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Spatial Distributions of Aquifer Hydraulic Properties from Pumping Test Data in Anambra State, Southeastern Nigeria

Christopher Chukwudi Ezeh¹, Austin Chukwuemeka Okonkwo^{1, *}, Emeka Udeze²

Abstract

Spatial distributions of aquifer hydraulic properties were carried out from direct pumping test data in Anambra State, Southeastern Nigeria. The study area lies within longitudes 06° 38^{I} and 007° 15^{I} E and latitudes 05° 42^I and 006° 45^IN within an area extent of about 4844sqkm (1870sqmi), underlain by four main geological formations. Pump testing was carried out in over one hundred (100) locations in the study area. The single-well test approach was used, employing the constant discharge and recovery methods. The Cooper-Jacob's straight-line method was used to analyze the pump test results. This enabled the computing of the aquifer hydraulic properties. Correlated borehole logs show total depth range of 80meters to 250meters, with lithologic sequence of top sandy clay – medium to coarse grained sand – clay/shale – sand/sandstone, with the medium to coarse grained sand thickly underlying the central part of the study area. Static water level ranges from 100meters to 260meters at the central part and 10meters to 90meters at the adjoining areas. Aquifer transmissivity values range from 5m^2 /day to 80m^2 /day, indicating variable transmissivity potentials, while hydraulic conductivity values range from 0.5 m/day to 80m^2 /day, indicating variable transmissivity, hydraulic conductivity, static water level, drawdown, aquifer yield, specific capacity, aquifer depth, hydraulic head and storativity were constructed to show their spatial distributions in the study area. These maps could serve as a better exploration model for groundwater production in future.

Keywords

Aguifer Hydraulic Properties, Pumping Test, Single-well Test, Cooper-Jacob

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1. Introduction

When considering a groundwater development project, one of the biggest problems to be encountered is often the lack of data upon which to base an assessment of the viability of aquifer [1]. The common problem is the scarcity of data [2] relating to the variations in the value of aquifer hydraulic properties. Understanding the architecture, extent and geometry of the groundwater-bearing zone, could be better basis for data extrapolations. Pumping test is one of the

favourable ways of computing reliable and representative values of the hydraulic properties in aquifers [3, 4]. Many methods of investigation are commonly employed with the aim of estimating the spatial distribution of aquifer hydraulic properties [5-9]. However, these methods, under favourable conditions, have not replaced pumping test [10]. Interpolating aquifer properties between boreholes [11] is often difficult with little or no data in which to base extrapolations. Hence, in this research work, larger data volume from pumping test exists which makes it easy and

Corresponding author

E-mail address:. okonkwoaustinchukwuemeka@gmail.com (A. C. Okonkwo)

¹Department of Geology and Mining, Enugu State University of Science and Technology, Enugu, Nigeria

²Anambra State Rural Water and Sanitation Agency (ANARUWASA), Awka, Nigeria

possible for extrapolations through spatial distributions.

2. Location and Physiography

The study area is located in Anambra State, Nigeria (Figure 1). The area lies between geographical co-ordinates, longitudes $06^{\circ}38^{1}E - 007^{\circ}15^{1}E$ and Latitudes $05^{\circ}42^{1}N - 006^{\circ}45^{1}N$, with an area extent of about 4844sqkm (1870sqmi). The project domain is bordered to the north and northwest by Kogi State, to the West by Delta State and to the South, Southeast and Northeast-east by Imo, Abia and Enugu State respectively (Figure 1). The topography in the

study area is characterized by geomorphic features, with typical cuesta of an escarpment region [12]. It shows two major types of landforms which consist of a high relief zone and lowland areas with undulating residual hills and valleys (Figure 2). The high relief zones are found within the southeastern part, around Agulu-Nanka-Ekwulobia-Aguata axis with an elevation of about 380meters (1246.4feet) above sea level (ASL). While the lowland areas are most profound in the Northwest – Southwest, around Anam-Atani axis with an elevation of about 20meters (65.6 feet). The residual hills are remnants, resistant feature found mostly at the flank of high relief zone.

