Assessment of Aquifer Characteristics and Delineation of Groundwater Potential Zones in Afikpo-North Local Government Area, Southeastern Nigeria

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Abstract: A hydrogeological study of Afikpo-North L.G.A, south-eastern Nigeria was carried out to determine the aquifer thickness and transmissivity values of the area. A total of twenty (20) Vertical Electrical Soundings (VES) and pumping tests respectively were conducted to determine these aquifer parameters. The area is underlain by Ezeaku and Nkporo formations. Aquifer thickness and transmissivity values range from 11.6m to 36.1m and 0.05m^2/day to 16.59m^2/day respectively. From the results obtained generally, aquifer thickness and transmissivity values were observed to be low. Regional maps of the various hydrogeological parameters have been produced and transmissivity values obtained were compared with Krásný transmissivity classifications and the results delineated the area into four potential groundwater zones; imperceptible, very low, low and intermediate zones for future exploration, development and choosing for drilling sites.

Index Terms: Aquifer thickness, transmissivity, Vertical Electrical Sounding (VES), Pumping test

I. INTRODUCTION

It is known that for a successful exploration, exploitation and management of groundwater, it requires a good knowledge of the spatial distribution of aquifer parameters such as aquifer thickness and other hydraulic properties. These aquifer parameters can only be estimated through application of geophysical methods. Geophysical methods are increasingly becoming relevant in hydrological applications and in determining aquifer hydraulic properties (Hubbard *et al*., 1997; Rubin and hubbard, 2005; Vereecken *et al*., 2005; Aizebeokhai and Oyebanjo, 2013. A well known and easy approach is Vertical Electrical Sounding (VES). This method which is quite often used in groundwater investigation can be used in geotechnics to assess potential fluid content and zone; hence in determining aquifer thickness (Ayolabi, 2004; Ayolabi *et al*., 2009).

Other than the VES, hydraulic properties of an aquifer can also be determined through pumping tests. The most reliable aquifer properties are those obtained from controlled aquifer tests with known pumping rates, pumping duration, accurate well locations and accurate water level measurements (Gannon, 2012). Pumping tests which are field experiments in which a well is pumped at a controlled rate and water-level response is measured in one or more surrounding observation wells and optionally in the pumped well (control well) itself; response data from pumping tests are used to estimate the hydraulic properties of aquifer such as transmissivity. Aquifer transmissivity is an integral part of aquifer hydraulics characterization. It is a concept that assumes flow through an aquifer to be horizontal (Fetter, 2001). Knowledge of transmissivity distribution in any area enables us to draw important decisions from hydrogeological research, and for this reason predominant transmissivity values are often represented in maps with its intention of enabling its understanding in compact and unambiguous depictions. Classification of transmissivity in magnitude and variations as provided by earlier scholars (Gheorge, 1978; Freeze and Cherry, 1979 and Krasny,1993), can be used to delineate hydrogeological basins from prolific to non-prolific aquifers.

The increasing population in *Afikpo*-North L.G.A. in South-eastern Nigeria and demand for potable water to cater for the needs of its growing populations who mainly depend on surface water and groundwater (springs), have prompted the present search for favourable potential zones in the area. Unfortunately, *Afikpo*-North L.G.A. lacks enough groundwater resources because of its distinct location and geological complexities. Much of the wells drilled in different parts of the area have become abortive or dried up due to lack of systematic and scientific investigation. A systematic and scientific approach is needed to overcome these problems. The quantity and transfer of groundwater depends on the host rock formation (Coker, 2012) and because its exploration is faced with a lot uncertainty, it is pertinent that right exploration techniques are employed in the delineation of aquifers. For this, it has become imperative to study the groundwater resource potentials in the study area through scientific identification and quantification of parameters governing groundwater exploration, exploitation and management in order to meet the projected water demand of the communities in the study area.

The main objective of the present study is to characterize the aquifer system in *Afikpo*-North L.G.A. of south-eastern base for government. The study would be helpful in understanding the aquifer thickness and transmissivity which would enhance the success rate of future groundwater development.

