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Using Geo-electric Techniques for Vulnerability and Groundwater Potential Analysis of Aquifers in Nnewi, South Eastern Nigeria

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Abstract. In Nnewi, Anambra State Nigeria, twenty vertical electrical sounding (VES) were performed to delineate vulnerability and transmissivity of identified aquifer within the study area. Hydraulic parameters (transverse resistance, longitudinal conductivity, hydraulic conductivity and transmissivity) were delineated from geoelectrical parameters (depth, thickness, and apparent resistance). The geo- parameters of the aquifer: apparent resistance from 1000.590 to 1914.480, thickness from 42.850 – 66.490 m and 65.530 to 100.400 m of depth. The estimated hydraulic parameters of the aquifers are transverse resistance 54264.383 - 104568.898 Ωm, longitudinal conductance 0.029 – 0.062 mho, hydraulic conductivity 0.664 – 2.015 m/day and transmissivity between 4.167 and 13.963 m^2/day. All aquifers have poor protective capacity, 40 percent of the aquifers have low classification with smaller withdrawal potential for local groundwater supply, while 60 percent of the delineated aquifer has intermediate classification and withdrawal potential for local groundwater supply. Due to its groundwater supply potential and protective capacity, the eastern part of the study area has stronger groundwater potential.

Keywords: Hydraulic Conductivity, Transmissivity, Transverse Resistance, Longitudinal Conductance

Використання геоелектричних методів з метою аналізу вразливості та потенціалу запасів підземних вод потенційно водоносних горизонтів у місті Неві Південно-Східної Нігерії

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Анотація. У Неві (штаті Анамбра в Нігерії), було проведено двадцять вертикальних електричних зондувань (ВЕЗ), для того щоб довести вразливість та проникність ідентифікованого водоносного горизонту у досліджуваній області. Гідравлічні параметри (поперечний опір, поздовжня електропровідність, гідравлічна провідність і проникність) були відмежовані від геоелектричних параметрів (глибини, товщини та видимого опору). Геопараметри водоносного шару: явний питомий опір від 1000.590 до 1914.480, товщина від 42. 850 - 66.490 м та глибина від 65.530 до 100.400 м. Розрахункові гідравлічні параметри водоносних горизонтів - поперечний опір 54264.383 - 104568.898 Ом, поздовжня електропровідність 0,029 - 0,062 См гідропровідність 0,664 - 2,015 м / добу і прохідність між 4,167 до 13,963 $м^2$ / добу. Усі водоносні горизонти мають низьку захисну здатність, 40 відсотків водоносних горизонтів мають низьку класифікацію із меншим потенціалом вилучення місцевих джерел ґрунтових вод, тоді як 60 відсотків відмежованого водоносного горизонту має проміжну класифікацію та потенціал вилучення місцевих підземних вод. Через свій потенціал подачі підземних вод та захисну здатність східна частина досліджуваної території має більш високий потенціал підземних вод.

Ключові слова: гідропровідність, проникність, поперечний опір, поздовжня провідність

Introduction.

Water is the most important necessity nature provides for flora and fauna to survive and thrive, and it also plays a monumental role in every mode of human life (Nwankwoala and Nwagbogwu, 2012). Hence, usable water quality is a significant metric of man's quality of living (Elueze, et al., 2004). Nonetheless, water quality is influenced by the features of the circulation and occurrence system. Typically, these sources are exposed to anthropogenic and industrial contaminants (Egbunike and Okpoko, 2018). Despite its importance, water is the planet's most undermanaged resource (Fakayode, 2005). The current urbanization and industrialization trend can contribute significantly to poor water quality through extrajudicial discharge of solid waste, industrial waste, or other hazardous waste. (Ugochukwu, year 2004).

Water is one of the important supporters of all aspects of living organism life (Vanloon and Duffy, 2005). It is usually collected from two key natural sources; surface water such as lakes, rivers and streams; and groundwater such as wells drilled by borehole and by hand (McMurray and Fay, 2004; Agbasi and Etuk 2016). Because of its hydrogen bonds, water has peculiar chemical composition which allows it to dissolve, engulf or suspend into many different compounds (WHO, 2007). Water is not pure in nature because it inherits toxins from its climate and those from humans and livestock, as well as from other ecological activities (Agbasi and Etuk 2016).