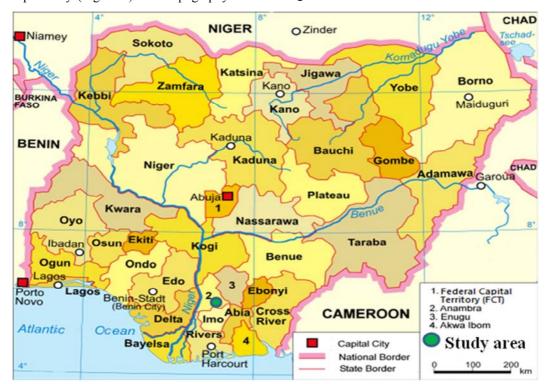


Figure 1. Map of the study area. Inset is map of Arica and Nigeria [21].

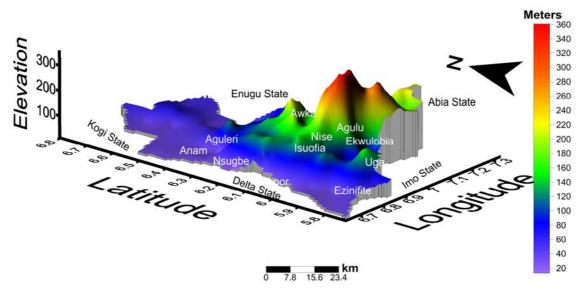


Figure 2. Relief map of the study area.

3. Geology and Hydrogeology

The study area falls within the Tertiary Niger Delta Basin [13]. The age range is from Paleocene to Recent. Four main geological formations underlie the study area (Figure 3); the Imo Shale, Ameki Group (Ameki Formation, Nanka Formation and Nsugbe Formation), Ogwashi-Asaba Formation and Alluvial Sands. The lithostratigraphic units have a thickness of up to 2500meters [14]. Hydrogeologically, the study area falls within (Figure 4) the Mamu River Basin [15]. It is a sub-basin of the Anambra River Basin. The River Mamu is a very important tributary of the Anambra River. The most important aquifers in the Mamu River Basin are the Ajali Formation, the Ebenebe,

Amenyi and the Nanka Sands. The Ajali Formation exhibit confined condition towards the center of the center of the basin. It is estimated that in Awka area, this aquifer could be encountered at much deeper levels of about 360m to 800m depth. Nanka sands around Nanka, Idemili, Oko, Agulu, Nnobi and Ekwulobia, the water table is generally very low, ranging from 30 to 300m in depth. Apart from Ajali Formation, shallow aquifers exist within the Mamu River Basin. They are the Ugwuoba Sandstone, also described as Ebenebe Sandstone and Amenyi sands. These aquiferous sand bodies are members of Imo Shale. Higher water tables conditions are obtained in boreholes located in the lowland areas or valleys usually interspersing the predominantly hilly country.

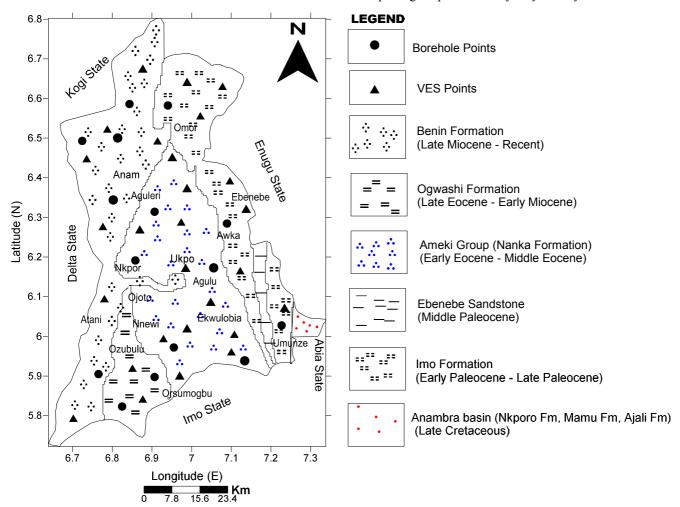


Figure 3. Geologic map of the study area showing VES and Borehole points.

