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APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM AND HYDROGEOCHEMISTRY IN THE ANALYSIS OF GROUNDWATER ACROSS OKELUSE AREA OF ONDO STATE, SOUTHWESTERN NIGERIA

Adeniyi Johnpaul Adewumi^{1}, Pauline Taiwo Ale¹, Babatunde Oloye¹*

¹ Department of Geological Sciences, Achievers University, P.M.B. 1030, Owo, Ondo State, Nigeria, (*adewumiadeniyi27@yahoo.com),
*Phone Number: +2348167870980

ABSTRACT: Hydrogeochemical study was carried out at Okeluse to know the level of chemical in the water of the area. Water sample were collected and analyzed by internationally acceptable procedures. Statistical analyses such as factor analysis, descriptive analysis, bivariate analysis and hierarchical cluster analysis were carried out to determine the relationship between ions in the groundwater. The mean value of SO₄ in the ground water of the study area is 222.05 mg/l. The bivariate analysis of the chemical data shows that Mg and SO₄ have a very good and positive relationship ($r=0.768$) in ground water of the study area. In component two SO₄ and K account for the principal factors that affect groundwater in the study area. Hierarchical cluster analysis shows that Cl, PO₄, Ca, Mg, Na and K have a relationship at level 5, while SO₄ have relationship with them at higher level. The groundwater belongs to Na+K-SO₄-Cl+SO₄ water group. Sodium Adsorption Ratio showed that the groundwater of the study area is suitable for irrigation. All parameter in the study area except pH falls within the WHO and the Canadian standard for drinking water. Hence, it is concluded that groundwater in the study area is safe for domestic and agricultural purposes.

KEYWORDS: Okeluse; Groundwater; Hydrogeochemistry; Spatial Variation, Statistical analysis, Geographic-Information-System

1.0 INTRODUCTION: Groundwater has become for resource both for human and industrial purposes. This may be affected by both natural and anthropogenic materials. Important natural processes contributing to pollution in groundwater are rock-water interactions, dissolution, precipitation, sorption and geochemical reactions (1). Anthropogenic activities such as waste disposals, leaching of salts, fertilizers, pesticide from the agricultural fields and salt intrusion due to over exploitation contribute to groundwater pollution. The hydrogeochemical processes help to get an insight into the contributions of rock-water interaction on groundwater quality. These geochemical processes are responsible for the seasonal and spatial variations in groundwater chemistry [(2), (3-4), (5-6)]. Groundwater chemically evolves by interacting with aquifer minerals or internal mixing among different groundwater along flow-paths in the subsurface [(5), (7), (8)]. Okeluse area of Ondo state, due to the large deposit of limestone found there has been exposed to artisanal mining especially by the local miners. The effluents and other mining wastes generated from this activity can be introduced into the groundwater system of the area thereby contaminating it. Only few hand-dug wells penetrate and tap the aquifer beneath subsurface around Okeluse area, therefore the need to protect this valuable resource from contamination has been become important. Also due to the viability of the limestone, future migration of people into the area is possible and the need to protect the inhabitants from drinking contaminated water is a necessity. Hence the aim of this research work is to determine the hydrogeochemical nature of the groundwater in the area (Figure I). The study area lies within longitude 5°35'E - 5°37'E and latitude 6°45'N - 6°49'N (Figure I). The study area has a low relief when compared to the Basement Complex area that surrounds it. Okeluse has an elevation of between 50 (164.04 ft) and 80 metres (262ft) above the mean sea level. The study area has numerous amounts of surface drainages that surrounds it,

which is dendritic in nature and are controlled by the topography of the area. To the east there exists the River Osse (Figure I) which serves as the boundary between Ondo and Edo states to the east. The river is perennial in nature.

2.0 GEOLOGY OF THE STUDY AREA: The study area is found within the Dahomey basin (Figure I) which is one of the main basins found in Nigeria on the western part of the Niger Delta. It extends from Southeastern Ghana through Togo and Benin Republic on the west side to the Okitipupa ridge on the east side in the southern part of Nigeria. Various workers [(9), (10), (11), (12)] had worked on the stratigraphic of the Eastern Dahomey basin from surface as well as sub-surface data. In most part of the stratigraphy is dominated by monotony of sand and shale alteration with minor proportions of limestones and clays (9). The stratigraphy of the Eastern margin of the Cretaceous to Tertiary sedimentary basin, which unconformably overlies the basement complex includes the following lithostratigraphic limits.

2.1 THE ABEOKUTA GROUP: The basement complex rock throughout the entire Dahomey basin is overlain unconformably by the Abeokuta group which is the oldest unit (10). It consists of conglomerates, sand stones, sandy siltstones, clays, shales and thin limestone beds. This unit has been from the Neocomian to Paleocene and it is the thickest single sedimentary unit in the basin. This unit contains heavy oil and it is the prime target for petroleum exploration. (11) subdivided the group into 3 district formation, based on the lithologic homogeneity and similarity of origin, the following are the subdivisions.

2.2 ISE FORMATION: This is the oldest formation in the group and it unconformably overlay the basement complex. It consists of conglomerate at the base, gritty to medium grained loose sand, capped by kaolinite clay [(9), (11)]. The maximum thickness of the members is about 1965m and 600m penetrated by the Ise-2 well, while similar section were exposed near Ode-Remo on the Lagos- Ibadan expressway. The grains are sub-angular to subrounded, poorly sorted, and positively skewed. From the grain size distribution, clastic sediments are leptokurtic, and nearly symmetrical. Clays from the major matrix and poor cementation makes the rock very friable. The age was given as Necomian and the unit has not been found to be bituminous both at surface and subsurface section.

2.3 AFOWO FORMATION: Afowo formation indicates the commencement of deposition in a transitional environmental after the entire basal and continental Ise formation. The sediments are composed of interbedded sands, shales and clays, which ranges from medium to fine grained in size [(9), (11)] outcrops of this formation are commonly encountered within the bituminous sands belt and are easily recognizable because of the presence of sticky and viscous heavy oil seeping out of the sand portion of the Afowo formation. The age is Mastrichitian.

