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Hydrogeology Of Nsukka Southeast, – A Preliminary Approach To Water Resources Development.

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Abstract: - The hydrogeology of Nsukka SE has been carried out as a preliminary approach to water resources development of the region. Topographic, maps, data from meteorological stations, and other departments, Geological maps, aerial photograph, fracture maps and satellite images of Anambra drainage basin were employed in the study. Inorganic analysis were undertaken using Atomic absorption spectroscophy, spectrophotometer, flame photometer, spekker absorption meter and turbimetric methods, while organic analysis was done using the most probable number Technique (MPN).

The result shows that the average precipitation of the area is 2.09×10^8 m^3 a year, while the rainfall intensity gives 0.15/year. Runoff for the area was calculated to be 1.06×10^7 m^3 / year, amounting to 5.07% of the total precipitation. Potential evapotranspiration amounts to 1057.98mm/year giving 8.112% of the water available from precipitation.

Depth to water table ranges from 106.70m to 9.15 from recharge area of the watershed to the farmland discharge low lying area. Aquifer type ranges from unconfined , semiconfined to confined. The average transmissivity values was calculated to be $3.25 \times 10^{-2} m^2/s$, while hydraulic conductivity gives 2.3×10^{-3} m/hr. Specific discharge is 2.24×10^{-4} m/yr, average groundwater linear velocity is 4.98×10^{-4} m/yr. The chemical constituents of deep and shallow aquifer waters show that iron concentration is on the high side. The deep aquifer waters show no pathogens while the shallow aquifers of the low lying discharge environment show heavy coliform presence. The water class for deep aquifer indicates magnesium and a no dominant anion and plotted on a transition between salt and fresh water, while the shallow aquifer water is Magnesium sulphate (hard water) and plots within the zone of salt water. The water meets the consumption standard, and industrial needs though acidic and of high iron content. The water is excellent for irrigation, and requires minor treatment. These information are ideal for reference during the water resources development of the region.

Keywords: - *Hydrogeology, Nsukka SE, Anambra basin, Southeastern Nigeria, Water Resources, development*.

I. INTRODUCTION

The primary objective of this study is to evaluate the hydrogeology of Nsukka SE within the Anambra basin of south-eastern-Nigeria; as a preliminary approach for the development of the water resources of the region. This evaluation consisted of physical, chemical and biological reconstruction of the properties of the underground water and aquifer systems, the total precipitation calculated for water years from gauging stations, the hydraulic head distribution, hydraulic connections between the available lakes / rivers and the aquifers, accessibility of the groundwater through the correlation of lithologs obtained from Vertical Electrical Soundings of the aquifer lithology, estimation of ground water movement direction as a prelude to contaminant migration and waste disposal siting (Viesman, 2004), distribution of geochemical constituents and classification of aquifer / water types. Hydrologic information collected from sources ranging from gauging stations to available literature were integrated to formulate recommendations for optimum development of aquifer system and to help facilitate maximum utilization of the available water resources of the study area. The areas affected by this study include Opiuno, Opi Agu, Ekwegbe Uno, Ekwegbe Agu Orba, Ehalumona and Ehandiagu. The area covers about $160km^2$ and lies within latitudes 6.42° N to 6.42° N and longitudes 7° 26′ to 7 36′ E (Iloeje, 1981). The 2006 population figure for the zone is about 100, 000 and this is likely to reach 1,000000 by the year 2010. (NPC, 2006). This calls for water resource development . Water table is very deep at the areas bordering the water divide (Opi Uno, EkwegbeUno and Eha-Alumona). Water table is relatively shallow at Ekwegbe Agu, Opi Agu and Eha Ndi-Agu low lying areas. This probably accounts for the few number of boreholes at the areas bordering the water shade and the relative abundance of hand dug wells at the low 'Agu' discharge or farmland areas. (Egboka, 1996).

II. METHOD OF STUDY

Description of Study

The study area falls within the Anambra basin of South-eastern Nigeria and lies within latitudes 6° 42′ N and 6° 48′ N, Longitudes 7° 26′E and 7° 36′E and encloses an area of about 160km^2 fig I.

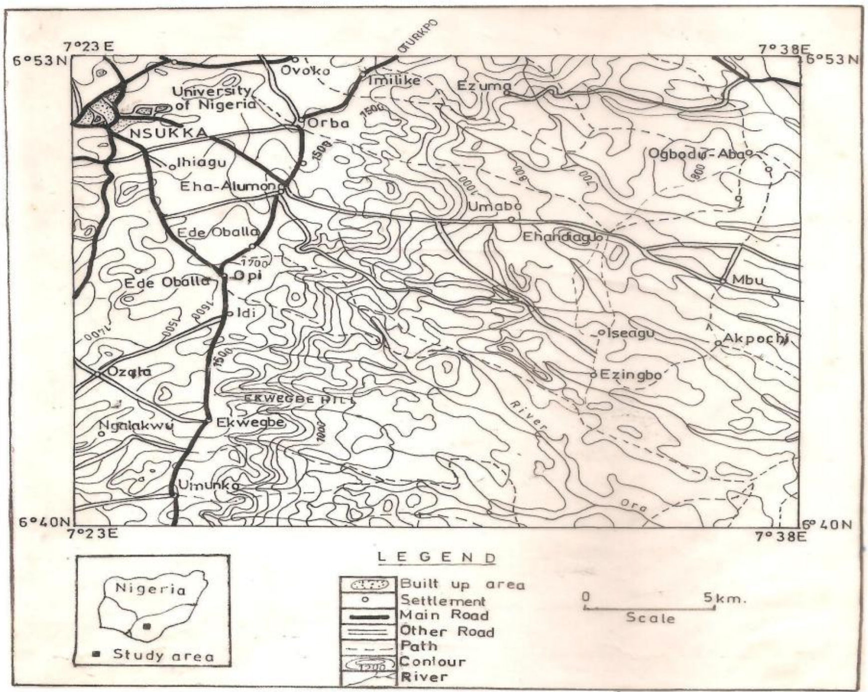

Fig. 1: Topographical Map and location of the study area

Geologically, the area is a part of Anambra basin whose rocks are upper cretaceous in age. The stratigraphic succession in Anambra basin is shown in table 1.

Table I: Generalized Sedimentary Sequence in South-eastern Nigeria (Reyment, 1965).

