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Aquifer vulnerability and protective capacity test of Lokoja, Kogi state, North-Central Nigeria

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ABSTRACT

The aquifer vulnerability test seeks to quantify the sensitivity of an aquifer system to groundwater degradation due to human and natural activities and shallow aquifers depth. As a result of the increasing trends in groundwater contamination, this research was carried out to determine the aquifer vulnerability of the Lokoja metropolis through IECs and GOD techniques. The IECs indices for lithologies that overlie the aquifers were computed using the interpreted layer resistivity and thicknesses. Twenty-five (25) VES stations were evaluated in which VES stations 15, 16, 17 and 18) are within the Sedimentary Basin and the remaining VES are within the Basement Complex with the vadose zone located at the second layer. VES station 5, 9 and 24 has five (5) layers and the aquiferous zone is found in the fourth layer while the remaining VES stations have four (4) layers and the aquiferous zone is found in the third layer. The Aquifers in the study area are shallow and are less than 40m deep. The IEC value observed in the area ranges from 0.02-0.56 and GOD values from 0.59-0.705 which indicates high to extreme vulnerability areas because the aquifer protective capacity is fairly weak. The aquifers exist under unconfined to partially confined conditions. The composition of the overlying materials varies from argillaceous materials to consolidated sandstone materials. Thus, the protection capacity offered by the overlying materials to the aquifer varies from weak to fair depending on the composition of the overlying materials that in many cases, depends on the paleotectonic events of the area.

Keywords: Aquifer Vulnerabilty, Protective Capacity, IEC, GOD, North-Central Nigeria

1. INTRODUCTION

The availability of quality water resources has always been the primary concern of societies in semi-arid and arid regions, even in areas of more abundant rainfall; the problem of obtaining adequate supply of quality water is generally becoming more acute due to ever increasing population and industrialization [1]. As a result of this, surface water cannot be dependable throughout the year, hence, the need to look for other alternatives to supplement surface water. This makes the world depend on the largest available source of quality fresh water which lies underground and this is referred to as Groundwater. It is the water held in the subsurface within the zone of saturation under hydrostatic pressure below water table [1]. Therefore, aquifer vulnerability test seeks to quantify the sensitivity of an aquifer system to groundwater degradation due to human activities. It is an intrinsic property of the groundwater system that depends on the sensitivity of the system to the human influence on the surface and/or natural events [2-3]. The vulnerability of groundwater cannot be measured directly; hence, it is a complex function of the hydrogeological parameters prevalent within the area of interest which can serve as protection to the underlying aquifer system or pathways of contaminant transport [4]. It could also be assessed from the stand points of analogue models and parametric systems [5]. Arising from the increasing trends in groundwater contamination studies, several techniques have been developed for quantitative assessment of aquifer vulnerability to contamination by surface, or near surface pollutants [5]. The electrical resistivity technique can be used to infer the distribution of shallow lithological materials from the variations in resistivity of such materials, since impermeable argillite-dominated lithology unit are characterized by low resistivity values in contrast to arenite-dominated lithologic units that will be more resistive [6]. Most aquifers in the study area are very shallow and highly vulnerable to contamination especially in areas overlain by arenaceous materials. This study is aimed at using electrical resistivity information and geological data to assess aquifers levels of vulnerability to contamination, generate aquifer vulnerability map for the area and suggest measures for efficient management and sustenance of groundwater quality.