II. STUDY AREA

The study area lies within latitude 5^o443^I N to 5^o953^I N and longitudes 7^o49 ^{I}E to 7^o933^I E with an area extent of about $240km^2$. It has a tropical climate with an average mean temperature and rainfall of 27.23^oC and 168.5mm respectively (EBADEP, 2001).

It is located in Ebonyi state, south-eastern Nigeria (Figure 1). It is a hilly area despite occupying a region low in altitude, which rises to about 108.4 m (361ft) above sea

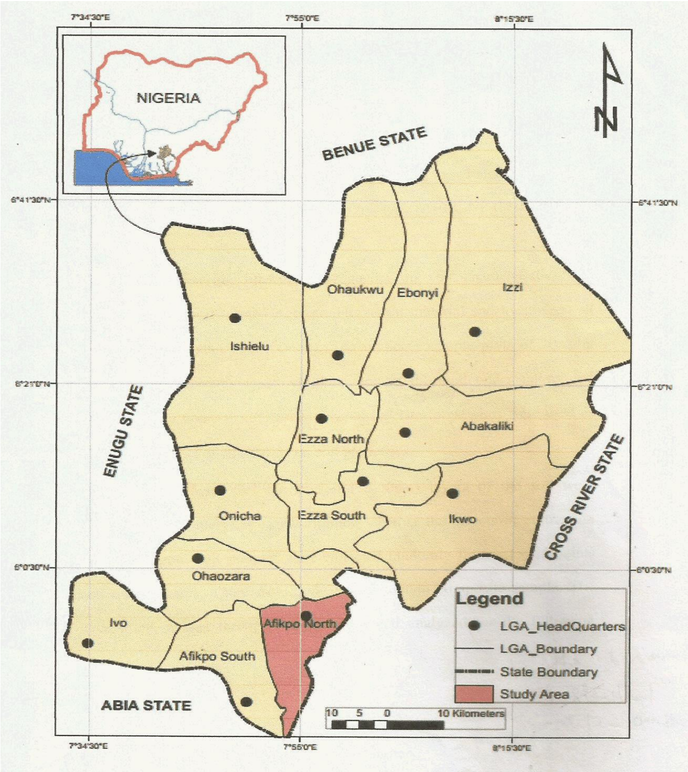

Figure 1: Map of Nigeria showing the study area (Abua *et al*, 2016)

Nigeria through aquifer hydraulic parameters obtained from Vertical Electrical Sounding and pumping tests in order to obtain hydrogeological groundwater resource mapping to delineate groundwater potential aquifers in the study area, aimed at establishing a hydrogeophysical data

level. It is located in the lower benue through and belong to the lower and middle hydrogeological groups of southeastern Nigeria. Geologically, its aquifers are underlain by *Ezeaku* and *Nkporo* formations (Nigeria Geological Survey Agency, 1984) (Figure 2). Low productivity of many boreholes already drilled in the area supports the difficulty to find sustainable water supplies. The geology of the study area have been described in details by various authors (Nwankwoala, 2015; Okoro *et al.*, 2012; Adelana *et al*, 2008; Reyment, 1965) and these formations consist of thin shallow but extensive unconfined aquifer, and deep and perched aquifer (Adelana *et al*, 2008). The formations have variable saturated thickness and generally less than 50m and 78m in aquifers found in its lower and middle hydrogeological groups respectively (Reyment, 1965).

