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HYDROGEOLOGY OF AWGU AND ENVIRONS, SOUTHEASTERN NIGERIA

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Abstract
The purpose of the study was to evaluate the hydrogeology and water resources potentials of Awgu local government area of Enugu State, Nigeria. The study area is underlain by shales, and sandstones of Awgu Formation (Coniacian) and Nkporo Group (Maastrichtian). The sandstones and fractured shale form a shallow, unconfined to confined aquifer systems that are tapped artificially by boreholes. The ground water flow direction is west northeast. Estimates of the water budget equation indicated that infiltration (i.e. recharge) is about 2.0 $x10^5$ to 8.10 x $10^6 m^3$/year. Hydraulic conductivity values of the aquifers range from 1.7 $x10^{-2}$cm/s to 4.72 x 10^{-2}cm/s but this was established from pumping test analysis and grain size analysis. Chemical analysis of the samples in the area indicates that they are mostly mildly alkaline in nature. Only few samples showed slight acidity (pH=5.0 – 9.0). The Total Dissolved Solid (TDS) ranges from 40mg/l to 300mg/l. Ca^{2+} ranges from 0.2mg/l to 28.1mg/l while Mg^{2+} varies from 1.07mg/l to 14.5mg/l. Na^+ ranges from 8.3mg/l to 199.0mg/l. The dominant anion is Cl^- but SO_4^{2-} varies from 0.1mg/l to 100.0mg/l while HCO_3^- is from 0.04mg/l to 80.0mg/l. There is indication of mild levels of nitrate enrichment in the water. Trilinear analysis from the borehole samples are chemically dominated by sodium, calcium and chloride (Na^+ – Ca^{2+} – Cl^-). Sodium absorption ratio (SAR) values and salinity hazardous calculations of the borehole samples indicated excellent quality for irrigation.

Keywords: Hydrogerology, Awgu, Hydraulic Conductivity, Groundwater

Introduction

Awgu and environs is a part southeastern region of Nigeria especially by many researchers, it is believed that Anambra basin has age ranging from Lower Cretaceous – Upper Cretaceous (Albian - Maastrichtian). Researchers such as Jones (1964), Adeleye (1975), Petters (1978), Whiteman (1982), Benkheil (1989) and more worked extensively on the Lower Benue Trough and Anambra Basin in particular. They described the individual or part of Nigeria sedimentary basins. Short and Stauble (1967) also noted the stratigraphic units of southeastern Nigeria with their respective associated age. Ogbukagu (1977), worked on the lithologic units in order to determine the area. Murat (1972) considered Anambra Basin as a direct consequence of the folding and uplift of Abakaliki-Benue area during the Santonian. Ladipo (1988) and Hoque (1977), described the sedimentary structures of Owelli Sandstone to include large scale tabular cross stratification, wedge shaped trough type of hummocky stratification. Okoro (1995), considered the Nkporo Group as the oldest lithostratigraphic unit of Anambra Basin and Afikpo Syncline.
The works of Igbozuruike, (1975), Ofomata (l978) and Inyang (1978) gave insight into the relief, drainage, landform and climate of the study area. A number of studies have been conducted on the hydrogeology of Nigeria. These studies primarily revolve around the hydraulic parameters such as hydraulic conductivity, transmissivity and storativity. Frohlich, and Kelly, (1985) studied the

relation between hydraulic transmissivity and transverse resistance in a complicated aquifer of glacial outwash deposits. Mazac et al. (1985) worked on the correlation between aquifer and geoelectrical parameters in both the saturated and unsaturated zones of the aquifers gives an overview of geology and hydrogeology of Nigera. Edet and Okereke (2002) opined the delineation of shallow groundwater aquifers in the coastal plain sands of Calabar area (southern Nigeria) using surface resistivity and hydrogeological data. Several studies have been carried out within the Lower Benue Trough and the Anambra Basin to investigate the interconnection between aquifer geoelectric properties and their hydraulic parameters such as hydraulic conductivity and transmissivity as well as aquifer protective capacity. Such studies include those of Uma and Onuoha (1990), who studied the groundwater resources of the Lower Benue Trough. Uma and Onuoha (1997) carried out a study on the hydrodynamics of flow in the Anambra basin. Utom et al, (2012), used geoelectric methods to delineate groundwater parameters in parts of Enugu, Southeastern Nigeria and successfully demarcated areas with good groundwater potential. Ekwe et al (2010) estimated aquifer hydraulic characteristics of low permeability (shaly) formation in Oduma town, Enugu State where they determined the aquifer hydraulic conductivity to fall between 0.624m/day and 5.5091m/day and transmissivity to range from 14.17 m^2/day to 174.89m^2/day. Okonkwo and Ezeh (2013) determined the aquifer hydraulics and groundwater quality zone of Oduma. Akudinobi and Egboka (1996) worked on the aspects of hydrogeological studies of the escarpment regions of southeastern Nigeria. Egboka, and Uma, (1986) researched on comparative analysis of transmissivity and hydraulic conductivity values from the Ajali Sandstone aquifer system of Nigeria. Nwankwor et al., (1988), established the groundwater occurrences and flow patterns in the Enugu coal mine area. The main focus of this study, which is modelling groundwater flow, builds upon the earlier works of Hazen (1911) and Darcy (1956). This study provided useful analytical insight into the conditions of flow in the area.

Study Area

The study area, Awgu is situated in Enugu State, southeastern Nigeria (Figure 1.0). The land surface of the study area lies between latitudes 6^0 04^1N and 6^0 14^1N and longitudes 7^0 22^1E and 7^0 32^1E and covers a total land area of 210 square kilometers. It is located on the southwestern part of Enugu State (Figure 1.0) and comprises eight (8) communities namely: Awgu, Ugbo, Ihe, Mgbidi, Mgbowo, Mmaku, Nkwe, Ohumagu, Achi and Amoli. The study area is accessible through Enugu-Port Harcourt Express way, which serves as gateway to the study area. The communities of the area are accessible through tarred roads, laterite graded roads and foot paths.

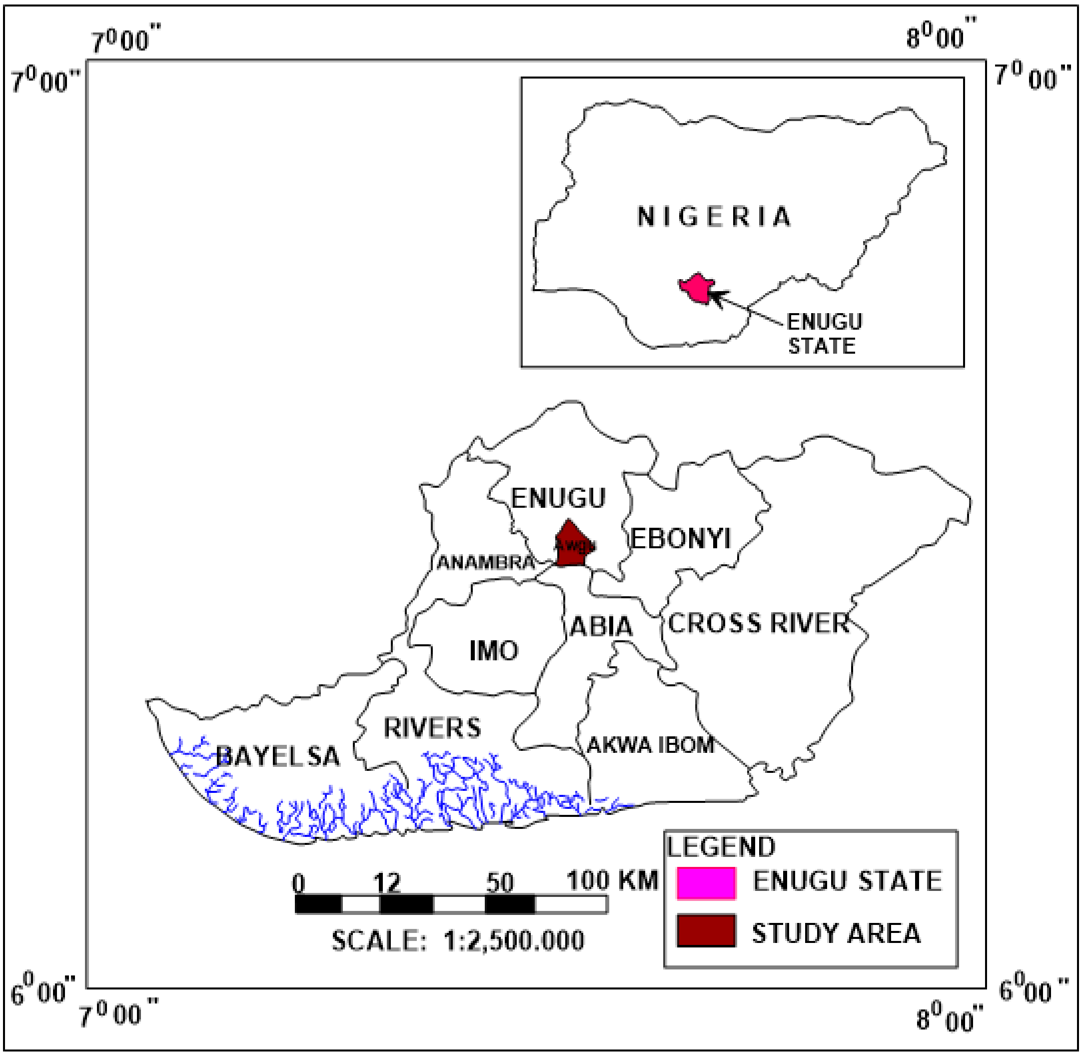

Figure 1: Location map of southeastern Nigeria showing the study area (Modified from Reijers, 1996).

