International Journal of Advanced Science and Research
www.allsciencejournal.com
ISSN: 2455-4227
Received: 27-11-2023, Accepted: 12-12-2023, Published: 28-12-2023
Volume 8, Issue 2, 2023, Page No. 7-11

Appraisal of vulnerability / protective capacity of overburden aquifers at Lodu - Imenyi and its environs in Abia state, Nigeria

Adindu Ruth U, Chigbu Timothy O
Department of Physics, Abia State Polytechnic, Aba, Nigeria

Abstract
This paper evaluated the Protective Capacity of aquifers at Lodu- Imeyi and its environs in Bende area of Abia State, Nigeria. It examined the extent of the aquifers' vulnerability to contaminate fluid migration on the basis of longitudinal unit conductance values. Fifteen (15) Schlumberger depth sounding data from the area were interpreted to delineate the aquifers. Aquifer resistivity ranged from (200 to 2800) Ωm with maximum value at Nkpa and Okoitem. Aquifer thickness in this area (68 – 102) m indicated high aquifer storability and good groundwater yield. Depth to Aquifer is however low, ranging from 22 m to 58 m implying shallow aquifers whereas, high transmissivity values (10,000 – 200,000) Ωm^2 were delineated across the area, demonstrating good to high groundwater potentials. Areas indicating high groundwater potentials (Ozuitem, Nkpa, Alayi and Igbere, Okoitem) also indicated poor – weak protective capacities (0.05 – 0.15) mhos. This signifies insufficient conductive materials in their litho-units and also the possibility of groundwater contamination. But Lodu, Akoli Imenyi and Elugwumba indicated moderate – good protective capacity (0.2 – 0.75) mhos, signifying impermeability of the aquifer overburden materials to fluid migration. Therefore, it is inferred that the aquifer overburden rock materials in this region is composed of sufficient shale materials that could effectively offer good protection to the aquifers from surface contamination. However, further investigations are recommended to ascertain this claim.

Keywords: Lodu, aquifer vulnerability, protective capacity, layer material, surface contaminant

Introduction

Ground water effluence is increasingly becoming a serious challenge in several countries of the world, including Africa and in some localities within Nigeria, due to the transport of contaminants into aquifer repositories. Movement of contaminants in the hydro-geological units is partly controlled by the hydrodynamic characteristics of the subsurface formation and also by the geological settings. Consequently, the knowledge of the flow dynamics is needed in order to reduce the risk of contaminate flow and also provide information that will help in a proper groundwater management and development strategy (Obiora *et al.* 2016 [14]; Aleke *et al.* 2018 [2]; Ibuot and Obiora, 2020).

Ground water pollution and vulnerability studies have gained both local and international scientific interest during the last decades. There have been many approaches and techniques used for its studies including electrical resistivity method with the approach of using geo-electric parameters of the near-surface materials overlying the aquifer (Bayewu *et al., 2018* [4]*;* Obiora and Ibuot, 2020; Olayiwola *et al.*, 2021 [17]; Joel *et al.*, 2022) [9]. Some other methods include: Spontaneous potential methods, Ground penetrating radar method which identify leakages in reservoirs and membrane lined sites and Aquifer Vulnerability Index (Olumuyiwa *et al*., 2017) [19]. Aquifer vulnerability Index method quantifies vulnerability of an aquifer by its hydraulic resistance to vertical flow of water through its protective layers (Aweto, 2011) [3].

Aquifer vulnerability to an imposed contaminant load is considered as the relative evaluation of the potential exposure of a groundwater resource to contamination from various human activities, fluid migration from landfill, industrial wastewater discharge, chemical fertilizers, pesticides and herbicides (Rizka, 2018) [20]. It is determined by the intrinsic characteristics of the aquifer system to respond to human activities. Therefore, constant monitoring and evaluation of groundwater resources has become necessary in order to avoid epidemics, seeing that there is a great dependence of the populace on groundwater resource for their water need (Chukwuma *et al*,. 2015) [6].

