Hydrogeology and Physico-Chemical Quality Assessment of Groundwater in Oke-Oyi Area and Environs, Kwara State, Nigeria

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Abstract:
An appraisal of the groundwater potential as well as its potability in Oke-Oyi area and its environs was undertaken. This was done in order to provide information on the evaluation of groundwater system in the area as well as on the physico-chemical quality of the groundwater for domestic and Agricultural purposes. The Study entails analysing pumping test data in order to compute the hydraulic characteristics of seven boreholes in the area. Fifteen groundwater samples were also collected from boreholes and hand-dug wells in the area and analysed for their physical and chemical properties.The two aquifer units in the area are weathered overburden aquifer and fractured crystalline aquifer. The boreholes tapping these aquifers have yields that range from 43.2m^3/day to 103.7 m^3/day with a mean value of 58.01 m^3/day, hydraulic conductivity values range between 1.17×10^{-1} m/day and 8.60 $\times10^{-2}$ m/day with a mean value of 6.27×10^{-2} m/day. Transmissivity varies from 0.95m^2/day to 3.16 m^2/day with an average value of 1.77 m^2/day. The storage coefficient (S) calculated shows values that range from 0.619 to 1.765 with a mean value of 1.238. Results obtained from the physico chemical analysis of the groundwater in the area shows that the physical parameters such as colour, taste and odour are within the acceptable limits of WHO (2006). Also, the major ions analysed are Ca, Mg, Na, K, Fe, SO_4, NO_3, Cl, CO_3 and HCO_3 and are all below the acceptable limits of WHO (2006). Hence the groundwater of the area is largely characterised as Mg-HCO_3^-Cl and Mg-HCO_3.The groundwater of the area has a low-medium salinity hazard and low sodium hazard, indicating that the groundwater is good for Agricultural purposes.The groundwater has a high recharge potential due to its low storage capacity. Also the groundwater is potable for domestic and Agricultural purposes, based on the physical and chemical parameters of the groundwater analysed which are within the acceptable limits of WHO as well as low-medium salinity hazard of the groundwater.
Keywords: Hydrogeology. Groundwater Potential and potability. Oke-Oyi area and its environs. Physico-Chemical. Nigeria

1. Introduction

Water is one of the most indispensable resources and the elixir of life. Water constitutes about 70% of the body weight of almost all living organisms and no life is possible on this planet without it. About 97.2% of water on earth is salty and only 2.8% is present as fresh water from which about 20% constitutes groundwater (Goel, 2000).

Most of rural areas in Nigeria have their water supply from rivers, streams and hand–dug wells while the urban settlements depend on treated pipe-borne water and boreholes for their water supply. The development of groundwater resources in Kwara State especially in rural areas has been a problematic issue prior to 1980. Series of efforts have been made to overcome this problem by many corporate and government establishments (Kwara ADP project, UNICEF water and sanitation Project, Utilities Board, and Biwater (Nig.) Limited) as well as individual workers such as Ologe, 1989.The efforts have increased the rate of assessing, exploring and exploiting groundwater resources in the state. The focus of these studies was on exploration and exploitation of the groundwater while information on quality of the groundwater was lacking. According to Okagbue, 1988, a complete appraisal of available water resources in any area is accomplished when aspects of water quality are included. Therefore, this study looks at the hydrogeology and groundwater quality assessment for drinking, domestic and Agricultural purposes in Oke-Oyi area and its environs, Kwara State. This study will provide useful information to Kwara State water board on quality of groundwater in the area as well as serving as a good guide and reference for any other researcher who intends to work on any related study in the area.

2. Location and geological setting

The Oke-Oyi together with its environs is located between latitudes $8^0$30`N and $8^0$45`N and longitudes $4^0$40`E and $5^0$00`E covering an area of about 1027 km^2 (Fig.1). The study area falls within the southern limits of the tropical savannah zone of Nigeria with mean annual rainfall of 1,231mm mean annual temperature of 28^{o}C and mean annual relative humidity of 56%. The monthly average of the relative humidity remains above 60% from July through October.