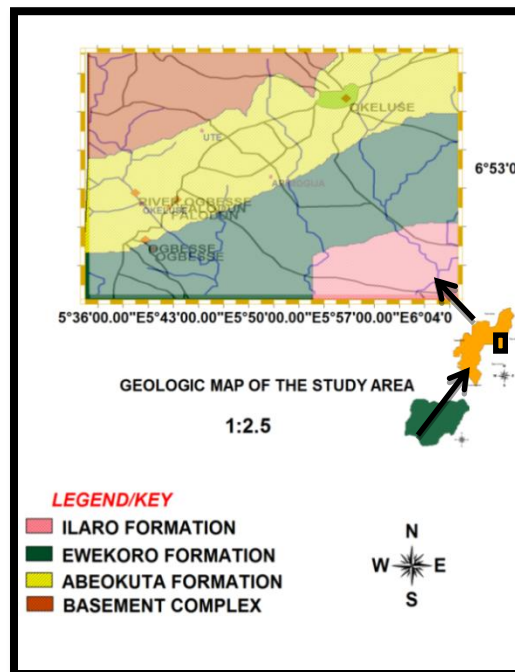


Fig. I: Geologic map of the study area [after (13)]

2.4 ARAROMI FORMATION: Sediments of the Araromi formation represent the youngest topmost sedimentary sequence in the group. The formation is composed of shales, fine-grained sand, thin interbeds of limestone clay and lignite

bands (9). It is an equivalent of a unit known as Araromi shale. The shale are grey to black in colour, are marine and rich in organic matter. The age range is from Maastrichain to Paleocene. The Abeokuta group, begin the thickest single sedimentary basin and consisting of interbeds of organic rich shale with porous and permeable sand stone together with its depth of burial makes it a prime target for petroleum exploration Dahomey basin, (9). The lithology in the study area shows an intercalation of sandstone and shale. The basal sediments are gravelly.

3.0 RESEARCH METHODOLOGY: The methodology approach for this research work include reconnaissance survey of the study area, groundwater sampling, chemical analysis and statistical analysis of hydrochemical data of the groundwater from the study area. Groundwater of the study was sampled very early in the morning using clean well labeled (OK1-OK11) uncontaminated containers. Eleven groundwater samples were collected in the area. Immediately after sampling, the groundwater samples were transported to the Sustainable Laboratory in Akure for chemical analysis. The pH of the groundwater in the study area was measured using a pH meter. The Total Dissolved Content (TDS) and Total Suspended Solids (TSS) of the samples were analyzed using gravimetry method. The turbidity of the sample was measured using NTU model WGZ 15. The colour of the samples was measured using low-bond competitor Hazen colorimeter. The electrical conductivity of the samples was analyzed using conductivity meter. Sulphate was analyzed using gravimetry method. Statistical analyses of both the physicochemical data were carried using SPSS 21 version. Spatial distribution map was generated using SURFER 10 software. This allowed for visual study and inspection of distribution of the physical and chemical parameters over the study area at a glance. The Sodium Adsorption Ratio (SAR), the Gibbs classification and the Wilcox classification were used to determine whether the groundwater from the area is good for irrigation. Also, the hydrochemical results were compared to the WHO drinking water standard to determine its suitability for drinking and other domestic purposes.

4.0 DISCUSSION OF RESULTS:

4.1 SPATIAL VARIATION OF PHYSICOCHEMICAL PARAMETERS: The result shows that the pH in the groundwater of the study area increases based on location in the following order OK11< OK1=OK4=OK9<OK3<OK6<OK10<OK8<OK5=OK2<OK7 (Figure II). This implies that location OK11 (pH=3.70) is highly acidic while location OK7 (pH=5.50) is moderately acidic (Table I). Total Dissolved Solid (TDS) in the groundwater of the area decreases in the order OK1> OK5>OK7>OK8>OK3>OK2>OK6>OK11>OK9>OK10>OK4 (Figure II). Figure shows that OK1 has the highest concentration of elements except for potassium. The temperature of the groundwater in the area decreases in the order OK10> OK7> OK4> OK9> OK3> OK5> OK8> O11> OK6> OK1> OK2. The turbidity of the area also decreases in the order OK7> OK11> OK10> OK8> OK5 >OK4> OK6. The colour in the groundwater in the area is 5 except in location OK7 which corresponds to the area of high turbidity. The electrical conductivity of the groundwater in the area decreases in the order OK1>OK5> OK7> OK11> OK8> OK3> OK2> OK6> OK9 > OK4> OK10. The Total Suspended Solids in the area are OK7> OK8> OK5> OK11> OK10> OK9> OK4> OK6> OK3> OK1> OK2. The chemical parameters measured in the groundwater of the study area are SO₄, Mg, Na, Cl, K, Ca and PO₄. The results showed that SO₄ decreases in the following order: OK1>OK8>OK5>OK6>OK10>OK3>OK7>OK11>OK9>OK2>OK4 (Figure III). The result further shows that Mg decreases in the following order: OK1> OK5> OK8> OK10> OK7>OK11>OK6>OK4>OK2>OK9>OK3 (Table II). Na decreases in the order: OK1> OK6> OK5> OK8>OK7>OK3>OK10>OK2>OK4>OK9>OK11. Cl decreases in the order of: OK1>OK11. K decreases in the order: OK5> OK4> OK8> OK10> OK11> OK7>OK2>OK6>OK1>OK9>OK3. Ca decreases in the order OK5>OK11. PO₄ decreases in the order OK5> OK1> OK8> OK11> OK4>OK7>OK6>OK10>OK2>OK9>OK3.

Location	pH	TDS (ppm)	Temp. (°C)	Colour	E Cond (µs/cm)	TSS (mg/l)
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OK1	3.80	142.00	29.00	5.00	286.00	5.00
OK2	5.40	33.00	29.00	5.00	46.00	2.00
OK3	4.50	34.00	28.00	5.00	50.00	6.00
OK4	3.80	12.00	27.00	5.00	17.00	7.00
OK5	5.40	72.00	28.40	5.00	101.00	27.00
OK6	4.60	30.00	28.50	5.00	45.00	7.00
OK7	5.50	58.00	27.00	15.00	84.00	49.00
OK8	5.00	41.00	28.40	5.00	64.00	31.00
OK9	3.80	21.00	27.60	5.00	34.00	15.00
OK10	4.90	9.00	26.00	5.00	15.00	21.00
OK11	3.70	24.00	28.50	5.00	78.00	25.12

Table:I Physical parameter of groundwater of the study area

Location	SO₄ (mg/l)	Mg (mg/l)	Na (mg/l)	Cl (mg/l)	K (mg/l)	Ca (mg/l)	PO₄ (mg/l)
OK1	452.65	3.43	14.10	0.05	7.30	4.60	0.15
OK2	53.49	3.16	5.60	ND	8.70	ND	0.10
OK3	176.95	3.16	5.40	ND	7.60	ND	0.10
OK4	45.19	2.92	4.00	ND	9.40	ND	0.12
OK5	358.01	3.07	4.80	ND	8.90	2.80	0.05
OK6	296.28	1.94	2.00	ND	8.60	ND	0.10
OK7	164.60	3.02	7.70	ND	6.70	ND	0.05
OK8	395.04	2.96	3.40	ND	8.90	ND	0.10
OK9	111.11	2.56	3.70	ND	8.30	ND	0.15
OK10	259.25	2.72	3.40	ND	9.30	ND	0.05
OK11	131.68	2.84	4.60	0.03	7.00	0.01	0.05