The study area has two main climatic seasons; the rainy and dry seasons. Inyang (1975) describe the study area as having four months in which precipitation is less than 60mm while the total annual rainfall for the area ranges between 1.875mm and over 2500mm. Rainy season starts from May and ends in October, there is a short break of rainy season for dry season known as August break and this is associated with an inversion of tropical maritime air mass which give the air mass to rise and cause conventional rainfall even when the humidity is high. The mean monthly temperature in the hottest period of February to April is about 33^0C. Dry season is experienced in the area from November to April; it is characterized by the predominance of Northeast trade winds which causes harmattan during the month of December to February. The study area is covered by rainforest-savannas vegetation (Igbozuruike, 1975). The study area drained by Mvuna River, Ogboshi Rivers and other numerous streams.

GEOLOGY

The study area is underlain by the following geologic Formations (from oldest to youngest), the Awgu Formation, the Nkporo Formation, the Owelli Sandstone and the Mamu Formation (Table 1 and Figure 2).

Table 1: Local Stratigraphic Sequence of the study area.

Age/Period	Epoch	Formation	Dominant Lithology
Cretaceous	Coniacian	Awgu Formation	Shale
	Campanian	Nkporo Formation	Shale and sandstone
	Campanian	Owelli Formation	Sandstone
	Lower Maastrichtian	Mamu Formation	Siltstone and shale
	Maastrichtian	Ajali Formation	Sandstone

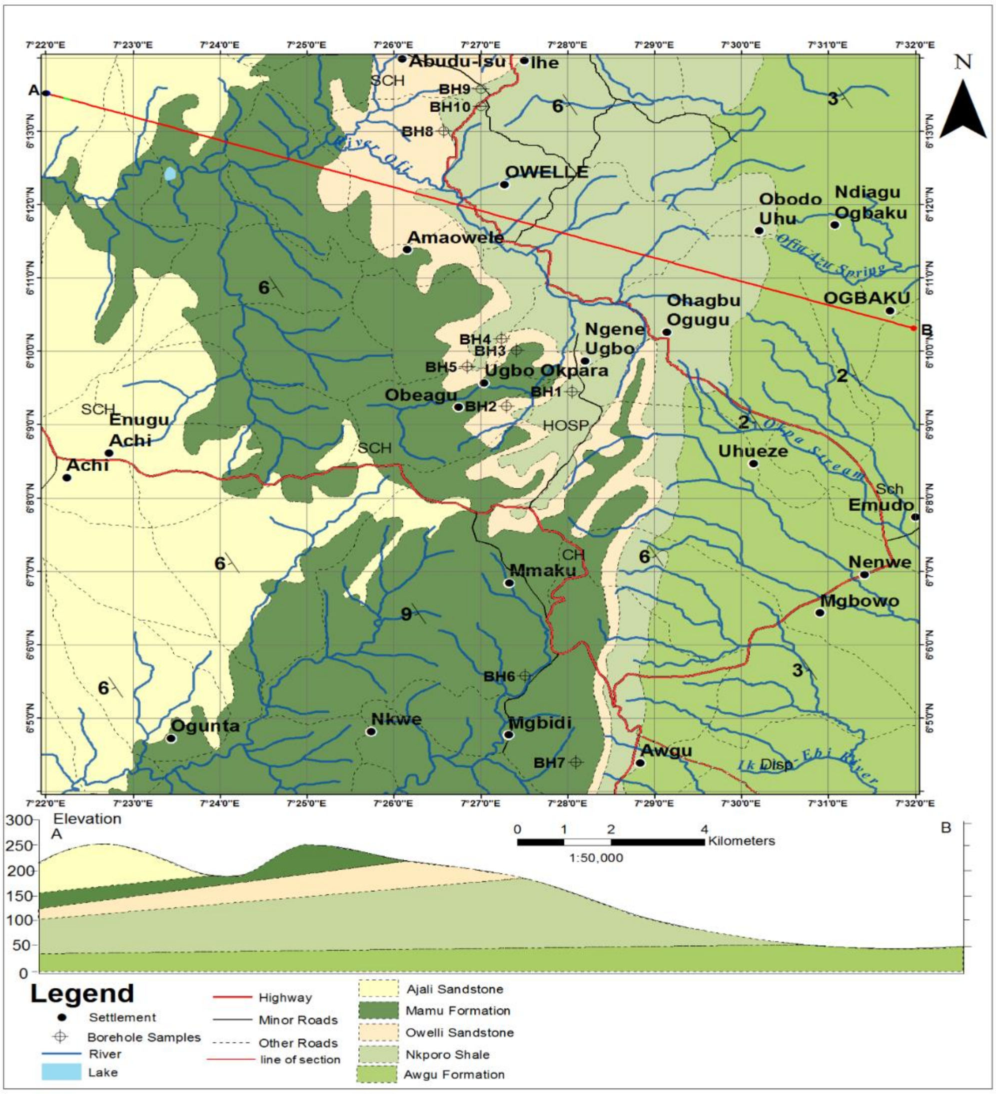

Figure 2: Geologic map of the study area.

Awgu Formation

The oldest sediment in the study area is Awgu Formation (Reyment, 1965). This formation was encountered along the Enugu-Port Harcourt expressway at Awgu junction. It is a road cut exposure of Awgu Shale with a vertical thickness of about 5 m and estimated lateral extent of about 20 m trending 46° N/226° S and dip amount of about 8°. The section begins at base with dark grey shale which is 1 m thick, with an extra-formational clast (Figure 3). It is overlain by dark grey shale of about 0.5 m thickness and continues into a parallel laminated siltstone which is about 0.1 m thick. The siltstone is succeeded by dark grey shale of about 0.5 m, bearing extra-formational clast. It passes into a heterolith and transits into dark grey shale of 1.2 m. The top of the section terminates with dark grey shale of 1 m thickness, which is interbedded with ironstone of about 2.5 cm thickness.