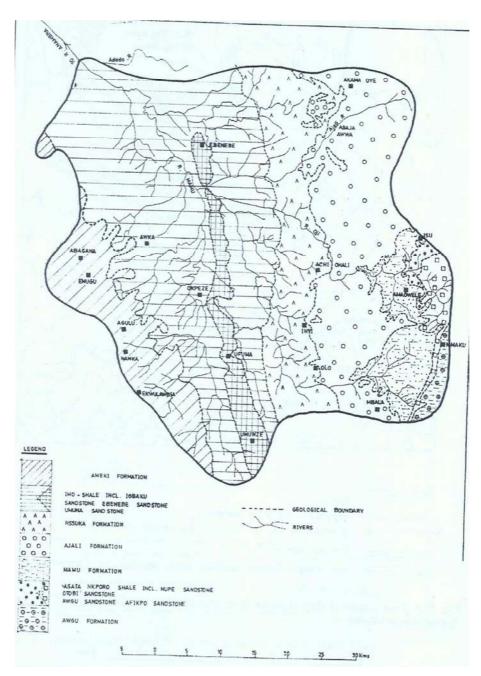


Figure 4. Geological map of the Mamu sub-basin [15].

4. Theory and Methods

Pumping test is a veritable scientific means of ascertaining the immediate and perennial yield of a drilled hole. The test in essence, involves abstracting water from the well at a known rate and then observing the decline in water level in the aquifer in the vicinity of the well. The objectives of this test among others include the following:

To ascertain the immediate and perennial yield of the well.

To determine and propose a future operational set-up for the hole.

To determine aquifer loss, well loss and efficiency of the well

To deduct aquifer parameters such as Transmissivity (T) and Hydraulic conductivity (*K*).

The test was carried out in over 100 (One hundred) locations, using the single-well test approach, employing the constant discharge and recovery methods. Heron Dipper-T (300meters) water level meter was deployed for this exercise (Figure 5). Well depth, screen length, pump capacity and depth of installation were well data inventories obtained during the exercise. Static water level (SWL) was measured and recorded before pumping. Time pumping began varied at all

locations. The drawdown due to water abstraction was taken at interval of 1minute for 10minutes. After this, it was taken at 2minutes for 20minutes at 5minutes interval for 40minutes. After this, it was 10minutes for another 60minutes. At the end of this, drawdown was measured for every 60minutes (1hour), for the remaining duration of pumping. 10 liters container was used to collect the pumped water with respect to time in order to compute the water discharge (Q). The water discharge was measured at 10minutes, 20minutes, 40minutes and 60minutes respectively. The Cooper-Jacob's straight-line method [16] was used to analyse the pump test results of drawdown with respect to time using log-log graph. Transmissivity (T) was estimated by fitting a straight line to drawdown on an arthmetric axis versus time on a logarithmic axis [17]. Quantitatively T was obtained using Equation 1.



Figure 5. Pump testing at Umuchu, Aguata LGA, Anambra State, Nigeria.

$$T = \frac{2.3Q}{4\pi\Delta(h_0 - h)} \tag{1}$$

Where Q is discharge and Δ (h - h₀) is the change in drawdown per cycle. Knowing T, it was possible to compute Hydraulic conductivity (K) using

$$T = kh \tag{2}$$

Where h is the aquifer thickness.

Similarly, Specific Capacity (SC) was obtained using

$$SC = \frac{Q}{\Delta(h_0 - h)} \tag{3}$$

An empirical relationship between Transmissivity and Specific capacity was developed [18]. The relationship was used in both continental and alluvial aquifers in Morocco. This relationship can be expressed as

$$T = 15.3 \left(\frac{Q}{\Delta h_0 - h} \right)^{0.67} \tag{4}$$

Where T is aquifer transmissivity (m²/day), Q is pumping rate (m³/day) and $\Delta h_0 - h$ is drawdown.