Table:II Chemical parameters of the study area

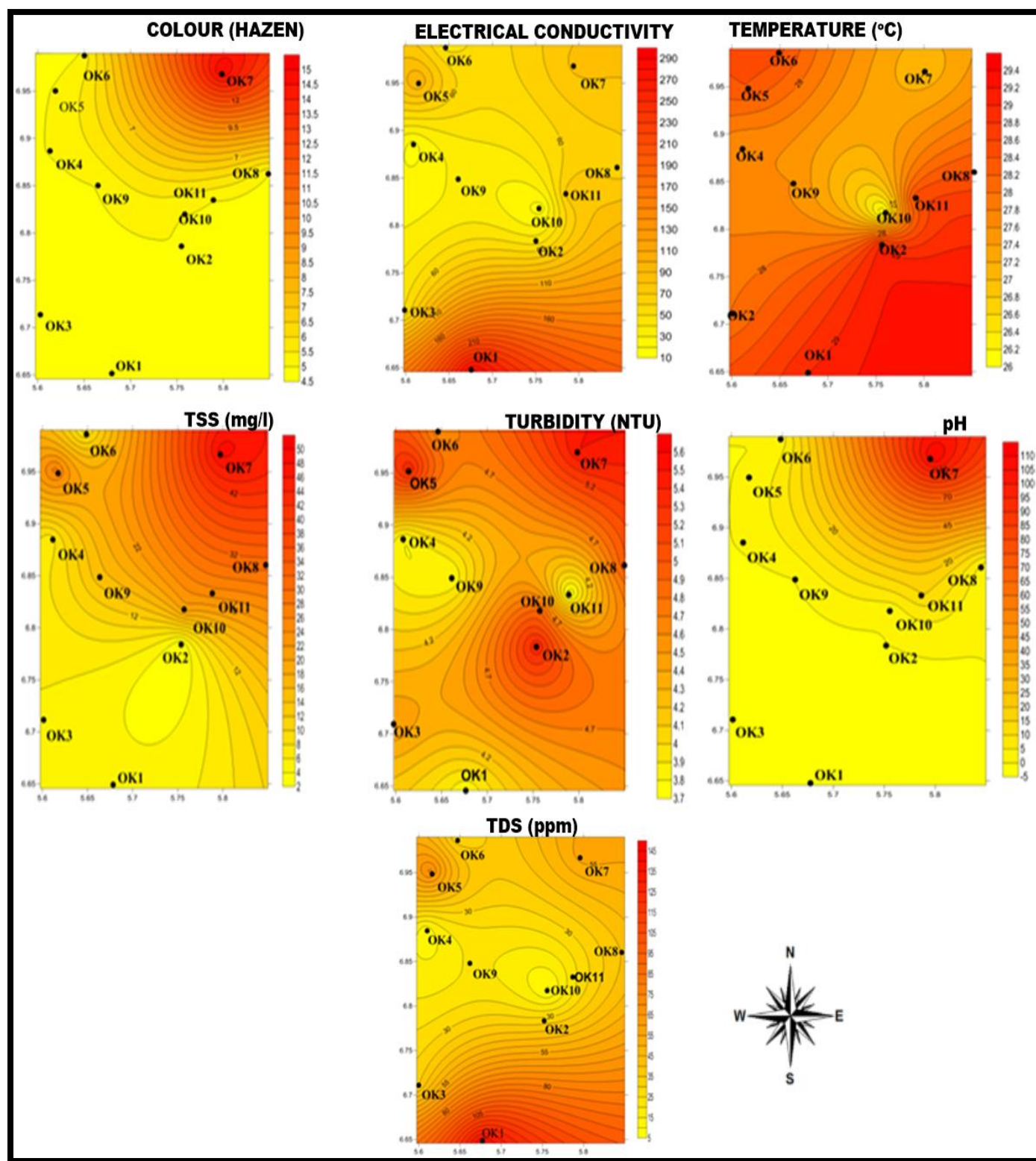


Fig. II: The spatial distribution of physical parameters in the study area

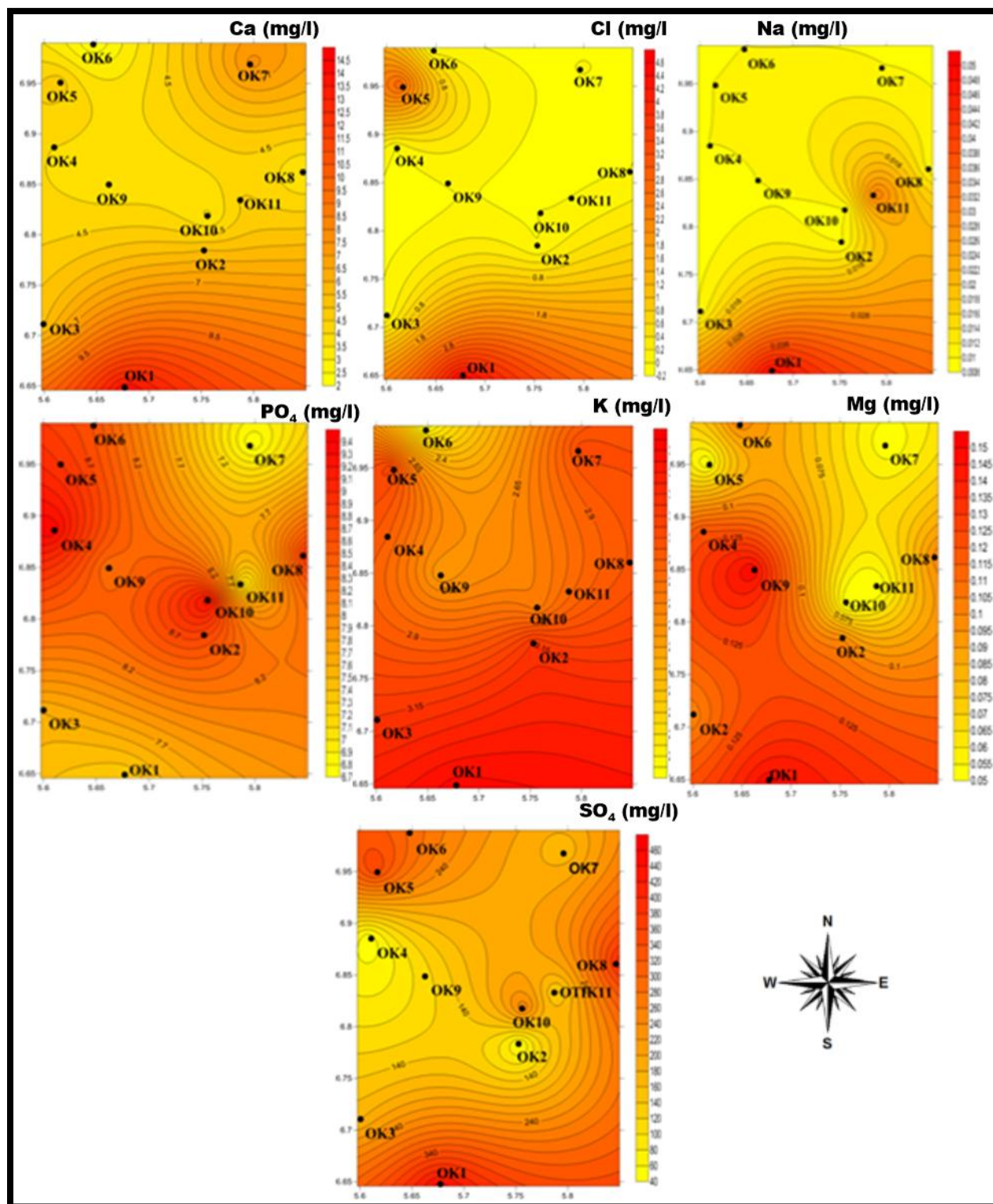


Fig:III Spatial distribution of chemical parameters in groundwater of the study area

4.2 STATISTICAL ANALYSIS OF PHYSICOCHEMICAL PARAMETERS IN GROUNDWATER OF THE STUDY AREA: The mean pH in the water of the study area is 4.58 while the mean Total Dissolved Solid (TDS) in the groundwater of the study area is 43.27 (Table III). The mean temperature is 28°C and the mean turbidity is 11.90, while the mean colour is 5.95. Furthermore, the mean Electrical Conductivity (EC) is 74.55 and that of the Total Suspended Solid (TSS) is 17.74. The standard deviation of pH, TDS, temperature, colour, EC and TSS is 0.71, 37.66, 0.90, 32.99, 3.01, 75.11 and 14.45 respectively. The range pH, TDS, temperature, colour, EC and TSS is 1.80, 133.00, 3.00, 110.49,

10.00, 271.00 and 47.00 respectively. The minimum value of pH in the area is 3.70 and the maximum is 5.50. The minimum value of TDS in the area is 9.00 and 142.00. Temperature of groundwater in the study area has a minimum value of 26°C and maximum temperature of 29°C. The groundwater of the study area has a minimum value of 0.01 and a maximum value 110.50. Table 6 shows that the mean value of SO₄ in the groundwater of the study area is 222.205 mg/l. The mean value of Mg is 2.889mg/l while that of Na is 5.336mg/l. The mean value of Cl is 0.016mg/l and that of K is 8.255mg/l. The mean value of Ca is 0.681mg/l and that of PO₄ is 0.093mg/l. The range of SO₄ is 407.460mg/l with a minimum value of 45.19mg/l and the maximum value of 452.65mg/l. the range of Mg is 1.490mg/l with a minimum