Groundwater, for more than half of the world's population, happens to be a far more sustainable source of water (Alabi et al., 2010; Anomohanran, 2013), and is described as that part of precipitation that enters the ground and percolates downward through unconsolidated materials and openings in bedrock until it reaches the water table. This unconsolidated soil, which can produce water in accessible amounts, is known as aquifer (Alabi et al., 2010). Aquifer properties which are known to influence the accessibility of groundwater involve aquifer thickness and the size and magnitude of pore space connectivity within the aquifer. These properties affect the ability of an aquifer to store and transmit groundwater (Ochuko, 2013). These approaches involve electrical resistivity, gravitational, gravity, magnetic and magnetulluric seismic refraction (Karani et al., 2009; Majumdar and Das, 2011; Todd, 2004). Method selection primarily relies on the depth of inquiry, and often the expense (Todd, 2004) of all such methods used in groundwater research has become the most commonly used method of electrical resistivity profiling. This is because its ionic content is immune to the resistance of rocks (Alile et al., 2011And the device's operation is unfussy, and data processing is economical (Ezeh and Ugwu, 2010; Anomohanram, 2011; Atakpo and Ofomola, 2012). The method of electric resistivity is used to estimate the depth of the bedrock surfaces and the thickness of the soil or rock (Nwankwo, 2011). The approach is also used for studying groundwater pollutants and their patterns of movement (Ehirim and Ofor, 2011).

Vertical electrical sounding (VES) has been shown to be efficient in most areas of Nigeria in resolving groundwater problems (Onuoha and Mbazi, 1988; Mbonu et al., 1991; Mbipom et al., 1996; Ekine and Osobonye, 1996; Eze and Ugwu, 2010; Namdie and Idara 2017). In the present study, an attempt had been made to establish the aquifer characteristics in the study area, an estimated the hydro-geophysical parameters of the aquifer to delineate their vulnerability for human usage.

Hydrogeology of the study area.

Anambra State occurs primarily within the Niger Delta Region, with the exception of the far southeastern portion apex of the state that is underlain by a section of Anambra Region. The geological origins of Anambra and Niger Delta Basins was exquisitely related to the mega-tectonic structural pattern correlated with the breakup of the Gondwanaland during the Late Jurassic to Early Cretaceous (Onuigbo et al., 2015). The Anambra Basin is theorized to have formed contemporaneously with the folding of the Benue Trough in the Santonian due to the depression of the region around the southern Benue Trough. Syngenetically, the Niger Delta Basin developed as a continuous subsidence of the Southern Benue Trough and Anambra Basin, as defined by the rupture zones of Chain, Charcot and Romanche. The Cenozoic Niger Delta is therefore superimposed on the Benue Trough and Anambra Basin in the south (Nwajide, 2013).

The Ameki Group's components are the Ameki, Nanka, and Nsugbe Formations that overlie the Imo shale group in conformity. Ameki Group's facie is underpinned by more than 35 percent of Anambra Province. Ameki and Nanka Formation lithofacies are loose, flaser-bedded, fine-medium-grained sand with very few mudrockbreaks (Nwajide, 1979).

Two formations underlie the study area; Eocene Nanka Sands Formations (Ameki group) and Quaternary Ogwashi-Asaba Formation (Nwajide, 2013). The Nanka Sands, Nnobi, Ojoto and some pieces of Nnewi underlie that. It is a sequence of lowly accumulated, poorly sorted, friable, medium