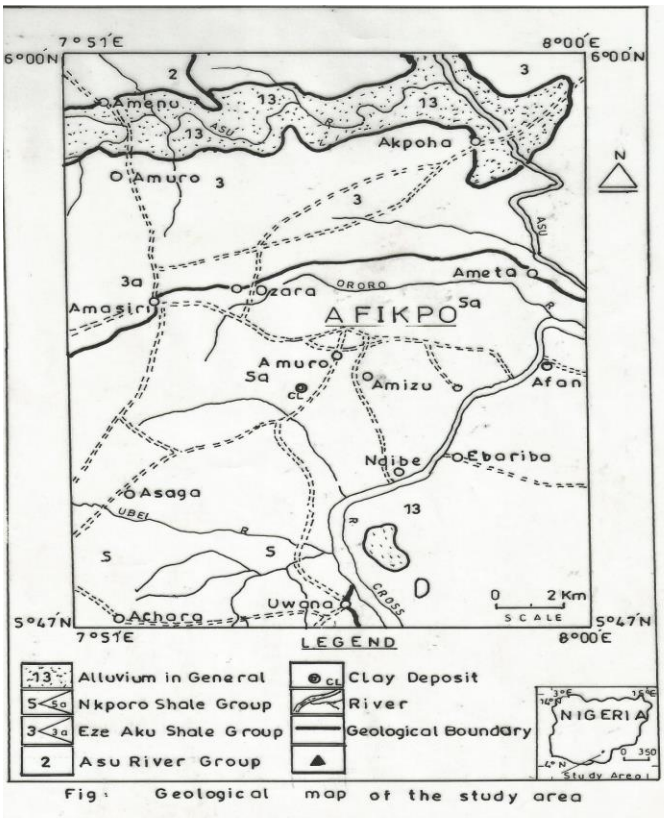

Figure 2: Geological map of the study area (Nigeria Geological Survey Agency, 1984)

III. METHODOLOGY

A total of 20 sites were selected for pumping tests within the study area so as to determine aquifer physical and hydraulic parameters: aquifer thickness and transmissivity respectively in order to characterize their aquifers. Variations of aquifer thickness were investigated with the help of geo-electric resistivity sounding. 20 Vertical Electrical Soundings (VES) were done using maximum current electrode separation

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ranging from 45m to 165m. Digital averaging equipment, the ABEM terrameter, was used for direct current (DC) resistivity work.

The Schlumberger electrode configuration was used in all the soundings. In this configuration, all the 4 electrodes were arranged collinearly and symmetrically placed with respect to centre. The potential electrodes were close to the sounding station and current electrodes at the end of the spreads. The distance between the potential electrodes was increased only when the signal was small to measure. The VES data were acquired and converted to apparent resistivity values by multiplying with appropriate schlumberger geometric factors given by Lowerie (2007):

$\Pi(a^2/b - b/4)$.......................... (1)

Where a = half current electrode separation
b = potential electrode spacing.

The apparent resistivity was plotted against the half current electrode spacing (m) on a double logarithmic study. The initial interpretations of the VES data were accomplished using method as provided by Igboekwe *et al*., 2006. Based on this preliminary interpretation, initial estimation of the resisitivities and thickness of the various geoelectric layers were obtained. These were later used as starting models for fast computer assisted interpretation 1-D sounding software (Interpex 1-D) that interprets 1-D electrical resistivity sounding data and produce layered resistivity models that reveals subsurface geology. The graph was read until a good match yielding true resistivity and thickness of aquifer values were gotten.

i. Pumping test

The recovery test method was used for the determination of transmissivity as drawdown observations were made in the test well (pumping well) itself, and there was no need of an observation well. A 1Hp submersible pump was installed into the well and pumping was done for 3 hours and stopped. After the pumping had stopped, the water level in the test well was allowed to rise due to recovery of the ground water level. Residual drawdowns (S') were measured in the test well at different instants of time (t') after the pumping was stopped. The measured values of S' were plotted on arithmetic scale against the values of [t/t'] on a log scale. The best-fit line was drawn through the plotted points. From the plot, he value of the difference of residual drawdown ($\Delta S'$) per log cycle of [t/t'] was found. The value of T was determined using Theis expression as given by Arora (2002):

$T=\frac{2.303Q}{4\Pi(\Delta S')}$...................................... (2)

Where T = transmissivity (m^2/day)
Q = pumping rate of the well (m^3/hour)
S' = residual drawdown per log cycle (m)
t = time elapsed since the starting of the pumping (min)
t' = time elapsed since the stopping of the pumping (min) (Arora, 2002)

IV. RESULTS AND DISCUSSION

Maps of aquifer thickness have been constructed using the results of VES across the locations. The study area shows variable aquifer thickness (Figure 3). From the study the aquifer thickness varies from 11.6m to 36.1m with an average of 39.45m. A similar result was obtained by Tijani *et al*., 2016 for the same hydrogeological groups. The smallest aquifer thickness was Nkpoghoro area whereas the highest was found in Ibii area.