value of 1.490mg/l and a maximum value of 3.430mg/l. The range of Na is 12.100mg/l with a minimum value of 2.000mg/l and a maximum value of 14.100mg/l. The range of Cl is 0.040 mg/l with a minimum value of 0.010mg/l and the maximum value of 0.050mg/l. The range value of K is 2.700mg/l with a minimum value of 6.700mg/l and a maximum value of 9.400mg/L. The range value of Ca is 4.590mg/l with a minimum value of 0.010mg/l and a maximum value of 4.600mg/l. The range of PO₄ is 0.100mg/l with a minimum value of 0.050mg/l and maximum value of 0.150mg/l (Table IV).

	pH	TDS	Temp. (°C)	Turbidity	Colour	EC	TSS
Mean	4.58	43.27	28.00	11.90	5.91	74.55	17.74
Standard deviation	0.71	37.66	0.90	32.99	3.01	75.11	14.45
Variance	0.51	1418.21	0.81	1088.84	9.09	5641.67	208.79
Skewness	-0.05	2.05	-1.123	3.21	3.31	2.58	0.97
Kurtosis	-1.77	4.81	1.153	10.47	11.00	7.51	0.57
Range	1.80	133.00	3.00	110.49	10.00	271.00	47.00
Minimum	3.70	9.00	26.00	0.01	5.00	15.00	2.00
Maximum	5.50	142.00	29.00	110.50	15.00	286.00	49.00
Sum	50.40	476.00	308.00	130.87	65.00	820.00	195.20

Table:III Descriptive analysis of physical parameters in the study area

	SO ₄ (mg/l)	Mg (mg/l)	Na (mg/l)	Cl (mg/l)	K (mg/l)	Ca (mg/l)	PO ₄ (mg/l)
Mean	222.205	2.889	5.336	0.016	8.255	0.681	0.093
Standard Deviation	139.277	0.392	3.261	0.013	0.943	1.546	0.039
Variance	19398.156	0.154	10.639	0.000	0.889	2.390	0.001
Skewness	0.345	-1.400	2.210	2.420	-0.485	2.216	0.183
Kurtosis	-1.189	3.002	5.702	5.510	-1.260	4.110	-1.210
Standard Error of Kurtosis	1.279	1.279	1.279	1.279	1.279	1.279	1.279
Range	407.460	1.490	12.100	0.040	2.700	4.590	0.100
Minimum	45.190	1.940	2.000	0.010	6.700	0.010	0.050
Maximum	452.650	3.430	14.100	0.050	9.400	4.600	0.150
Sum	2444.250	31.780	58.700	0.170	90.700	7.490	1.020