A similar approach to the analysis of specific capacity data with transmissivity data for karstic aquifers in Texas was developed [19].

$$T = 0.76 \left(\frac{Q}{\Delta h_0 - h} \right)^{1.03} \tag{5}$$

Where T is aquifer transmissivity (m²/day), Q is pumping rate (m³/day) and $\Delta h_0 - h$ is drawdown (m).

In this study, the simulation by [17] equation 1 was utilized in computing aquifer transmissivity (T). Attempts was made to compute Storativity, with the assumption that the radial distance (r) to the well equals zero (r = 0), since it was Single-well test. Hence,

$$S = \frac{2.25Tt_0}{r^2} \tag{6}$$

Where S is the Storativity (dimensionless), T is aquifer transmissivity (m^2/day), t_0 is the time where the straight line intersects the zero-drawdown axis, r^2 is the radial distance to well.

5. Results and Discussion

5.1. Correlation of Borehole logs

Correlation of some selected borehole logs (Figure 6) was carried out. The borehole logs cut across all the geological formations in the study area and trending in a SW - NE direction. From the correlation, there is a total depth (TD) variation from the SW to the NE. TD ranges from 80meters to 250meters. The TD appears to be a little bit shallow at the extreme SW around Atani, Ogbaru and Onitsha, fairly deeper at Oba and Nnewi axis and very deep at Amesi, Umuchu, Isofia, Ekwulobia, Aguata and shallow at the extreme NE. Four lithologies were correlated from the logs; Top sandy clay, Medium to coarse grained sand, clay/shale and Sand/sandstone. The clay/shale horizon occurred at a depth of about 45 -60meters at Atani and Oba respectively. At Nnewi and Aguata areas, the clays were very sandy and in most cases do not appear in some locations. While at Achalla, Ukwulu and Nawgu, the clay/shales were well developed, with thickness more than 100meters.

5.2. Aquifer Hydraulic Properties

Spatial distribution 2D maps of static water level (SWL), Drawdown, aquifer yield (Q), Specific Capacity (SC), Transmissivity (T), Hydraulic conductivity (K), Hydraulic head, and Storativity (S) were constructed. SWL (Figure 7) is generally much deeper around the country Ekwulobia, Nanka, Agulu, Oko etc, with values ranging from about 100meters to 260meters and shallows to adjourning town

and villages. Drawdown is variable in the study area (Figure 8). High drawdown (20meters to 34meters) is observed at the southwest, around Ihiala and moderate values (10meters to 20meters) around Ekwulobia and a trend in a SE-NW direction. Moderate and high yields (Q) are observed (Figure 9) at the SW around Ihiala and Atani, and trend in the SE-NE direction respectively. Yields around Ekwulobia, Ihiala, Nkpor etc range from 100m³/day to about 280m³/day. While around Awka, Anam, Mgbakwu, Achalla etc have yield ranges of about 20m³/day to about 80m³/day. Specific capacity (Figure 10) values of 120m³/day/m to 320m³/day/m exist along Ogbunka-Ekwulobia-Nkpor and down to Atani. Along Awka-Anam axis low specific capacity of $20\text{m}^3/\text{day/m}$ to 80m³/day/m exists. Moderate transmissivity (T) values occur along Ogbunka-Ekwulobia-Nkpor axis (Figure 11). At Ekwulobia, T values of $60\text{m}^2/\text{day}$ to $80\text{m}^2/\text{day}$ is observed, while along Awka-Anam low T of 5m²/day to 15m²/day is observed. At the country around Ihiala, T of 5m²/day to 10m²/day is observed. This indicates that the transmissivity is variable. Hydraulic conductivity (K) is variable (Figure 12) in the study area. K values of 1.5m/day to 5m/day exist along Ogbunka-Ekwulobia-Nkpor-Atani and Omor axis. Low K values of 0.5m/day to 1m/day occur along Awka-Anam axis. Hydraulic head is the difference between surface elevations at borehole locations and the SWL. This determines the direction of groundwater. High hydraulic head (Figure 13) along Ogbunka-Ekwulobia and Nkpor and Atani axis. Most likely the hydraulic head is topographically controlled. While low hydraulic head areas are around Anam, Omor, Awka and Ihiala. High values range from 100meters to 240meters and low areas range from 10meters to 90meters. However, the groundwater flow direction is roughly divergent. Storativity in the study area (Figure 14) was based on single-well test, as there were no observation wells. However, it was computed using equation (6) assuming that r = 0. Values obtained fall within the acceptable limits of 0.02 to 0.30 [22]. Storativity of 0.2 for country around Ekwulobia is good owing to the nature of the underlying geology. Aquifer depth (Figure 15) varies, showing highest depth of 280meters at Ekwulobia, with lowest at Awka, 40meters. The aquifer depth in most cases is a function of the topography [20].