In the Northern part, underlain by *Ezeaku* formation, the thickness range between 30.0m and 42.0m with an average of 35.88m, the Southern part underlain by *Nkporo* formation range between 24m and 57.0m with an average of 41.83m. The eastern part has higher aquifer thickness than western part and this could be attributed to its closeness to two perennial rivers: *Asu* and Cross rivers (Figure 2) which could have contributed to seepage and lateral flows; causing increase in saturation of the aquifers. More so, this could be as a result of sedimentation and natural groundwater recharge arising from drainage of this in a shallow marine environment (Murrat 1972; Ukaegbu and Akpabio, 2009).

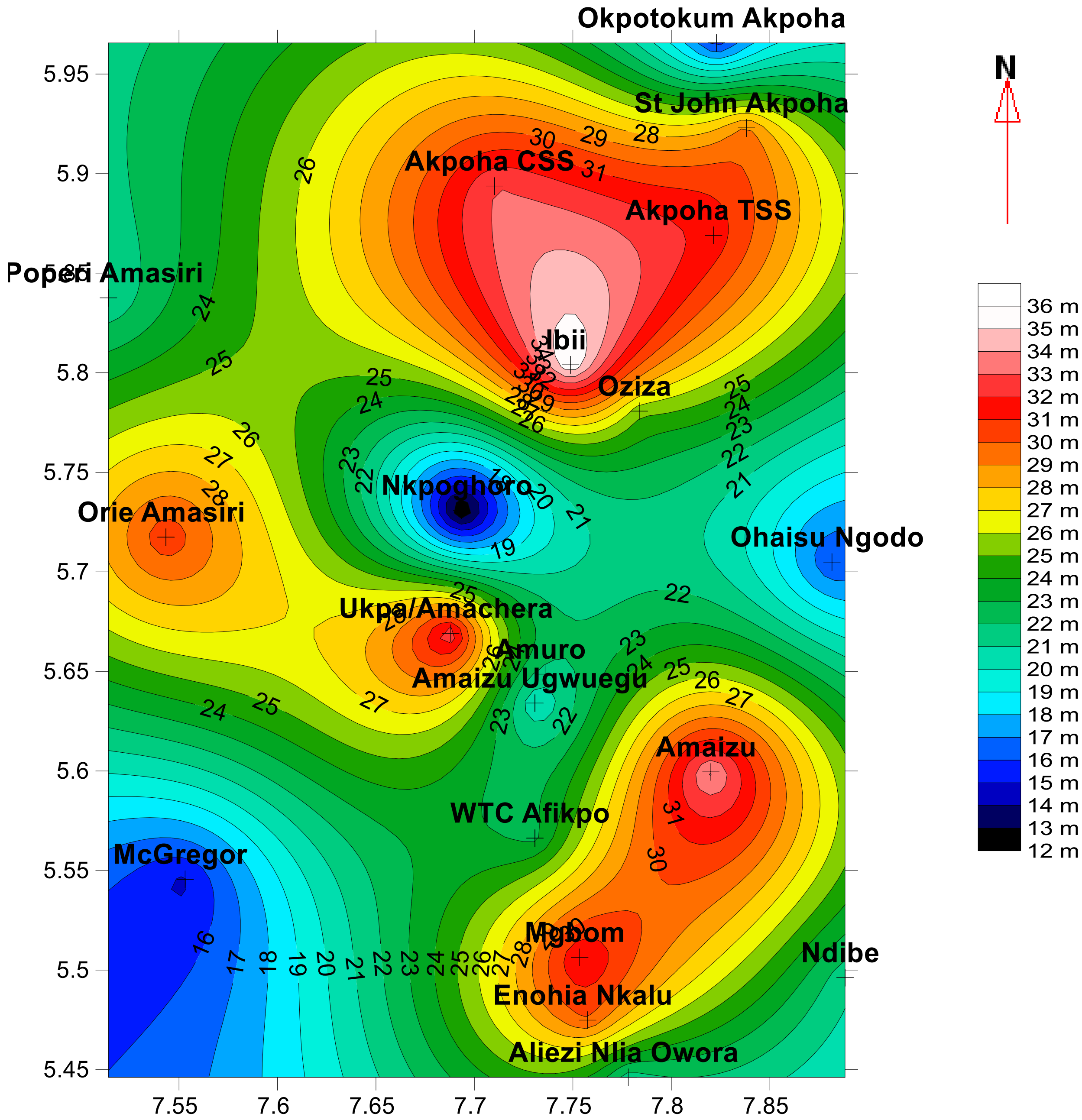

Figure 3: Map of the study area showing the ranges of aquifer thickness (in m)