Table IV: Descriptive analysis of chemical parameters of the study area

4.3 BIVARIATE CORRELATION OF PHYSICO-CHEMICAL PARAMETERS IN GROUNDWATER OF THE STUDY AREA:

The bivariate correlation of the physical parameter from (Table V) the study area shows that there

is a negative and very weak correlation between pH and TDS ($r = -0.04$). Also, there is negative and very weak correlation between pH and temperature ($r = -0.129$). These show that no relationship exists between pH and TDS and temperature. However, there exists a positive but weak correlation between turbidity and pH ($r = 0.381$). Also, positive but weak correlation between turbidity and Total Dissolved Solid (TDS) ($r = 0.104$). However, there is negative and weak correlation between turbidity and temperature ($r = -0.353$). A very strong and positive correlation exists between Electrical Conductivity (EC) and TDS ($r = 0.968$) at 2-tailed. Also, a positive but a weak correlation exists between pH and temperature ($r = 0.480$). A positive but very weak correlation also exists between EC and turbidity ($r = 0.039$) and colour ($r = 0.042$). A strong and positive correlation occurs between Total Suspended Solid (TSS) and pH ($r = 0.434$). Also a very strong and positive correlation exists between TSS and turbidity ($r = 0.753$) and colour ($r = 0.717$) significant at two tail. However, a negative and weak correlation exists between TSS and TDS ($r = -0.001$). A negative but strong relationship exists between TSS and temperature ($r = -0.410$) and EC ($r = -0.62$). Table 7 shows that Mg and SO_4 have a very strong and positive relationship ($r = 0.768$) in the groundwater of the study area. Na and SO_4 has a weak but positive relationship ($r = 0.351$). also Na and Mg has a strong and positive relationship ($r = 0.699$) in groundwater of the study area. Na and Cl has a very strong and positive relationship ($r = 0.796$). K has a negative relationship with SO_4 , Mg, Na and Cl ($r = -0.005$, -0.281 , -0.566 and -0.514 respectively) (Table VI). Ca has a positive and strong relationship with SO_4 ($r = 0.667$), a positive and strong relationship with Mg ($r = 0.493$), a positive and very strong relationship with Na ($r = 0.768$) and a negative relationship with K ($r = 0.172$) respectively. PO_4 has a positive but weak relationship with SO_4 ($r = 0.022$), Mg ($r = 0.430$), Na ($r = 0.296$), Cl ($r = 0.289$) and Ca ($r = 0.241$). However, PO_4 has a very strong and positive relationship with K ($r = 0.900$).

	pH	TDS	Temp.	Turbidity	Col.	EC	TSS
pH	1						
TDS	-0.04	1					
Temperature	-0.129	0.465	1				
Turbidity	0.381	0.104	-0.353	1			
Colour	0.427	0.130	-0.368	0.991*	1		
EC	-0.199	0.968**	0.480	0.039	0.042	1	
TSS	0.434	-0.001	-0.001	-0.410	0.753**	0.717**	1

*, Correlation is significant at the 0.05 level (2-tailed).

**, Correlation is significant at the 0.01 level (2-tailed).

Table V: Bivariate correlation of physical parameters in groundwater samples from the study area

	SO_4	Mg	Na	Cl	K	Ca	PO_4
SO_4	1						
Mg	0.768	1					
Na	0.351	0.699*	1				
Cl	0.411	0.408	0.796**	1			
K	-0.005	-0.281	-0.566	-0.514	1		
Ca	0.667*	0.493	0.768**	0.717*	-0.172	1	
PO_4	0.022	0.430	0.296	0.289	0.90	0.241	1

*, Correlation is significant at the 0.05 level (2-tailed). **, Correlation is significant at the 0.01 level (2-tailed).

Table VI: Bivariate correlation of chemical parameters in groundwater of the study area

4.4 FACTOR ANALYSIS OF PHYSICOCHEMICAL PARAMETERS IN GROUNDWATER OF THE STUDY AREA: Factor analysis (also known as the Principal Component Analysis) is important in understanding the contribution of physical and chemical components in the groundwater. The factor analysis of the physical parameters (Table VII) of groundwater in the study area shows that the physical properties contributing to the groundwater are two components (Figure VIII). This components are designated as component one and component two in Table IV. In component one, pH contribute twenty-five (25) percent, while turbidity and colour contributes about thirty-nine (39) percent respectively to groundwater. Total Suspended Solid (TSS) contributes about thirty-seven (37) percent to total

physical properties of groundwater in the study area. In component two however, Total Dissolved Solid (TDS) contributes about thirty-seven (37) percent, while electrical conductivity contributes about thirty-seven (37) percent to the total physical properties of groundwater in the study area. The first component accounts for 47.05% of the total variance, while the second component accounts for 52.94% of the total variance. The result of the factor analysis (Table VIII) shows that three components exists for chemical parameters in the groundwater of the study area (Figure IX). In component one SO_4 , Mg, Na, Cl and Ca accounts for the principal factor that affects the groundwater. SO_4 accounts for 14.58% of component one, Mg accounts for 17.93% of component one, Na accounts for 25.59% of component one, Cl accounts for 23.93% of component one and Ca accounts for 23.74%. In component two, SO_4 and K account for the principal factor that affects the groundwater of the study area. SO_4 accounts for 38.64% of component two while K accounts for 45.26% of component two. In component three, only PO_4 accounts for the principal factor that affects the groundwater of the study area and accounts for 182.54% of component two.

	Component			Total Variance Explained		
	1	2	3	Total	% of Variance	Cumulative %
SO_4	0.537	0.595	-0.507	3.525	50.350	50.350
Mg	0.660	-0.305	0.029	1.232	17.605	67.956
Na	0.952	-0.161	0.107	1.015	14.494	82.450
Cl	0.881	-0.024	0.064	0.754	10.772	93.221
K	-0.517	0.697	0.063	0.260	3.718	96.939
Ca	0.874	0.345	-0.139	0.151	2.153	99.092
PO_4	0.294	0.393	0.847	0.064	0.908	100.000

Table:VII Factor Analysis of Physicochemical Parameters in Groundwater of the Study Area

	COMPONENT				TOTAL VARIANCE		
	One	%Component	Two	% Component	Total	% Variance	Cumul. %
pH	0.575	25	0.027	1.05	3.145	44.929	44.929
TDS	-0.137	-5.95	0.965	37.40	2.259	32.267	77.196
Temperature	-0.587	-25.60	0.505	19.74	0.827	11.811	89.007
Turbidity	0.910	36.69	-0.284	-11.01	0.430	6.144	95.152
Colour	0.910	36.69	0.291	11.28	0.324	4.625	99.777
EC	-0.237	-10.34	0.943	36.55	0.015	0.209	99.985
TSS	0.859	37.46	0.133	5.55	0.001	0.015	100.000
Total	2.293	99.86%	2.580	100.56%			

Table:VIII Factor analysis of physical parameters in groundwater of the study area

4.5 HIERARCHICAL CLUSTER ANALYSIS OF PHYSICOCHEMICAL PARAMETERS IN GROUNDWATER OF THE STUDY AREA: The hierarchical cluster analysis (Figure IV) of the physical parameters in groundwater of the study area shows that pH and colour at the same cluster (level 5) have a close relationship. These in turn has a close relationship with temperature and Total Suspended Solid (TSS) at a higher level of 10. Turbidity, Total Dissolved Solid (TDS) and Electrical Conductivity (EC) have separate cluster from the rest but are still in relationship with each other at a higher level. Therefore it is safe to infer from figure that pH, colour, temperature and TSS have a closer relationship in the groundwater of the study area, while turbidity, TDS and EC have a closer relationship.