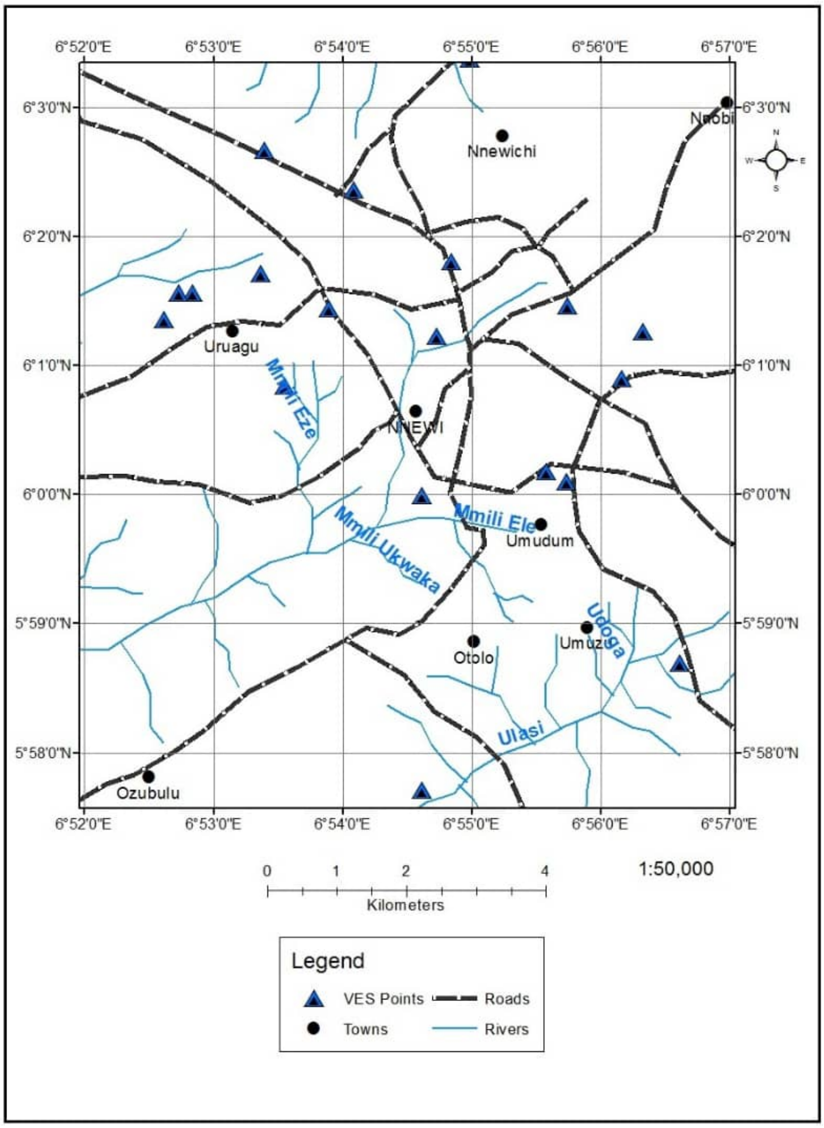

Fig. 1: Map of the study area showing the VES points

to coarse Eocene age sands in the study region. The formation includes thin clay stone, siltstone, and shale bands. The units have strong permeability and porosity. The aquiferous sandstone unit is (Nwajide, 1979). The Ogwashi-Asaba Formation overhangs the Nanka Sands, this consists of the lignite and clay intercalations.

Nanka Sands underlines the upper parts of the study region which are Nnewichi, Nnewi, these have unconsolidated color, loose and cool, white to brownish sand. (Onu, 2017).

In the study region, the presence of several streams and rivers indicates rapid percolation of rainwater through the soil. This is also due to the extremely porous and permeable soil character. Nanka Sand is very aquiferous and this accounts for the many water boreholes that have been drilled into the site.

The aquifer depth in the region ranges from 134 m to 237 m below the ground. Water levels occur in the plains and river courses at shallow depths, and in the highlands at greater depths. Groundwater in the field of research is recovered through rainfall absorption and surface runoff. The cost of deep aquifer extraction is high among the study area residents with the associated risk of drilling abortive boreholes because most of the time there were no professionals involved in exploration (Obeta, 2015).

Methodology.

Geophysical electrical resistivity studies describe a subsurface medium consisting of layers of materials with different resistivities, assuming all the layers are horizontal.

A material resistivity ρ is a function quantifying how much the material retards electrical current flow. The resistivity differs greatly from one substance to the next, because of this great variety, calculating the resistivity of an unknown substance, provided no more detail, has the potential to be very useful in identifying the substance. Throughout field studies a material resistivity can be combined with reasoning along geological lines to classify the materials that make up the different underground layers.

The amount of water recharging an unconfined aquifer is calculated by:

- the amount of precipitation that is not lost by evapotranspiration and runoff and is therefore available for recharge;
- the vertical hydraulic conductivity of surface deposits and other strata in the aquifer recharge region, which determines the volume of recharged water capable of moving down.