Age	Sequence	Formation	Lithology
Tertiary	**Miocene-recent**	**Benin Formation**	**Medium-coarse grained, poorly consolidated sands with clay lenses and stringers.**
	Oligocene-miocene	**Ogwashi Asaba Fm.**	**Unconsolidated sands with lignite seams.**
	Eocene	**Ameki Fm**	**Grey clayey sandstone and sandy clay stones.**
	Paleocene	**Imo Shale**	**Laminated clayey shales**
Upper Cretaceous	**Upper Maaastritchian**	**Nsukka Fm**	**Sandstones intercalating with shales**
		Ajali sst	**Poorly consolidated sandstone, typically cross beded with minor clay layers.**
	Lower Maastritchian	**Mamu Fm**	**Shales, sandstones, mudstones and coal seams.**
	Campanian	**Nkporo/Enugu Shale**	**Dark grey shale, clayey shale with clay lenses**
	Santonian	**Awgu Fm**	**Bluish grey shale with clay lenses.**
	Turonian	**Ezeaku Fm**	**Black shale with clay and limestone lenses.**

The three geologic formations which outcropped in the area include Mamu Formation (lower Maastritchian), Ajali sandstone (upper Maaastritchian) and Nsukka Formation (Damian) Fig. 2. Nsukka Formation is described as cap rock previously known as upper coal measures (Simpson, 1954, Reyment 1965). The Mamu Formation consists of mudstone, sandy shales and fresh water sandstones. Reyment (1965) noted the presence of ammoniferous shales in some parts of the formation. The formation strikes N-S and dips west wards, with the average dip between 4° to 8° (Umeji, 1980). Mamu Formation has fine grained sandstone and provides the shaley impermeable base on which the waters of Ajali aquifer are trapped, as the later is conformably underlain by shaley units of Mamu Formation. The Ajali Sandstone (upper Maastritchian) is about 451m thick (Agagu et al 1985). Lithologically the Ajali sandstone consists of medium to coarse –grained, poorly consolidated white sands with characteristic cross bedding and clay intercalations. Agagu et al (1985) have reported presence of such ostracods as cytherella, ovocytherides and a few foraminifera such as Hyplophragmoids and Ammobaculites. Overlying Ajali sandstone sequence is Nsukka Formation. The formation is related to Mamu Formation in many aspects only that Nsukka Formation has no coal seams in the study area. Outliers of Nsukka Formation dot the area with Ajali sandstone providing the base (Egboka, 1996).

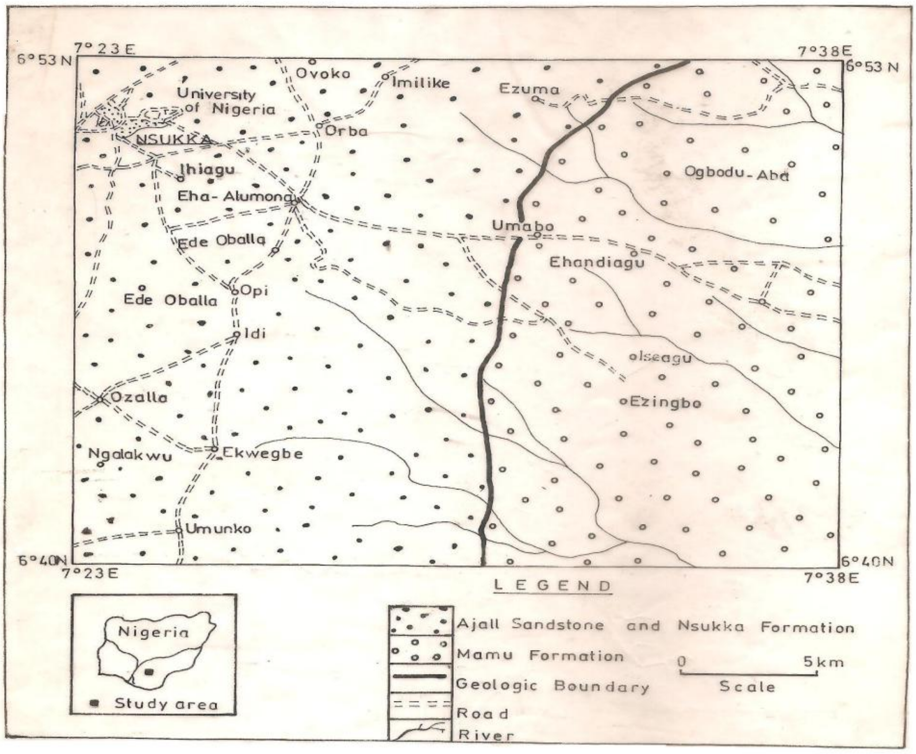

Fig. 2: Geological map of the Study Area (Reyment 1965)

Two climatic seasons characterize the study area – the dry and wet seasons. According to Udo (1978), the dry season generally begins about the middle of October and ends around March, while the rainy season sets in April and ends in early October (Iloeje 1995). According to the author, the mean annual rainfall is 1304.2mm, while the mean monthly maximum temperature is 28.73°C. Also the mean annual relative humidity is 58.28% mean vapour pressure is 21.68, pitche evaporation is 4.32 and mean monthly minimum temperature is 21.26°C. According to Ogbukagu (1976), the physiography is dooted by numerous cone shaped hills that are laterite capped and are the outliers of Nsukka Formation. The conical hills are often separated by low lands and broad valleys. The surface run off on these valleys is virtually nil due to the high permeability of the red earth mantle and soil as well as the thick underlying Ajali Sandstone. The most prominent topographical features in the study are the North- South trending cuesta over Ajali sandstone. The dip slope of the cuesta is generally South-east wards (Edokwe, 1976).

The vegetation and soil types are related. The study area lies within the tropical rain forest / Guinea Savannah belt of Nigeria (Iloeje, 1978). The author classified the soil as the rain forest and lateritic soils. The rainforest soils are rich in humus derived from rainfall in the forest, unfortunately the soils are highly leached by heavy rainfall. Soils underlying savannah type of vegetation have low organic matter content and low cation exchange capacity. Their pH values are very low (3.3 to 4.3) and this may be due to excessive leaching ((Edokwe, 1976). The major characteristic of the vegetation of this area is the abundant combination of varied plant groups whose branches intertwine to form a continuous canopy of leaves. The major plant and grass species include iroko, palm tree, obeche, Eupatorium Odoratum and imperata sylindrica.