The hierarchical cluster analysis of chemical parameters in groundwater of the study area shows that Cl, PO_4 , Ca, Mg, Na, K and SO_4 belongs to the same cluster at level less than 5. This shows that Cl, PO_4 , Ca, Mg, Na, K and SO_4 have some relationship. Ca, Mg, Na, K and SO_4 have a more closer relationship in groundwater of the study area at a higher level.

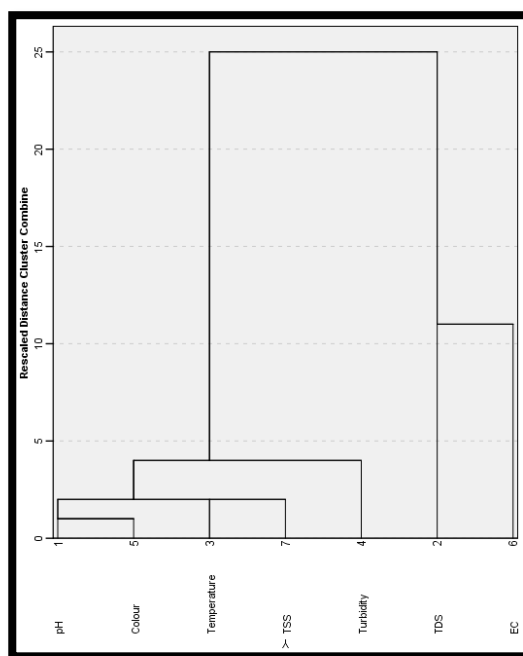


Figure:IV Hierarchical cluster of physical parameter in groundwater of the study area

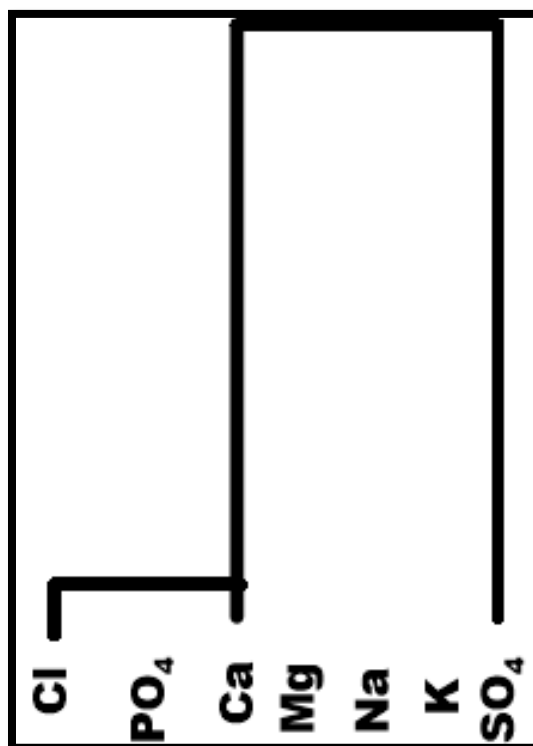


Figure:V Hierarchical cluster of physical parameter in groundwater of the study area

4.6 GROUNDWATER CLASSIFICATION:

4.6.1 ORIGIN OF IONS IN THE GROUNDWATER OF THE STUDY AREA: [14] graph was plotted to determine whether the ions in the groundwater samples of the study area are either as a result of the following processes: evaporation, dialation and weathering. The result (Figure X) shows that the ions in the groundwater of the study area originated from weathering of rocks in the study area. The Piper diagram (1994) diagram was used in the geochemical classification of groundwater in the area. Figure VII shows the groundwater in the area belongs to Na+K-SO₄-Cl+SO₄ type.

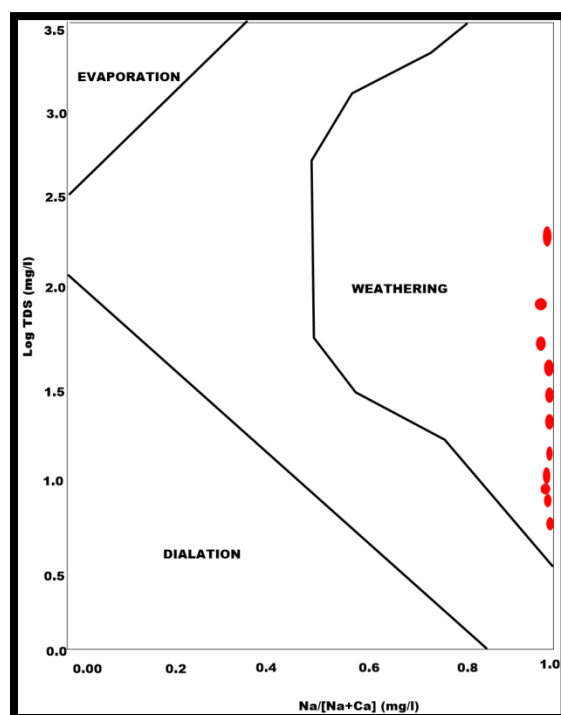


Figure :VI [14] graph of TDS against Na/[Na+Ca] ratio for groundwater of the study area

4.7 GROUNDWATER QUALITY ASSESSMENT:

4.7.1 SUITABILITY OF GROUNDWATER AROUND THE STUDY AREA FOR IRRIGATION: Sodium Adsorption Ratio (Table IX) shows that the groundwater of the study area is excellently suitable for irrigation as all of them fell below SAR of 10. Wilcox plot was used to determine the salinity of the groundwater in the area and to know whether the groundwater can be used for irrigation. It confirms the result of the SAR diagram used. All the groundwater sampled in the study area falls within the excellent to good region of the Wilcox plot (Figure X)

Location	Sodium Adsorption Ratio (SAR)	SAR Status
OK1	10.77	Good
OK2	5.00	Excellent
OK3	4.82	Excellent
OK4	3.64	Excellent
OK5	3.66	Excellent
OK6	2.01	Excellent
OK7	7.00	Excellent
OK8	3.04	Excellent
Ok9	3.49	Excellent
OK10	3.15	Excellent
OK11	4.22	Excellent

Table:IX Suitability of groundwater of the study area for irrigation using Sodium Adsorption Ratio (SAR)