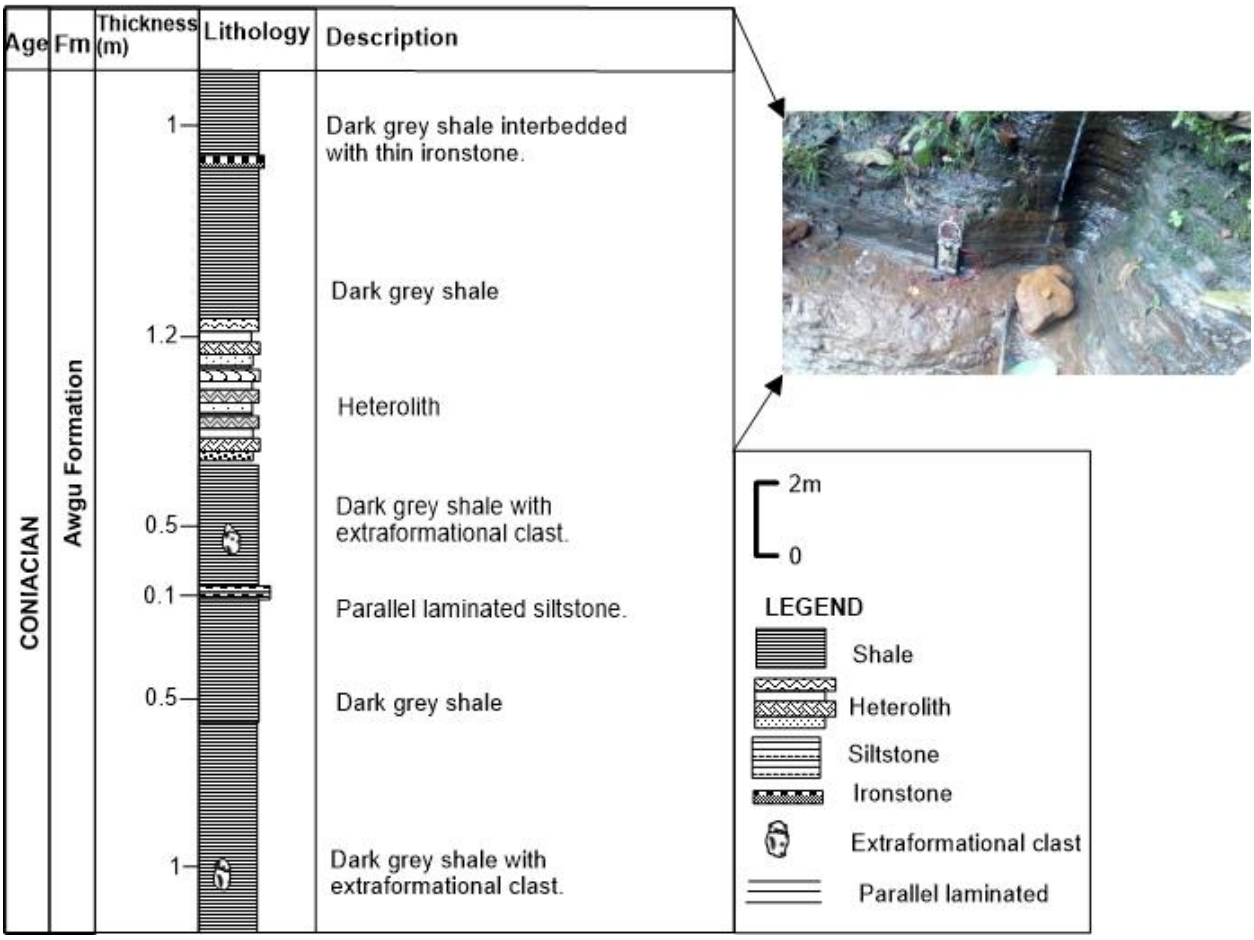

Figure 3: Lithologic section of Awgu Formation exposed at banks of river Ikube-Ebi. Co-ordinate: 6°26' N and 7°29' E.

Nkporo Formation

This is a road cut exposure at Awgu town representing Nkporo Formation. It is about 54 m thick (Figure 4) and has a lateral extent of about 1.5 km. Based on the different lithologies observed, the formation can be differentiated into shale facies, sandstone facies and sandy shale facies. The basal part of the outcrop starts with a dark shale resting unconformably on Awgu Formation. It has a vertical thickness of about 3 m. It trends 038° N/218° S direction with a dip of 6°. This is overlain by a thin bed of ferruginized fine brown sandstone of about 5 cm with groove casts. This is later succeeded by black shale of about 0.8 m containing micrite and gypsum nodules, joints and rootlets. It progresses into thin ferruginised brown shale of about 5 cm, containing bivalves and groove structures which are succeeded by grey shale of about 1 m, having traces of bivalves and gypsum nodules. The section passes into an indurated mudstone of about 4 cm. It is overlain by grey shale of 2 m thick, interbedded with mudstone and ferruginised ironstone at the upper part.

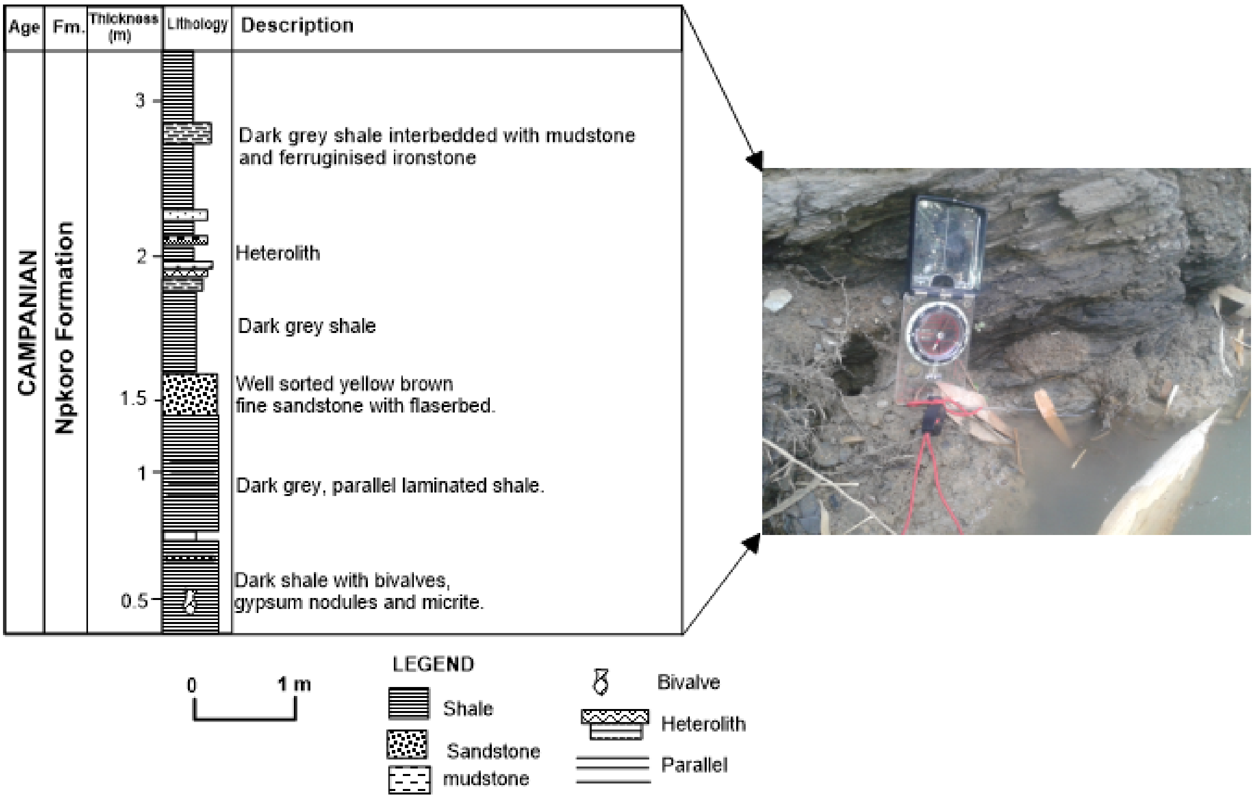

Figure 4: Lithologic section of Nkporo Formation exposed at Enugu-Port Harcourt express way.

Owelli Sandstone

The Owelli sandstone had earlier called the Awgu Sandstone by Simpson (1955) and later renamed Owelli Sandstone by Reyment (1965). The exposure was encountered at the northern and southern parts of the study area. The sequence begins with a grey to brown weathered shale which is 2 m thick interbedded with thin mudstone. It is succeeded by 1.2 cm brown mudstone. The section continues with about 0.6 m thick parallel laminated fine to medium grained greyish white sandstone.

The sequence is overlain by 0.7 m thick cross bedded yellowish white, poorly sorted, clayey, fine to medium sandstone. It continues into a poorly sorted, clayey, fine to medium grained whitish sandstone which is 0.4 m thick and characterized by herringbone structure (Figure 5). It trends 60° N/240° S and has a dip amount of about 10°. Successively overlying this, is a parallel laminated, ferruginised, reddish white, fine to medium sandstone about 1 m thickness and passing into a cross bedded, ferruginised, coarsening upward, fine to medium grained white sandstone of about 0.7 m with Ophiomorpha burrows. The top of the section terminates with a dark grey sandy shale of 0.1 cm thickness, which is interbedded with ironstone of about 2.5 cm thickness.