i. Transmissivity

Results from pumping tests during the study indicate that transmissivity values are low over the entire area under study. The minimum transmissivity is about 0.0535m^2/day at *Aliezi Nlia Owora*, however the maximum is about 16.59m^2/day at Ibii axis. The average aquifer transmissivity for the entire area was also calculated and found to be 5.05m^2/day (Table 1), this shows that the area is not a zone of prolific (Adelana *et al*., 2008).

The variations in the ability of the aquifers to transmit groundwater throughout its entire saturated thickness, reflects well productivity and indicates the likely well yield that can be expected in these areas, and can be used to determine the volumetric groundwater flow. Furthermore, the map for the distribution of transmissivity values in the basin has provided a basis for future groundwater exploitation, development, abstraction and protection, and above all draw important conclusions from hydrogeological studies in the area.

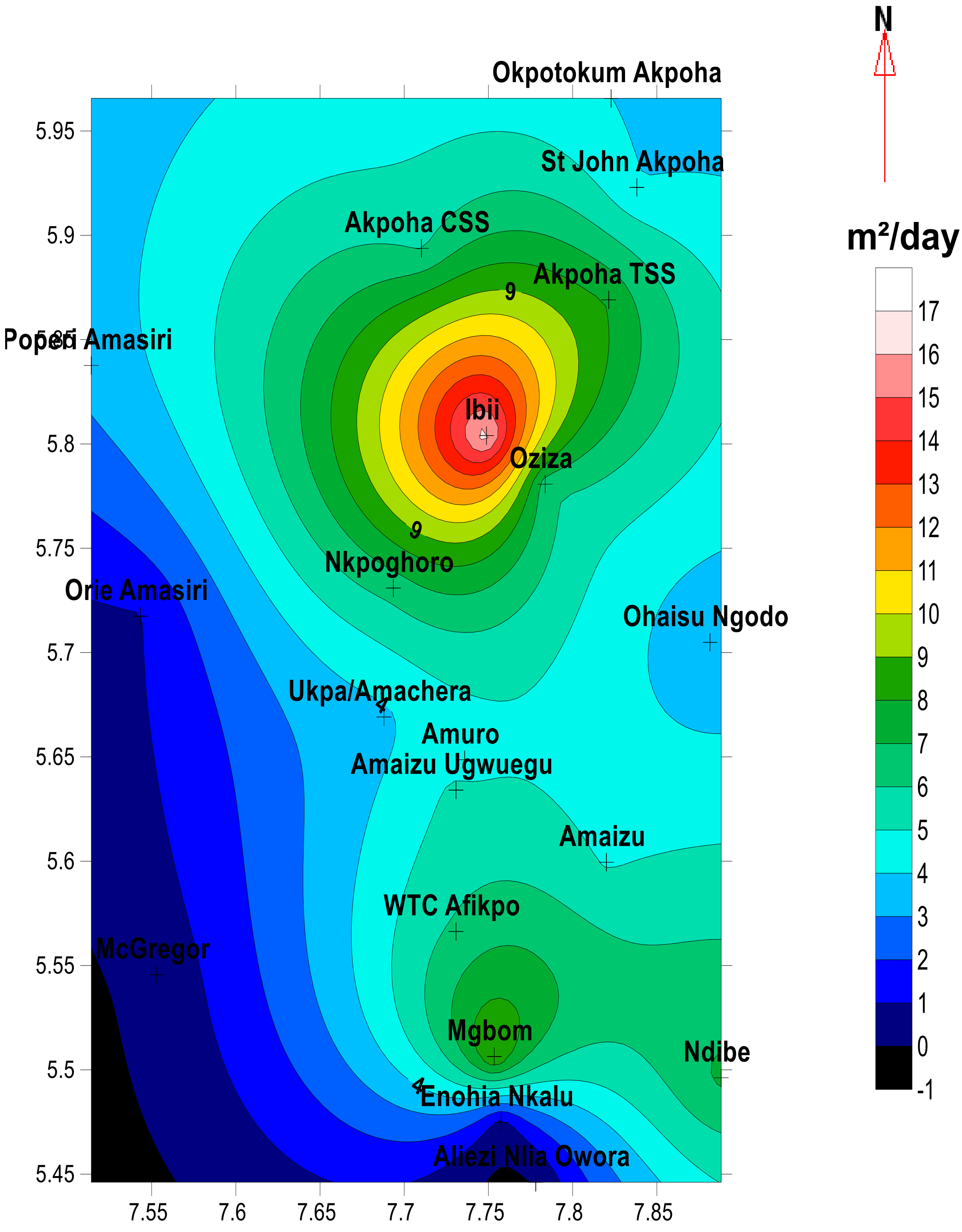

Figure 4: Map of the study area showing the variations of transmissivity in m^2/day

ii. Groundwater Potential Evaluation

The present evaluation of the groundwater potential of the study area has been based on hydraulic parameter (transmissivity) obtained from pumping test results. Taking into account the classification provided by Krasny (1993) (Table 2), the overall results have been used to delineate the study area to imperceptible, very low, low and intermediate zones for groundwater exploration/exploitation, with the North-central zone (Figure 5) having the highest potential based on high transmissivity.

The aquifers in the study area does not show being prolific except in the North-Central the posses moderate transmissivity capacity which offers withdrawal that meets local water supply (small community, plants etc).