Should an aquifer transfer the full amount of water, any possible regeneration in the recovery region is more than likely rejected. In humid areas (as in the study area) this is always the case. Unless the water level below shows that the aquifer may not flow at maximum capacity, the recharge region is possibly either deficient in possible recharge or poor vertical hydraulic conductivity, retarding downward motion (Fetter Jr., 2014).

The relationship between hydraulic parameters and geo-electric parameters is strongly influenced by the aquifer substratum composition (Agbasi, et al., 2019; Harry et al., 2018). In a standard unit column of the aquifer, both current and the hydraulic flows are prevalently horizontal for an extremely resistive substratum, and the correlation between hydraulic conductivity (K) and apparent resistivity (ρ) is inverse. If the substratum is strongly penetrable, the hydraulic flow would still be vertical, while the present flow is prevalently vertical in a characteristic unit column. Therefore, there is a clear correlation between K and ρ. If the aquifer material is sliced from top to bottom in the shape of a vertical prism of the unit cross-section, fluid flow and current flow in the aquifer substance simultaneously follows Darcy's law and Ohm's law. Thus, the transmissivity of the aquifer is described as: for current and fluid flows in a directional manner:

$$T = \sum_{i=1} K\rho S = \sum_{i=1} Kh \quad (1)$$

where ρ is the bulk resistivity and

$$S = \sum_{i=1} \frac{h}{\rho} \quad (2)$$

S is the longitudinal unit conductivity of the aquifer material with thickness *h*.

For a lateral hydraulic flow and current flowing transversely, the transmissivity of the aquifer becomes

$$T = \sum_{i=1} \left(\frac{K}{\rho}\right) R = \sum_{i=1} Kh \quad (3)$$

where ρ is the bulk resistivity and

$$T = \sum_{i=1} \left(\frac{K}{\rho}\right) R \quad (4)$$

where R is the transverse unit resistance of the aquifer material

For hydraulic conductivity K, we have

$$K = 8 \times 10^{-6} e^{-0.0013\rho} \quad (5)$$

Then

$$T = (8 \times 10^{-6} e^{-0.0013\rho}) h \quad (6)$$

If the aquifer is saturated with water with uniform resistivity, then the product *Kρ* or *K/ρ* would remain constant. Thus, the transmissivity of an aquifer is proportional to the longitudinal conductivity for a highly resistive basement where electrical current tends to flow horizontally, and proportional to the transverse resistance for a highly conductive basement where electrical current tends to flow vertically (Umoren, et al., 2017). The above equations may therefore be written as:

$$\rho^2 = \sum_{i=1} \frac{S}{R} \quad (7)$$

The model resistivity values derived from the inversion method were used from these relations to evaluate the aquifer unit longitudinal unit conductance and transverse unit resistance.

Considering that most minerals have high electrical resistivity (outlier: saturated clay, metal ores, and graphite), the electrical current flows primarily via the pore water.

The major equipment used in the field is the ABEM SAS 1000 Terrameter. Other accessories used for the field work are measuring tape (for taking distance measurement), Global Positioning System (for determining the location and elevation of sampling points), battery (12V used to power the Terrameter), electrodes (a total of four electrodes were used), and hammers (are used to drive the electrodes into the ground to ensure good contact).

Results.

Twenty vertical electrical sounding, conducted in Nnewi, Anambra state. Figure 2 show the interpretation of the VES data. In the twenty VES stations six (6) geoelectric layers have been identified. The form of a curve within the study area is shown in the Table 1.

The top soil resistivity is between 759.56 – 3308.18 Ωm with a thickness varying from 1.94 – 9.12 m. The second geoelectric layer consists of a lateral shale with a thickness of 1.68 – 30.75 m and apparent values of resistivity varying from 539.15 to 2330.89 Ωm. The third geoelectric layer is superficial