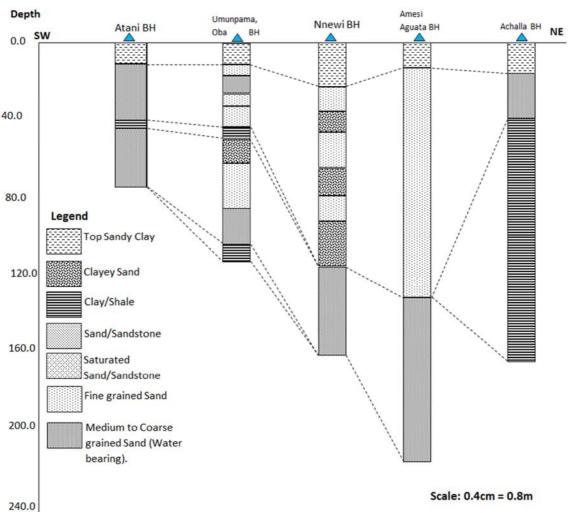


Figure 6. Correlation of some borehole logs in the study area.

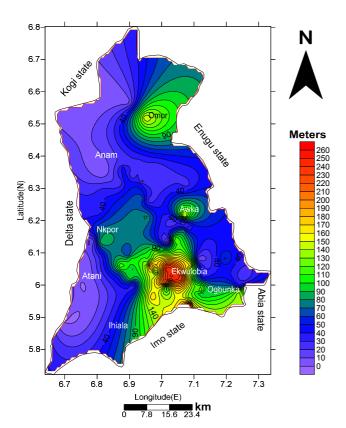


Figure 7. 2D spatial distribution map of static water level in the study area.

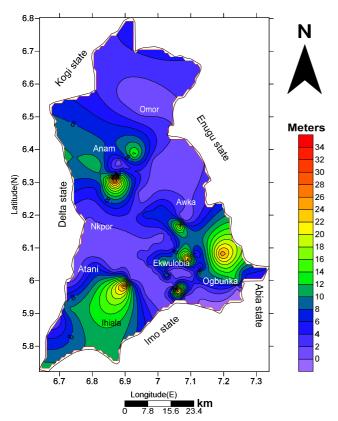


Figure 8. 2D spatial distribution map of Drawdown in the study area.

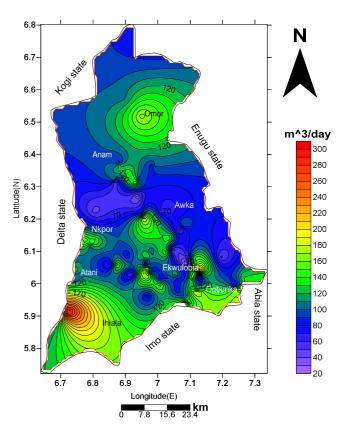


Figure 9. 2D spatial distribution map of Aquifer yield in the study area.

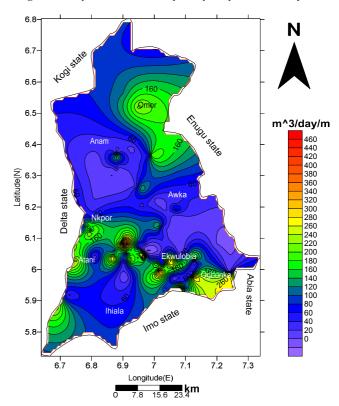


Figure 10. 2D spatial distribution map of Specific capacity in the study area.