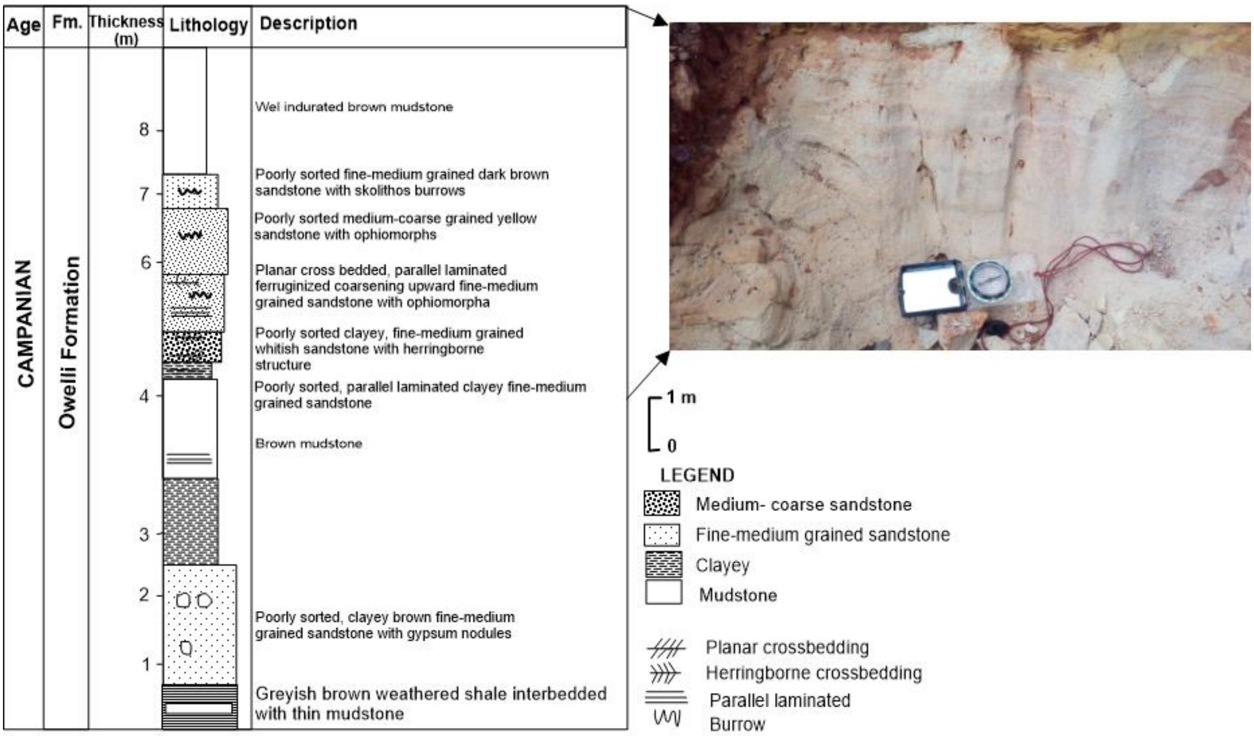

Figure 5: Lithologic section of Owelli Formation exposed at Ogbaku.

Mamu Formation

The Mamu Formation (Simpson, 1954) is the youngest Formation in the study area. The age ranges from Lower to Middle Maastrichtian from south to north, and is accompanied by both vertical and lateral facies changes (Ladipo et al., 1992). It outcrops further west of Awgu, around Mgbidi area. It is made up of a sequence of siltstone, shale and sandstone. The section begins with parallel laminated grey siltstone of about 6.5 m thickness that is overlain by parallel laminated grayish to yellowish siltstone which is about 2.5 m thick. This is successively overlain by 1.5 m thick dark grey shale and then by 0.5 m thick parallel laminated fine grained sandstone. Overlying this sequence is a 5 m thick parallel laminated brownish yellow siltstone which is overlain by massive grayish yellow siltstone about 2 m thickness and then capped by a heterolith of silt and sandstone of 2.5 m thickness.

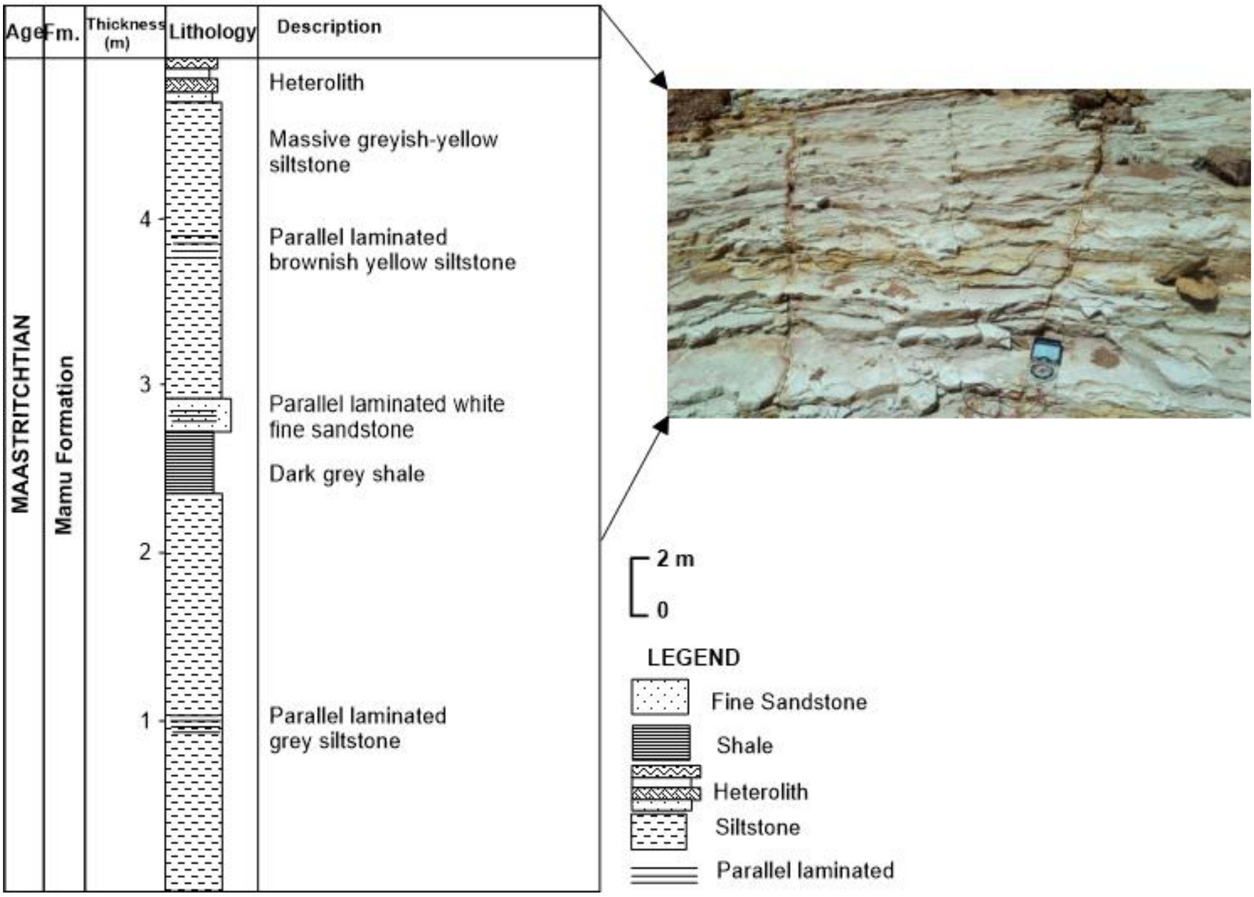

Figure 6: Lithologic section of Mamu Formation exposed at Ugbo Okpala Village. Co-ordinate: 6^{o} $10^{1}40.58^{11}$ N and $7^{o}27^{1}56.69^{11}$ E.

Ajali Formation

The Ajali Sandstone (Upper Maastrichtian) has been discussed as white false-bedded sandstone (Reyment, 1965). In this study, this was evidenced at the Enugu Achi hill top spring (Figure 6). The Ajali Sandstone exhibits a characteristic white friable, moderate to poorly sorted, coarse to medium grained, pebbly and cross-bedded sandstones, sometimes occurring with stains of iron with some sparsely distributed kaolinitic clay. It dips 6^{0}-8^{0} SW and strikes 270-320NE.