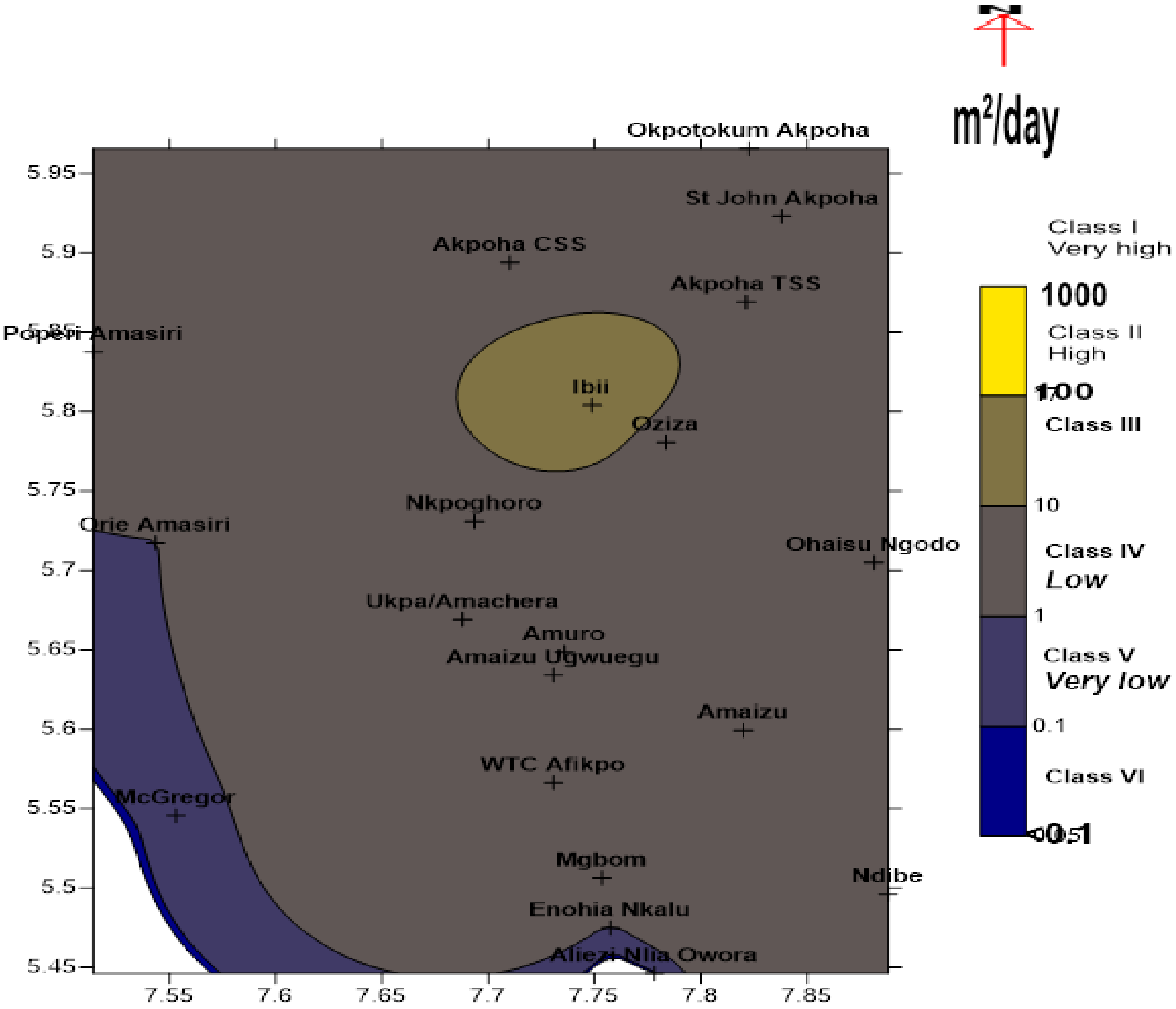

Figure 5: Map of the study area showing groundwater potential

V. CONCLUSION

This study has helped to provide data on the aquifer transmissivity and aquifer thickness of the aquiferous zone. The estimated aquifer parameters revealed the transmissivity and aquifer thickness range from 0.05m^2/day to 16.59m^2/day and 11.6m to 36.1m respectively. These findings are indicative of *Ezeaku* and *Nkporo* formations.

A groundwater potential map of the study area has also been produced from the aquifer hydraulic data; transmissivity. From the classification and delineation of the transmissivity values from the study, it was found out that on the average the study area does not possess prolific aquifer for high groundwater withdrawals which is typical of the hydrogeological groups; indicative for smaller withdrawals for private consumption. However, the North-central (around *Ibii*) have moderate groundwater potential and its well yield can serve local water supply because the aquifer will provide withdrawals that meets communal needs.

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Table 1: Interpreted aquifer parameters from geo-electric resistivity soundings and pumping tests from Afikpo-North L.G.A

Location No.	Location	Aquifer thickness (m)	Transmissivity (m^2/day)