Method of Study:

The work was carried out in stages and involved literature review and reconnaissance work. Topographic and geologic maps were employed in the identification of rock formations and in establishing their stratigraphic / structural relationships also detailed surface / subsurface geologic and hydrogeologic studies were carried out. Activities involved the determination of volume mean annual recharge measurement of static

water levels, collection of water samples from streams, springs, hand dug wells and bore holes. The final phase was used for laboratory studies in which chemical analysis of water samples and sieve analysis of aquifer sands were carried out. From sieve analysis data, aquifer hydraulic properties were determined.
Data Acquisition: The instrument used for data acquisition include topographic map of the area, geologic map, aerial photograph, fracture maps, satellite images of Anambra drainage basin. Hydrogeological investigations were carried out by identifying areas of ground water seepage. Lithological logs of three bore holes in the area were obtained from Enugu state water corporation GSN BH 3131 (OPI), GSN BH 3146 (Ehaalumina and GSN BH 2020 (Ekwegbe). The aim of the lithologs is to identify geologic stratification of the sub surface materials, hence the aquifers.

A total of seven water samples were collected for organic and inorganic analysis using Atomic absorption sepectrocopy for Ca^{2+}, Na^{+}, Mn^{2+} , Cl^{-} Pb, Cd Zn, copper was analysed with the aid of spectrophotometer, while K^{+} was determined using flame photometer method. pH was measured with standard pH meter concentrations of total iron (Fe^{2+}) were determined calorimetrically using Spekker absorption meter. Total dissolved Solids (TDS) was determined using glass fiber filter. The concentrations of $Ca^{2+,}$ Mg^{2+} and Na^{2+} in milliequivalent per litre were used to obtain sodium absorption ratio. (SAR). Turbimetric method was used to assess turbidity. Physical parameters like pH and dissolved oxygen were measured insitu in the field with appropriate standard meters, while anions like HCO_3^{-} were estimated by titrimetric method water levels were estimated using calibrated tape. Clean plastic containers were used to contain the water samples, they were rinsed several times with the same water samples to be analysed, then covered with air tight cork, carefully labeled and sent to the laboratory for chemical analysis within 24 hours of collection. All details of analytical procedures are reported in Omidiran (2000).

III. RESULTS

Result from all available water resources records of the area Hydrology, and borehole logs were presented and all necessary calculations made.

Tables 2 (a-f) shows Average Hydrological data for six water years (1985-1990) obtained from University of Nigeria Nsukka (UNN) Meteorological Station

Table 2 Average Hydrological data for 1985/86 Water Year

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(a)

Average	**Max. Temp.**	**Min. Temp.**	**Rel. Humidity**	**Vapour Pressure**	**Piche Evap.**
	29.86	**19.61**	**74.58**	**25.18**	**4.0**

Average Hydrological data for 1986/87 Water Year

(b)

Average	**Max. Temp.**	**Min. Temp.**	**Rel. Humidity**	**Vapour Pressure**	**Piche Evap.**
	28.9	**19.80**	**74.32**	**22.23**	**4.04**

Average Hydrological data for 1987/88 Water Year

(c)

Average	**Max. Temp.**	**Min. Temp.**	**Rel. Humidity**	**Vapour Pressure**	**Piche Evap.**
	28.74	**21.2**	**68.56**	**29.1**	**4.0**

Average Hydrological data for 1988/89 Water Year

(d)

Average	**Max. Temp.**	**Min. Temp.**	**Rel. Humidity**	**Vapour Pressure**	**Piche Evap.**
	28.30	**20.27**	**73.69**	**21.88**	**4.09**

Average Hydrological data for 1989/90 Water Year

(e)

Average	Max. Temp.	Min. Temp.	Rel. Humidity	Vapour Pressure	Piche Evap.
	27.97	27.27	72.61	23.68	3.92

Average Hydrological data for 1990/91 Water Year

(f)

Average	Max. Temp.	Min. Temp.	Rel. Humidity	Vapour Pressure	Piche Evap.
	27.97	27.27	72.61	23.68	3.92

Lithological logs from the 3 available boreholes of the area is shown in fig. 3

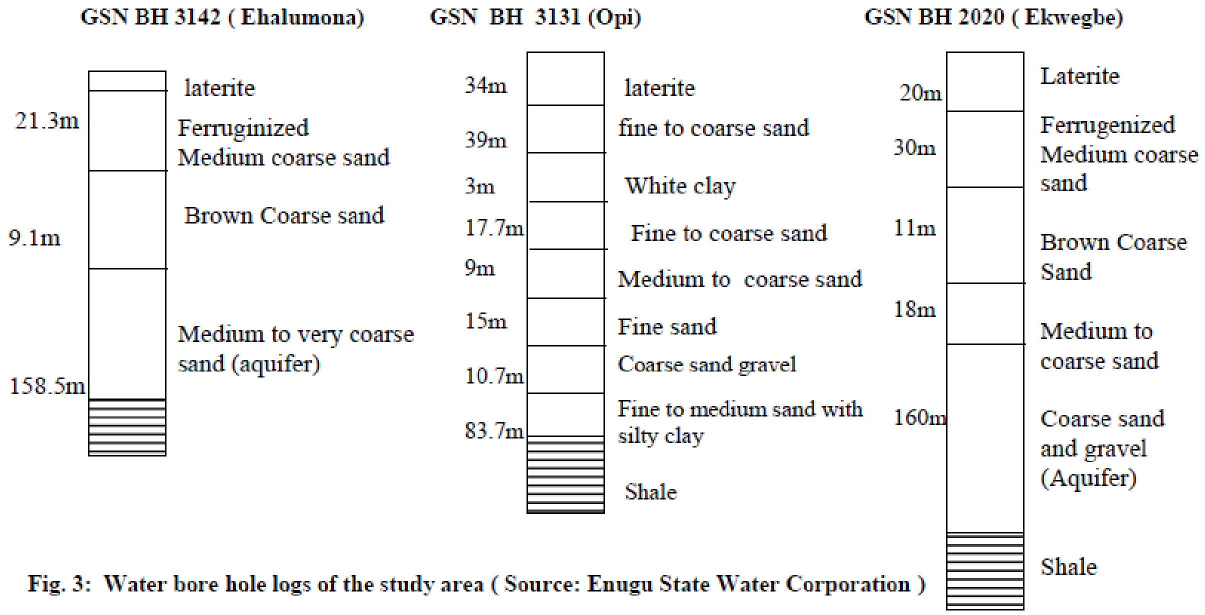


Fig. 3: Water bore hole logs of the study area (Source: Enugu State Water Corporation)

