ISSN: 2048 – 3112
Volume 9, Number 1, 2022
International Research Journal of Pure and Applied Sciences

POTENTIAL AND LEVEL DISTRIBUTION PATTERN OF GROUNDWATER IN PARTS OF OGBA/EGBEMA/NDONI LOCAL GOVERNMENT AREA, RIVERS STATE, NIGERIA.

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ABSTRACT

Electrical resistivity data acquired in thirty (30) locations using vertical electrical sounding method of Schlumberger configuration have been used to study the hydrogeological properties and groundwater storage potential of aquifers in some parts of Ogba/Egbema/Ndoni Local Government Area of Rivers State, Nigeria, to identify productive aquifer zones for citing boreholes for community water supply. The data acquired were processed and interpreted using auxiliary curve matching and computer automated method to delineate the different geo-electric layers, their resistivities, thicknesses, and depths. The hydraulic conductivity, transmissivity, storativity, and groundwater level (SWL) were estimated, measured and plotted in 2D maps to describe the spatial variations of these parameters in the study area. The estimated aquifer thickness ranges from 17 m to 102.5 m with an average value of 62.6 m. The values of the hydraulic conductivity range from 1061.6 m/day to 3895.3m/day with an average value of 2408.94 m/day, the estimated transmissivity ranges from 18047.2 m^2/day to 401220.2 m^2/day with an average value of 163823.3 m^2/day, while the estimated storativity values range from 2.20×10^{-5} to 1.34×10^{-4} with an average value of 8.10×10^{-5}. The water level range from 5 to 10.7 m with an average value of 6.96 m. A joint evaluation of the hydraulic conductivity, transmissivity, and storativity suggests that the aquifers in the western, southern, eastern, and northern parts of the study area have the highest potentials for groundwater in terms of borehole yield, aquifer recharge, and storage potential. High values of groundwater static level were recorded in the central and eastern parts of the study area suggesting areas with high topography and elevation which could be less susceptible to vulnerability contamination.

Keywords: Groundwater potentials, Vertical electrical sounding, Hydraulic conductivity, Transmissivity, Storativity, Groundwater level.

INTRODUCTION

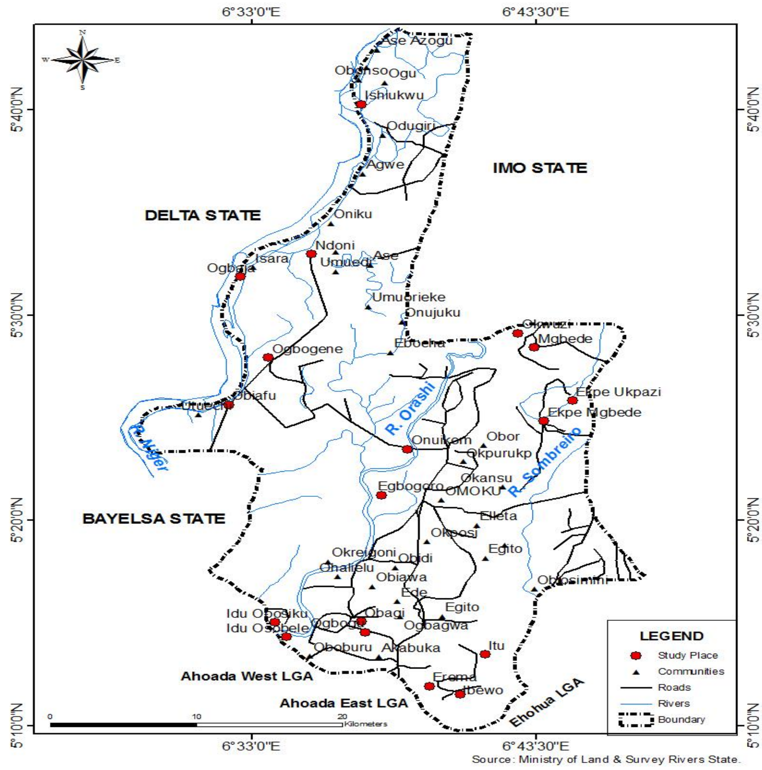
Groundwater is free from air pollution and other pollutants that can easily pollute water from its pure form and wisely managed and protected against undue exploitation and contamination by the users Reddi 1986. Groundwater is dynamic natural resources that can be recharged most during the rainy season by the rainwater for the rest of the year. Over withdrawal of groundwater causes decline in the water table due to the stress and distorting the aquifer and may also lead to adverse surface and subsurface environmental effect (Hasan *et al.*, 2003). Its recharge is usually influenced by climate variability and human withdrawal and the rest. The movement of groundwater in soils and rocks depends on the hydraulic characteristics of the shape and size of void spaces. It is available only when the rocks in the zone of saturation are permeable enough to transmit sufficient quantity of water to wells, springs or streams. Groundwater is the subsurface water which fully saturates the pores and behaves in response to gravitational force (Abiola, *et al.*, 2009). (Kalinski, *et al.*, 1993). The availability, quantity and exploitability of groundwater depend on the porosity, and permeability of the host rocks. Both play important roles in groundwater movement and recovery. The occurrence of groundwater in a given environment is determined by the interconnection of pores existing in rock particles and fragments, the shapes, size, and distribution of such pores both in depth and area through the zone of saturation (Warmate *et al.*, 2018). The evaluation of spatially quantitative dynamic properties of aquifers requires deep understanding of the intrinsic rock properties that are not directly measurable by geophysical surveys, but can be indirectly inverted from the estimates of closely related parameters such as transmissivity, hydraulic conductivity, etc. (MacDonald *et al*., 2012; Raji and Abdulkadri, 2020b) . Also, direct measurements of groundwater volume in bedrock aquifer is a difficult task. But, quantitative estimates of aquifer thickness, porosity, storativity, among others, may be used to predict the volume of groundwater storable in an aquifer. Therefore, the evaluation of groundwater potentials and availability in aquifers should be based on sub-regional evaluation of aquifer properties rather than the local, on the spot, assessment as commonly done for borehole survey.