1	Poperi Primary School, Amasiri	21.1	3.3992
2	Mgbom	32.0	9.2000
3	Amuro Elu square	21.6	4.6008
4	Amaizu Town hall	34.2	4.9009
5	Amaizu/Ugwuegu Town hall	20.0	5.2000
6	Ndibe Health centre	21.3	7.1994
7	Nkpoghoro	11.6	6.3997
8	Ohaisu Ngodo square	16.0	3.2848
9	Orie Market square, Amasiri	30.8	0.9610
10	Akpoha Technical Secondary School	31.6	7.9000
11	Ukpa/Amaechara	33.0	3.8016
12	WTC primary School Afikpo	22.7	6.1994
13	Enohia Nkalu Primary School	30.0	0.5400
14	Mcgregor Primary School Afikpo	14.8	0.3404
15	Imama Oziza	25.3	6.4009
16	Ibii community Primary School	36.1	16.5880
17	Okpotokum Primary School Amata-Akpoha	15.4	4.0102
18	St. John’s Catholic Church, Akpoha	29.38	4.0815
19	Aliezi Nlia Owora	21.4	0.0535
20	Akpoha comprehensive Sec. School.	33	5.9136

Table 2: Standards of transmissivity

Transmissivity (m^2/day)	Designation	Groundwater supply potential
>1000	Very high	Withdrawal of great regional importance
>100 – 1000	High	Withdrawal of lesser regional importance
>10 – 100	Intermediate	Withdrawal of local water supply (small community, plants, etc)
>1 – 10	Low	Smaller withdrawal for local water supply (private consumption)
> 0.1 – 1	Very low	Withdrawal for local water supply (private consumption)
< 0.1	Imperceptible	Sources for local for local water supply are difficult

(Source: Krasný, 1993)

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