Table 3: result of Rain fall data (mm) for the years 1985-91

Months	1985/86	86/87	87/88	88/89	89/90	90/91
April	60.61	90.4	14.5	107.9	62.4	60.5
May	266.8	212.2	115.6	128.7	250.8	248
June	11.3	230.1	172.4	202	104.3	105.2
July	298.3	312.6	153.7	374	264.5	238.4
August	151.4	179.5	100.5	285	150.7	140.8
Sept.	239.8	255.5	242.3	249.7	225.5	220
Oct	193.7	54.5	48.2	125	135	160
Nov.	0.0	18.5	34.2	103.5	12.4	18.5
Dec.	0.0	0.0	0.0	0.0	0.0	0.0
Jan.	17.5	0.0	0.0	0.0	0.0	0.0
Feb.	48.3	0.0	0.0	4.5	0.0	5.3
March	5.5	12.4	47.5	30.5	50.3	40.8
Total	1454	13.35	928.9	1614.8	1255	1237.5
Monthly Av.	121.17	111.31	77.41	134.57	104.60	103.13

The result obtained from meteorological stations in table 2 and 3 were used to compute the hydrological balance equation as:

P = 1 + R + E ……………….(1)

Where P = precipitation, 1 = infiltration, R = Runoff

E = Evapotranspiration . The above equation helps in the estimation of the amount of water leaving or entering a basin. (Iloeje , 1995). The mean annual rainfall from University of Nigeria Nsukka rain guage station gives 1304.2mm, while the area of study was measured from ordinance survey map of Nigeria (1990), and this gives 160k m^2. The amount of water available from precipitation (p) gives 2.09 x $10^8 m^3$ year (1304mm x $160km^2$). Viessman (1972) gave a formular for estimating the quantity of water which occurs as runoff from the relation:
Q = C. I.A……………(2)

Where Q = Peak discharge or runoff coefficient.
I = Rainfall intensity in mm/ hr, A = Catchment area in Km^2 Scoup (1978) gave the average runoff coefficient (c) for Anambra basin as 44% (0.44). The rainfall intensity (I) calculated for the area gives 0.15mm/yr. Therefore with catchment area of $160km^2$, the peak discharge in terms of runoff was calculated to be 1.06 x $10^7 m^3$/yr. Table 4 gives potential Evapotranspiration of Nsukka area

Table 4: Prefeasibility report on the Anmabra River basin (Source: Skoup 1978)

Jan	Feb	March	April	May	June
4.5	**5.5**	**4.9**	**4.7**	**4.3**	**3.7**
July	**August**	**Sept.**	**Oct.**	**Nov.**	**Dec**
3.5	**3.3**	**3.5**	**3.9**	**4.2**	**4.3**

From table 3, the actual evapotranspiration for a year is taken as 70% of potential evapotranspiration (Skoup 1978) and amounts to 1057.98mm/yr and represents 8.112% of water available from precipitation.

Infiltration (I) is calculated from the following:

Infiltration (I) = p - R - E……………..(3)

Where P (Precipitation) = 2.09 x $10^8 m^3$ or 100%

R (Runoff) = 1.06 x $10^7 m^3$ or 5.07%

E (Evapotranspiration) or 8.112%

The percentage of water infiltrating down to the groundwater table (13.182%) shows that the area has a relatively high recharge potential (Ofomata 1985). The runoff of 5.07% is significantly low because of the high permeability of the underlying soil mantle and Ajali sandstone that directly underlie the soil over much of the are (Agagu et al. 1985). The result from the three (3) available well logs and field investigations of the lithologies within the gorges reveal the aquifer systems. It was observed that Nsukka Formation provides perched aquifer units trapped by the basal shale units on the flanks of its outliers (Tattam, 1981) Ajali sandstone consists of thick, poorly, consolidated medium to coarse

Grained sands inter layered with thin white clay bands, silty clays and fine grained sands. The mode of occurrence of clay is significant in the area. The clays have greater thickness when they occur as silty clays. This formation some what confines the Ajali aquifer waters stored between the silty clay and the upper limit of the imperious shale unit of Mamu Formation. This shows that the waters of Ajali aquifer in the area is unconfined to semi confined to confined. Generally, the basal shale unit of Nsukka Formation and upper limit of Mamu Formation confined the Ajali waters. In all the head waters (Gorges) visited the underground water flows under a thick deposit of silty white sand about 60 m thick. This water is confined between the underlying Mamu Shale and overlying Nsukka shale unit. However, from observations where white clay units occur near the surface, the Ajali sandstone furnishes perched water. The Ajali sandstone which is predominantly aquiferous has aquitard units (Nwankwor et al, 1988). The medium to coarse grained sand units of the formation from the aquifers, while the thin clays, silty clays and fine grained sand units of the formation form the aquitards. Aquitards in the area are not prominently developed at the upper horizons. They rather occur in discontinuous bands that trap some perched water especially during the rainy seasons, this perched aquifers (springs) dry up during dry seasons Uma (1989). The base flow for the area therefore occurs above the shale unit of Mamu Formation. The average measured water table in the recharge environment of the watershed gives 106.7om, while at discharge environment (OpiAgu, Ekwegbe Agu, Ehandiagu), the average value is 9.15m, indicating a progressive decrease from the recharge to the discharge zones of the area. The shallowness of the static water table at the farmland lowlying discharge environment likely shows that those areas are located at the shallow Ajali sandstone – Mamu Formation boundary and shallow wells tap the aquifers which are likely to be polluted (Freeze and Cherry 1979).

Aquifer characteristics : The characteristics of the aquifer of the area were obtained from the work of Egboka and Uma (1986). The data are shown in table 5 and 6.

Table 5: transmissivity Values for the Ajali aquifer system computed from pumping analysis (Source: Egboka and Uma, 1986).

S/No	Location	Step Draw down T (m^2h^{-1})	Recovery T (m^2h^{-1})	Jacobs T(m^2h^{-1})	Logans T (m^2h^{-1})
1	Ibeawaka	3.10	25.64	-	19.2
2	Udi	1.46	-	-	7.79
3	Ekwegbe	4.16	35.26	-	48.99
4	Ohafia	0.83	1.55	-	5.75
5	Ighere	0.28	1.79	6.16	2.68
6	IhaAlumona	0.35	2.19	2.62	4.44
7	AkpugoEze	0.57	0.75	-	-
8	Opi	0.40	0.12	0.22	0.55
9	Ezimo	0.80	5.58	3.36	6.05
10	Ngwo	0.51	2.29	3.60	13.74
11	Ovim	0.41	2.58	2.45	3.95
12	Amiyi	-	0.26	2.33	1.00
13	Okpuje	1.48	12.95	-	38.87
	Average	4.5×10^2	3.158×10^3	1.11×10^3	4.96×10^3

