ZIBELINE INTERNATIONAL PUBLISHING

Geological Behavior (GBR)

DOI: http://doi.org/10.26480/gbr.02.2020.63.67

ISSN: 2521-0890 (Print)
ISSN: 2521-0491 (Online)
CODEN: GBEEB6

RESEARCH ARTICLE

EVALUATION Of GROUNDWATER VULNERABILITY IN FRACTURED AQUIFER USING GEOELECTRIC LAYER SUSCEPTIBILITY INDEX AT OJU, SOUTHERN BENUE TROUGH NIGERIA

M. O. Eyankware[a*], A. O. I. Selemo[b], P.N. Obasi[a], O. M Nweke[a]

[a] Department of Geology, Faculty of Sciences, Ebonyi State University, Abakaliki, Ebonyi State. Nigeria.
[b] Department of Geosciences, Federal University of Technology Owerri. Imo State, Nigeria.
**Corresponding Author Email: geomoses203@gmail.com*

ARTICLE DETAILS

Article History:

Received 20 January 2020
Accepted 13 March 2020
Available online 22 April 2020

ABSTRACT

A combination of geoelectric and hydrogeologic concept was used in the assessment of groundwater vulnerability in fractured aquifers of Oju and environs. The study area is underlain by the sediments of the Asu River Group, Southern Benue Trough Nigeria. A total of twenty-seven (27) Vertical Electrical Sounding (VES) was carried out within the study area. Geoelectric parameters (layer, resistivity and thickness) of the overlying layers across the study area were determined and used to evaluate the vulnerability of the underlying aquifers. Three charts were compared using geo-electrically derived models; LC (Longitudinal Conductance), GLSI (geoelectric layer susceptibility indexing) and GOD (groundwater occurrence, overlying lithology and depth to the aquifer. Results obtained from LC revealed that the study area fell within the moderate category, GLSI showed that aquifer vulnerability were categorize within negligible to low category and GOD fell within low to moderate category. On the average, groundwater within the study area is considered moderate vulnerable to groundwater contamination.

KEYWORDS

Groundwater, Asu River Group, Shale, Aquifer vulnerability and Aquifer Parameters.

1. INTRODUCTION

Aquifer vulnerability as an integral part of the hydrological system is gaining more attention globally, due to increase in anthropogenic activities that pose threat to groundwater contamination/pollution. Various studies emphasized the importance in the protection of water resources. Lately, various researches have been carried out to reduce the water resources pollution and create awareness on the protection from various form of pollution (Edet, 2004; Ojur and Bankole, 2013; Oke, et al., 2018). Water resource contamination can be reduced if properly monitored, but there is great difficulty to repair an already contaminated groundwater sources (Vrba and Zaporozec., 1994).

In hydrogeology, stated that aquifer vulnerability describes the comparative assessment of the potential exposure of groundwater as a result of anthropogenic activities to contamination (Thirumalaivasan et al., 2003). A group researchers further describes it as a qualitative reflection of the natural tendency for an aquifer to be affected by human activities from surfaces such as chemicals, dumpsites and wastewater discharges (Sadkaoui et al., 2013). Todd, further elucidates the extreme difficulty in detecting and controlling subsurface water pollution (Todd, 1980). A group researchers pointed out that various approach has been developed and applied in the systematic process for assessing the vulnerability of groundwater to contamination (Foster et al., 2002). Each method has its advantages and limitations, and none can be considered the most appropriate for all situations. Most of the vulnerability assessment approaches, (GOD) are largely hydrogeologic oriented and subjective, while few electromagnetic parameters such as terrain conductivity, longitudinal conductance embrace geophysical approach of measurement. Various authors have integrated GOD, GLSI and Longitudinal conductance method in evaluation of groundwater vulnerability (Huan, et al., 2012; Khemiri, et al., 2013; Eyankware, et al., 2020; Saha, et al., 2011). Various studies have been conducted on aquifer vulnerability around the globe (Oke, et al., 2016; Oke, et al., 2018; Aweto, 2011). The evaluation of groundwater vulnerability provides a basis for initially protective measurement for groundwater resources. A group of researchers pointed out that the assessment of water resource vulnerability to pollution helps to determine the proneness of groundwater contamination and hence essential for managing and preserving the groundwater quality (Huan et al., 2012). The objective of this study therefore, is to determine the aquifer vulnerability of the fractured aquifers in Oju and environs by integrating the LC, GOD and GLSI, hydrogeologic parameters. This work will be a vital tool to water sanitation and supply agencies as well as environmental management departments.