The parameters affecting vulnerability are mainly permeability and thickness of the protective layers. For unconsolidated sediments, the permeability is strongly related to the clay content and can be deduced indirectly from resistivity methods. Moreover, the intrinsic resistivity of the unconsolidated overburden and that of the aquifer differ by orders of magnitude. This makes geoelectric methods suitable in mapping aquifers thickness and extent of its overburden thickness. The use of longitudinal conductance parameter of the resistivity method has become an easy way of assessing the uppermost geo-electric layer materials overlying the aquifer. Longitudinal conductance have been used by Golam *et al.*, (2014) [7] and Oborie and George, (2016) [15] in groundwater potential and aquifer vulnerability studies. High longitudinal conductance values usually signify high protective capacities and are accorded the highest priority in terms of groundwater vulnerability assessment (Chukwuma *et al.*, 2015) [6]. This study seeks to obtain guided information on the extent to which the groundwater resource is prone to surface contaminant fluid migration by evaluating the aquifer overburden rock materials and ascertain if they could effectively protect the aquifers from surface contaminants.

Location of the study area.
The study area is located in Bende Local Government Area of Abia State, Southern Eastern Nigeria. It lies within latitude 5°28 N – 5°33 N and longitudes 7° 30 E - 7°3 9 E. The area comprises the towns of Bende, Alayi, Uzuakoli, Nkpa, Ozuitem, Umu-Imenyi, Igbere, Ugwueke and Item. It has a tropical rain forest climate and exhibits two major seasons (the rainy and dry seasons (Fig.1). The two major geologic formations found within this area are Shales and Ajali sandstone formations.

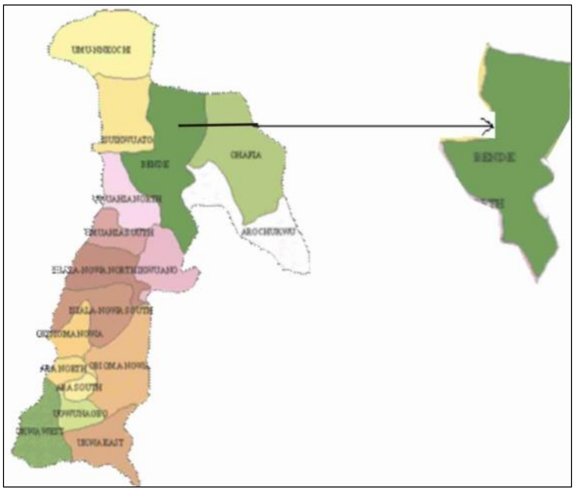

Fig 1: Map of the Study Area

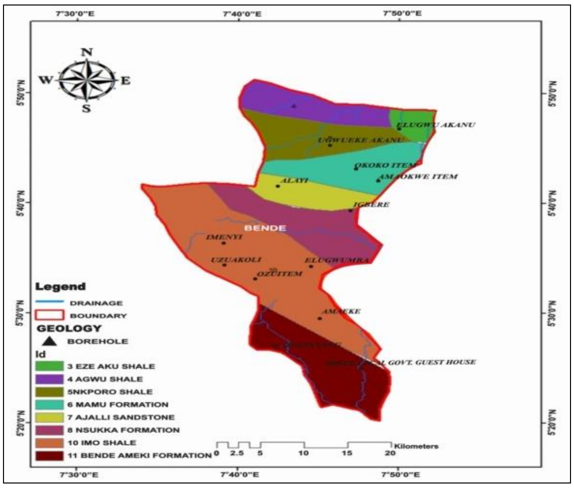

Fig 2: Geology Map of the Study Area

Vulnerability assessment method
In recent years various methods of groundwater vulnerability assessment have been developed with different approaches. These approaches have been categorized into three; the subjective rating (classic) methods, the statistical method and the process-based methods.
Classic vulnerability methods includes the GOD and AVI, empirical methods such as DRASTIC, SINTACS, and SI. They are based on overlay and indexing techniques, depend on the type of aquifer, the type of pollutant and the availability of data. Index and overlay method are based on combining maps of various physiographic attributes (geology, soil, aquifer media, depth to water) controlling groundwater vulnerability of the region by assigning a numerical score or rating to each attribute using GIS technique. The significance of GIS-based mapping in this case comes from its ability to produce geo-databases and to create vulnerability maps.
Statistical method ranges from descriptive statistics of the concentration of a contaminant to more complex regression analysis. Incorporation of data on known pollutant and their distribution provide information on potential contamination for the specific geographic area. Additional information on factors affecting the intrinsic vulnerability of the resource can be obtained by using logistic regression