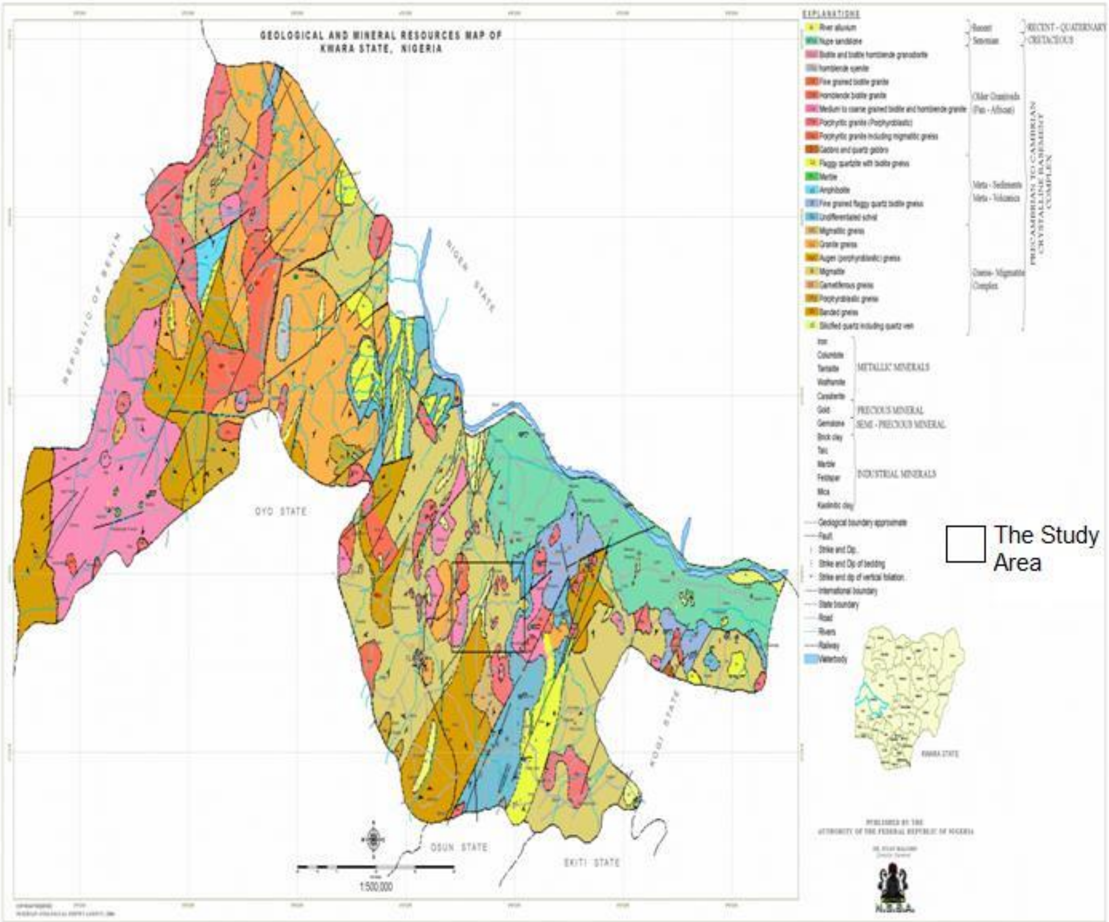


Fig. 1: Geological map of Kwara State showing the study area (modified after Nigerian Geological Survey Agency, 2006).

The study area is underlain by the rocks of the basement complex of south-western Nigeria, which is of Precambrian to Lower Palaeozoic in age (Jones and Hockey 1964; Rahaman, 1976). It comprises biotite-granite, granite-gneiss and metasediments which are mainly quartz-mica schist and quartzite. In some locations, the area is overlain by boulders of laterites which obscure the underlying geology and serve as the superficial deposits. The area is well drained by River Oyi and its tributaries and flows in north-east direction with a dendritic drainage pattern. River Oshin is another major river flowing in the same direction with River Oyi and both the rivers are seasonal.