2. GEOLOGY OF THE STUDY AREA

The study area is located in Oju and environs in Oju, Local Government Area of Benue Sate. It lies between latitude 6°45'N - 6°56'N and longitude 8°23' E - 8°29' E (Figure 1 and Table 1). The area is accessible by Otukpo/Oju road, with some other minor road Nkache, Ameke and others (Figure 1). The area lies within the Federal Survey of Nigeria topographic sheet 289 of (1:100,000) Ejekwe sheet. The stratigraphy of the Southern Benue Trough has been described by Murat, (Murat, 1972; Murat, 1977).

Quick Response Code	Access this article online	
	Website: www.geologicalbehavior.com	**DOI:** 10.26480/gbr.02.2020.63.67

Cite The Article: M. O. Eyankware, A. O. I. Selemo, P.N. Obasi, O. M Nweke (2020). Evaluation of groundwater vulnerability in fractured aquifer using geoelectric layer susceptibility index at Oju, Southern Benue Trough Nigeria. *Geological Behavior, 4(2): 63-67.*

Hoque using the concept of three tectonic sedimentary cycles (Hoque, 1977). Three cycles of marine transgressions and regressions occurred from the Albian to the Coniacian (Nwajide, 2013). Murat stated that the first marine transgression of the Benue Trough occurred in the middle Albian period, with the deposition of the Asu River Group in the Southern Benue Trough (Figure 2) (Murat, 1972). Reyment pointed out that Asu River Group sediments are predominantly shales, siltstone, sandstone and limestone facies as well as extrusive and intrusive igneous rocks (Reyment, 1965). The Asu River Group has an average thickness of about 2000 m and uncomfortably overlies the Precambrian Basement (Benkhelil, 1989). The Santonian tectonic phase resulted in series of fracturing and folding of these rocks, giving rise to chains of anticlines and syncline known as the Abakaliki Anticlinorium (Reyment, 1965). The major fracture system which hosts the lead-zinc forming minerals is in NW- SE and NNW- SE Figure 2 (Farrington, 1952). Groundwater within the study area exist in fractured shale (Nwajide, 2013).

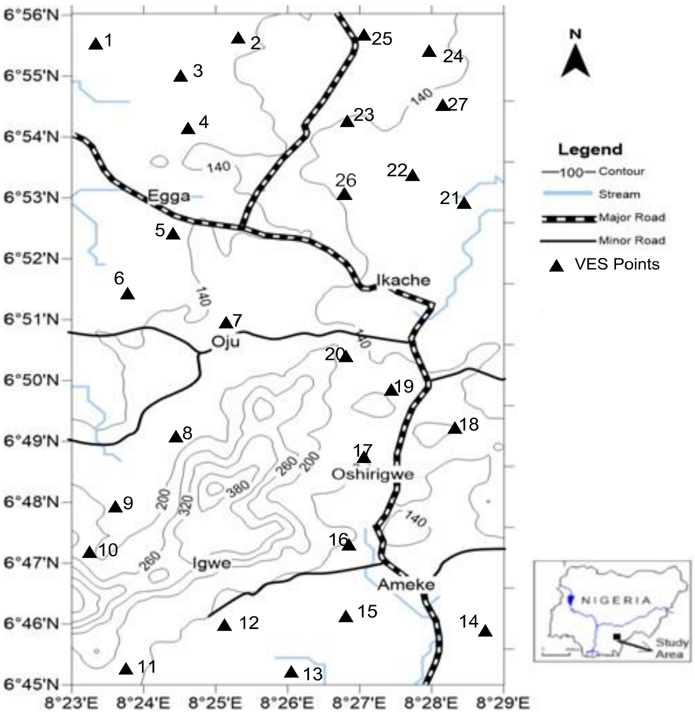


Figure 1: Topography and VES points map of the study area.