Electrical resistivity survey (ERS) is the most commonly used geophysical method for groundwater study in different geological terrains. It is a non-invasive depth probing techniques that is most suited for shallow subsurface study in built-up and underdeveloped environments. It is environmental friendly, operationally simple, cost effective, time inexpensive, and easy to deploy regardless of the geological terrain. The parameters which describe freshwater potential have been highlighted to include geometry of the pore spaces, geometry of the rock particles, secondary geologic processes such as secondary deposition, faulting and folding. All these parameter jointly affect the rate and pattern of groundwater flow. The freshwater potentials and groundwater level distribution pattern are significantly important based on the positive indicators of high resistivity values, clean coarse sand formation materials, the thickness of the established aquiferous saturated zone and the shallow depth to locating the aquifer, which is approximately from 22 meter that can facilitate the easy harnessing and supply safe, sustainable and portable water to the people of the area. Lack of expertise might be a leading problem that might bring about poor water production or drilling. This is a situation whereby the drillers are not able to properly decipher the rudiment of borehole drilling and they just step into the line of drilling business without knowing the right thing to do. The measurement of groundwater level in a well is frequently conducted in conjunction with groundwater sampling to determine the phreatic water surface. This potentiometric surface measurement can be used to establish groundwater direction and gradients. Groundwater level and well depth measurements are needed to determine the volume of water or drawdown in the well casing for proper purging. All groundwater level and well depth measurements should be made relative to an established reference point on the well casing (Abdullahi and Garba, 2015).

The rate of abortive boreholes and the scarcity of potable water in the study area is the motivation for this study. The aim of the study is to interrogate the subsurface geology for groundwater availability and identify the productive aquifer zones for groundwater development in the study area. The objectives of the study are to: characterize the subsurface geo-electric layers, determine depth to aquifers, delineate groundwater level, and describe the dynamic hydraulic properties of the aquifers such as hydraulic conductivity, transmissivity and storativity.

The Study Area

Ogba/Egbema/Ndoni is a Local Government Area of Rivers State, Nigeria under Rivers West Senatorial District, with its capital at Omoku, with about 258,700 people according to 2006 Census. It is bounded by Imo, Delta, Bayelsa, Abia and Akwa Ibom states and also by Ahoada West, Ahoada East and Emohua Local Government Areas of Rivers State (Collins and Cookey, 2019).



