elapsed time of water since infiltrating through the rock) and they contribute to pH variation in the groundwater (Rajmohan and Elango, 2004). Similarly, Cl^- had a positive correlation with HCO_3, Ca, Mg, K, and Na indicating similar transport mechanisms and belongs to the same formation linked to geogenic origin. The presence of these elements in the groundwater also suggests mineral dissolution. The main minerals responsible for the presence of Cl^- in groundwater include sodalities, apatite, micas and hornblende. High concentration of chloride in water may also be attributed to contamination by sewages, seawater and saline residues in soil (Hem,1985).

The strong relationship between Ca and Mg suggests they shared similar sources linked to weathering of rocks in the study area (Talabi, 2017). Geogenic sources of Ca includes plagioclase feldspars and carbonate minerals. The sources of Na have also been linked to carbonates and feldspar minerals.

3.3.2 Principal components Analysis

Principal component analysis provides insights pertinent to source identification and the contributing factors of the dissolved hydrochemical constituents in the groundwater (Giri and Singh, 2023). The results of principal component analysis (PCA) of hydro-chemical constituents in groundwater after being normalized by the verimax rotation is as shown in Table 5 revealed four principal components were extracted; PC1, PC2, PC3, and PC4 contributing to the total variance of 79.358 % PC1 accounting for 43.712% of the total variance show high loadings of (> 0.6), EC, TDS, PO4, Ca, Mg, Na, K and Cl . The implication is that they share similar sources that may be attributed to the geological history of the area such as sea water intrusion, mineral dissolution and reverse cation exchange (Ekwere et al., 2012). This findings also corroborates the result of correlation of hydro-chemical constituents analyzed in this study. PC2 contributed 16.035 % of the variance. PC3 exhibited high loadings of NO_3 in the groundwater indicating influence of land use agricultural practice, nitrogenous organic waste and industrial effluents (Salem et al., 2021). PC4 contributing 8.432 % indicates high loadings of hardness, which could be attributed to elevated concentrations of Ca and Mg in the water. They reports that increase in water hardness is due to dissolution of carbonate and silicate minerals (Elemile, et al., 2021).

Table 3: Total variance and component matrix of dissolved hydrochemical constituents in groundwater

Component	Initial Eigenvalues			Elements	Components			
	Total	% of Variance	Cumulative %		1	2	3	4
1	5.683	43.712	43.712	pH	0.463	-0.283	-0.174	-0.096
2	2.085	16.035	59.748	EC	**0.878**	-0.433	0.041	0.011
3	1.453	11.179	70.926	TDS	**0.878**	-0.433	0.041	0.012
4	1.096	8.432	79.359	SUL	0.145	0.091	0.821	-0.028
5	.831	6.390	85.749	PHOS	**0.667**	0.319	0.120	-0.264
6	.661	5.081	90.830	NIT	0.167	0.280	**0.770**	0.284
7	.395	3.038	93.867	CHL	**0.876**	-0.436	0.034	0.009
8	.344	2.647	96.514	HAR	0.464	0.318	-0.274	**0.700**
9	.287	2.211	98.725	BICAR	0.570	-0.660	0.117	0.104
10	.104	.803	99.528	Ca	**0.798**	0.456	-0.083	0.229
11	.061	.472	100.000	Mg	**0.811**	0.436	-0.187	0.152
12	5.600E-5	.000	100.000	K	**0.697**	0.444	-0.073	-0.398
13	2.050E-6	1.577E-5	100.000	Na	**0.589**	0.344	-0.035	-0.448

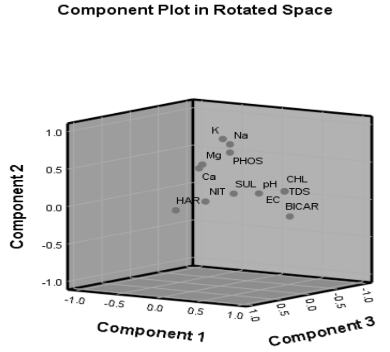

Figure 7: Principal component analysis plots

3.3.3 Hierarchical cluster analysis (HCA)

Cluster analysis is used to determine the relationship among the variables in groundwater, thereby grouping variables of the same geochemical source (Yang et al., 2020; Babu et al., 2013). This relationship is determined by evaluating the distance between the variables. In this study the result of cluster analysis as presented in Figure 6 indicate that five (5) clusters. Group one show strong clusters of Phosphates, Nitrates, Na, Sul, and Ca, indicating that these variables share the same geochemical origin attributed to anthropogenic sources such as application of fertilizers, mine effluents and nitrogenous organic wastes linked the groupings of Phosphates, Nitrates, Na, Sulphates, and Ca, to industrial effluents, surface run off (Salem et al., 2021). The second cluster placed Bicarbonate ($HCO3^-$) and potassium (K) in the strong relationship, indicating they share similar geochemical sources linked to weathering of carbonate rocks (marbles and dolomitic marbles) in the study area. The third groups suggest that pH, Mg and Hardness originates from the same source. This implies that Mg might contribute to hardness of the groundwater, and that pH influences the concentration of the dissolved ions in the water.