3. Field Methods

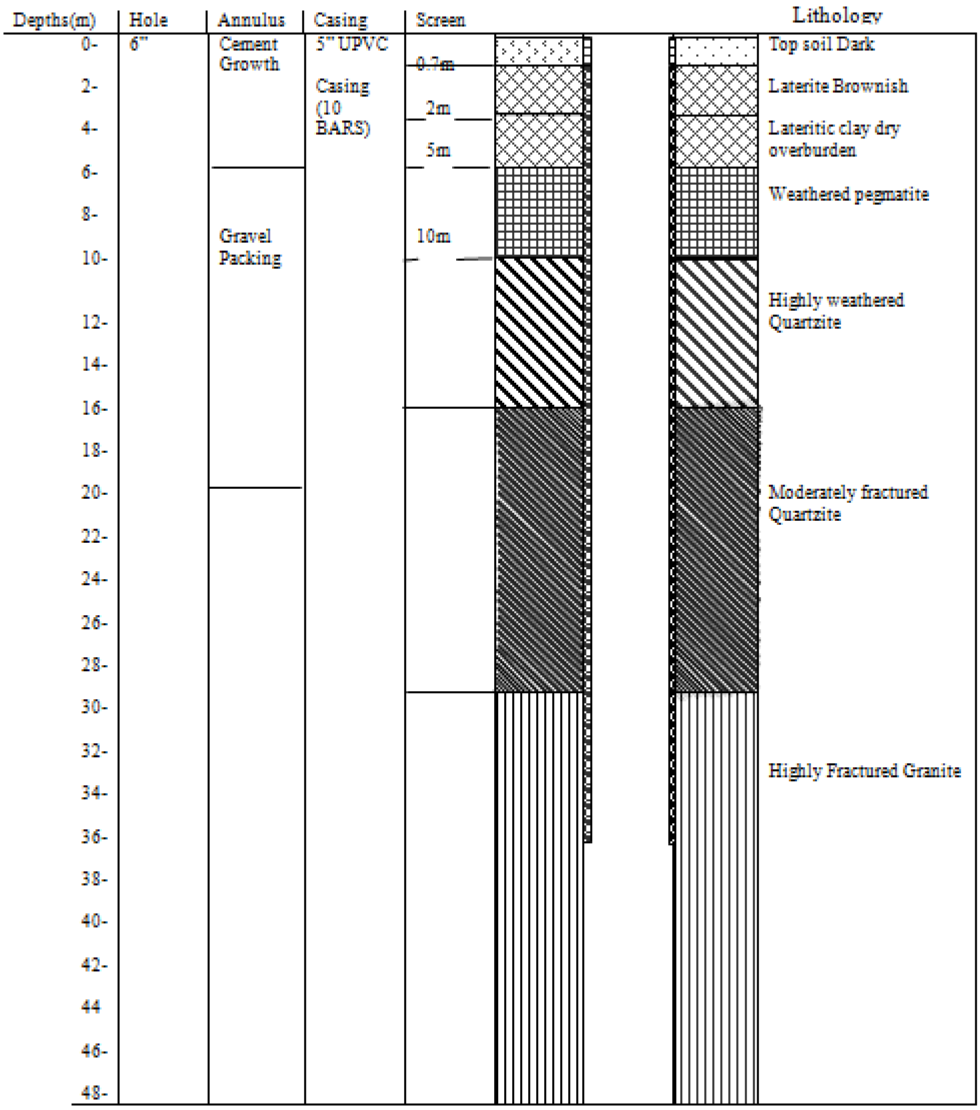
Detailed hydrogeological and geological mapping of the area were carried out, in which repeated water levels measurement were undertaken in hand dug wells for both the dry and wet seasons. Borehole drilling was supervised and lithological log constructed onsite (Fig.2). A total of fifteen (15) groundwater samples collected mainly from boreholes and hand dug wells in the study area were also analysed. Standard procedures for sampling were followed and at each sampling point certain physical parameters such as temperature, electrical conductivity and pH were measured in-situ using thermometer, portable electrical conductivity cell and pH meter respectively. Analysis of the collected water samples for their major cation and anion components was carried out at the Public Health Laboratory, Department of Water Resources and Environmental Engineering, and at the Centre for Energy Research and Training (CERT), both at Ahmadu Bello University, Zaria.

4. Results and Discussion

4.1 Hydrogeology of the Study Area

Groundwater is held in porous formations which are rocks containing relatively large portion of void spaces (Deming, 2002). The study area is underlain by crystalline rocks and generally, crystalline rocks have porosities of less than 3% (Bouwer, 1978). As such rocks of the Basement Complex, when not weathered are practically impermeable and have no storage capacity. However, appreciable porosity and permeability might have been developed in the rocks through fracturing and weathering processes (Davis and De Wiest, 1966), depending on the lithology and

Location: Budo-Oyo (Oke-Oyi), Drill-Date: 27-06-2011
All measurements are in meters. Hole and casing diameters in inches



Source: Lanfar Nig.Limited/UNICEF,Ilorin
Figure 2: Borehole log of Budo-Oyo (Oke-oyi) in the study area depicting a fractured crystalline aquifer texture of the original rock. Therefore, groundwater occurs in the Basement Complex in the weathered overburden or in the joints and fractures system within unweathered rock units of the study area.