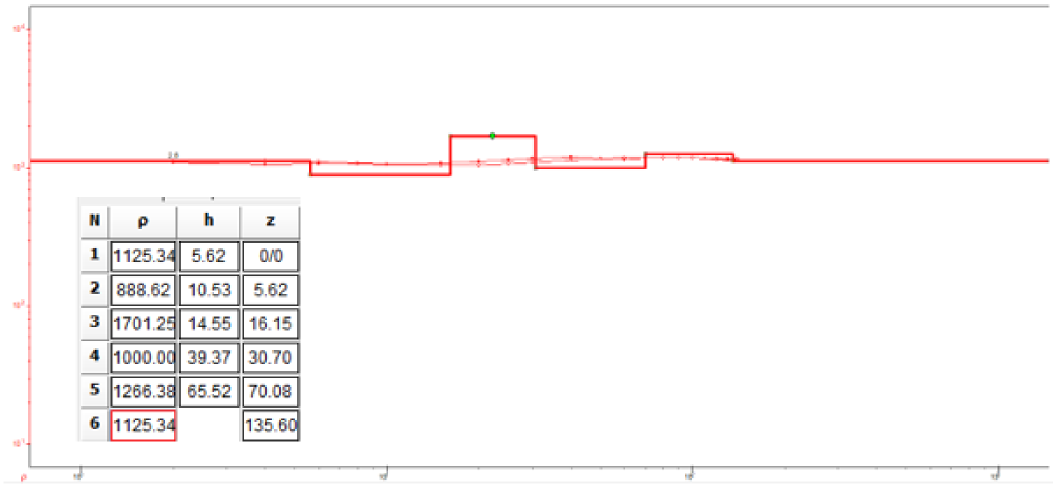

Fig. 2: A fragment of a computer iterated analysis based on a VES station

in nature with an apparent layer of resistivity of 750.74 to 2240.93 Ωm with a thickness of 14.23 to 29.30 m. The fourth geoelectric layer is the sandstone layer, between 835.60 and 1804.72 Ωm the range of apparent resistivity. The aquifer layer is identified in the fifth geoelectric layer, they have an apparent resistivity value between 1060.82 – 1914.48Ωm with thickness of 51.28 – 66.49m across the twenty (20) VES stations in the study area.

The Figure 3 displays a 2D contour map and 3D surface of apparent resistivity variance in the aquifer across the study area. The central parts of the area have moderate apparent resistance values compared to other parts, and the northwest part of the study area also shows an increasing value of apparent resistance.

Table 1. Curve type of the various VES stations

VES	Curve Type
1	HH
2	AQ
3	QH
4	KQ
5	HQ
6	AH
7	KH
8	QH
9	HA
10	QK
11	QA
12	HA
13	KK
14	AH
15	HH
16	HK
17	KK
18	QH
19	KK
20	KK

Figure 4 shows the 2D contour map and 3D surface of the aquifer thickness in the study area. The south-western part has the highest aquifer thickness, with the majority of the VES station in the eastern part of the study area having a moderate thickness.

Figure 5 shows the 2D contour map and 3d surface of the longitudinal conductivity across the aquifers in the study area. The majority of the study area of moderate longitudinal conductivity is expected to have high longitudinal conductivity values for the northwest parts of the region.

The 2D contour map and 3D surface of hydraulic conductivity (Fig. 6) shows a pattern of increasing from the west to the eastern, with the lowest values found around the northwest parts of the study area.

The Figure 7 with the 2D contour map and 3D surface of the transmissivity shows higher values in the eastern and northern portions of the study area compared to the western southern and northern parts.

The Table 2, shows the aquifer geoelectric and hydraulic parameters calculated in the study area, a standard table (tables 3 and 4) were used to infer the hydraulic parameters of the aquifers, which is presented in the Table 5. All the aquifers in the study area have poor protective aquifer. 40% of the aquifers in the study area have low designation and smaller withdrawal for the local water supply (private consumption), while the other 60% have Intermediate and Withdrawal of local water supply (Small community, etc.) for designation and groundwater supply potential respectively.