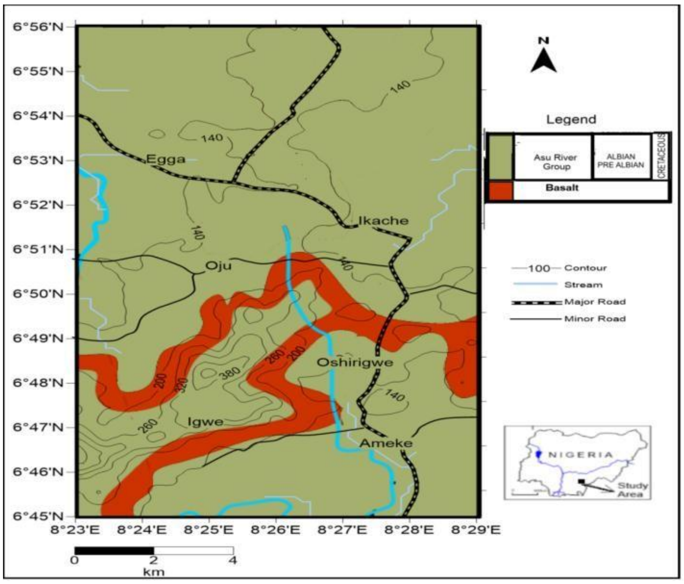


Figure 2: Geology map of the study area.

3. METHOD OF STUDY

Twenty-seven (27) VES were carried out using the Schlumberger configuration with maximum electrode spacing of 200 m using Abem SAS 1000 Terrameter, measured earth resistances were multiplied by a geometric factor resulting from the array used to obtain the apparent resistivity. The converted electrical resistivity values were manually plotted in the field to check the data quality. Standard curve smoothening techniques were applied to the data (Bhattacharya and Patra, 1968). Qualitative interpretation of the smoothened curves was performed using master curves and standard charts after which they were subjected to computer modeling using the IX1D software (Orellana and Mooney, 1966). Three boreholes well data and pumping test data was collected, for better interpretation of resistivity values of vertical electrical sounding within the study area.

Table 1: Name of Locations and their Co-ordinate

VES Points	Co-ordinate	Location
1	$6^0$55/28// - $8^0$23/42//	Okiledu, ObuhuOju
2	$6^0$54/13//- $8^0$25/51//	IdajoEdumoga
3	$6^0$54/52//- $8^0$24/10//	Ono OhumaUkpa
4	$6^0$53/16// - $8^0$24/29//	IhiobilaAdumOwo
5	$6^0$52/18// - $8^0$24/08//	EpwaIodele, Oju
6	$6^0$51/26// - $8^0$23/43//	EpwaIhyeOchiche Opie
7	$6^0$51/04// - $8^0$25/13//	Opposite Julie Resort, Oju
8	$6^0$49/04// - $8^0$24/22//	AgwalaObohu, Oju
9	$6^0$48/52// - $8^0$23/18//	AnchimehaOjegbeIyeche
10	$6^0$47/33// - $8^0$23/10//	Ihigele
11	$6^0$45/09// - $8^0$23/56//	EhirekpeObachita
12	$6^0$45/48//- $8^0$24/50//	AnchimodeEbontaUkpa
13	$6^0$45/06// - $8^0$26/06//	EkwoluObachita
14	$6^0$45/38// - $8^0$28/54//	ImohoIbilla
15	$6^0$46/01// - $8^0$26/49//	Ameke
16	$6^0$47/05// - $8^0$26/17//	AnyogbeOchodu
17	$6^0$48/41//- $8^0$26/14//	Oshirigwe
18	$6^0$49/04// - $8^0$28/09//	Ochoro, Obibagwu
19	$6^0$49/18// - $8^0$27/18//	AnyawokaOshirigwe
20	$6^0$50/04//- $8^0$26/11//	AnyalgwumOshirigwe
21	$6^0$52/03// - $8^0$28/29//	AnyoboOhumaUkpa
22	$6^0$52/48// - $8^0$27/13//	Obibagwu
23	$6^0$53/21// - $8^0$26/38//	Anyobe, Ochodu
24	$6^0$55/19// - $8^0$27/21//	Ujwime, Edumoga
25	$6^0$55/23// - $8^0$27/14//	Agbadichuo, Ainu Ete
26	$6^0$48/07// - $8^0$28/06//	Ochoro, Otakini
27	$6^0$54/03// - $8^0$27/16//	Anchimika, Opoma