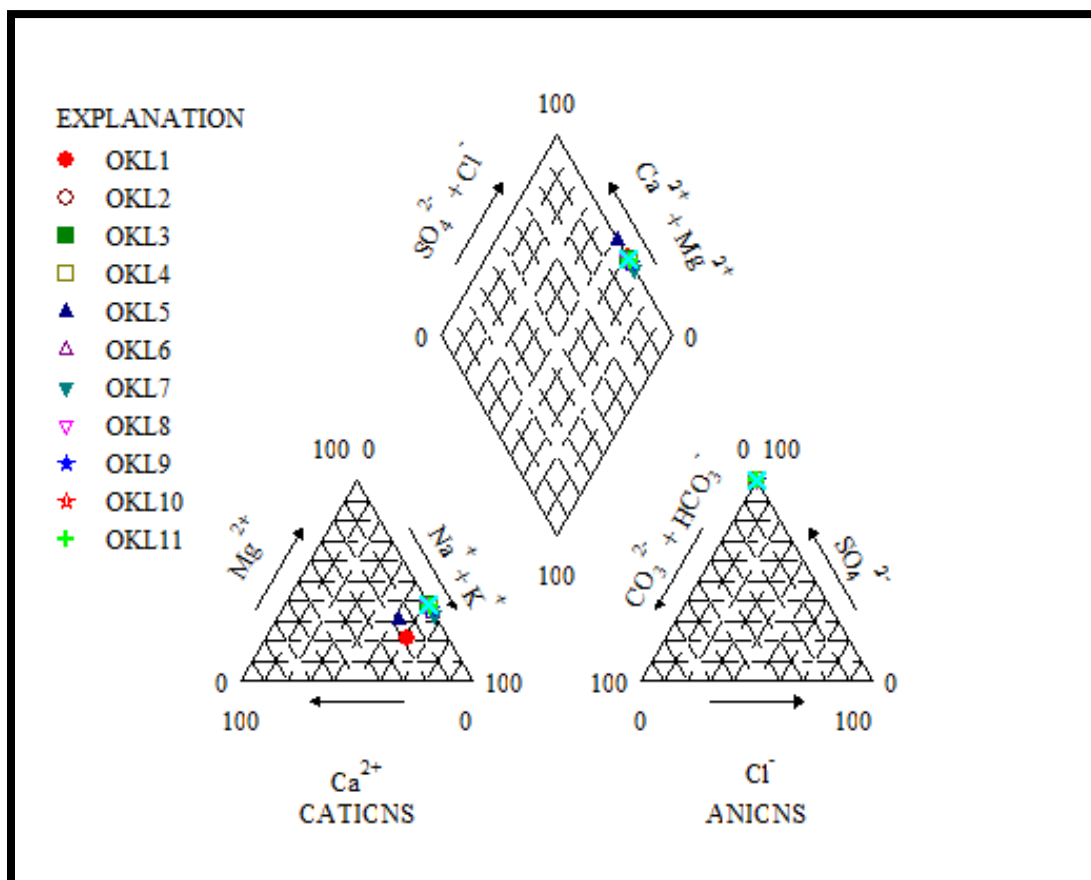


Figure:VII Groundwater classification of groundwater of the study area using Piper's diagram

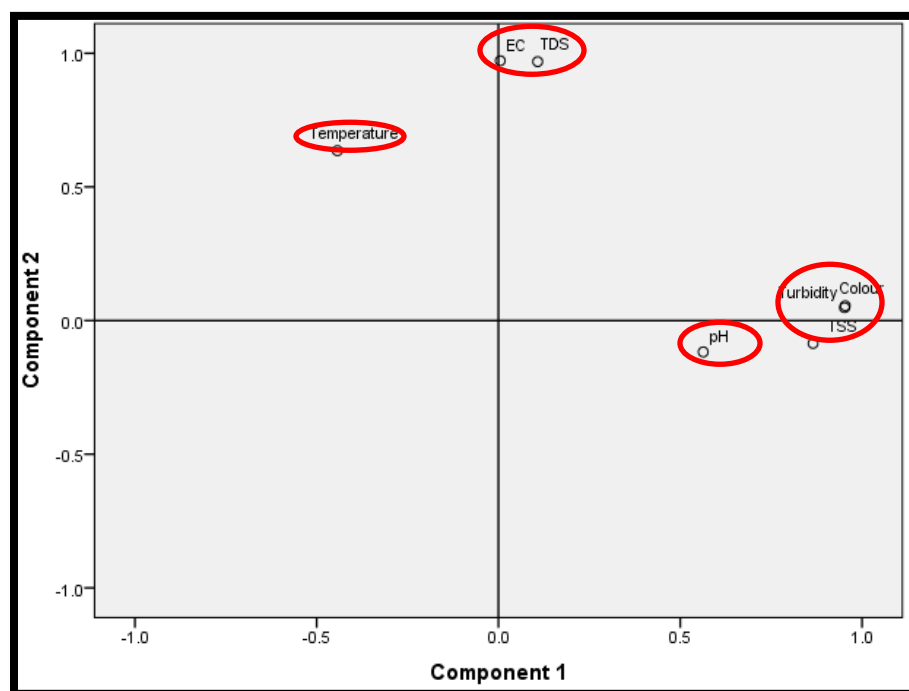


Figure:VIII Component plot for factor analysis of physical parameters in groundwater of the study area

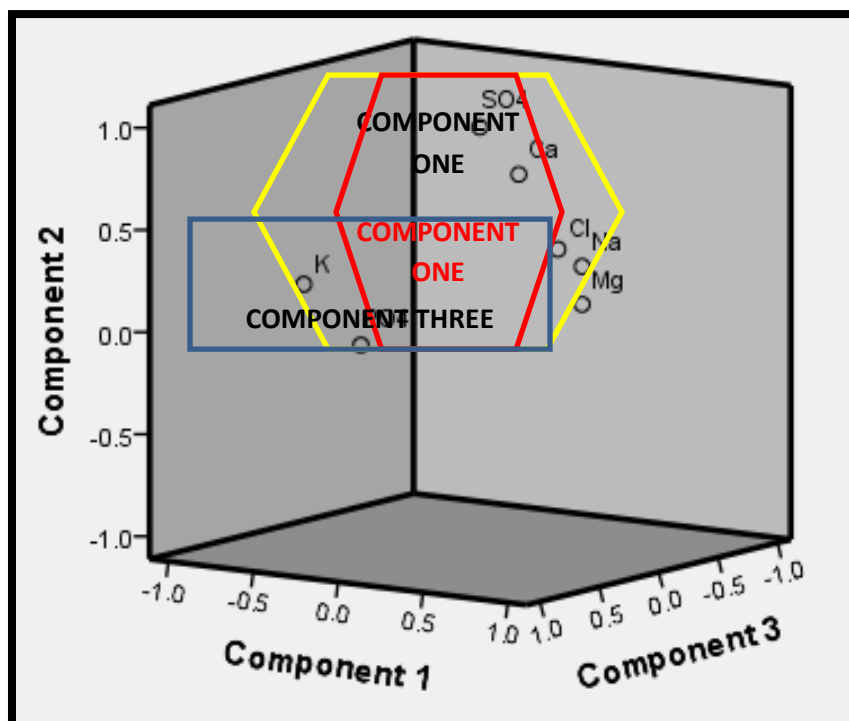


Figure:IX Component plot for factor analysis of chemical parameters in groundwater of the study area