Basically, two major aquiferous zones are identified in the study area and these are the weathered overburden aquifer unit and fractured crystalline rock aquifer. These two aquifers are of different groundwater potentials and characteristics. The depth to the weathered zone varies and depends largely on the composition and texture of the parent rock together with the density of the regional fracture field.

The assessment of aquifer hydraulic characteristics from well performance data is complicated by the interdependence of well design, the aim of each drilling testing programme, the sitting techniques used and the hydrogeological properties of the aquifers.

The hydraulic aquifer characteristics calculated in the study area include: hydraulic conductivity denoted by (K) which sometimes is referred to as coefficient of permeability, coefficient of transmissivity denoted by (T) and coefficient of storativity or storage coefficient denoted by (S). These parameters were calculated for seven boreholes in the study area.

The hydraulic conductivity values of the aquifers range from 1.17×10^{-1}m/day to 8.60×10^{-2}m/day with a mean of 6.27×10^{-2}m/day, Transmissivity values of the aquifers range between 0.95 m^2/day and 3.16 m^2/day with an average value of 1.77 m^2/day and Storage coefficient values vary from 0.619 to 1.765 with a mean of 1.238. Table 1 shows the values of the calculated parameters.

Table1: Calculated Values of Hydraulic Conductivity, Transmissivity and Storage coefficient obtained from the seven boreholes.

Names of the boreholes	Hydraulic Conductivity(m/day)	Transmissivity (m^2/day)	Storage coefficient	Bedrock types
Jolasun borehole	1.17×10^{-1} m/day	3.16 m^2/day	1.322	Granite-gneiss
Sentu borehole	5.08×10^{-2} m/day	1.22 m^2/day	1.418	Granite-gneiss
Budooyo borehole	3.51×10^{-2} m/day	1.26 m^2/day	1.756	Granite gneiss
Aramonu borehole	8.6×10^{-2} m/day	2.53 m^2/day	1.765	Granite-gneiss
Panada borehole	6.1×10^{-2} m/day	1.72 m^2/day	1.079	Granite-gneiss
Apado borehole	5.3×10^{-2} m/day	1.52 m^2/day	0.707	Granite
Alokolaro borehole	3.61×10^{-2} m/day	0.95 m^2/day	0.619	Granite

From table 1 above, it was observed that the storage coefficient of Apado and Aloko-laro boreholes (0.707 and 0.619 respectively) are lower than the storage coefficients of Jolasun, Sentu, Budo-Oyo, Aramonu and Panada boreholes (1.322, 1.418, 1.756, 1.765 and 1.079 respectively). This is due to the fact that the first five boreholes are of metamorphic origin with thicker overburden than the last two boreholes, which are of granitic origin.

4.2 Hydro-Chemical parameters of Groundwater Samples in the Study Area

The objectionable physical qualities of groundwater samples in the area such as tastes odours and colours are within the acceptable limits, although a few of the water samples (locations 5, 6 and 9) are highly turbid. (Table 2). The pH values of groundwater samples in the area range from 8.7 to 10.6 with a mean of 9.7. This shows that the groundwater in the area is slightly alkaline.

Table 2: Result of physico-chemical analyses of groundwater samples of the study area