Theoretical framework
The earth medium acts as a natural filter to percolating fluid. Its ability to retard and filter percolating fluid is a measure of its protective capacity (Olorunfemi *et al*., 1998) [18]. The ability of the earth to filter fluids is subject to the aquifer thickness, the covering rock materials and the protective capacity of the overlying overburden of the aquifer (Chukwuma *et al*., 2015) [6]. An effective groundwater protection is given by protective layers with sufficient thickness and low hydraulic conductivity (Aweto, 2011) [3] and also depends on the aquifer characteristics, the geological and hydrological environment. Silts and clays are suitable aquitards which often constitute good protective geologic barriers when found above an aquifer. They protect the aquifer from surface and near-surface contamination, as their low hydraulic conductivity leads to high residence time of percolating water (Lenkey *et al*., 2005) [10].
The longitudinal conductance 'S' (a combination of the resistivity and thickness in the Dar Zarrouk parameter) could be of direct use in aquifer vulnerability studies (Henriet, 1976) [8]. It measures the impermeability of the aquifer protective layers (otherwise known as Protective Capacity 'P. C'.) of the aquifer overburden rock material. The Protective capacity of the overburden rock material is given by,

$$S = \Sigma(h_i / \rho i) \;= P.C \qquad (1)$$

Where S is the longitudinal conductance, h_i is a layer thickness and ρ is the aquifer resistivity
High longitudinal conductance values signify high protective capacity and are accorded the highest priority in terms of groundwater vulnerability assessment. The longitudinal conductance/protective capacity rating as presented by Oladapo *et al*., 2004 [16]; Aweto, 2011) [3] rated values of longitudinal conductance as: >10 (excellent), 5 to 10 (very good), 0.7 to 4.9 (good), 0.2 to 0.69 (moderate), 0.10 to 0.19 (weak) and < 0.1 (poor). These ratings enable the classification of P. C. of an area into various grades. Areas of good, very good and excellent classification indicates high protective geological formation to contamination, whereas areas of weak and poor classification are rated as most susceptible to contamination.

Method of study
Using the Schlumberger electrode array with a maximum spread of AB/2 = 400, fifteen VES data were obtained at random at various point within the study area using ABEM Terrameter SAS 3000. Current was sent into the subsurface through the current electrodes and the resulting potential difference was measured. Measurements of resistance were taken progressively from the smallest spacing to the maximum spread. From the field data, the apparent

resistivity (ρ_a) of the soil material in ohmmeter, was calculated. Values of the ρ_a for each location were then processed using a computer software (the RESIST) to obtain geoelectric layer parameters. From these parameters, aquiferous units and Dar'Zarrouk parameters are calculated. The Dar'Zarrouk are used for further interpretation of groundwater potentials and vulnerability. Total longitudinal conductance (S) and total transverse resistance (T) were derived from the basic parameters of resistivity and thickness according to Maillet (2007) [11]. These have been illustrated as the Dar'Zarrouk parameters which are mathematically given as:

Total Transverse Resistance (T)

$$T = h_1\rho_1 + h_2\rho_2 + h_3\rho_3 + \ldots + h_n\rho_n \; (\Omega m^2) \quad (2)$$

Total Longitudinal Conductance (S):

$$S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \cdots + \frac{h_n}{\rho_n} \; (\text{mhos}) \quad (3)$$

Results and discussion

Contour maps of aquifer characteristics depicting groundwater resource potential zones and its vulnerability to contaminations are presented in Figures (3 – 8). Aquifer characteristics of the area are shown pictorially as contour maps below. Color discrimination distinguishes each parameter variation showing the minimum, moderate and maximum values.