Table 6: Hydraulic Conductivity values for the Ajali Aquifer sytem (Egboka and Uma, 1986)

S/No	Location	Stepdraw down (mh^{-1})	Recovery (mh^{-1})	Jacob (mh^{-1})	Logans (mh^{-1})	Statistical Methods		
						Haleman (mh^{-1})	Hazen (mh^{-1})	Masch and Denny
1	Ighere	0.17	0.119	0.411	0.179	1.07	1.66	0.30
2	Obinofia	0.023	0.146	9.175	0.296	0.831	1.30	0.648
3	Ohafia	0.055	0.103	-	0.383	0.5540	0.864	0.518
4	Akpugoeze	0.035	0.045	-	0.328	0.749	1.166	0.559
5	Udi	0.09	-	-	0.48	0.576	1.166	0.551
6	EhaAlumma	0.053	0.372	0.224	0.403	1.066	0.90	0.421
7	Ngwo	0.034	0.153	0.24	0.249	1.066	1.663	0.6345
8	Ovim	0.027	0.172	0.163	0.26	1.4	1.663	0.794
9	Amiyi	-	0.017	0.022	0.066	1.4	-	-
10	Ekwegbe	0.26	2.18	-	3.30	-	-	-
11	Akpuje	0.097	0.85	-	2.55	-	-	-
12	Opi	0.003	0.008	0.015	0.036	-	-	-
13	Ngwo	0.19	1.59	-	1.19	-	-	-
	Average	0.126	0.480	1.457	0.748	-	-	-

IV. RESULT FROM STATISTICAL METHODS

The data obtained from sieve analysis of aquifer samples of Ajali sandstone are presented in table 7. The statistical method applied are those of Hazen (1993), Harleman et al (1963), Masch and Denny (1966). The statistical methods are based on size analysis of Ajali aquifer samples. From table 6, it is possible to use the various statistical methods to calculate hydraulic conductivity (k) Transmissivity

Table 7: Grain Size Calculation from statistical using sieve analysis method

Location	Dmm_{10}	Dmm_{50}	Q_5	Q_{80}	Q_{95}
Opi	1.0	.43	-.4	1.0	1.6
OpiAgu	1.8	.91	-1.1	1.95	2.9
EhaAlumona	1.2	.48	- .9	2.25	3.6
Ekwegbe	1.60	.65	.95	-	-
Orba	1.44	.50	.07	2.1	2.9

(T) values for the aquifer system (Todd 1979). The average screen length in the three bore holes of the area is 20m. The transmissivity was calculated based on this . Transmissivity (T) is defined as the ease with which an aquifer transmits water through its entire thickness and has been defined mathematically by Freeze and Cherry (1979) as

$$T = kb \ (m^2/s..........) \quad (4)$$

Where k = hydraulic conductivity (m/s), b = saturated thickness of the aquifer (Screen length). The average T value obtained using 20m Screen length (b) is 3.25×10^{-2} m^2/s.

Specific Discharge and Average linear velocity: The hydraulic gradient of the area computed from difference in head in static water level in borehole between EhaAlumona and Opi gives 0.00975 specific discharge from Freeze and Cherry 1979 is computed as vd = ki …………(5)

Where vd = Specific discharge , k = hydraulic conductivity, i = hydraulic gradient . From equation 5, the average hydraulic conductivity for the area is 2.3 x 10^{-3} m/h. This value is then multiplied by the average hydraulic gradient (0.00975). The specific discharge is obtained as 2.24 x 10^{-4}. The average linear groundwater velocity Va can then be computed from equation 6 given as

$$Va = \frac{vd}{n} \quad \ldots\ldots\ldots\ldots\ 6$$

Where n = Porosity. The porosity of the aquifer which consists of medium to coarse grained sand is estimated from Table 8

Table 8: Porosity of various sand sizes (Source: Petijohn 1974)

Size of material	Porosity (in Percentage)
Coarse Sand	39-41
Medium Sand	41-48
Fine Sandy Loam	50-59
Fine Sand	44-49

For the study area, the mean estimated porosity is 45%. The average linear ground water velocity (va) is obtained as 4.98 x 10^{-4} m/yr . The measurements of water quality obtained from various stations are shown in table 9 for inorganic constituents of deep aquifer and table 10 for shallow aquifers.

Table 9: Chemical constituents of water samples from deep aquifer in mg/L for the recharge area of water shed.

Table 10: Chemical Constituents if water samples from shallow aquifer- hand dug wells and springs of the discharge farm land settlement

Location	pH	Hardness	Colour	Alkalinity	SO_4^{2-}	Nitrate	Phosphate	Iron	Calcium	Magnesium	Ca^{2+}/Mg^{2+}	Sodium	Chloride	Tds	K^+
Ehakumona	6.9	20	4	10	11	2.7	.76	1.7	4.7	14.6	.3	0	4	92	0
Orba	6.8	20	3.2	3.2	8	2.7	.8	2.1	4.7	14	.3	.1	4	76	0
Opi	6.3	20	10	10	8	2.7	.8	2.1	6.3	14.6	.4	1.2	7	44	10
Opi Agu	7.2	20	5	10	8	1.1	2	2.2	1.2	9	.5	.4	4	68	0
Orba Agu	4.7	12	10	8	15.2	-	2.3	2.7	6.3	9.7	.2	2.7	4	40	8
Ekwegbe	6.1	12	12	10	15	-	2.2	1.1	4	9.0	.2	.2	5.7	53	0
Average	6.3	17.3	7.37	8.53	10.97	2.3	1.48	1.98	4.53	11.8	.32	0.92	6.67	62.17	3
WHO 1984	6.5 -8.5	250		250	250	45	10	0.3	75	50	-	200	250	500	200