Longitudinal conductivity and the study area transverse resistance were also measured using geoelectric parameters of the aquifers. It has been found that most parts of the study region have an

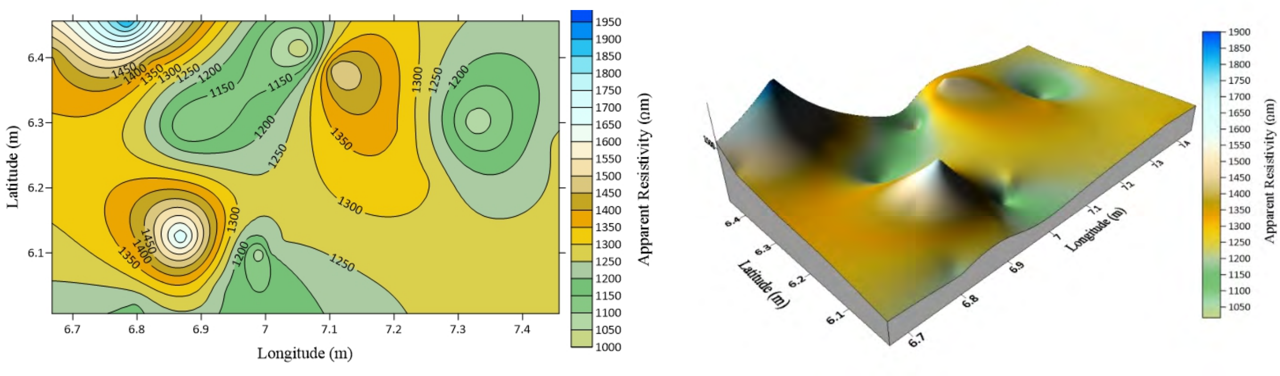

Fig. 3. 2D contour map and 3D surface of apparent resistivity variance in the study area