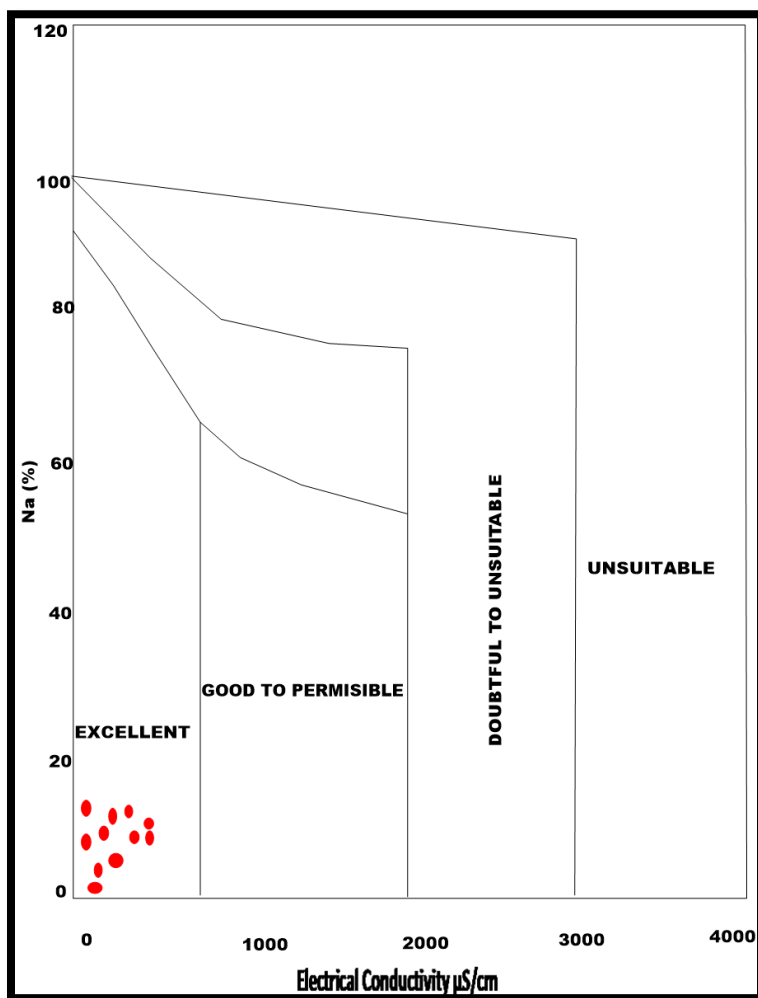


Figure:X Wilcox diagram used for identifying the suitability of groundwater of the study area for irrigation.

4.7.2 ASSESSMENT OF GROUNDWATER QUALITY OF THE STUDY AREA: Table X shows that the parameters measured in the groundwater of the study area falls within the internationally acceptable limits for the concentration of these parameters in groundwater. The results of the analysis were compared to the [15] and the Canadian standard. Hence it is safe to conclude that as at the time of analysis of the groundwater samples in the study area, the water is safe to drink.

SAMPLES	OK1	OK2	OK3	OK4	OK5	OK6	OK7	OK8	OK9	OK10	OK11	[15]	CANADIAN STANDARD
SO ₄	452.65	53.49	176.95	45.19	358.01	296.28	164.60	395.04	111.11	259.25	131.63	-	-
Mg	3.43	3.16	3.16	2.92	3.07	1.94	3.02	2.96	2.56	2.72	2.84	50	50.0
Na	14.10	5.60	5.40	4.00	4.80	2.00	7.70	3.40	3.70	3.40	4.60	-	200
K	7.30	8.70	7.60	9.40	8.90	8.60	6.70	8.90	8.30	9.03	7.00	20	-
Ca	4.60	ND	ND	ND	2.80	ND	ND	ND	ND	ND	ND	-	-
HCO ₃	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-
EC	286.00	46.00	50.00	17.00	101.00	45.00	84.00	64.00	34.00	15.00	78.00	1400	-
TSS	5.00	2.00	6.00	7.00	27.00	7.00	49.00	31.00	15.00	21.00	25.12	-	-
PO ₄	0.15	0.10	0.10	0.12	0.05	0.10	0.05	0.10	0.15	0.05	0.05	-	-
pH	3.80	5.40	4.50	3.80	5.40	4.60	5.50	5.00	3.80	4.90	3.70	6.8-8.5	6.5-8.5
TDS	142.00	33.00	34.00	12.00	72.00	30.00	58.00	41.00	21.00	9.00	24.00	500.100	-
Temp	29.00	29.00	28.00	27.60	28.40	28.50	27.00	28.40	27.60	26.00	28.50	-	-
Cl	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	-	0.10

Table:X Comparison of parameters in the groundwater of the study area with internationally acceptable limits

5.0 CONCLUSION: The hydrogeochemical assesment of groundwater across Okeluse area was carried out to ascertain it variability across the study area. Eleven groundwater were sampled and analysed for various physicochemical parameters. The study revealed that there are variability in the distribution of the different physicochemical parameters in the groundwater of the study area. Statistical analysis shows that there the mean concentration of the parameters are within the acceptable limits for human consumption. The study further revealed that a strong and positive correlation occurs between Total Suspended Solid (TSS) and pH ($r=0.434$). Also a very strong and positive correlation exists between TSS and turbidity ($r= 0.753$) and colour ($r=0.717$). Also, Mg and SO₄ have a very strong and positive relationship ($r=0.768$) in the groundwater of the study area. also Na and Mg has a strong and positive relationship ($r=0.699$) in groundwater of the study area. Na and Cl has a very strong and positive relationship ($r=0.796$). Positive and strong relationship with Mg ($r=0.493$), a positive and very strong relationship with Na ($r=0.768$) and a negative relationship with K ($r=0.172$) respectively. Principal Component Analysis shows that the physical properties contributing to the groundwater are divided into two components. The first component accounts for 47.05% of the total variance, while the second component accounts for 52.94% of the total variance. The groundwater in the area belongs to Na+K-SO₄-Cl+SO₄ class of groundwater. The groundwater of the study area is excellently suitable for irrigation and good for drinking as at the time of analysis.

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