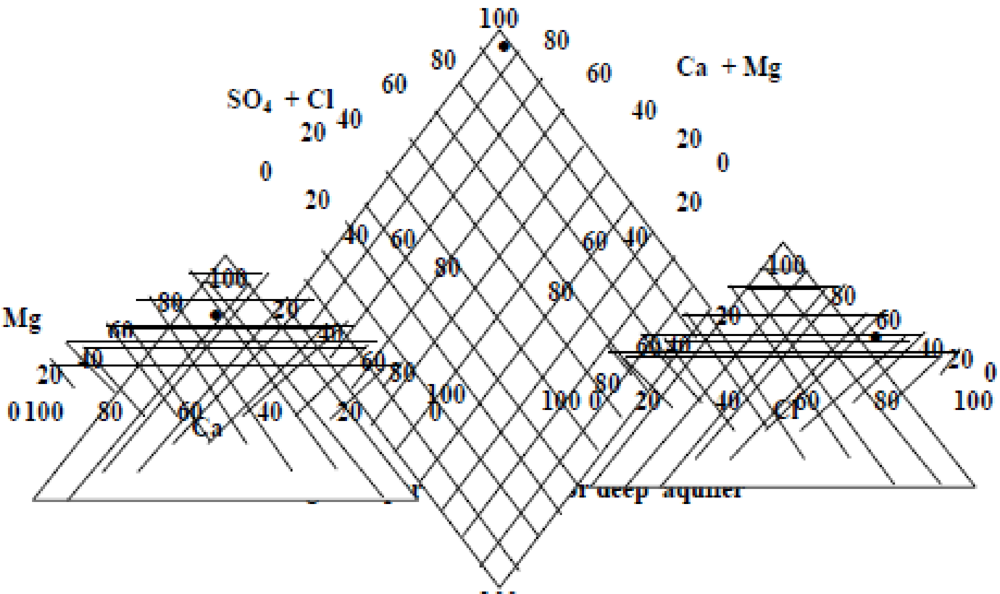
Table 11: Coliform analysis of selected shallow aquifer of the area

Location	pH	Hardness	Colour	Alkalinity	$SO4^{2-}$	Nitrate	Phosphates	Iron	Magnesium	Ca+/Mg2+	Sodium	Chloride	Tds	K+	Calcium
EhaAlumona	6.6	12	5	25	-	-	-	.38	12	.33	97`	15	-	0	4
Opi I	5.6	12	5	10	15.2	2.7	2.2	1.68	9.7	.41	.4	17	56	0	4
Ekwegbe (I)	6.7	20	5	10	11.6	3.7	.92	1.68	14.6	.32	0	4	60	0	4.7
Orba (I)	5.4	20	10	10	16	3.6	1.84	.68	9.7	0.86	.80	12	4.8	6	7.8
Ekwegbe (II)	5.5	8	8	10	11.6	3.2	1.84	1.68	9.7	.22	.8	6	24	0	3.2
Opi (II)	6	16	4	8	15.2	1.5	1.8	2.7	14.6	.22	0.1	1.5	0.24	4	3.2
Orba (II)	5.4	12	4	10	15.2	2.7	1.5	2.1	9.7	.32	.5	4	56	0	3.2
Average	6.3	17.3	7.37	8.53	10.97	2.3	1.48	1.98	11.8	0.32	0.92	6.67	62.17	3.0	4.53
WHO 1984	6.5-8.5	250		250	250	45	10	0.3	50	-	200	250	500	200	75

The result of the Biochemical examination of the shallow aquifer is shown in table 11. From analysis , the deep aquifers show no pathogenic presence. However, the shallow aquifers have anthropogenic infestations as table 11 clearly indicates.

EhandiAgu	**1/3**	**0/3**	**0/3**	**MPN**	**4/100ml**
Opi Agu	**0/3**	**1/3**	**0/3**	**MPN**	**3/100ml**
Ekwegbe Agu	**1/3**	**0/3**	**1/3**	**MPN**	**7/100ml**

Sawyer and Mc Carty (1967) indicated that pathogenic micro-organisms survival can be expected to be greater when Normal biological activity is the least such as under low temperature and anaerobic conditions. In the analysis of table 11, the coliform count ranged from 3/100ml to 7/100ml. From the table of drinking water standard water with more than 1 per 100ml bacterial content is not good for drinking (Who 1984). Therefore this geological environment of the study area has excessive quantity of coliform bacteria . Freeze and Cherry (1979) indicated that coliform presence is due to wastes of humans and farm animals. The water chemistry of the area for both the shallow and deep aquifer was classified using pipers' diagram as shown in figures 4 and 5



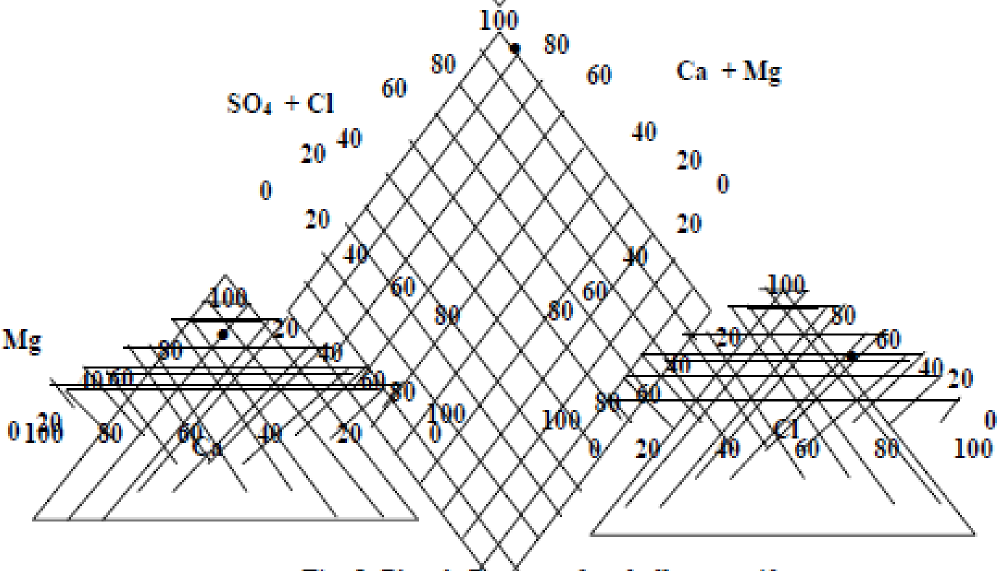


Fig. 5: Piper's Diagram for shallow aquifer

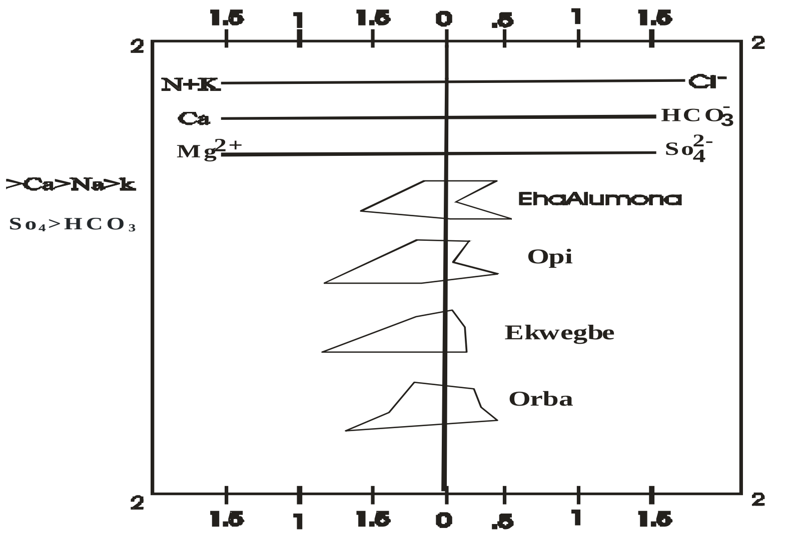
Table 12: Cations and anions computations in milliequivalent per litre for deep aquifer waters