Latitudes/ Longitudes	Locations	pH	Temp. (°C)	Elect.Cond. µS/cm	TH (mg/l CaCO$_3$)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Fe^{2+} (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (Mg/l)	Bedrock types
08.578°/04.715°	1	9.6	28.0	169.0	272.7	69.0	2.812	6.622	10.2	6.7	0.02	8.49	10.0	15.2	0.0	182.2	Medium-carse grained biotite
08.579°/04.717°	2	9.5	30.0	371.0	171.7	132.4	11.728	9.427	13.3	7.8	0.02	39.48	10.0	7.7	0.0	125.0	Medium-carse grained biotite
08.584°/04.717°	3	9.9	29.0	61.0	282.8	120.1	3.523	5.761	15.0	3.4	0.00	27.99	10.0	3.5	Negl.	267.0	Medium-carse grained biotite
08.625°/04.706°	4	9.2	31.0	183.0	454.5	249.0	2.407	4.845	11.1	2.3	0.02	12.99	20.0	ND	0.8	114.5	Medium-carse grained biotite
08.596°/04.738°	5	9.8	32.0	77.0	262.6	61.5	3.443	3.308	10.0	4.0	0.52	8.49	15.0	12.3	1.6	420.0	Medium-carse grained biotite
08.615°/04.783°	6	8.9	26.0	50.0	242.4	25.8	1.585	2.396	9.6	1.8	0.17	7.99	15.0	Negl.	0.0	256.2	Quartz-mica Schist
08.618°/04.799°	7	9.9	32.0	633.0	707	60.0	8.758	24.785	14.6	13.8	ND	46.48	5.0	ND	0.6	457.0	Quartzite
08.588°/04.814°	8	10.1	29.5	152.0	535.3	49.9	18.541	7.704	14.8	42.0	0.00	36.98	20.0	6.9	0.0	330.0	Quartzite
08.562°/04.819°	9	10.6	29.0	390.0	606	147.5	28.938	9.833	9.8	10.0	0.03	6.99	25.0	2.9	0.0	300.0	Quartzite
08.543°/04.796°	10	10.1	28.0	248.0	343.4	128.2	10.802	7.666	11.7	20.4	0.04	12.99	0.00	4.3	0.0	212.0	Coarse-porphyric granite
08.631°/04.816°	11	8.7	29.0	527.0	303.0	204.0	24.557	16.986	15.6	10.7	0.11	138.95	5.0	3.8	0.0	127.5	Quartzite
08.659°/04.869°	12	10.0	30.0	502.0	575.7	114.5	15.814	14.157	14.6	1.5	0.00	32.98	10.0	4.9	1.2	285.0	Quartzite
08.713°/04.889°	13	9.8	30.0	504.0	808.0	198.0	6.825	21.058	14.7	3.7	0.10	44.98	20.0	4.9	0.0	329.0	Coarse-porphyric granite
08.663°/04.947°	14	9.9	31.0	433.0	141.4	146.4	29.742	16.151	16.3	2.6	0.01	65.97	35.0	2.1	0.0	277.2	Granite-gneiss
08.631°/04.898°	15	9.6	30.0	591.0	878.7	229.0	16.090	36.920	13.6	8.0	0.03	37.98	5.0	7.8	0.8	110.5	Fine-grained granite

Temperature of the groundwater varies between 26°C and 32°C with a mean of 29.6°C. The corresponding values of the total dissolved solids (TDS) measured in the laboratory range between 25.8mg/l and 249mg/l with a mean of 129.02 mg/l. This indicates that the groundwater is fresh when compared with 500 mg/l permissible limits by World Health Organization (WHO) for crystalline basement rocks.

Calcium (Ca^{2+}), Magnesium (Mg^{2+}), sodium (Na^{+}) K^{+} and iron (Fe) in the water samples have concentrations varying from 0.08 meq/l to 1.48 meq/l with a mean of 0.62 meq/l, from 0.20 meq/l to 3.04 meq/l with a mean of 1.03meq/l, from 0.42 meq/l to 0.71 meq/l with a mean of 0.57 meq/l, from 0.04meq/l to 1.07meq/l with an average value of 0.24meq/l and from 0.01 meq/l to 0.02 meq/l with a mean of 0.002 meq/l respectively. The concentrations of these cations are all below their desirable and maximum permissible limits of 4.74 meq/l, 14.39 meq/l, 8.69 meq/l and 0.3 mg/l respectively as recommended by the World Health Organization (WHO, 2006). The order of abundance of the cations is $Mg^{2+}>Ca^{2+}>Na^{+}>K^{+}>Fe$.