3.1 Equation used for Assessing AquiferVulnerability

$$GLSI = \frac{((\rho_{1r+h_{1r}})/2+(\rho_{2r+h_{2r}})/2+(\rho_{3r+h_{3r}})/2...(\rho_{nr+h_{nr}})/2)}{N} \quad \text{(eqn 2)}$$

$$G.O.D\ Index = G \times O \times D \quad (eqn\ 3)$$

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_i}{\rho_i} + \frac{h_2}{\rho_2} + \cdots + \frac{h_n}{\rho_n} \quad \text{(eqn 4)}$$

where **S** = Longitudinal Conductance, h = thickness and ρ= resistivity

3.2 Geoelectric layer susceptibility indexing (GLSI)

The GLSI is a hydrogeologic approach that indexes the geoelectric parameters generated from the vertical resistivity sounding, contrast between lithological sequences in the subsurface. It is an empirical concept introduced to complement other methods of vulnerability assessment (Oni, et l., 2017). Unlike the longitudinal conductance approach where the ratios of the geoelectric parameters (layer resistivity and thickness) are assigned indices, the GLSI assigns index to each geoelectric parameter (layer resistivity and thickness) GLSI is determined (Table 2 and 3)

Table 2: Geoelectric layer Susceptibility index rating for resistivity Parameters (Oni, et al., 2017)

Resistivity range (Ω-m)	Lithology	Susceptibility
<20	Clay/silt	1
20-50	Sandy clay	2
51-100	Clayey sand	3
101-150	Sand	5
151-400	Lateritic Sand	2
>401	Laterite	1

Table 3: GLSI Parameter Rating (Oni, et al., 2017)	
Vulnerability Rating	Index Rating
Low	1.0 – 1.99
Moderate	2.0-2.99
High	3.0-3.99
Extreme	4.0

3.3 Groundwater Occurrence, Overlying Lithology and Depth to the Aquifer (GOD)

A group researchers stated that GOD method was developed by the AVI (Aquifer Vulnerability Index) by the National Hydrology Research Institute (NHRI) in Canada (Van et al., 1992). Better explanation on GOD method could be found in the original publications or elsewhere, since detail explanation is beyond the scope of this paper. The GOD method is a simple and systematic method used as exploratory approach towards determination of groundwater contamination risk, being the acronym for three attenuator parameters: G (Groundwater hydraulic confinement) represents the hydraulic confinement of groundwater in the aquifer and is meant to attribute different vulnerabilities to water table, semi-confined or confined aquifers; O (Overlying strata) describes the type of materials present in the unsaturated zone above the aquifer, in keeping with their ability to neutralize contaminants; and D (Depth to groundwater table) measures the depth to groundwater level, being a proxy to the time that contaminants require to reach the aquifer. In the evaluation of GOD vulnerability, each composing parameter is assigned a value between 0 and 1, where 0 represents minimum vulnerability and 1 represents maximum vulnerability. The G.O.D index used to evaluate the aquifer vulnerability in the area was calculated by multiplication of the influence of the three parameters namely; groundwater occurrence (confinement of the aquifer), overlying lithology of the aquifer, depth to the aquifer (Oni et al., 2017).

The GOD index was then calculated by multiplying the influence of the various parameters together in Eq. (2); Table 4 and 5 show attribution of notes for GOD model parameters and the vulnerability index rating.

Where G = Type of aquifer, O = Overlying lithology, D = Depth to Aquifer.

Table 4: The GOD parameters rating method (Oni, et al., 2017).	
Vulnerability Rating	**Index rating**
Negligible	0 – 0.1
Low	0.3
Moderate	0.3 – 0.5
High	0.5 – 0.7
Extreme	0.7 – 1

Table 5: Attribution of notes for GOD model (Khemiri et al., 2013)					
Aquifer Type	Note	Lithology (Ω-m)	Note	Depth of Aquifer (m)	Note
Non-Aquifer	0	<60	0.4	>2	1
Artesian	0.1	60-100	0.5	2-5	0.9
Confined	0.2	100-300	0.7	5-10	0.8
Semi-confined	0.3-0.5	300-600	0.8	10-20	0.7
Unconfined	0.6-1	>600	0.6	20-50 50-100	0.6 0.5
Aquifer Type	Note	Lithology (Ω-m)	Note	Depth of Aquifer (m)	Note