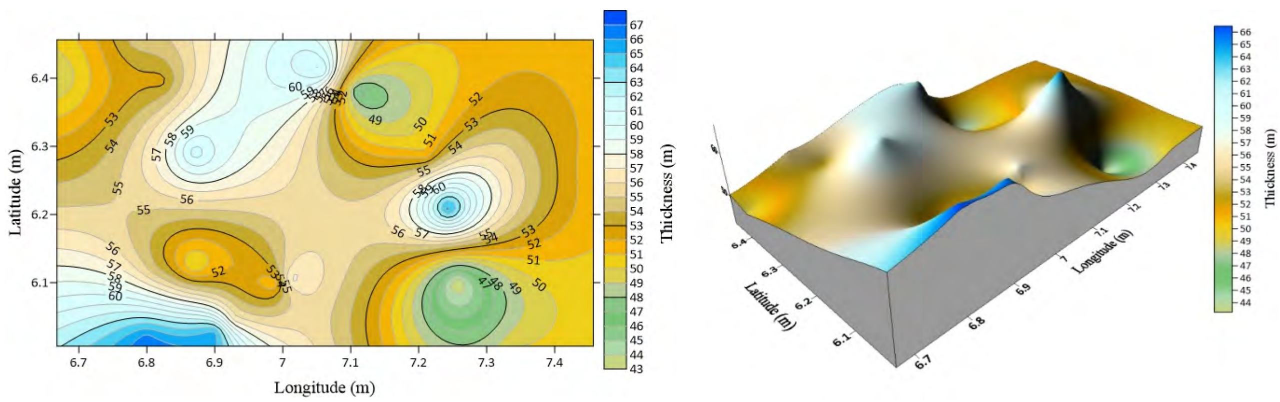

Fig. 4. 2D contour map and 3D surface of the aquifer thickness in the study area

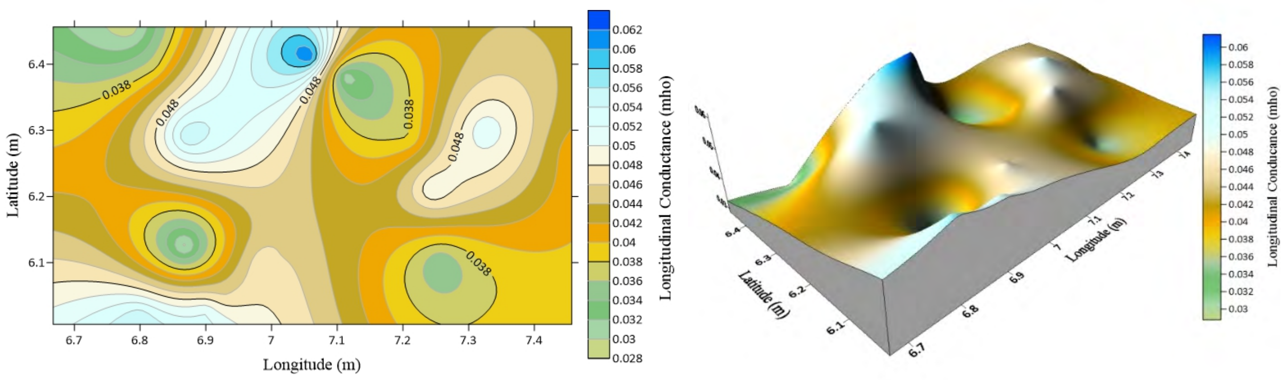

Fig. 5. 2D contour map and 3D surface of longitudinal conductance in the study area

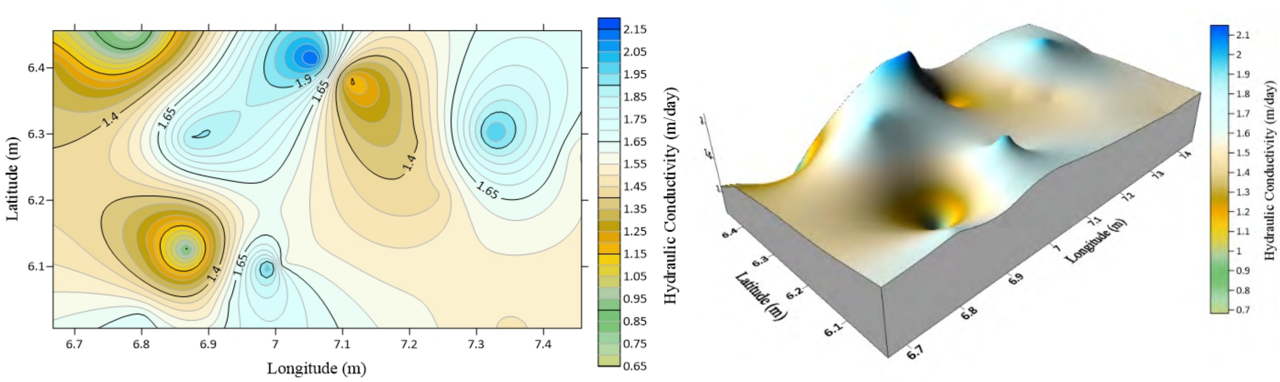

Fig. 6. 2D contour map and 3d surface of hydraulic conductivity in the study area