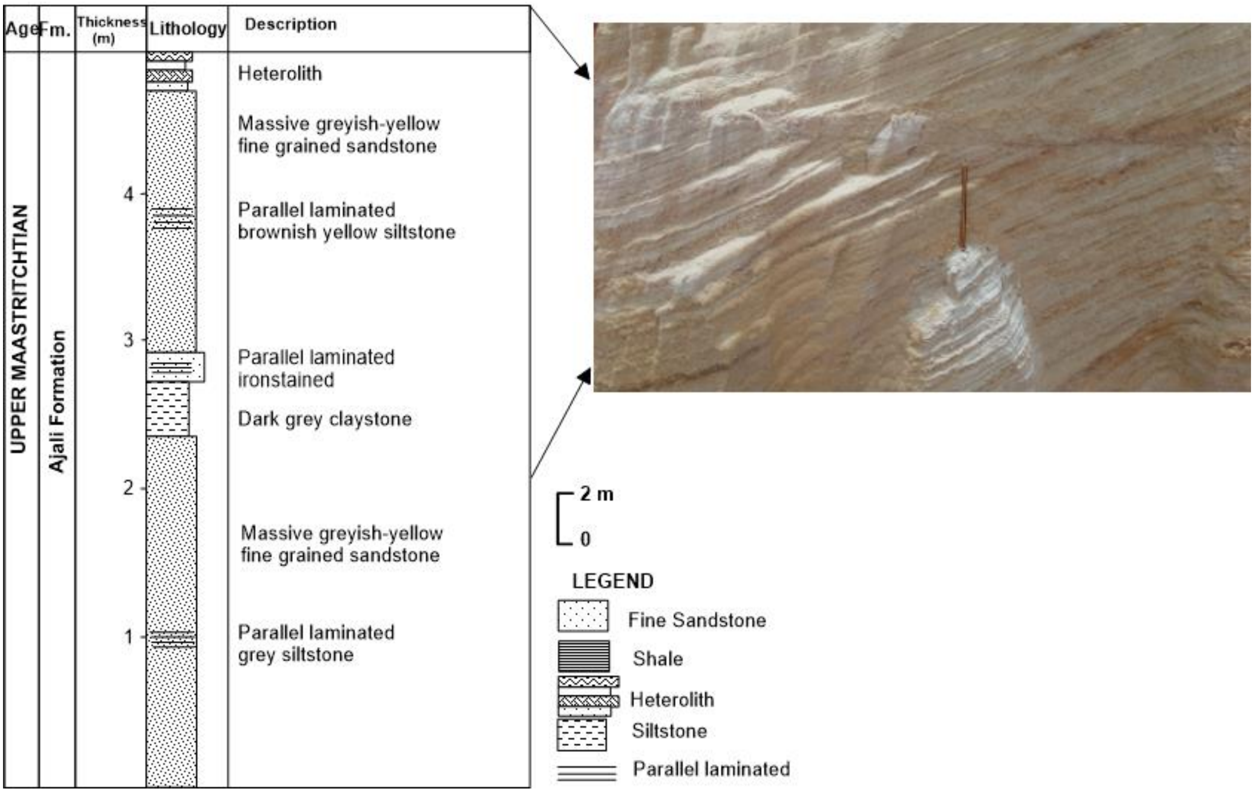

Figure 6: Lithologic section of Ajali Formation exposed at Enugu Achi hill top spring.

HYDROGEOLOGIC SETTING

CALCULATION OF AQUIFER CHARACTERISTICS FROM PUMPING TEST DATA

To provide a basis for any meaningful evaluation of the regional groundwater flow pattern is necessary to determine the hydraulic head distributions in the area. The Geoprobe Nigeria Limited recently installed 10 boreholes within the study area. The wells, presently being used to supply water to the area, penetrated a water-table aquifer to various depths. The static water levels in these wells were used to determine the hydraulic head values and to calculate the hydraulic head gradients. The patterns of groundwater outcrops, of effluent seepages along the road cuttings and that of surface drainage were used to establish further the extent of potential aquifers and the groundwater flow pattern. The summary of the calculated parameter is seen bellow (Table 2)

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Table 2: Summary of Aquifer Constants from Pumping Test Analysis of Borehole Data

Location	Storativity (m)	Sp.Storage (m^3/hr/m)	Transmissivity (m^2/d)	Aquifer Thickness (m)	Hydraulic Conductivity (m/s)
Ngene Ngbo Borehole 1	8.73×10^{-7}	5.0×10^{-4}	7.47	41	1.5×10^{-2}
Ngene Ngbo Borehole 2	1.10×10^{-7}	5.0×10^{-4}	9.43	25	2.5×10^{-9}
Ngbo Okpala Borehole 1	9.88×10^{-7}	5.0×10^{-4}	8.45	32	2.35×10^{-3}
Ngbo Okpala Borehole 2	1.16×10^{-7}	5.0×10^{-4}	9.98	55	1.2×10^{-2}
Ngbo OkpalaBorehole 3	7.51×10^{-7}	5.0×10^{-4}	6.42	35	2.5×10^{-5}
Mgbidi Borehole 1	6.98×10^{-7}	5.0×10^{-4}	5.97	40	4.2×10^{-5}
Mgbidi Borehole 2	1.14×10^{-7}	5.0×10^{-4}	9.81	39	5.5×10^{-7}
Ihe Borehole 1	7.42×10^{-7}	5.0×10^{-4}	6.35	8	5.8×10^{-3}
Ihe Borehole 2	7.30×10^{-7}	5.0×10^{-4}	6.24	20	2.0×10^{-6}
Ihe Borehole 3	7.02×10^{-5}	5.0×10^{-4}	6.0	11	3.8×10^{-2}

GROUNDWATER FLOW DIRECTION IN THE STUDY AREA

With the analysis so far made on the data a model concept of flow in Awgu and environs is now presented. Groundwater flow direction of the study area is associated with the topography of the area. The northwestern portion of the study area comprising Owelli, Ihe, Obudu Isu, constitute the groundwater divide where flow goes west and east away from the divide. Macroscopically, the recharge area includes the whole of Awgu escarpment with contributions from localized mounds like Nkwe mound, Mmaku mound, Ohu+magu mound. Flow from the groundwater divide diverges to the west; southwest and northwest, with the bulk fluid flow westwards. Subregional discharge areas exist at the Idimoke and Ikube-Ebi Rivers southeast-northeast of the area and further northwest from Mgbidi area. While surface water bodies were not identified by this researcher at the northwestern portion of the study area, the hydraulic status as a discharge area manifests in shallowing water table and water logged environment. Two flow systems exist within the study area. The upper system results from the overlying Mamu Formation. This system is a perched system that does contribute to but does not affect the hydraulics of the regional system. The individual flow cells within the upper system are not essentially in hydraulic continuity with the adjacent system cells. Flow in the upper system is therefore controlled by secondary structures and stratigraphic pinch out. Flow is in the main, seasonal but perennial in places. The region system starts from the groundwater divide in the north at a potential value of about 323m. The divide trends in a NE-SW axis and flow originates from this mound and diverges west, east, southwest, north and northwest, being controlled by slope variation. There is a progressive decrease in potential from East to West and from the recharge mound in the east to the north portion. Here the pattern changes to essentially east west flow line. The aquifer conductivity conforms to three identifiable patterns:

a) The southern part of the recharge mound is associated with low hydraulic conductivity and low specific capacity of boreholes.

b) The Northwest of the area is associated with high specific capacity boreholes. The hydraulic conductivity pattern appears to be associated with aquifer thickness and the degree of consolidation of the aquifer materials; the pattern observed in the south may also be associated with the generally smaller thickness of the aquifer near the escarpment.

c) The Northeastern portion is also associated with low capacity boreholes. This may indicate proximity to the escarpment and hence smaller aquifer thickness and age of the aquifer materials.

d) The whole of the plateau area is a through flow area but further westwards the system partly discharges into the Idimoke River at an elevation of 180m. The base flow goes further west under confinement of the Mamu Formation to the River Ikube-Ebi.

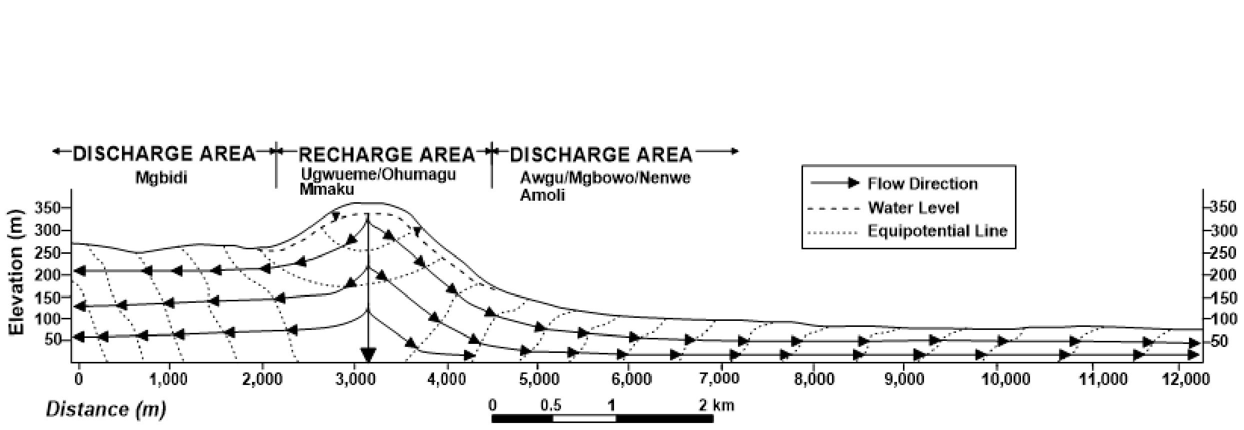

Figure 7: A conceptual model of the groundwater flow pattern in the study area

MATERIALS AND METHODS

METHOD OF SAMPLING

Groundwater samples were collected from ten [10] boreholes drilled recently by Geoprobe Nigeria Limited within the study area. The ten [10] borehole samples collected from Ngene Ugbo Boreholes were designated as BH1 and BH2; Ugbo Okpala Boreholes are BH1, BH2 and BH3; Mgbidi Boreholes are BH1 and BH2 while Ihe Boreholes are also designated as BH1, BH2 and BH3. Sample containers were flushed with detergent and rinsed with de-ionized water, thereafter rinsed with sample fluids prior to collection. Rinsing with sample waters was a precautionary measure taken to avoid any interference that may arise from using contaminated sample containers. Water samples were preserved in a cool box and subsequently taken to the laboratory for chemical analysis.