4. RESULTS AND DISCUSSION

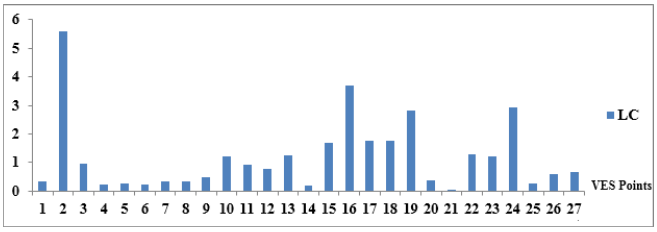
Table 6: Results of Parameters			
VES Points	**Longitudinal Conductance**	**GOD**	**GLSI**
1	0.33 (moderate)	0.25 (moderate)	1.62 (low)
2	5.58 (moderate)	0.05 (negligible)	1.60 (low)
3	0.96 (moderate)	0.048 (negligible)	1.69 (low)
4	0.22 (moderate)	0.00 (negligible)	1.50 (low)
5	0.27 (moderate)	0.084 (negligible)	1.80 (low)
6	0.21 (moderate)	0.108 (low)	1.80 (low)
7	0.32 (moderate)	0.108 (low)	1.16 (low)
8	0.32 (moderate)	0.09 (negligible)	1.87 (low)
9	0.48 (moderate)	0.048 (negligible)	1.70 (low)
10	1.21 (good)	0.07 (negligible)	1.70 (low)
11	0.92 (good)	0.09 (negligible)	1.50 (low)
12	0.76 (moderate)	0.048 (negligible)	1.80 (low)
13	1.24 (moderate)	0.07 (negligible)	1.50 (low)
14	0.20 (moderate)	0.00 (negligible)	2.33 (moderate)
15	1.70 (moderate)	0.09 (negligible)	1.50 (low)
16	3.68 (good)	0.245 (low)	1.37 (low)
17	1.76 (good)	0.16 (low)	1.60 (low)
18	1.76 (good)	0.192 (low)	1.60 (low)
19	2.82 (good)	0.09 (negligible)	1.75 (low)
20	0.36 (moderate)	0.126 (low)	1.50 (low)
21	0.01 (weak)	0.192 (low)	1.38 (low)
22	1.29 (good)	0.00 (negligible)	1.66 (low)
23	1.20 (good)	0.096 (negligible)	1.70 (low)
24	2.91(good)	0.00 (negligible)	1.50 (low)
25	0.27 (moderate)	0.048 (negligible)	1.37 (low)
26	0.59 (moderate)	0.126 (low)	1.62 (low)
27	0.68 (moderate)	0.00 (negligible)	1.49 (low)

Other group of researchers classified protective capacity of water bearing unit into various class (Table 7) (Henriet, 1976; Oladapo et al., 2004). From Figure 5a and Table 6 it shows closure of good to moderate category, this could be attributed to the laterite topsoil, on the other hand, shale is the predominant rock within the study area (aquiclude) known to be porous but not permeable, hence it serves as protection for water bearing formation (Table 6)

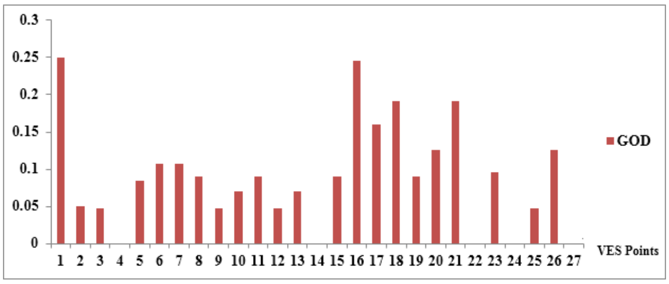
Table 7: Modified longitudinal conductance/water bearing protective capacity rating (Henriet, 1976; Oladapo, et al., 2004)	
Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5-10	Very Good
0.7-4.9	Good
0.2-0.69	Moderate