Elevation of the study area

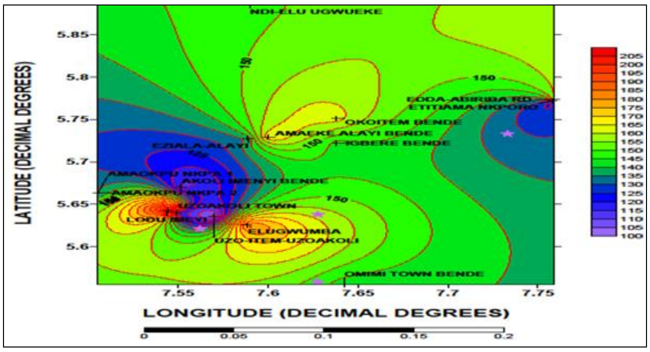

Fig 3: Elevation map of the study area

The elevation map showed an elevation range between 100 m – 205 m, with high values around Lodu, Eluwumba, Okoitem and Amaeke-Alayi communities. Areas of low values include Nkpa, Akoli-Imenyi, Uzoakoli, Igbere and Ezeala – Alayi with value range between 104 m – 143 m. Areas of high values indicate highlands whereas, the lowlands/plains are indicative of the low values. Ground water table follows the topography of an area.

Aquifer resistivity

Aquifer resistivity (Fig. 4) varies spatially across the area, depicting low values (0 – 800) Ωm; moderate values ranging from (1000 – 1600) Ωm and high values ranging from (1800 – 2800) Ωm. Moderate to high values were delineated in a southwest – northeast direction in localities such as Eziala-Alayi, Ameke – Alayi and Okoitem region With a maximum at Okoitem. The southern region of the area comprising Lodu, Akoli Imenyi, Nkpa, Uzoakoli and its environs are characterized by low resistivity values.

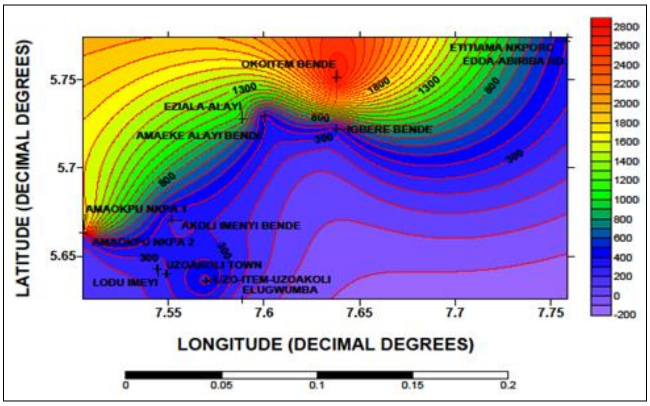

Fig 4: Aquifer Resistivity map of the study area

These are possible areas of less sand materials and high clay content. Resistivity interpretation gives the under laying lithology of the subsurface material within the surveyed points and indicates material of which the soil is composed of. Areas of high resistivity values imply areas of increasing sand beds and low conductive materials in its litho-units, indicating insufficient clay materials in the lithology (Ugada *et al.*, 2013) [21]. This characteristic is attributed to the Ajali sandstones which underlay the area. Adindu *et al.*, (2021) [1] associated the Ajali sandstones with high groundwater potentials.

Aquifer thickness

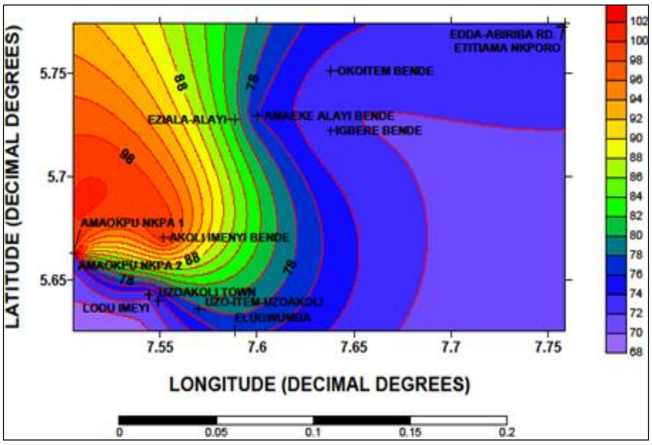

Fig 5: Aquifer thickness map of the area.