Figuer 1: Map of ONELGA Showing the Different Communities and Locations of Study (Sourse: Collins & Cookey, 2019)

The study environment falls within the tropical rainforest belt characterized by dense vegetation. The relative humidity is about 55.5% in the hot dry season and 96% in the wet season. However, the annual rainfall is over 2500 mm/year, with two maxima peaks in June and October.

The area has a gentle topographic layout which is marked by shallow valleys that often accommodate streams and rivers. However the study area is drained by numerous tributary rivers and seasonal streams which flow towards the creek. The drainage pattern is dendritic a reflection of lack of structural control. The area is accessible through a network of tarred and untarred network of roads which are used for the geophysical exercise (Rim, 2005).

Geology of the Study Area

Ogba/Egbema/Ndoni local government Area of Rivers State, is geologically located in the Niger Delta Basin. The geology and geomorphology of the Niger Delta have been described in details by various authors. Strati-graphically, three formations are locally designated in the Niger Delta Basin. From the bottom is the Akata Formation, Agbada Formation and Benin Formation respectively which are in turn overlain by quaternary sediments (Reijers, 2011).

The topmost unit is the Benin formation; it is comprised of over 90% sandstone with shale intercalations. It is coarse grained, gravely, locally fine grained, poorly sorted, sub angular to well-rounded and bears lignite streaks and wood fragments. The thickness of the Formation ranged from 0 to 2,100m. The unit is thickest in the central area of the Delta (Eke *et al*., 2016). The contact with the underlying Agbada formation is defined by the base of sandstones which also corresponds to the base of the fresh water bearing strata. However, the formation lacks faunal content and this makes it uneasy to date although an Oligocene Recent age is generally accepted. The Benin Formation is generally water bearing formation. This formation is the most prolific aquifer in the region. It is the main source of potable groundwater in the Niger Delta area (Omosivie *et al*., 2019).

MATERIALS AND METHOD

Properties that contribute to the identification and characterization of aquifer are porosity, hydraulic conductivity, permeability, transmissivity, specific yield, specific storage, storativity, etc.

Porosity

Porosity (n) is the intrinsic characteristic of a substance and refers to the amount of void or empty space in each material. The porosity (void space) occurs between the fragments of soil or rock. It is defined by the ration between the volume of the void space and the volume of rocks/soils.

$$n = \frac{V_v}{V} * 100\% \qquad (1)$$

Where V_v is the volume of void space in a unit volume of earth material; and V is the unit volume of earth material (solids and voids).

Hydraulic Conductivity and Permeability

Permeability is defined as the ability of water movement through rock or soil which is directly related to porosity and it applies to the interconnection of pore spaces in rock or soil. Considering the relationship between driving and resisting forces on a microscopic scale during flow to porous media, hence, the permeability, k, is a function only of the area where the hydraulic conductivity K is defined:

$$k = K\frac{\mu}{\rho g} \qquad (2)$$

Where k is the permeability, K is the hydraulic conductivity, g is the acceleration due to gravity, ρ is the fluid density, and μ is the viscosity. Hydraulic conductivity (K) is a physical characteristic tha calculates the capacity of substance in the contex of an applied hydraulic gradient to transfer water across the pore spaces and fractures of rock/soil (Freeze and Cherry, 1979). It depends on various physical variables including porosity, the structure of the soil matrix, grain size distribution, type of soil fluid, particle arrangement, water contents, void ratio, and other factors. (Kalhor *et al.*, 2019; Johnson, 1967).

Transmissivity

The transmissivity (T) is the rate of discharge where the water is transferred under a hydraulic gradient over a unit width of an aquifer. It is calculated by a formula and expressed in m^2s^{-1}, or m^2/day.

$$T = Kb\ (confined\ aquifer \qquad (3)$$

$$T = Kh\ (unconfined\ aquifer \qquad (4)$$

where K is the hydraulic conductivity, b is the aquifer thickness, and h is the equivalent to the depth of confined aquifers.