The fifth cluster also show that EC and TDS originates from the same area, indicating that they contributes to the overall presence of dissolved ions in the groundwater.

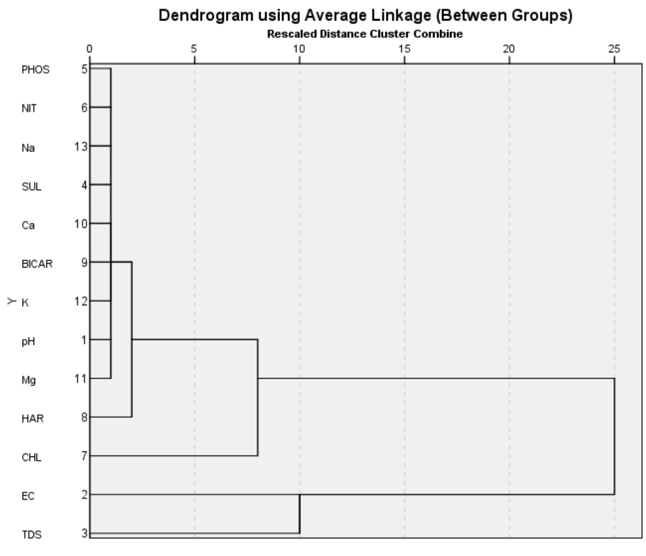

Figure 8: Hierarchical Cluster Analysis of the hydrogeochmical constituents

Table 4: Correlation of physicochemical parameters analyzed in groundwater samples

	pH	*ECµS/cm*	*TDS*	*SO4 Mg/l*	*PO_4 Mg/l*	*NO_4 Mg/l*	*CL Mg/l*	*HAR*	*HCO_3 Mg/l*	*Ca Mg/l*	*Mg Mg/l*	*K Mg/l*	*Na Mg/l*
pH	1												
EC	0.42	1											
TDS	0.42	0.99	1										
SO_4	0.03	0.08	0.08	1									
PO_4 Mg/l	0.11	0.45	0.45	0.11	1								
NO_4 Mg/l	-0.10	0.07	0.07	0.45	0.22	1							
CL Mg/l	0.42	0.99	0.99	0.07	0.45	0.07	1						
HAR	0.10	0.27	0.27	-0.06	0.19	0.08	0.26	1					
HCO_3 Mg/l	0.33	0.73	0.73	0.12	0.16	-0.01	0.72	0.08	1				
Ca Mg/l	0.28	0.47	0.47	0.10	0.57	0.24	0.46	0.63	0.22	1			
Mg Mg/l	0.28	0.50	0.50	0.03	0.56	0.12	0.49	0.61	0.19	0.92	1		
K Mg/l	0.30	0.41	0.41	0.06	0.60	0.13	0.41	0.16	0.03	0.67	0.73	1	
Na Mg/l	0.11	0.36	0.36	0.16	0.49	-0.01	0.36	0.20	0.12	0.48	0.50	0.62	1

4. Conclusion

In conclusion, the result of this study has shown that most of the groundwater samples are suitable for drinking. However, the presence of coliform bacteria in some water samples especially those from hand dug wells raise a serious concerns about waste disposal patterns and the siting/proximity of septic tanks to the boreholes/hand dug wells in the study area. The result of Correlation, PCA and hierarchical cluster analysis in the study indicates that sources of most dissolved geochemical constituents (EC, TDS, HCO3, Hardness, Cl, Mg, K, Ca, and Na) were geogenically derived (residence time, leaching and mineral dissolution) while sources of SO_4^{2-} and NO_4^{-} were linked to anthropogenic sources including mine nitrogenous wastes, effluents, agricultural runoffs and atmospheric deposition. Spatial distribution of major cations (Mg, K, Ca, and Na) delineates the Southern part of the area as hotspot of mineral dissolution. It can therefore be recommended that though the groundwater is suitable for drinking, and the dissolved hydrochemical constituents linked to geogenic sources, further studies on groundwater chemistry should be carried out to ascertain the dominant geogenic sources (rock-water interaction, precipitation and evaporation) that prevail in the area. In addition groundwater flow model should be developed in order to identify recharge areas and mitigation of contaminant migration. This would also help to identify pollution sources.

Data Availability Statement

The data used for this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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