LABORATORY ANALYSIS

From the studied area, the selected boreholes are used for drinking, and domestic use. All the water samples were analyzed for physical and chemical water quality parameters including: pH, temperature, TDS and EC were measured in the field whereas the concentrations of the major cations and anions were analyzed at the laboratories of the General Agency of Groundwater using standard analytical procedures (APHA, 1998). Sodium and potassium was analyzed using flame photometer. Calcium, magnesium, chloride, carbonate and bicarbonate were determined by titrimetric method using the relevant reagent. Sulfate concentration was determined following the turbidity method by using of spectrophotometer.

RESULTS AND DISCUSSION

The results obtained from the physico-chemical analysis of the borehole samples from the study area is summarized in Table 3 and were compared with USEPA and WHO guidelines.

Table 3: Result of hydrochemical analysis of water sample from the study area

Location	pH	EC	TDS (mg/l)	$CaCO_3$ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Cl^{-} (mg/l)	SO_4^{2-} (mg/l)	HCO_3^{-} (mg/l)	NO_3^{-} (mg/l)
Ngene Ngbo Borehole 1	6.5	139	40	100	12.02	2.43	40.0	40.0	283.68	18.0	40.0	0.05
Ngene Ngbo Borehole 2	6.5	380	40	100	12.0	2.40	8.30	20.8	284.0	100.0	40.0	0.05
Ngbo Okpala Borehole 1	8.5	1683	58.40	23.0	28.1	1.45	57.8	17.2	173.5	100.0	23.0	0.05
Ngbo Okpala Borehole 2	9.0	1822	65.0	23.0	28.0	1.5	189.7	10.4	319.0	100.0	23.0	0.05
Ngbo Okpala Borehole 3	8.8	1751	56.20	21.0	18.0	10.5	61.1	30.0	400.0	100.0	20.0	0.05
Mgbidi Borehole 1	9.0	1922	63.60	24.0	7.2	10.0	173.3	23.1	199.0	5.0	24.0	0.05
Mgbidi Borehole 2	6.5	605	200	40	1.00	9.57	47.9	20.4	61.3	5.5	0.05	28.0
Ihe Borehole 1	5.0	140	200	77.19	0.25	3.55	82.5	0.10	189.7	0.15	60	28.1
Ihe Borehole 2	5.0	139	120	27.04	0.20	1.07	199.0	0.23	57.8	160.0	72	2.10
Ihe Borehole 3	5.0	188	300	73.01	0.30	7.10	72.1	0.80	81.30	0.10	80	0.98
Ugbagulu Stream	7.1	0.12	58	21.02	1.36	6.81	109	6.19	14.6	15.1	5.4	6.2
Iyinwanu	6.6	0.16	84	15.41	0.12	1.18	0.57	3.81	12.2	6.7	4.3	2.1

The pH values for the water samples examined ranged from 4.0 – 9.0 at Ugbagulu stream, Iyinwanu spring, Orji stream, Opusu, Ngene Ugbo and Ugbo Okpala borehole water samples, while boreholes measured at Mgbidi and Ihe borehole water samples varies between 5.0 – 9.0. The pH values show marginally alkaline trends except Ihe boreholes, Mgbidi borehole 2 and Ngene Ugbo boreholes that are slightly acidic. According to the WHO (2006) guideline, the range of desirable pH values for drinking water is 6.5 – 8.5. There are no water samples with values outside the desirable ranges except Ugbo Okpala borehole 2 and Mgbidi Borehole 1 that measures pH of 9.0 respectively. The values of electrtical conductivity ranged between 0.12 – 0.16 µs/cm at Ugbagulu Stream, Iyinwanu Spring, Opusu Borehole, Orji Stream and 139 - 188µs/cm at Ihe borehole water samples whereas Mgbidi, Ngene Ugbo and Ugbo Okpala borehole water samples have EC range from 139 – 1922 µs/cm; with the highest value coming from Mgbidi borehole 1 while the lowest values was from Ihe borehole 1 and Ngene Ugbo borehole 1.

The observed total dissolved solid values in all the water samples fluctuate from 0.10 – 0.52mg/L at Ugbagulu Sream, Iyinwanu Spring, Opusu Borehole, Orji Stream and 40.00 – 65.00mg/l in

Ngene Ugbo and Ugbo Okpala borehole water samples whereas Mgbidi and Ihe water borehole samples varies from 120.00 – 300mg/l. The permissible limit of TDS for drinking water is 1000mg/l by WHO (2006). Hence, the observed TDS values in all samples are well within the fresh water limit. The concentration of $CaCO_3$ measured in the entire water samples were found in the range 40.00 – 100.00mg/l of which fall between soft and moderately hard water respectively. The observed total alkalinity values in Ngene Ugbo borehole water samples (Figure 8) are related to the main rock in the area.

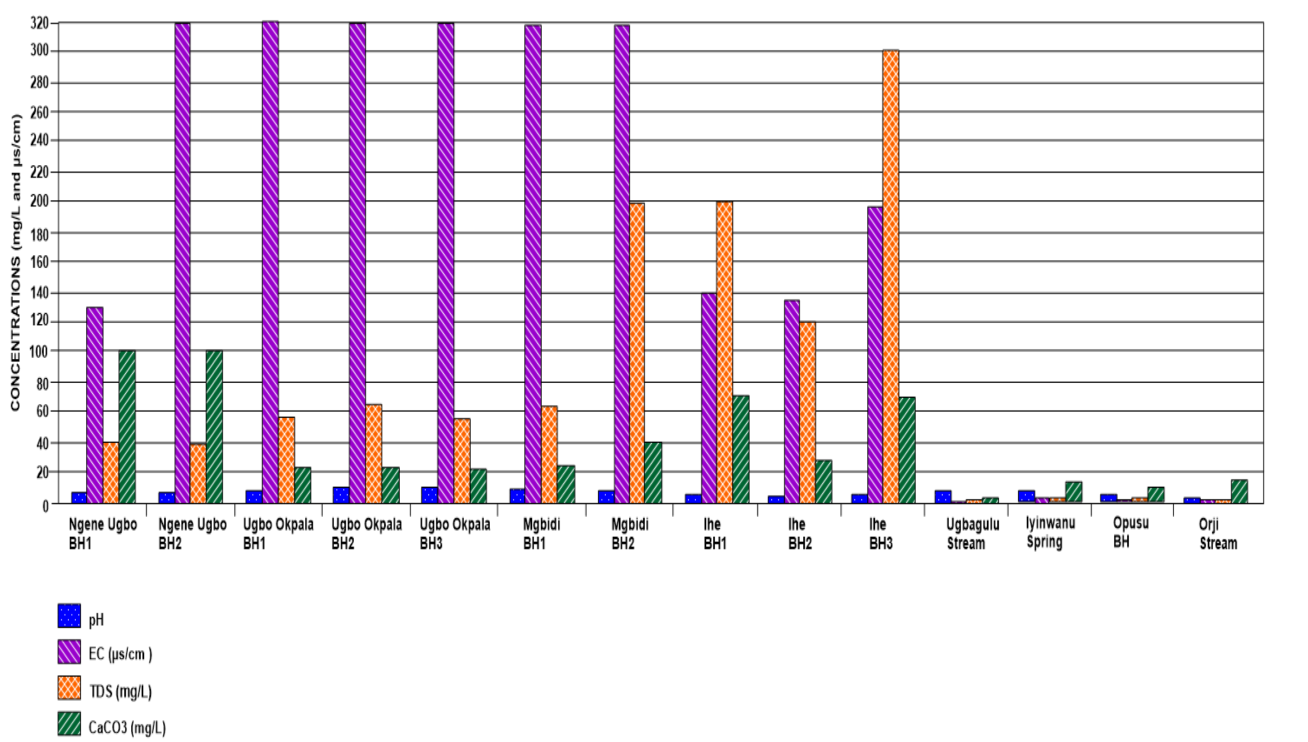

Figure 8: Concentrations of pH, EC, TDS and $CaCO_3$ in the study area.