For clean saturated aquifers whose natural fluid characteristics are fairly constant (that is, no appreciable impact on the general ground water quality by surface contaminants loads), the hydraulic conductivity is proportional to the resistivity of the aquifer. This implies that in the absence of a pumping test data, the aquifer hydraulic conductivity K can be approximated to the true resistivity of the aquifer derived from geoelectric investigation (Robin and Hubbard, 2005). But, the product of the resistivity to its thickness is the transverse resistance (R_T), which is numerically equal to the transmissivity. Therefore,

$$T_r = R_T = Kh = \rho h \qquad (5)$$

Equation (5) is adopted to estimate the hydraulic conductivity and the transmissivity in this study.

Specific Yield

Specific yield (S_y) as defined by Freeze and Cheery (1979), is the storage term for unconfined aquifer where the amount of water from the unconfined aquifer releases from the storage per

unit surface area of aquifer per unit decline in the water table. It is also known as unconfined storativity.
In other view, specific yield can be defined as the ratio of the volume of water that a saturated rock or soil will yield by gravity to the total volume of the rock or soil (Kalhor *et al.*, 2019). It is expressed in percentage.

$$S_y = \frac{V_w}{V} * 100\% \qquad (6)$$

where V_w denotes the volume of water in a unit volume of earth materials, V indicates the unit volume of earth material, including both voids and solids.

Specific Storage

Specific storage (S_s) is the volume per unit amount of a saturated formation that is a deposit from the storage because of the compressibility of the mineral skeleton and the pore water per unit change in head. The specific storage is given by Jacob (1940) and is typically represented in cm^{-1} or m^{-1}.

$$S_s = \rho_w g(\alpha + n\beta) \qquad (7)$$

Where ρ_w denotes water density, g is the acceletation due to gravity, α shows compressibility of the aquifer skeleton, n indicate porosity, β is the compressibility of water.

Storativity

The amount of water an aquifer can release or take into storage is known as the storage coefficient. The numerical value assigned to an aquifer is the storativity, a dimensionless value determined from pumping tests. In a pumping test the storativity represents the storativity from saturated thickness contributing to the well bore, storativity is defined according to the equation

$$S = S_y + S_s b \qquad (8)$$

Where S_y is the specific yield, S_s is the specific storage, and b is the aquifer thickness
The specific yield is approximately equal to the total storativity value for most unconfined aquifers. The usual range of storativity values in unconfined aquifer is 0.03 to 0.3 (Fetter, 1994). The value of specific storage (S_S) in unconfined aquifers is practically negligible, unless there are sections within the aquifer where the grain size is very small. The standard value of storativity is $S \leq 0.005$ (Fetter, 2007).
The storativity S, of the confined aquifer system and the deep and thick unconfined aquifer which may be hydraulically similar to it may be estimated from the tumb equation given by (Lohman, 1972 and Todd, 1980). The equation (9) was adopted in this work.

$$S = 1.3 \times 10^{-6}\, b \qquad (9)$$

Resistivity Surveying

In groundwater system, evaluation geophysical method such as electrical resistivity have been well recognised. The electrical resistivity survey is one of the tools is very effective to identify subsurface profiles without interfering with the structure of the soil (Larsen*,* 2008). The usage of the method enables the measurement of groundwater quantities and qualities. This includes detailed knowledge concerning the geological and hydrological information of the groundwater system such as subsurface mapping to identify aquifer protective structures, the analysis of infiltration of the vadose zone, measuring the extent of volume and internal aquifer structure, and groundwater contamination (Almadani *et al.,* 2019). It is effectively used to estimate soil porosity and soil permeability as a non-destructive process.
Consequently, it is a good potential technique for the study of alternation zones in hard rocks, electrical resistivity in rocks influenced by differing weathering degrees.
Schlumberger array system (Keller, 1966) was used to perform the the resistivity survey at thirty (30) locations whose points were precicely measured in latitude and longitude using global positioning system (GPS). "ABEM SAS 1000 Terrameter" was used to perform the Vertical Electrical Sounding (VES). For resistance measurement, four electrodes were selected at a

certain time. Two existing electrodes situated on the outside of the potential electrodes were inserting currents into the field. The potentially different electrodes were quantified and the ground resistance was measured by the equation (10).