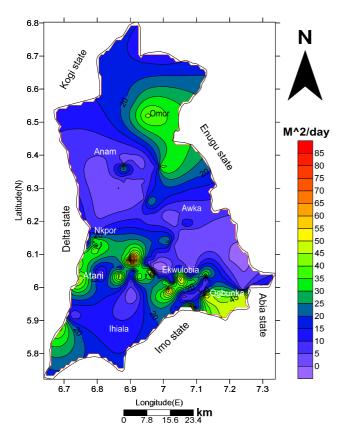


Figure 11. 2D spatial distribution map of Transmissivity in the study area.

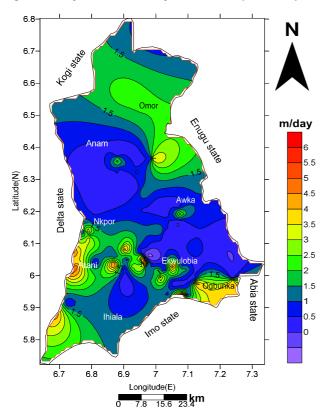


Figure 12. 2D spatial distribution map of Hydraulic conductivity in the study area.

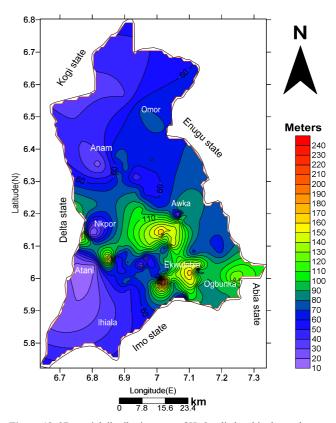


Figure 13. 2D spatial distribution map of Hydraulic head in the study area.

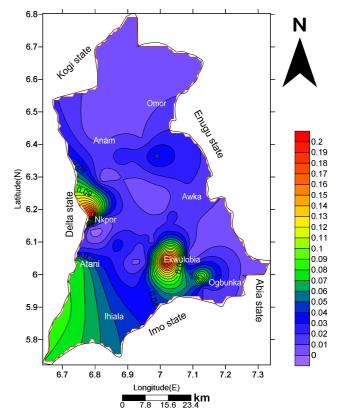


Figure 14. 2D spatial distribution map of Storativity in the study area.

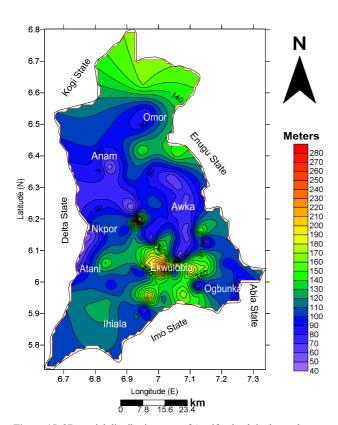


Figure 15. 2D spatial distribution map of Aquifer depth in the study area.

6. Conclusion

Spatial distributions of aquifer hydraulic properties in the study area have proved plausible for data extrapolation. The spatial distributions had enabled quantitative inference of aquifer parameters in localities where there is doubt in the aquifer production rate. From the spatial distributions of the aquifer hydraulic properties, the aquifer properties discussed show appreciable excellent values within the central part of the study area. This is as a result of the thickly underlying Nanka Formation, with practically deep water wells. Adjoining areas show moderate values. Presently, the available pumping test data used for the quantitative extrapolation has proved plausible in the study area. Adjoining areas in the study area with moderate and low aquifer hydraulic properties may require detailed geosounding in order to determine better sandy horizons. The various regional 2D maps will serve as a useful guide for groundwater explorations and development.