The major cations (Figure 9) below of the boreholes are dominated by sodium and calcium belong to the group of $Na^+ – Ca^{2+}$ water type, followed by calcium, magnesium and potassium. Calcium is an important element for good health and levels between 20 – 75 mg/L are desirable in drinking water. Very high levels of calcium, however, will produce scale and clog up water pipes. In the study area, the concentrations calcium varies from 12 – 28.1mg/l at Ngene Ugbo and Ugbo Okpala borehole water samples and from 0.08 – 1.36 at Ugbagulu Stream, Iyinwanu Spring, Opusu Borehole, Orji Stream; whereas Mgbidi and Ihe borehole water samples ranged from 0.2 – 1.00mg/l. The highest concentrations of calcium were observed in Ugbo Okpala borehole 1 and 2 respectively.

The source of calcium in these borehole water samples may be from carbonate minerals found within the Awgu formation, though most of the water samples have calcium levels that are below permissible limit stipulated by regulatory agencies. A level of magnesium around 50mg/l is desirable in drinking water. Very high levels of magnesium will produce scale and clog up water pipes. The results of these chemical parameters show that the Mg^{2+}, ranged between 1.18 – 6.81 at

Ugbagulu Stream, Iyinwanu Spring, Opusu Borehole, Orji Stream and between 1.45 – 10.5mg/l at Ngene Ugbo and Ugbo Okpala borehole water samples and 1.07 – 10.0mg/L in Mgbidi and Ihe borehole water samples with the highest value of 10.5mg/L at Ugbo Okpala borehole 3, the least value recorded in 1.45mg/l at Ugbo Okpala borehole 1. The borehole water samples are within the recommended value therefore no pollution was recorded by magnesium in the study area. Sodium concentrations in the investigated water samples from the study area are found in the range of 0.41 –199mg/l with minimum and maximum values, respectively. The highest concentrations were observed in borehole 2 water samples at Ihe and Ugbo Okpala while some low concentrations ranging from 0.41 – 0.96mg/L were recorded from Iyinwanu Spring, Opusu Borehole and Orji Stream. Most of the samples have sodium levels within the permissible limit of 200 respectively (WHO 2006). The potassium values of the water samples range from 0.1 to 41.5 mg/l and most of the samples in the study area fall within the guideline levels; however, groundwater belonging to Mg–HCO3 and Na–Cl water types show higher potassium concentrations. The sources of potassium in the water samples are attributed to the dissolution of silicate minerals or agricultural activities.

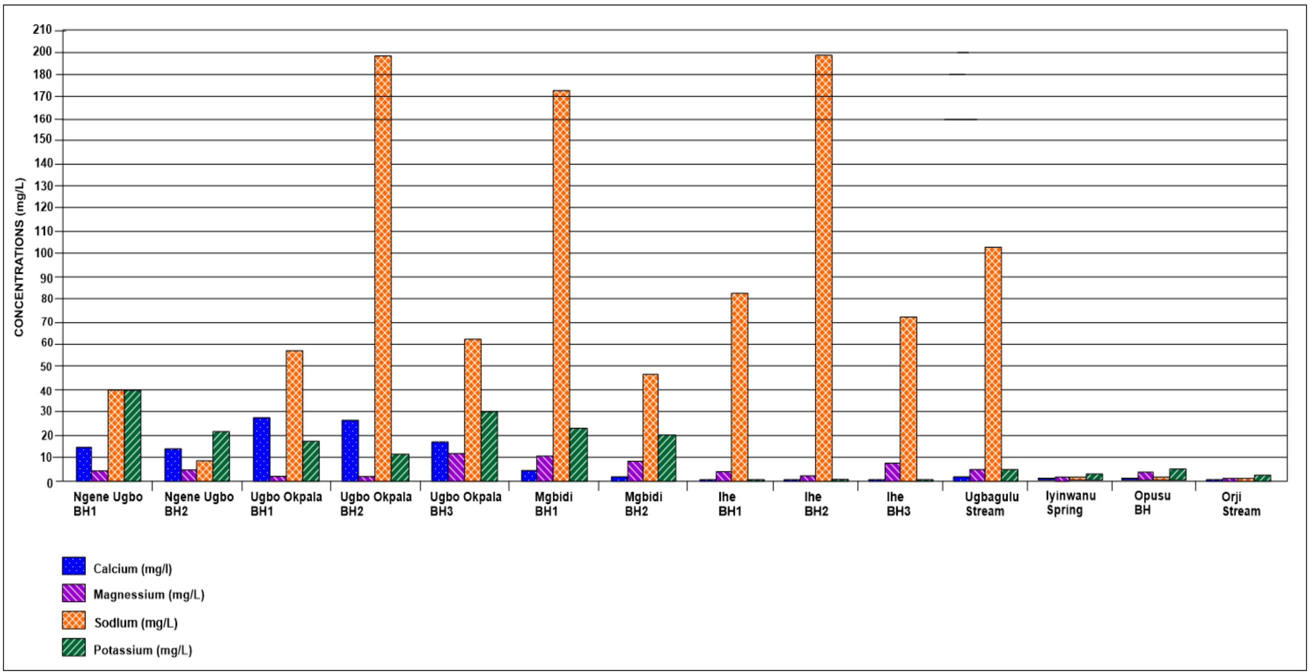

Figure 9: Concentrations of Cations in the study area.

The major anions (Figure 10) below of groundwater dominated by chloride and sulphate belong to the group of Cl^{-}–SO_4^{2-} water type, followed by bicarbonate and nitrate. Chloride is present in all natural waters, usually in relatively small amounts; however, chloride also can be derived from human sources. High concentration of chloride in water is known to cause health hazard. The concentration of chloride is high and range between 11.11 – 400.0mg/L, which is above the maximum allowable concentration of 250 mg/L (WHO, 2006). The highest concentration was recorded in the Ugbo Okpala borehole 3 and lowest concentration in Ihe borehole 2. The sulphate concentration in water samples ranged from 0.1 – 160mg/l. The highest values were observed in

Ihe borehole 2 (160mg/l) and Ngene Ugbo borehole 1 & 2, Ugbo Okpala borehole 2 & 3 (100 mg/l) groundwater; however, all of the samples are within the maximum allowable limits WHO (2006) standards. The high concentration of sulphate is likely due to the dissolution of gypsum minerals which is common in the study area. Nevertheless, high concentrations of sulphate in boreholes of Ugbo are attributed to the proximity of the sampling locations to the Owelli Formation. Most bicarbonate ions in groundwater are derived from carbon dioxide in the atmosphere, carbon dioxide in the soil and dissolution of carbonate rocks. Nitrate is a major problem in some shallow aquifers and is increasingly becoming a threat to groundwater supplies. There are numerous sources of nitrogen in groundwater systems. Most of them are strongly influenced by human activities. Nitrogen fertilizers are widely used in agricultural practice, organic nitrogen is present in number of waste products, notably sewage effluents, animal excrement and manure and municipal wastes. The nitrate concentrations in groundwater samples are lower than 10 mg/l in 14 different water sample locations. The maximum value is 84.0mg/l which is recorded in Ihe borehole 3.