Aquifer thickness indicates the storage capacity of an aquifer and its possible yield. The aquifer thickness map of the area as delineated (Fig. 5) is characterized by good values (68m – 76m) in the Northeast – Southeast direction, in localities such as Lodu, Akoli-Imenyi, Uzoakoli, Igbere, Amaeke and Okoitem. High values (80 -88) m were delineated around Akoli, Nkpa and its environs. This indicates that the aquifers in this area have good – high potentials in groundwater storage and are expected to have high aquifer yield to boreholes. Aquifers with high storability yield sufficient groundwater to wells and streams (Chowdhury *et al.*, 2017) [5].

Aquifer depth

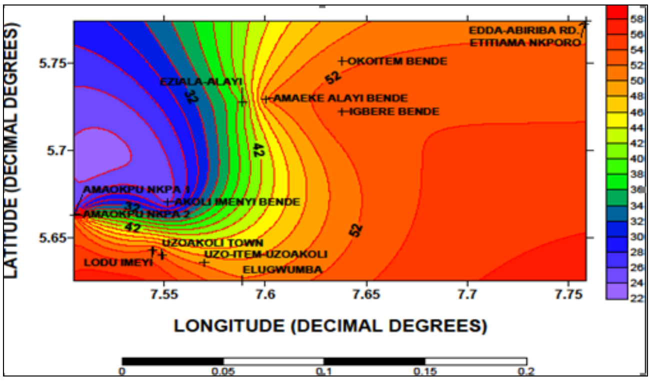

Fig 6: Aquifer depth map of the study area.

Depth to aquifer units is an important parameter in quantitative interpretation of VES data. It is one of the major factors on which vulnerability of an aquifer depends on. In this area, depth to aquifer values seems to be low ranging from 22 m – 52m. Its trend seems also to contradict the thickness map trend, in that areas of high aquifer depths (Fig. 6) correspond to areas of low aquifer thickness in Fig. 5. More so, areas of low aquifer depths correspond to areas of high aquifer thickness. This implies that the area is characterized by shallow aquifers with high groundwater storage capacity (thickness) and deep aquifers with low storability. Shallow aquifers with increasing sand beds and insufficient clay materials in its protective layers or overburden rock material implies the possibility of surface contaminant migration into the aquifer system of the area. Obiora and Ibuot (2022) noted that vulnerability is greatly enhanced by the groundwater flow velocity of the covering (protective) layers and the depth of the water table. The protective layers must have very high thickness and low hydraulic conductivity for effective groundwater protection.

Groundwater potential of the area

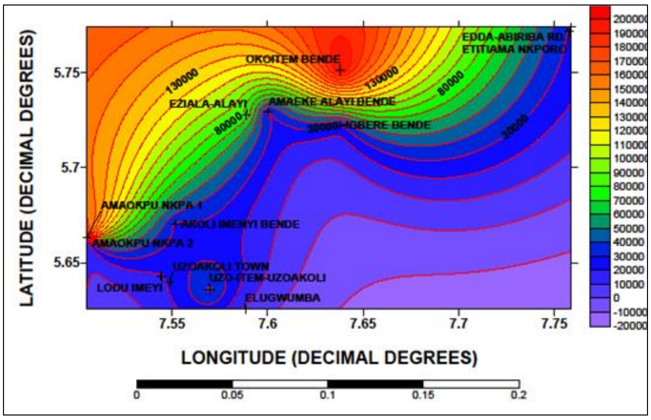

Fig 7: Aquifer transverse resistance map of the study area.

The total transverse resistance (T) is associated with groundwater potential. It has a direct relation with transmissivity. Highest "T" values reflect most likely the highest transmissivity values of the aquifers or aquifer zones. In the Southwest – Northeast direction, comprising localities such as Lodu, Akoli Imenyi, Uzoakoli, Ozuitem, Elugwumba and Igbere low transverse resistance ranging from 10,000 Ωm^2 to 50,000Ωm^2 are delineated. These areas are categorized as areas of low ground water potentials. Areas where transverse resistance ranged from 60,000 Ωm^2 – 110,000 Ωm^2 are categorized as areas having moderate groundwater potentials. This include the regions of Alayi and Edda – Abiriba Road. Transverse resistance >110,000 Ωm^2 is classified as having high groundwater potentials. Such areas include Amaokpu Nkpa and Okoitem. They are expected to sustain regional groundwater resource development within the area.