0.1-0.19	Weak
< 0.1	Poor

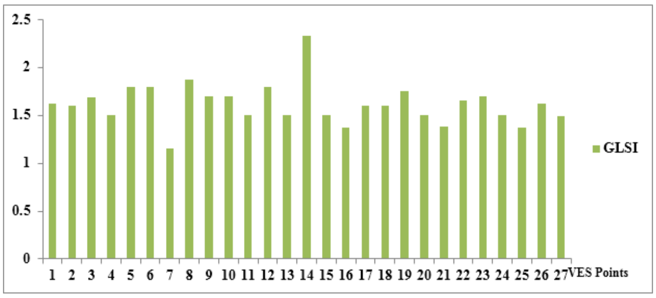
Lithology, thickness and vadose zone are important parameter in preparing overlying index map of GLSI chart (Figure 5b; Table 2 and 3). Figure 5b shows that the entire study area falls within the low with value ranging from 1.16 to 2.33. Except for VES 14 which fell within the moderate category, this implies that the area is moderately vulnerable to pollution. From (Figure 5c; Table 4, 5 and 6). It was observed that from VES 1 to 27 fell within the low category with value ranging from 0.00 to 0.25, this implies that the study is considered not vulnerable to pollution. This could be attributed to the fact that the area is predominantly underlain by shale. Plot of GOD against VES points revealed that VES 1 has the highest value with value of 0.25 it fell within the moderate category, VES 2 to 27 fell within low to negligible category. From this study it was observed that GOD reported low to negligible except VES 1 that fell within the moderate category (Figure 5a). The low to negligible category showed degree of vulnerability than the LC and the GOD methods because it gives higher preference to the inherent properties of the geo-materials in terms of degree of compaction and consolidation of subsurface lithology. Plot of GLSI against VES points showed that VES 14 has the highest GLSI value it fell within the moderate category with value of 2.33, other VES points fell within low category, hence considered vulnerable to contamination (Figure 5b)



(a)



(b)



(c)

Figure 5: a) Plot of LC against VES Points, b) Plot of GOD against VES Points, c) Plot of GLSI against VES Points.

5. SUMMARY AND CONCLUSION

Electrical resistivity method involving vertical electrical sounding (VES) using Schlumberger configuration was successfully applied in aquifer vulnerability assessment of Oju, Southern Benue Nigeria. Geoelectric parameters obtained from the VES assists in the production of the vulnerability index maps. The maps enabled the area to be categorized into different vulnerability zones (high, medium, low). The protective capacity/vulnerability of the area was determined by comparing three different models from hydrogeophysical and hydrogeological points of view (i.e. longitudinal unit conductance, GOD and GLSI models). The study showed that the protective capacity of the vadoze zone ranges from poor to moderate in the study area. The value obtained from longitudinal conductance revealed that area around Alebo, Okopodon II, Oshirigwe, Oju, Ukwukwu hills tends to have high protective capacity, when compared to other parts of the study area. The GLSI and GOD models exaggerates the degree of susceptibility to contamination than the longitudinal conductance.

REFERENCES

Aweto, K.E., 2011. Aquifer Vulnerability assessment at Oke-ila area, Southwestern, Nigeria. International Journal of Physical Sciences, 6(33), 7574-7583.

Benkhelil, J., 1989. The origin and evolution of th Cretaceous Benue Trough (Nigeria). Journal of African Earth Sci., 8, 251-282.

Bhattacharya, P.K., Patra, H.P., 1968. Direct current geoelectric sounding. Principles and Interpretation. Elsevier Publ. Co., New York, pp. 135.

Edet, E.A., 2004. Vulnerability evaluation of a coastal plain sand aquifer with a case example from Calabar, southeastern Nigeria. Environmental Geology, 5, 1062-1070. https://doi.org/10.1007/s00254-004-0969-9.

Eyankware, M.O., Ogwah, C., Selemo, A.O.I., 2020. Geoelectrical Parameters for the Estimation of Groundwater Potential in Fracture Aquifer at Sub-Urban Area of Abakaliki, SE Nigeria. Int J Earth Sci Geophys, 6, 031.

Farrington, J.I., 1952. A Preliminary Description of the Nigerian Lead Zinc Field. Economic Geology, 47, 583-608.

Foster, S.S.D., Hirata, R.C.A., Gomes, D., D'elia, M., Paris, M., 2002. Quality Protection Groundwater: Guide for Water Service Companies, Municipal Authorities and Environment Agencies. World Bank, Washington, DC. http://dx.doi.org/ 10.1596/0-8213-4951-1.

Henriet, J.P., 1976. Direct Application of Dar Zarrouk Parameters in Groundwater Survey. Geophys. Prospect., 24, 344–353.

Hoque, M. 1977. Petrographic Differentiation of Tectonically Controlled Cretaceous Sedimentary Cycle Southeastern Nigeria, Geol., 17, 235-245.

Huan, H., Wang, J., Teng, Y., 2012. Assessment and validation of groundwater vulnerability to nitrate based on a modified DRASTIC model: a case study in Jilin City of northeast China. Science of the Total Environment, 440, 14-23.