Cations	Conc (mg/L)	Atom Wt (g)	Charge	Conversion factor	Conc Mg/L	Miliequivalent per litre
Ca^{2+}	4.3	40.08	2	.04990	0.2	16.67
Mg^{2+}	11.43	24.31	2	.08226	.94	74.60
Na^{+}	1.7	22.98	1	.04350	.07	5.56
K^{+}	1.43	39.10	1	.02557	.04	3.17
Total					1.26	100
Anions						
HCO^{3-}	0.32	61.02	1	0.01639	.005	0.900
No^{3-}	2.73	62.0	1	0.01613	.04	7.21
$SO4^{2-}$	13.18	96.06	2	1.02082	.27	48.65
Cl^{-}	8.5	35.45	1	0.02821	.24	43.24
TOTAL					0.555	100.0 0

Table 13 : Cations and anions computations in milliequivalent per litre for shallow aquifer waters

Cations	Conc (mg/L)	Atom Wt (g)	Charge	Conversion factor	Conc Mg/L	Miliequivalent per litre
Ca^{2+}	4.53	40.08	2	0.0499	0.23	17.42
Mg^{2+}	11.80	24.31	2	0.08226	0.97	73.48
Na^{+}	0.92	22.98	1	0.04350	0.04	3.03
K^{+}	3.0	39.10	1	0.02557	0.08	6.06
Total					1.32	100
Anions						
HCO^{3-}	0.25	61.02	1	0.01639	0.004	0.72
No^{3-}	2.3	62.0	1	0.01613	0.04	7.22
$SO4^{2-}$	15.17	96.06	2	0.02082	0.32	57.76
Cl^{-}	6.67	35.45	1	0.02821	0.19	34.30
TOTAL					0.554	100

Tables 12 and 13 were also used to classify the deep and shallow aquifers using pipers' diagram (Pipers 1944). From the plots the deep aquifer classification fig 4 show that the water falls within Mg^{2+} type and a no dominant anion class and plotted between salt and fresh water while the shallow aquifer classification – fig 5 shows a magnesium sulphate water and plots on the right side of the diamond shape of the pipers plot indicating salt water (Pipers 1944). The shallow ground water is therefore hard with $MgSO_4$ (Edward 1978). From the stiff diagram fig 6 and 7, it is clear that there is more dissolved constituents in the deep aquifer waters.



Cations (Meq/L) Anions (Meq/L)

Fig. 6: Stiff diagram for deep aquifer

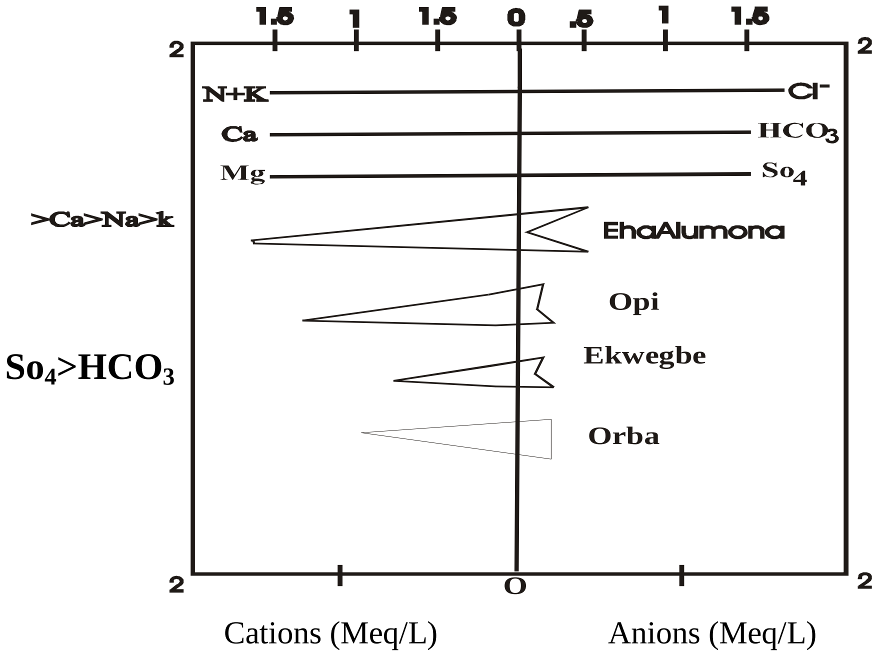


Fig. 6: Stiff diagram for deep aquifer

Calcium content was used to classify water quality of the area for irrigation purpose because of its reaction with soil to reduce permeability (Etu Efeotar 1981). Thus the relation sodium Absorption Ration (SAR).

$$SAR = \frac{Na+}{(Ca^{2+} + Mg^{2+})^{1/2}} \text{ (Meq/L)} \quad \ldots\ldots\ldots\ldots\ldots 5$$

Equation 5 was employed to determine the suitability of the water for irrigation purposes. According to Etu Efeotor 1981, water class based on SAR is classed as 0-10 – excellent, 10-18 – Good , 18-26- Fair , while > 26 is poor. Using equation 5, The average SAR for components derived from tables 12 and 13 gives 0.58 for deep aquifer and 0.32 for shallow aquifer indicating water excellent for irrigation in both cases (EtuEfeotor, 1981). The ground water resources of the area was compared with American water works association (AWWA) as to assess their usability in industries. This is shown in tables 14 and 15

Table 14: Ground water analysis result compared with American water works association (AWWA) for deep aquifer.

Parameters	Average Value of sample analysed mg/L	AWWA (1991) Accepted Standard Mg/L
Tds	37.46	50-500
Total Hardness	14.29	0.250
Iron (Fe2+)	2.27	0.1-10
pH	5.09	6.5-8.3
Chloride (Cl-)	8.5	20- 250
Manganese	-	0-0.5

Table 15: Ground water analysis result compared with American water works association (AWWA) for shallow aquifer.