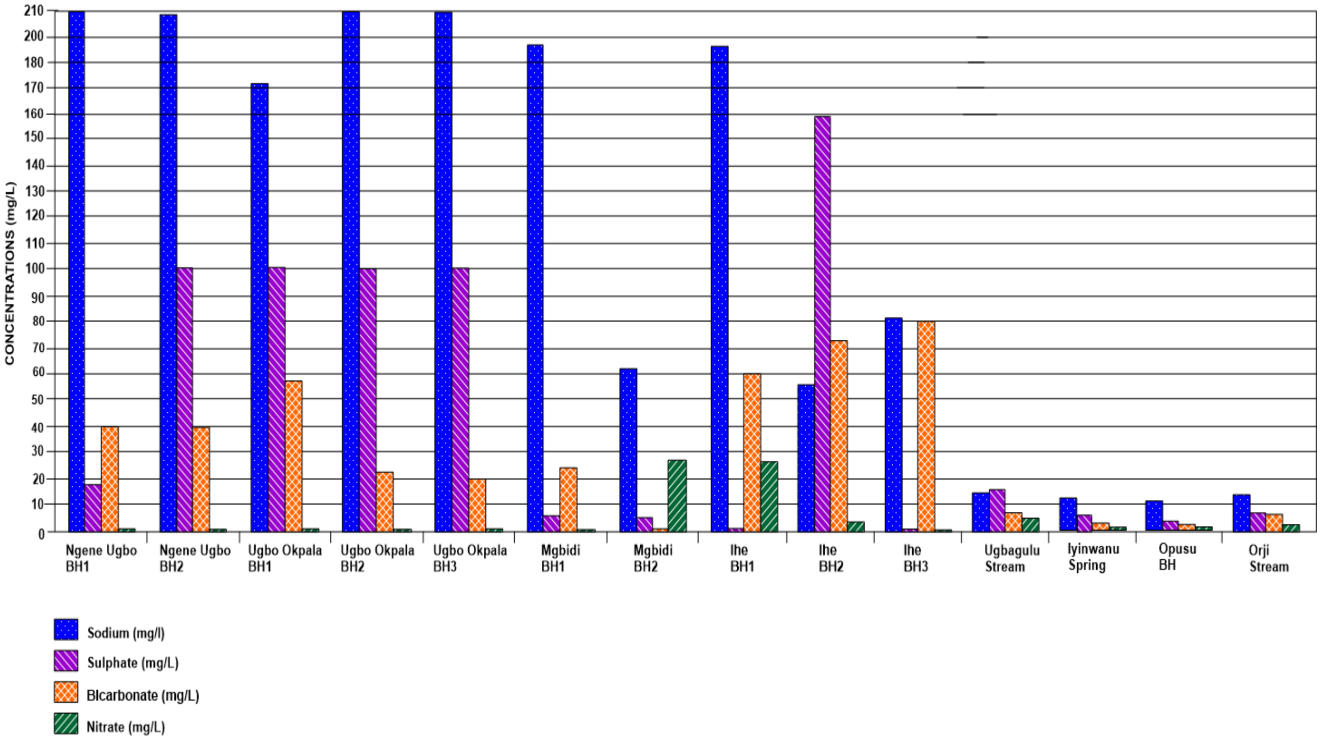

Figure 10: Concentrations of Anions in the study area.

Trilinear diagram developed with the available groundwater chemistry data are presented in Figure 11 below. Trilinear analysis indicates that most of the available groundwater samples from the borehole samples (92%) are chemically dominated by alkaline-earth metals (calcium and Magnesium) and bicarbonate. Sodium concentration exceed 40% of the sum of major cations in only 8 samples, but variations in sodium levels are observed among samples.

The combined chloride and sulfate concentration exceeds 50% of the sum of major anions in only 2% of the samples. Trilinear analysis suggests that the groundwater from all the borehole samples belong to a distinct hydrochemical facies. Most samples from these borehole water samples are chemically dominated by sodium, calcium, and chloride (Na-Ca-Cl).

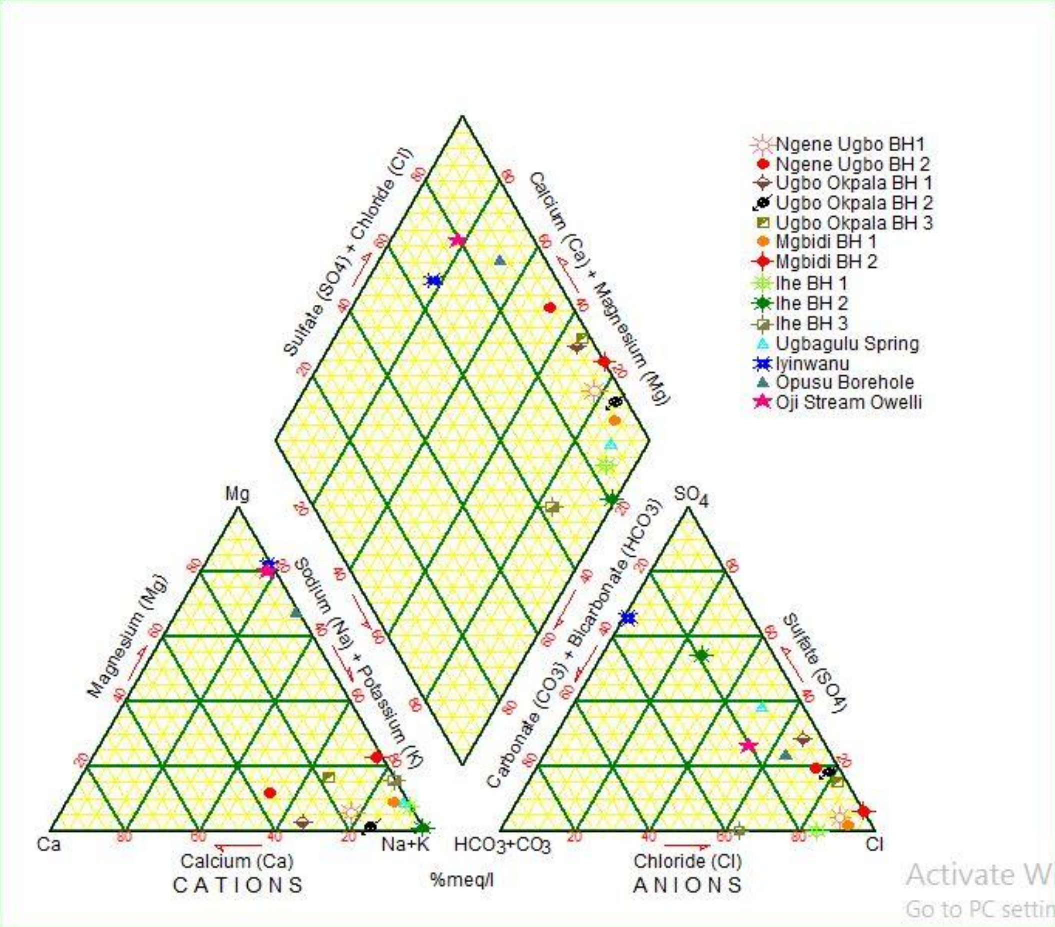

Figure 11: Piper diagram of surface and groundwater samples

CONCLUSION

This research work has provided detailed idea of aquifer hydraulics of the Awgu and environs. The establishment of aquifer hydraulics and the nature of flow boundaries have greatly enhanced the understanding of groundwater conditions in the area. Groundwater flow in Awgu and environs is topography driven. At the western boundary of flow domain is the groundwater divide of about 12km long across its major axis from Mgbidi through Mmaku to Ohumagu and about 2.5km at the minor axis across Amoli.

Two distinct flow systems exist in the area: Local flow system LFS emanating from the fractured shale of the Awgu Formation in which flow is limited to cells that may not be hydraulically connected, and a regional flow system RFS that partly discharges to the Ikube-Ebi River and continues further east to the Asu River. The smaller gradients are generally associated with high transmissivity while the steeper gradient reflects a general increase of flux per unit area towards discharge area. Stratigraphic analysis of borehole lithologs and statistical analysis of the hydraulic conductivity field all point to the presence of at least one layer within the Owelli Sandstone. The area is characterized by storativity ranging from (1.10×10^{-7} to 9.88×10^{-7}m), hydraulic conductivity (1.7×10^{-2}cm/s to 4.72×10^{-2}cm/s), transmissivity (5.97m^2/d to 9.98m^2/d) and specific storage (5.0×10^{-4}m). It is a medium to fine grained sandstone layer. The results of hydrochemical analyses also indicate that all the other parameters fall within the recommended limits of World Health Organization (WHO, 2006) and thus largely suitable for irrigation and domestic purposes. The values of total dissolved solids (<250 mg/L), electrical conductivity (<3 μs/m), soluble sodium percentage (2.22 to 85%), permeability index (28.7 to 131.36%), residual sodium bicarbonate (<1.0) and sodium adsorption ratio (<9) obtained for most of the water samples were found to be within the safe limits. In addition, most of the other irrigation indices of the sampled water also fall within the permissible level indicating low sodic waters. The surface and groundwater will neither cause salinity hazards nor have an adverse effect on the soil properties and are thus largely suitable for irrigation purpose. Future research in the area of flow and transport should focus on the quality of input data for the model simulations and validation. Government and Private Agencies should pay more attention to pumping test exercise, which contributes to the overall understanding of the aquifer system.

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