Khemiri, S., Khnissi, A., Alaya, B.A., Saidi, S., Zargrouni, F., 2013. Using GIS for Comparison of intrinsic parameter Methods Assessment of Groundwater Vulnerability to Pollution in Scenarios of Semi arid Climate. The case study of foussana groundwater in central of Tunsia. Journal of water Resources and Protection, 835-845.

Murat, R.C., 1972. Stratigraphy and Paleogeography of the Cretaceous and Late Tertiary in Southern Nigeria. In Desauvagie T.F. and A.J. Whiteman, (edt), African Geology. University of Ibadan press, pp. 251-266.

Murat, R.C., 1977. Stratigraphy and Paleogeography of the Cretaceous and lower Tertiary in Southern Nigeria. In Proc. of the Conf. on African Geology held at Ibadan, Nigeria, pp. 251-266.

Nwajide, C.S., 2013. Geology of Nigeria's Sedimentary Basin.CSS. Bookshops Ltd Lagos, pp. 565.

Ojuri, O.O., Bankole. O.T., 2013. Groundwater vulnerability assessment and validation for a fast-growing city in Africa: A case study of Lagos Nigeria. Journal of Environmental Protection, 4, 454-465. htps://doi.org/10.4236/jep.2013.45054.

Oke, S.A., Vermeulen, D., Gomo, M., 2016. Aquifer 13. Sener, E., S. Sener and A. Davraz, 2009. Vulnerability assessment of the Dahomey Basin using the RTt method. Environmental Earth Sciences, 75 (11), 1-9. https://doi.org/10.1007/s12665-016-5792.

Oke, S.A., Vermeulen, D., Gomo, M., 2018. Intrinsic vulnerability assessment of shallow aquifers of the sedimentary basin of southwestern Nigeria. Jàmbá: Journal of Disaster Risk Studies, 10 (1), a333. htps:// doi.org/ 10.4102/ jamba.v10i1.333.

Oladapo, M.I., Mohammed, M.Z., Adeoye, O.O., Adetola, O.O., 2004. Geoelectric Investigation of the Ondo State Housing Corperation Estate; Ijapo, Akure, Southwestern Nigeria. J. Mining Geol., 40, 41-48.

Oni, T.E., Omosuyi, G.O., Akinlalu, A.A., 2017. Groundwater Vulnerability Assessment using Hydrogeologic and Geoelectric Layer Susceptibility Indexing at Igbara Oke, Southwestern Nigeria. NRIAG Journal of Astronomy and Geophysics in press view.

Orellana, E., Mooney, H.M., 1966. Master tables and curves for vertical electrical sounding over layered structures. InterscienceIdadrid, pp. 150.

Reyment, R.A., 1965. Aspects of the Geology of Nigeria: The Stratigraphy of the Cretaceous and Cenozoic Deposits. Ibadan University Press.

Sadkaoui, N., Boukri, S., Bourak, A., Lakhili, F., Mesrar, L., Chaouni, A.A., Lahrach, A., Jabrane, R., Akdim, B., 2013. Groundwater pollution Sais Basin (Morocco), vulnerability mapping by drastic, GOD and PRK methods, involving geographic information system (GIS). Present Environ. Sustain. Dev., 7(1), 296-308.

Saha, D., Alam, F., 2014. Groundwater vulnerability assessment using DRASTIC and Pesticide DRASTIC models in intense agriculture area of the Gangetic plains India. Environ. Monit. Assess., 186 (12), 8741-8763.

Thirumalaivasan, D., Karmegam, M., Venugopal, K., 2003. AHP-DRASTIC: Software for Specific Aquifer Vulnerability Assessment Using DRASTIC Model and GIS. Environmental Model & Software, 18 (7), 645-656.

Todd, D.K., 1980. Groundwater Hydrology. John Wiley and Sons Inc., New York.

Van, S.D., Ewert, L., Wassenaar, L., 1992. AVI: A Method for Groundwater Protection Mapping in the Prairie Provinces of Canada, Canada, PPWB Report No. 114, Saskatoon Saskatchewan: National Hydrogeology.

Vrba, J., Zaporozec, A., 1994. Guidebook on Mapping Groundwater Vulnerability. International Association of Hydrogeologists, International Contributions to Hydrogeology, 16, 131.