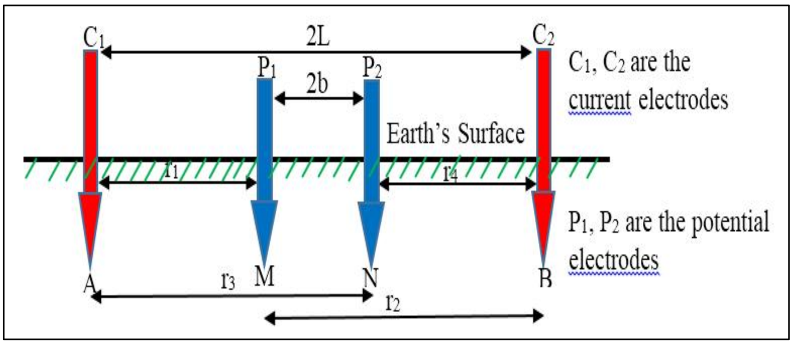


Figure 2: Schematic diagram of a Schlumberger array

$$\rho = K_g * resistance\ of\ earth = K_g * \frac{V}{I} \qquad (10)$$

$$K_g = \frac{\left\{\pi\left(\frac{AB}{2}\right)^2 * \left(\frac{MN}{2}\right)^2\right\}}{MN} \qquad (11)$$

Where ρ denotes the apparent resistivity (Ωm), K_g is the geometric constant, I indicate current (ampere), V is the voltage (volt), AB is spacing between the current electodes (m) and MN is spacing between the potential electrodes (m). The geometric factor (K_g) is based on field observation calculation and by multiplying the geometric factor with data of resisitance, the apparent resistivity values can be calculated.

Groundwater Level Distribution

Vertical distribution gives the distribution of water in various stages. To access the movement of water either horizontally or vertically based on on geological condition. Most of the well which gives high yield gives the surface to subsurface runoff easily through vertical distribution of groundwater. It helps the quantity of water available in the system (David, 2006).

In this research work, water level meter was applied to measure the water level in the study area. This meter is reliable and operates on simple but accurate principle of conductivity of water. It is portable, and handy and gives accuracy up to 1mm (or 1/100feet). The probe and the tape are usually made of durable and confined materials. The transducer is pressure-proof and the tape has the long-wearing plastic covering with readable scale in American and European measurement standards.

RESULTS AND DISCUSSIONS

Hydraulic Conductivity and Transmissivity

Table 1 and figures 3 & 4 show the summary of the aquifer/hydraulic parameters and the spatial distribution contour maps of hydraulic conductivity and transmissivity of the study area.

Table 1: Summary of Aquifer/Hydraulic Parameters

VES Location	*d* (m)	*b* (m)	*ρ* Ωm	*T* (m^2/day)	*K* (m/day)	*S* ($x\,10^{-4}$)
Erema	52	44.5	1592.64	70872.39	1592.64	0.58
Ibewa	125	102.5	1849.78	189602.86	1849.78	1.33
Akabuka	125	99.0	2746.36	271889.15	2746.36	1.29
Omuku	125	93.5	3367.49	314884.25	3367.49	1.22
Ogbidi	125	58.5	2857.75	167178.14	2857.75	0.76
Ogbogu	125	80.5	2578.57	207575.21	2578.57	1.05
Egbeda	125	98.0	3191.47	312763.57	3191.47	1.27
Ndoni	30	27.0	1203.44	32492.91	1203.44	0.35
Ogbagi	125	97.0	2631.35	255240.76	2631.35	1.26
Obezimini	125	53.5	3499.79	187238.49	3499.79	0.70
Obite	125	95.5	2631.35	251293.73	2631.35	1.24
Itu	127	77.0	2158.26	166186.17	2158.26	1.00
Ohalielu	125	97.0	2109.52	206732.96	2109.52	1.26
Obiyebe	125	103	3895.34	401220.02	3895.34	1.34
Egita	125	93.0	3255.34	302746.62	3255.34	1.21
Oboburua	125	91.5	3181.22	291081.63	3181.22	1.19
Akabuta	125	97.5	2322.50	226444.14	2322.50	1.27
Mgbede	125	90.0	3273.26	294593.40	3273.26	1.17
Obigwe	20	16.8	1679.93	28222.82	1679.93	0.22
Ede	5	17.0	1061.60	18047.20	1061.60	0.22
Obukaegi	40	30.0	2342.25	70267.53	2342.25	0.39
Idu osobele	40	30.0	3059.49	91784.70	3059.49	0.39
Obirikom	40	27.0	2172.92	58668.84	2172.92	0.35
Osiakpu	50	32.0	2351.75	75256.13	2351.75	0.42
Ebocha	50	37.0	2397.22	88697.03	2397.22	0.48
Kreigani	50	39.5	1724.80	68129.48	1724.80	0.51
Ikiri	50	45.0	1656.99	74564.42	1656.99	0.59
Ohiaga	50	37.0	1515.17	56061.40	1515.17	0.48
Okuezi	50	41.5	1932.76	80209.50	1932.76	0.54
IduObisikwu	40	27.0	2027.95	54754.65	2027.95	0.35