References

- Hamill L, Bell FG, (1986). Groundwater resources development. University press Cambridge. 344 p.
- [2] Rushton KR, (1973). River Basin groundwater development. Symp. J. Inst. Water Engrs Sci. Vol. 27, pp 275-276.
- [3] Kruseman GP, de Ridder NA, (1994). Analysis and evaluation of pumping test data. International Institute for land reclamation and development, Wageningen. 3rd Edition. Vol. 11

- [4] Ayers JF, (1989). Conjunctive use of geophysical and geological data in study of an alluvial aquifer. Groundwater. Vol. 27, pp 625-632.
- [5] Allen DJ, Brewerton LJ, Coleby LM, Gibb BR, Lewis MA, MacDonald MA, Wagstaff SJ, Williams AT, (1997). The physical properties of major aquifers in England and Wales. British Geological survey technical report. WD/97/34.
- [6] Olayinka A, Barker R, (1990). Borehole siting in Crystalline Basement areas of Nigeria with a Microprocessor- Controlled Resistivity traversing system. Groundwater. Vol. 28, No. 2, pp 178-183.
- [7] Mc Neil JD, (1990). Use of Electromagnetic methods for groundwater studies. Society of Exploration Geophysicists (SEG) Tulsa. Vol. 11, pp 191-218.
- [8] Beresnev IA, Hruby CE, Davies CA, (2002). The use of Multielectrode Resistivity Imaging in Gravel prospecting. Journal of Applied Geophysics. Vol. 49, No. 4, pp 245-254.
- [9] Dahlin T, (1996). 2D Resistivity surveying for Environmental and Engineering applications. First Break. Vol. 14, No. 7, pp 275-283.
- [10] Sattar GS, Keramat M, Shalid S, (2014). Deciphering transmissivity and hydraulic conductivity of the aquifer by vertical electrical sounding (VES) experiments in Northwest Bangladesh. Applied water science. Original article.
- [11] MacDonald AM, Burleigh J, Burgess WG, (1999). Estimating Transmissivity from surface resistivity sounding: An example from the Thames Gravels. Quarterly Journal of Engineering Geology. Vol. 32, pp 199-205.
- [12] Okoro EI, Egboka BCE, Anike OL, Enekwechi EK, (2010). Evaluation of Groundwater potentials in parts of the escarpment areas of Southeastern, Nigeria. International Journal of Geomatics and Geosciences. Vol. 1. No. 3. Pp 544-551
- [13] Nwajide CS, (2013). Geology of Nigeria's sedimentary Basins. CSS press. 1st edition. 565 p.
- [14] Reyment RA, (1965). Aspects of Geology of Nigeria. Ibadan University press. 136 p.
- [15] Offodile ME, (2002). Groundwater study and development in Nigeria. 2nd Edition. Mecon geology and Engineering services Ltd. Jos, Nigeria. 453 p.
- [16] Cooper HH Jr, Jacob CE, (1946). A generalized graphical method for evaluating formation constants and summarizing well-field history. Transactions, American Geophysical Union. Vol. 27, pp 526-534.
- [17] Oborie E, Udom GJ, (2014). Determination of aquifer transmissivity using geoelectrical sounding and pumping test in parts of Bayelsa State, Nigeria. Peak Journal of physical and environmental science research. Vol. 2, No. 2, pp 32-40.
- [18] Razack M, Huntley D, (1991). Assessing transmissivity from specific capacity data in a large and heterogeneous alluvial aquifer. Groundwater. Vol. 29, No. 6, pp 856-861.
- [19] Mace RE, (1997). Determination of transmissivity from specific-capacity tests in a Karst aquifer. Groundwater. Vol. 35, No. 5, pp 738-742.

- [20] Okonkwo AC, Ezeh CC, Opara AI, (2013). Estimates of Aquifer transmissivity from Specific capacity data in Sandstone aquifers in Enugu State, Southeastern Nigeria. Int. Res. J. Geo & Mining. Vol. 3, No. 8, pp 291-297.
- [21] World Gazette. (2011). Colourful map of Nigeria with 36 states. www.World-gazette.com.
- [22] Fetter CW, (2001). Applied Hydrogeology. Prentice hall, Inc. 4^{th} Edition. 596 p.