Parameters	Average Value of sample analysed mg/L	AWWA (1991) Accepted Standard Mg/L
Tds	62.17	50-500
Total Hardness	17.30	0.250
Iron (Fe2+)	1.98	0.1-10mg/L
pH	7.5	6.5-8.3
Chloride (Cl-)	6.67	20- 250
Manganese	-	0-0.5

In both cases the water resource of the area is ideal for industrial applications (AWWA, 1991). The pollution Index of Horton (1995) was employed to calculate the pollution index of the deep and shallow aquifer as to assess their extent of pollution. The Harton scale is shown in Fig 8

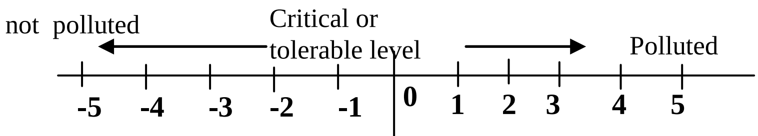


Fig. 8 Hortons Scale (1995)

Unit value (1) indicates tolerable standard, but above this value (1) the water is polluted and below this value the water is not polluted (Harton 1995). The pollution index (piji) was calculated using equation 6 as shown below

$$\sqrt{\frac{(\max\ Ai / wij)^2 + (\text{mean}\ Ai / wij)^2}{2}} \ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where Ai is the measured parameter and wij is the universal standard

Table 16: Deep Aquifer pollution Index Computation

Parameter	Ai	Wij	Ai / wij	Result
Phat 29°C	5.09	6.50-8.50	0.78	
Turbidity (NTU)	21.50	5.0	5.70	Mean $\frac{Ai}{Wij}$
Conductivity (ms)	30.24	100	0.30	
Tds	37.46	500	0.75	
Iron (Fe^{2+})	2.27	0.3	7.57	= 1.29
Calcium (Ca^{2+})	4.30	50	0.38	
Magnesium (Mg^{2+})	11.43	30	0.38	
Potassium (K^+)	1.43	50	0.03	Max Ai / wij
Sulphate (SO_4^{2-})	13.18	250	0.05	
Phosphate (PO_4^{2-})	1.68	10	0.17	
Nitrate (NO_3^-)	2.73	45	0.06	= 7.57
Chloride (Cl^-)	8.5	250	0.04	
Carbonate (CO_3^-)	14.29	250	0.06	
Manganese (Mn)	-	0.5	-	
Mean	10.39		1.29	

From equation 6, employing parameters in table 16 and referencing fig 8, the pollution index of deep aquifer is 5.43 in the same way that of shallow aquifer is 4.69. This indicates pollution in both cases.

V. DISCUSSION

The average precipitation of 2.09 x $10^8 m^3$ a year signifies the total water presence which can always be referred to during water budgeting. This is quite high indicating high recharge. High temperature and vegetation of the region bring about high evapotranspiration of 1057.98mm/year amounting to 8.112% of the water available from precipitation. This in essence indicates that during dry periods of intense heat, the underground water is likely to be a function of base flow. The depth of water table of 106.70m to 9.15m from recharge to discharge lowlying areas of farm settlement indicates difficulty and expensive nature of water exploitation of the upland recharge areas, though this water will be free from pathogens due to natural attenuation processes (Raymond, 1979).On the other hand, the waters of the lowlying discharge areas should be easy to exploit though polluted and the terrain would be ideal for commercial agriculture due to high water table. The high values of transmissivity, (3.25 x 10^{-2}, m^2/yr) hydraulic conductivity (2.3 x 10^{-3} m/h). Specific discharge (2.24 x 10^{-2}) and average linear velocity of 4.98 x 10^{-4} m/yr indicate aquifer of high efficiency, specific capacity and yield and would be ideal for water resources development (Hazen, 1993).
Water chemistry indicates for deep water aquifer the order $mg^{2+} > Ca^{2+} > K^+ > Na^+$ for cations and $SO_4^{2-} > Cl^- > HCO_3^-$ for cations $mg^{2+} > Ca^{2+} > Na^+ > K^+$ with low Ca^+ / Mg^{2+} ratio. This indicates that Magnesium is the major contribution of water hardness. The high coliform content of the shallow aquifers of the discharge environment is due to indiscriminate pit latrines while the low pH (the acidic environment) is due to the carbonaceous unit of Mamu Formation (Reyment, 1965). The water Chemistry indicates that there is the need for water treatment due to pathogens, high acidity, above all the water is saline, and brackish in nature. The coliform presence is due to waste of humans, farm animals and probable soil erosion (Uma, 1989). The

presence of soluble cations is due to the fact that most metallic elements are soluble in acid ground water (Viesman, 1972). The problem of low Ph (acidic) is that when it is below 5, the hydrogen ion concentration can reactivate some poisons found in sediments (Viesman, 1972) The water hardness is due to $MgSO_4$. This is probably due to presence of pyrite or gypsum in the underlying shales in the area. Water containing 500mg/L of sulphate tastes bitter and may be cartartic , this is the major fear in the area. Saline water may likely lead to saline soil (Nacl and $NaSO_4$). These types of soils will support little or no plant growth. Excess chloride may be due to contamination from excretion products (livestock and human defaecation). The major dissolved solids in the area arise due to calcium and magnesium ions. The average range for the area is 4.3 to 11 mg/L. The high iron content in the area is likely to be due to lateritic nature of the outliers of Nsukka Formation, as the latter contains iron and Aluminum compounds (Reyment , 1965). Removal of iron in groundwater is desirable because it can form rust (iron oxides) deposits causing staining of plumbing fixtures, laundered clothes and manufactured product, as well as imparting metallic taste to the water (Mc. Carty , 2001)

VI. CONCLUSION AND RECOMMENDATION

The water resource of the study area is practically good for every purpose, but the problems of pollution due to pathogens, iron and acidity should be addressed . Removal of iron consists of aeration of raw water in aeration tanks, providing for the oxidation of ferrous to ferric iron $Fe^{2+} + ¼ O_2 + OH^+ \longrightarrow Fe_3^+ + ½ H_2O$. On the other hand, the soil of the area should be made alkaline by the use of alkaline fertilizer, this reduces acidity. Modern toilet facility should replace pit latrines. Above all, deeper water borehole exploitations is recommended for he low lying discharge environment, such bore holes should be over 50 m deep and the upper 30 m cased or properly lined to prevent the ingress of bacteria. For industrial applications, chloride treatment is quite desirable.

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