Groundwater protection / Aquifer vulnearability

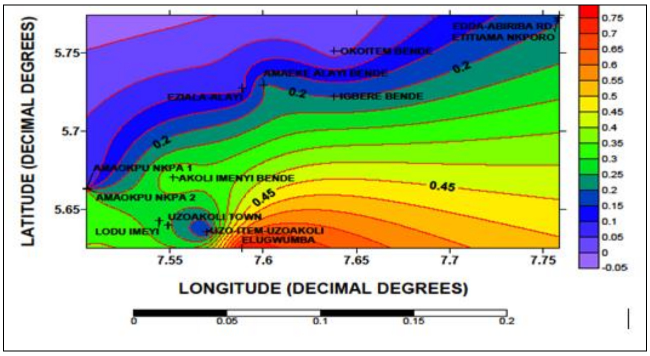

Fig 8: Longitudinal Conductance map of the study area.

This study assessed the protective capacity of the aquifer system in the study area based on the Longitudinal Unit conductance. From Fig. 8, the delineated longitudinal unit conductance (S) values ranged from 0.05 to 0.75 mhos. A low value trend (0.05 – 0.15 mhos) is observed in the Southwest – Northeast region of the study area including Ozuitem. In accordance with Oladapo *et al*., (2004) [16]; Aweto, (2011) [3], this implies poor - weak aquifer protective capacity for the region, due to insufficient conductive layers in its overburden rock materials. It could be noted that this region is characterized by high resistivity values and consequently have thin or no shale layers that serves as protective covers for the aquifers. Therefore it is expected that aquifers in Ozuitem, Nkpa, Eziala Alayi, Ameke Alayi, Igbere, Okoitem and Edda – Abiriba Road region will exhibit vulnerability to contaminate fluid migration.

Across the southwest - Eastern region, a different trend in the conductive characteristics of the overburden rock material is observed. The layers of conductive materials offer moderate – good protective capacity for the aquifer system in Lodu Imeyi, Akoli Imenyi amd Elugwumba. There is relatively high aquifer protection which is apparent in the value of the Longitudinal Conductance (0.2 – 0.75) mhos delineated within this region. These values indicate significant impermeability of the aquifer overburden materials with high aquifer protection due to clay and shale formations. Also, areas of moderate - good aquifer longitudinal conductance indicates good protective geological formation to contamination, whereas areas of weak and poor classification are rated as most susceptible to contamination (Adindu *et al*., 2021) [1].

Conclusion

Vulnerability Assessment/ Protective Capacity of the overburden aquifers at Lodu - Imenyi and its environs in Abia State, Nigeria has been done using the longitudinal unit conductance as a criterion. It was observed that Ozuitem, Nkpa, Eziala Alayi, Ameke Alayi, Igbere and Okoitem in the Southwest – Northeast region of the study area have poor - weak aquifer protective capacity. This implies the absence of clayey or shale layer formation that could protect the groundwater resource of this region from surface contaminant fluid migration. Therefore aquifers in this region are susceptible to contamination.

The Southwest - Eastern region exhibited moderate – good protective capacity for the aquifer system at Lodu, Imeyi amd Elugwumba. This is probably because of increasing shale layer thickness which serves as conductive soil material and good protective layer for the aquifers. It is therefore inferred that the aquifer system in this region is less prone to surface contaminant fluid migration due to the shale material that provide good aquifer protective capacity for the groundwater resource of the area.