On the other hand, sulphate (SO_4^{2-}), chloride (Cl^{-}) nitrate (NO_3^{-}), and bicarbonate (HCO_3) range from 0.10 meq/l to 0.73meq/l with a mean of 0.28meq/l, from 0.20 meq/l to 3.92 meq/l with a mean value of 0.99meq/l, from 0.03 meq/l to 0.19 meq/l with a mean of 0.07 meq/l 0.00 meq/l to 0.05meq/l with a mean of 0.01meq/l and from 1.81 meq/l to 7.40 meq/l with a mean of 4.14 meq/l respectively. Also, sulphate (SO_4^{2-}), chloride (Cl^{-}), nitrate (NO_3^{-}) and bicarbonate (HCO_3^{-}) have concentrations in the water samples which are all far below their desirable and upper permissible limits of 4.16 (meq/l), 7.05 (meq/l), 0.73 (meq/l) and0.80(meq/l)respectively as recommended by WHO (2006). Hence, the order of abundance of these anions is $HCO_3>Cl^{-}> SO_4^{2-}>NO_3^{-}> CO_3^{-}$.

The occurrence of the above mentioned ions far below their respective permissible limits of World Health Organization (WHO) shows that the groundwater is good for domestic purposes without causing any physiological ill health to the body.

For irrigation purpose, the water samples in the study area are of low–medium salinity hazard, indicating that the groundwater is excellent to good for irrigation. The low to medium salinity hazard of the groundwater is due to the conductivity which ranges in values from 50 µS/cm to 591 µS/cm making the water to fall between low and medium salinity hazard class (Fig.3).

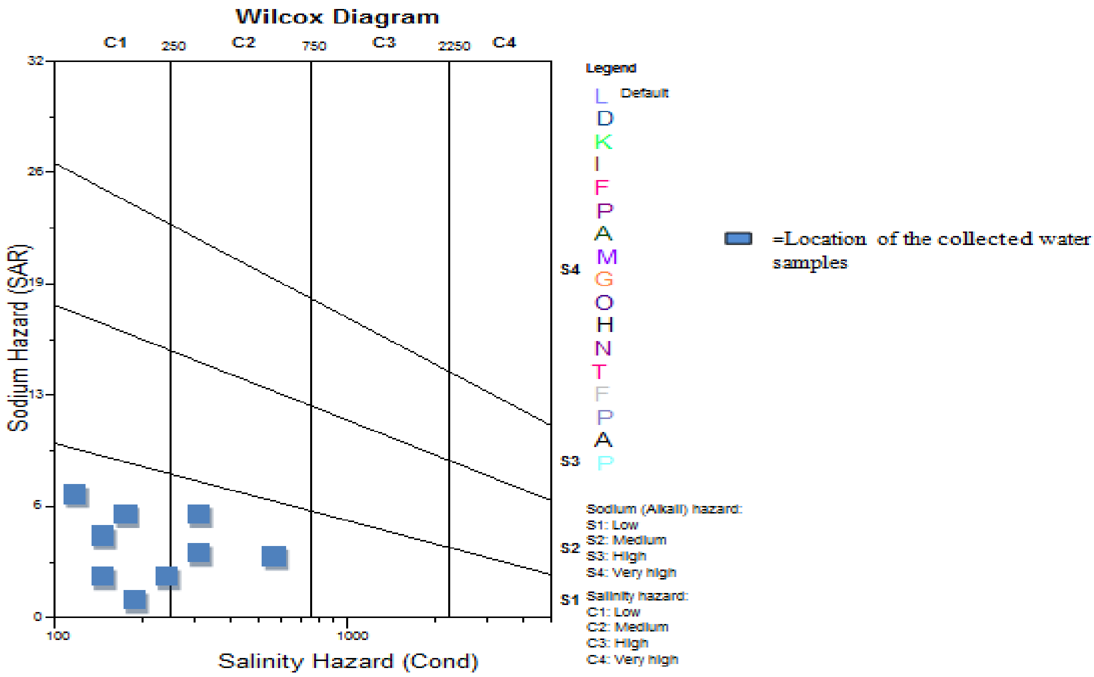


Fig.3: Wilcox quality classification of irrigation waters (1948) showing location of the collected water samples in the study area.