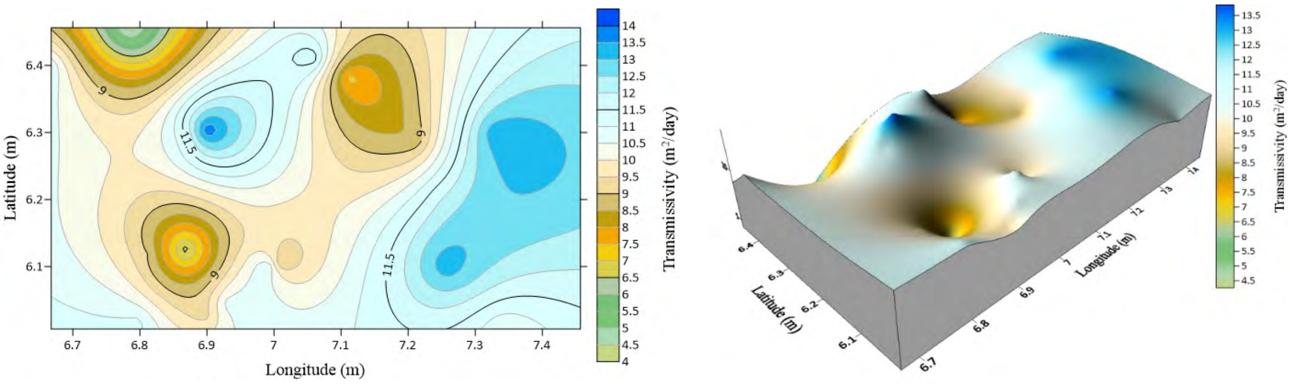

Fig. 7: 2D contour map and 3D surface of transmissivity in the study area

Table 2. Geoelectric and hydraulic properties of the aquifer in the study area

VES	Apparent Resistivity (Ωm)	Thickness (m)	Depth (m)	Transverse Resistance (Ωm²)	Longitudinal Conductivity (mhos)	Hydraulic Conductivity (x 10^6) (m/day)	Transmissivity (m²/day)
1	1266.380	65.520	70.080	82973.218	0.052	1.542	9.337
2	1193.780	66.490	75.660	79374.432	0.056	1.695	11.079
3	1217.500	56.560	75.100	68861.800	0.046	1.643	10.663
4	1103.410	61.710	69.950	68091.431	0.056	1.906	11.519
5	1060.820	55.110	76.550	58461.790	0.052	2.015	13.324
6	1241.700	57.370	65.530	71236.329	0.046	1.592	9.016
7	1343.400	51.260	71.640	68862.684	0.038	1.395	8.636
8	1060.820	51.260	62.740	54377.633	0.048	2.015	10.920
9	1000.590	62.270	62.740	62306.739	0.062	2.179	11.810
10	1317.220	65.870	94.420	86765.281	0.050	1.443	11.776
11	1914.480	54.620	72.620	104568.898	0.029	0.664	4.167
12	1397.330	52.640	68.710	73555.451	0.038	1.300	7.722
13	1291.550	49.950	81.110	64512.923	0.039	1.492	10.459
14	1704.250	49.890	82.810	85025.033	0.029	0.873	6.244
15	1511.780	46.530	75.550	70343.123	0.031	1.121	7.317
16	1266.380	51.230	96.910	64876.647	0.040	1.542	12.912
17	1397.330	48.930	96.890	68371.357	0.035	1.301	10.889
18	1266.380	42.850	100.400	54264.383	0.034	1.542	13.377
19	1103.410	59.890	84.790	66083.225	0.054	1.906	13.963
20	1425.100	54.370	83.060	77482.687	0.038	1.255	9.003

unprotected aquifer as shown by low longitudinal conductivity values below 0.1. The low longitudinal conductivity across the study area is representative of the high permeability, hydraulic conductivity and low clay volume characterizing the study area. The high transverse resistance values indicate the yield of aquifer units from local water supply between low and intermediate determination of transmissivity and withdrawal.

Conclusion.

Geophysical investigations involving the use of vertical electrical sounding (VES) using the Schlumberger electrode configuration, carried out in the study area, to ascertain hydraulic unit flow and protective capacity of the aquifers. All identified aquifers in the study area have poor protective capacity; therefore, it is necessary for further treatment of groundwater after withdrawal. Also, the study area is likely prone to groundwater contaminations, because it is located in an industrial area with poor drainage facilities. About 60 percent of the investigated aquifer area has intermediate designation and withdrawal potential of local groundwater supply, while 40 percent of aquifer area has low designation and smaller withdrawal potential of local groundwater

Table 3 Standard transmissivity vales for groundwater supply potential **(**Agbasi and Etuk, 2016)

Transmissivity (m/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, plant 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	Impermeable	Sources for local water supply are difficult

Table 4 Standard longitudinal conductivity value for protective capacity (Agbasi and Etuk, 2016)

Longitudinal Conductivity (mhos)	Protective capacity
> 10	Excellent
5 – 10	Very good
0.7 – 0.49	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
< 0.1	Poor

Table 5. Interpretation of hydraulic parameters of the 20 VES station in the study area

VES	Designation	Groundwater Supply Potential
1	Low	Smaller withdrawal for local water supply (Private consumption)
2	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
3	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
4	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
5	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
6	Low	Smaller withdrawal for local water supply (Private consumption)
7	Low	Smaller withdrawal for local water supply (Private consumption)
8	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
9	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
10	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
11	Low	Smaller withdrawal for local water supply (Private consumption)
12	Low	Smaller withdrawal for local water supply (Private consumption)
13	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
14	Low	Smaller withdrawal for local water supply (Private consumption)
15	Low	Smaller withdrawal for local water supply (Private consumption)
16	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
17	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
18	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
19	Intermediate	Withdrawal of local water supply (Small community, plant etc.)
20	Low	Smaller withdrawal for local water supply (Private consumption)

supply. The evaluated hydraulic flow parameters identified for the study area are highly suitable in groundwater assessments both for industrial and residential purposes.

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