The aquifer thickness ranges from 17 m at Ede to 102.5 m at Obiyebe with an average value of 62.6 m. Areas having thick aquifer are potential places for groundwater storage. Figure 3 shows the spatial distribution of the estimated hydraulic conductivity (K) in the study area. The values range from 1061.6 m/day at Ede to 3895.3m/day Obiyebe with an average value of 2408.94 m/day with the highest values concentrated in the western and southern parts including Mgbede area within the northeastern part of the study area indicated with light blue to blue colors. Hydraulic conductivity is an indicative parameter for aquifer recharge potential. It describe the vertical movement of water in the aquifer and can be used to express aquifer potentials recharge where borehole pump data are unavailable (Heigold *et al*., 1979; George *et al*., 2015)

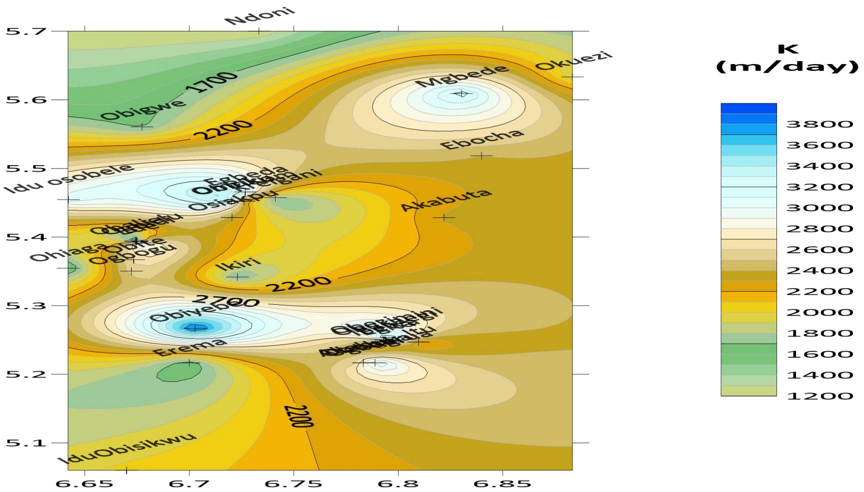


Figure 3: Spatial Distribution of the Hydraulic Conductivity in the Study Area.

The aquifer transmissivity (T) plot (spatial distribution map) presented in figure 4 shows that the estimated transmissivity ranges from 18047.2 m^2/day at Ede to 401220.2 m^2/day at Obiyebe with an average value of 163823.3 m^2/day. Highest values were recorded in the western, northern and southern parts of the study area indicated with light blue to blue colors. Aquifer transmissivity is an indirect indicator of yield (MacDonald et al., 2012), and it describes lateral movement of groundwater in aquifers. This is why some authors like Acheampong and Hess (1998) and Graham *et al.* (2009) have found boreholes yields to be directly related to trandmissivity.