Table 3 shows the range of electrical conductivity values for different salinity hazard classes

Table 3: Suitability of water for irrigation in respect of Salinity Hazard (After Wilcox, 1948)

Salinity Hazard	Range of Electrical conductivity (µS/cm)
Low	Less than 250
Medium	250 to 750
High	750 to 2250
Very high	Greater than 2250

Also, the sodium hazard is low in groundwater samples of the area; hence the groundwater is excellent for irrigation in accordance with the water classification for irrigation purposes based on Sodium Adsorption Ratio (Table 4). The SAR was obtained from the following expression:

Sodium Adsorption Ratio: $Na^{+}/\sqrt{(Mg^{2+} + Ca^{2+})/2}$

Where: Na, Mg and Ca are measured in milli equivalents per litre. Table 4 shows the values for SAR calculation.

Table 4: Water classification for irrigation purposes based on Sodium Adsorption Ratio (SAR) (After Hem 1959)

SAR	WATER CLASS	QUALITY
0-10	Excellent	Low sodium
10-18	Good	Medium sodium
18-26	Fair	High sodium
26-100	Poor	Very high sodium

Table 5: Data Used in Calculating Sodium Adsorption Ratio

Sample Number	Na^{+}(meq/l)	Ca^{2+}(meq/l)	Mg^{2+}(meq/l)	$\frac{(Ca^{2+} + Mg^{2})}{2}$	$Na^{+}/\sqrt{(Mg^{2+} + Ca^{2+})/2}$
1	0.44	0.14	0.54	0.34	0.6
2	0.58	0.59	0.78	0.69	0.69
3	0.65	0.18	0.47	0.33	1.14
4	0.48	0.12	0.39	0.26	0.94
5	0.43	0.17	0.27	0.22	0.93
6	0.42	0.08	0.19	0.14	1.14
7	0.64	0.44	2.04	1.24	0.58
8	0.64	0.93	0.63	0.78	0.73
9	0.43	1.44	0.81	1.13	0.41
10	0.51	0.54	0.63	0.59	0.66
11	0.68	1.23	1.39	1.31	0.59
12	0.64	0.79	1.16	0.98	0.65
13	0.64	0.34	1.73	1.04	0.63
14	0.71	1.48	1.33	1.41	0.59
5	0.59	0.80	3.04	1.92	0.42

The major types of water in the study area were obtained by using Piper's trilinear diagram (Piper, 1944). The Piper trilinear diagram is a diagram that illustrates the various percentages of anions and cations in the two triangular fields and a combined position of all major ions in the diamond-shaped field (Fig.4). Percentages of anions and cations are based on total equivalents per litre of the major ions. Piper diagram shows the effects of mixing between waters, because mixtures of two different waters will plot on a straight line. From the plot, two major water types were observed, and these are:

(i) Mg-HCO_3-Cl
(ii) Mg–HCO_3

The (Mg)-HCO_3-Cl is the most abundant water type in the area amounting to 20% of samples collected from groundwater that occurs in coarse-grained granites and metasediments in the study area. The Mg (most abundant cation with average value of 1.03meq/l) would have been leached from some mineralogical constituents such as hornblende, pyroxene and olivine present in the rock types of the area

The next in abundance to Mg-HCO_3-Cl is Mg-HCO_3 water type. This water type amounts to 13.3% of water samples from groundwater occurring in biotite granite in the study area

Table 6 shows the water types obtained from the Aquachem piper plot for the fifteen water samples, of which the dominant or major types were determined.

The most probable geochemical process responsible for the evolution of the above mentioned hydrochemical facies is the dissolution of minerals in the various rock types occurring in the area.

Magnesium (Mg^{2+}) is sourced from the breakdown of some mineralogical constituents present in rocks of the area. Such minerals include hornblende, pyroxene and olivine as it is been evident by Raji and Alagbe (1997) to have present in schist and quartzite present in Asa drainage basin in Kwara State. The evolution of bicarbonate (HCO_3) may be attributed to the CO_2-charged recharge.