References

1. Adindu RU, Ehirim CN, Ebeniro JO. Evaluation of groundwater potential and aquifer protection from geoelectric data in northern parts of Abia State, Nigeria. *Int J Innov Environ Stud Res*,2021:9(4):1-16.
2. Aleke CG, Ibuot JC, Obiora DN. Application of electrical resistivity method in estimating geohydraulic properties of a sandy hydrolithofacies: a case study of Ajali Sandstone in Ninth Mile, Enugu State, Nigeria. *Arab J Geosci*,2018:11:322-331.
3. Aweto KE. Aquifer vulnerability assessment at Oke-Ila area, Southwestern Nigeria. *Int J Phys Sci*,2011:6(33):7574-7583.
4. Bayewu OO, Oloruntola MO, Mosuroa GO, Laniyana TA, Ariyo SO, Fatoba JO. Assessment of groundwater prospect and aquifer protective capacity using resistivity method in Olabisi Onabanjo University campus, Ago-Iwoye, Southwestern Nigeria. *NRIAG J Astron Geophys*,2018:7:347-360.
5. Chowdhury K, Saha DK, Chakraborky P. Geophysical study for saline water intrusion in a coastal alluvial terrain. *J Appl Geophys*,2017:46(2):189-200.
6. Chukwuma EC, Orakwe LC, Anizoba DC, Amaefule DO, Odoh CC, Nzediegwu C. Geo-electric groundwater vulnerability assessment of overburden aquifers at Awka in Anambra State, South-Eastern Nigeria. *Eur J Biotechnol Biosci*,2015:3(1):29-34.
7. Golam SS, Keramat M, Shahid M. Deciphering transmissivity and hydraulic conductivity of the aquifer by vertical electrical sounding (VES) experiments in Northwest Bangladesh. *Appl Water Sci,* 2014, 1-6.
8. Henriet JP. Direct applications of the Dar Zarrouk parameters in groundwater survey. *Geophys Prospect,*1976:24:344-353.
9. Joel ES, Oyanameh OE, Fatoye OV, Ayeni JK, Sunday RM. Investigation of groundwater potential in Atan-Ota, Ogun State, South-western Nigeria. *Anchor Univ J Sci Technol*,2022:2(2):37-47.
10. Lenkey L, Hamori Z, Mihalffy P. Investigating the hydrogeology of a water-supply area using direct-current vertical electrical sounding. *Geophys,*2005:70(4):1-19.
11. Maillet R. The fundamental equations of electrical prospecting geophysics. *Geophysics,*2007:12(4):529-556.
12. Obiora DN, Ajala AE, Ibuot JC. Evaluation of aquifer protective capacity of overburden units and soil corrosivity in Makurdi, Benue State, Nigeria, using electrical resistivity method. *J Earth Syst Sci*,2015:124(1):125-135.
13. Obiora DN, Ibuot JC, George NJ. Evaluation of aquifer potential, geoelectric and hydraulic parameters in Ezza North, southeastern Nigeria, using geoelectric sounding. *Int J Environ Sci Technol*,2016:13:435-444.
14. Obiora DN, Ibuot JC. Geophysical assessment of aquifer vulnerability and management: a case study of University of Nigeria, Nsukka, Enugu State. *Appl Water Sci*,2020:10(29):2-11.
15. Oborie E, Udom GJ. Determination of aquifer transmissivity using geoelectrical sounding and pumping test in parts of Bayelsa State, Nigeria. *Peak J Phys Environ Sci Res*,2014:2(2):32-40.
16. Oladapo MI, Mohammed MZ, Adeoye OO, Adetola BA. Geoelectrical investigation of the Ondo State Housing Corporation Estate, Ijapo Akure, Southwestern Nigeria. *J Mining Geol*,2004:40(1):41-48.
17. Olayiwola O, Fagbemigun T, Ojo B, Amosun J, Oyebamiji A. Geophysical assessment of groundwater vulnerability to diesel contamination at a telecommunication mast in Adebayo Area, Ado-Ekiti, Southwestern Nigeria. *Ann Sci Technol*,2021:6(1):1-8.
18. Olorunfemi MO, Ojo JS, Oladapo MI. Geological, hydrogeological and geophysical investigation of exposed 20″ Escravos-Lagos pipeline. *Tech Rep,* 1998, 1-10.
19. Olumuyiwa OF, Yemisi A, Olajumoke O. Groundwater assessment and its intrinsic vulnerability studies using aquifer vulnerability index and GOD methods. *Int J Energy Environ Sci*,2017:2(5):103-116.
20. Rizka M. Comparative studies of groundwater vulnerability assessment. *IOP Conf Ser Earth Environ Sci*,2018:118:1-8.
21. Ugada U, Opara AI, Emberga TT, Ibim FD, Omenikoro AI, Womuru EN. Delineation of shallow aquifers of Umuahia and environs, Imo River Basin, Nigeria, using geo-sounding data. *J Water Resour Prot*,2013:5:1097-1109.