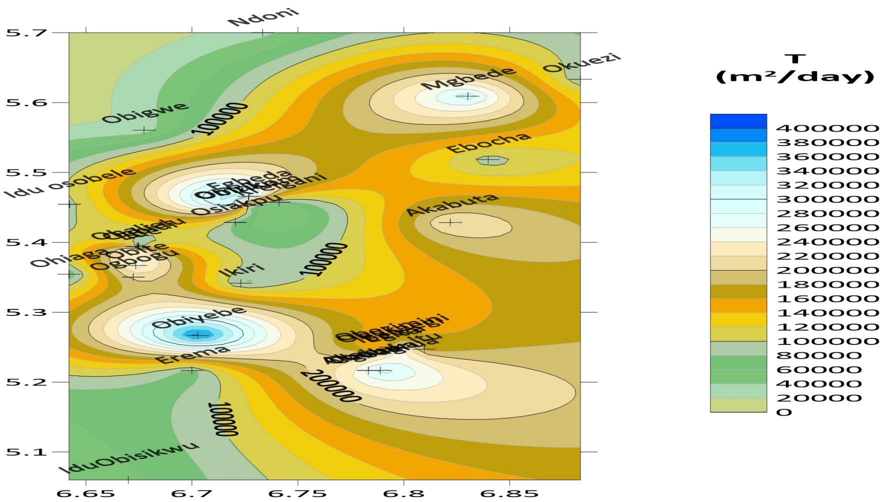


Figure 4: Spatial Distribution of the Transmissivity in the Study Area.

Storativity

The spatial distribution map of the aquifer storativity is presented in figure 5. The estimated storativity ranges from 2.20 x 10^{-5} at Ede and Obigwe to 1.34 x 10^{-4} at Obiyebe with an average value of 8.10 x 10^{-5}. Highest values were recorded in the western, northern, southern, and eastern parts of the study area indicated with light blue to blue colors. Aquifer storativity is an indirect indicator of the amount of water an aquifer can release or take into storage.

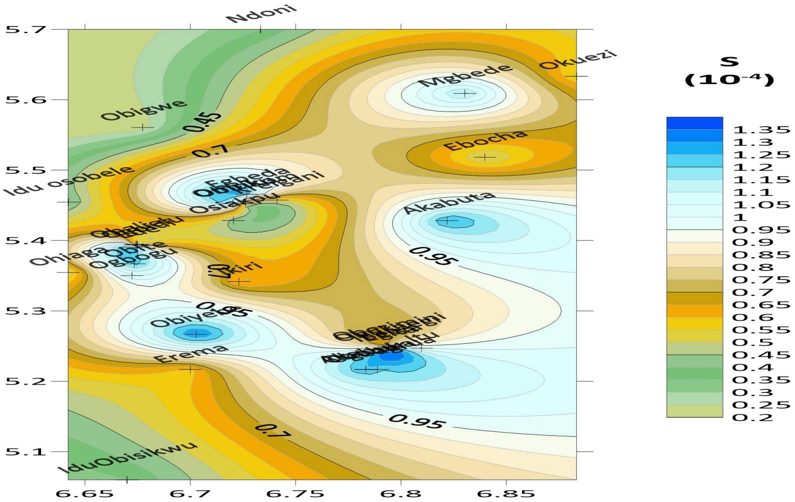


Figure 5: Spatial Distribution of Aquifer Storativity in the Study Area.

Comparing figures 3, 4 and 5, the spatial distribution of hydraulic conductivity is similar to that of the transmissivity and storativity. A joint evaluation of the three parameters suggests that the aquifers in the western, southern, eastern, and northern parts of the study area have the highest potentials for groundwater in terms of borehole yield, aquifer recharge, and storage potential.

Static Water Level (SWL) Distribution Pattern

Table 2 and figure 6 show the water level data and spatial distribution contour map of the study area.

Table 2: Water level Data in Parts of Ogba/Egbema/Ndoni

Location	Water level SWL (m)	Easting	Northing	Elevation (m)
Akabuka	6	5.21667	6.78333	17
Egbeda	10	5.46569	6.72677	19
Mgbede	5	5.60908	6.83025	20
Ndoni	8	5.70000	6.73333	13
Obagi	9.1	5.21667	6.78328	18
Obirikom	9.1	5.45222	6.72622	21
Obite	10.7	5.36688	6.67343	18
Ogbidi	5	5.39390	6.67490	18
Ogbogu	5	5.35021	6.67232	18
Ohiaga	5	5.35447	6.64198	15
Ohiali Elu	5	5.39390	6.67415	18
Omoku	7.6	5.45239	6.72015	19
Uju	5	5.41434	6.72001	18

The water level range from 5 to 10.7 m. The spatial distribution map and the 3D model of the static water level (figure 6a & b) show areas of high and low static water level. The spatial distribution map showed that areas such as Obagi, Omoku, Obirikom, Egbeda, Ndoni and Obite communities are of deep static water level. Highest values were recorded in the central and eastern parts of the study area indicated with light blue to blue colors, suggesting areas with high topography and elevation. The areas with light green to orange coded shade show communities that have SWL depth between 5 m and 7 m suggesting areas of low elevation and topography which could be susceptible to high aquifer vulnerability contamination.