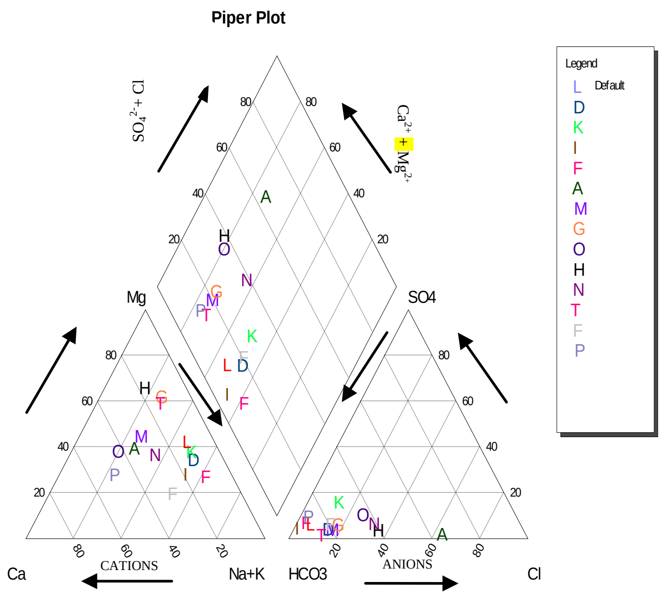


Fig.4. piper trilinear diagram showing chemical characters of groundwater in

Table 6: Water types obtained from Aquachem piper plot

Sample ID	Sampling Date	Water Types	Station ID	Location
IU 1	2/28/2011	Mg-HCO_3	Loosa, Oke-oyi	L1
IU 2	2/28/2012	Mg-Ca-Na-HCO_3-Cl	Elemosho, Oke-Oyi	L2
IU 3	2/28/2011	HCO_3-Cl	Eleran, Oke-Oyi	L3
IU 4	2/28/2011	Na-Mg-HCO_3-SO4	Loosa	L4
IU 5	2/28/2012	HCO_3	Badi	L5
IU 6	2/28/2012	HCO_3	Adelu	L6
IU 7	2/3/2012	Mg-HCO_3-Cl	Panada	L7
IU 8	3/1/2012	K-HCO_3-Cl	Agbeyangi	L8
IU 9	3/1/2012	Ca-HCO_3	Oloruntele	L9
IU 10	3/1/2012	Mg-HCO_3	Idiapa	L10
IU 11	3/1/2012	Mg-Ca-Cl-HCO_3	Ita-Alade	L11
IU 12	3/1/2012	Mg-HCO_3-Cl	Kure-Oja	L12
IU 13	3/1/2012	Mg-HCO_3-Cl	Woru-Oja	L13
IU 14	3/1/2012	Ca-Mg-HCO_3-Cl	Lajolo	L14
IU 15	3/1/2012	Mg-Ca-HCO_3-Cl	Marafa	L15

5. Summary and Conclusion

The study of hydrogeology as well as potability of groundwater in Oke-Oyi Area and its environs in Ilorin-East Local Government Area of Kwara State has been carried out. The area is underlain by rocks of the Basement Complex which are essentially biotite-granite, granite-gneiss and metasediments (schists and quartzite) which possess varying textures and structures.

Calculated aquifer hydraulic characteristics using borehole pumping test data shows that hydraulic conductivity range between 1.17×10^{-1} m/day and 8.60×10^{-2} m/day with a mean value of 6.27×10^{-2} m/day. Transmissivity values of the aquifers vary from 0.95 m^2/day to 3.16 m^2/day with an average value of 1.77 m^2/day. The storage coefficient (S) calculated for the boreholes in the area shows values that range between 0.619 and 1.765 with a mean value of 1.238. The Physico-Chemical analysis of groundwater samples in the area has shown that the groundwater is slightly alkaline with an average pH value of 9.7. The mineralization of the water (TDS) has an average value of 129.02 mg/l, far below its acceptable limit of 500mg/l of World Health Organization (WHO). This shows that the groundwater is fresh. The groundwater in the area is largely classified as Mg-HCO_3-Cl and Mg-HCO_3 water types using Piper trilinear diagram. The electrical conductivity value indicates low-medium salinity Hazard and Sodium Adsorption Ratio (SAR) shows low sodium hazard in the groundwater samples of the area, indicating that the groundwater is good for irrigation purpose.

In conclusion, this research has been carried out and has helped in arriving at the fact that: the geology of the area revealed that the rocks found in the area are mainly intrusive and metamorphic rocks. Groundwater occurrence in the area depends on the presence and extent of weathered overburden and the presence of joints and fractures in the underlying bed rock.

The result of the physico-chemical analysis of groundwater samples in the area has shown that the groundwater is potable based on the World Health Organization recommendations. The groundwater quality for irrigation based on Sodium Adsorption Ratio (SAR) calculated and low-medium salinity hazard shown indicate that the groundwater in the study area is suitable for irrigation purposes.

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