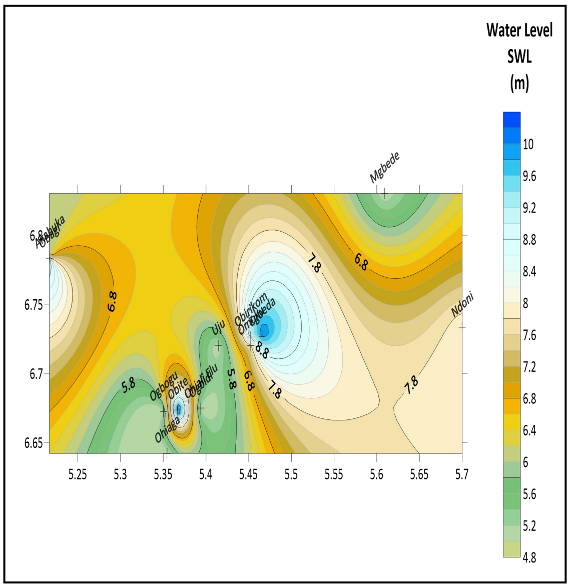


Figure 5a: Spatial Distribution of the Static Water Level in the Study Area.

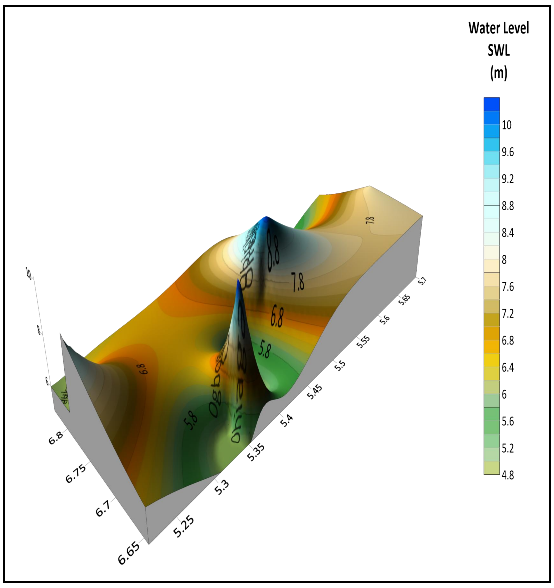


Figure 5b: 3D Model of the Static Water Level in the Study Area.

CONCLUSION

Aquifer parameters and hydraulic properties of rocks estimated geo-resistivity data acquired in thirty (30) Vertical Electrical Sounding (VES) station in Ogba/Egbema/Ndoni Local Government Area, Rivers State, Nigeria, have been used to evaluate the groundwater potential of the aquifer in the area. The estimated aquifer thickness ranges from 17 m to 102.5 m with an average value of 62.6 m. The values of the hydraulic conductivity range from 1061.6 m/day to 3895.3m/day with an average value of 2408.94 m/day, the estimated transmissivity ranges from 18047.2 m^2/day to 401220.2 m^2/day with an average value of 163823.3 m^2/day, while the estimated storativity values range from 2.20 x 10^{-5} to 1.34 x 10^{-4} with an average value of 8.10 x 10^{-5}. A joint evaluation of the hydraulic conductivity, transmissivity, and storativity suggests that the aquifers in the western, southern, eastern, and northern parts of the study area have the highest potentials for groundwater in terms of borehole yield, aquifer recharge, and storage potential. High values of groundwater static level were recorded in the central and eastern parts of the study area suggesting areas with high topography and elevation which could be less susceptible to vulnerability contamination. The western, southern, and northern parts of the study area were recommended for citing boreholes for community water supply. Although the groundwater potential model is subject to improvement for a more robust estimate, the consistencies between the hydraulic conductivity, transmissivity and the storativity maps of the aquifer confirmed the appropriateness of the model, developed in this study, for estimating groundwater potential of bedrock aquifers.

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