2. MATERIALS AND METHODS

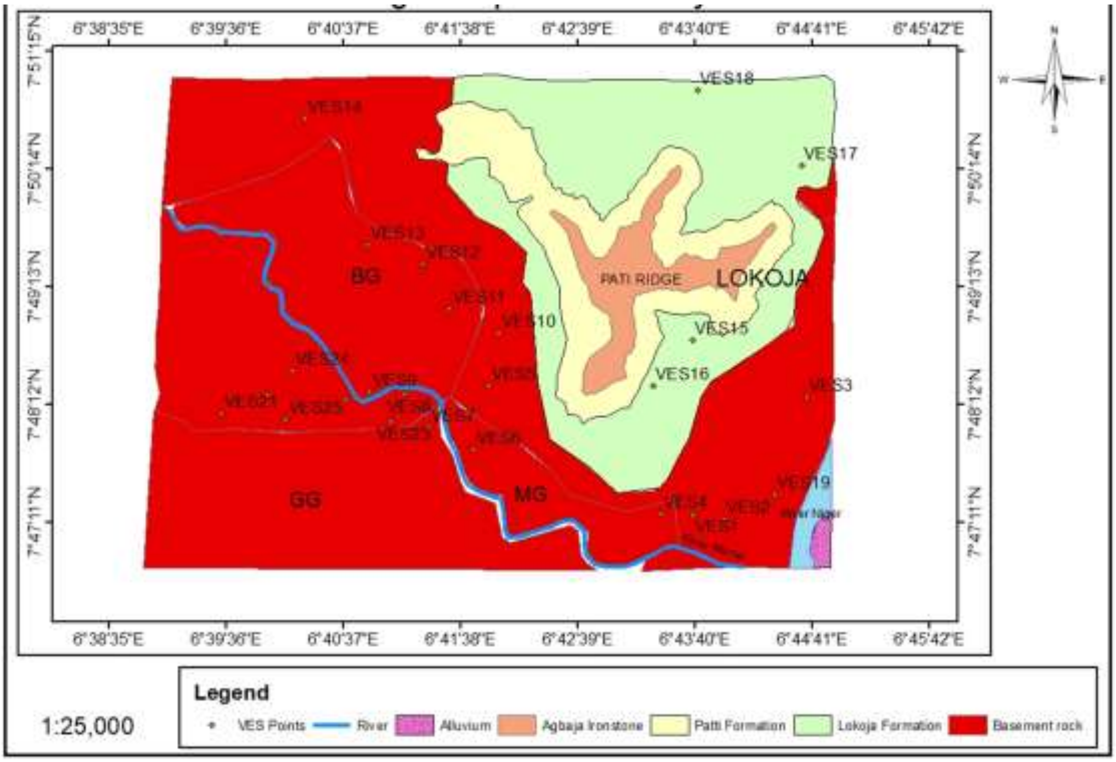
2.1. Location and Geology of the study area

The study area (Fig. 1) is in Lokoja Metropolis, Kogi State, Nigeria. The survey area lies within latitude N 7° 41′ 00″ and N 7° 51′ 00″ and longitude E 6° 39′ 00″ and E 6° 45′ 00″ which covers an approximate area of 40 km^2. The study area is accessible through network of roads and well developed footpaths which were traversed during the work. It is dominantly underlain by the Precambrian Basement Complex. However, part of the area is underlain by Cretaceous sediments which unconformable overlie the Basement Complex. Migmatite covers about half of the study area outcropping at the southwest, west, northwest and central parts of the area [7]. The South and the southeast parts of the area are underlain by undifferentiated older granite, mainly porphyroblastic granite, granite gneiss with porphyroblastic gneiss and fine grained biotite granite. The northern part of the area is made of ridges (Mount Patti) of Cretaceous sediments of the Southern Bida Basin (Lokoja Sub- Basin) which are the Lokoja, Patti and Agbaja formation. The ridges are dominantly composed of feldspathic sandstone and siltstone which are separated by the biotite hornblende gneiss [8]. Conglomerates, coarse falsebedded sandstones, fine to medium-grained sandstone, siltstone and claystone are known to occur in Lokoja Formation [8]. The Agbaja Ironstone is the youngest oolitic ironstone unit in the southern Bida Basin. It is well exposed at Agbaja, where three subfacies i.e. oolitic, concretional and massive ironstones have been recognized [8].

2.2. Geophysical Data acquisition

Twenty-five (25) Vertical Electrical Sounding surveys were carried out in different parts of the study area with DDR3 Sensor Earth Resistivity Meter using the Schlumberger electrodes array (Fig. 2). The obstruction

Table 3. Systematic enumeration of algae identified



caused by the presence of building, roads, and other engineering infrastructure prevented regular spacing of VES stations. Current electrode spacing (AB/2) ranges from 1-200m while potential electrode spacing (MN) ranges from 0.5-10m. The GPS coordinates and elevation of every survey point were measured and recorded against the survey number for easy geo-referencing. Resistance measured and resistivity computed was recorded against the respective current (AB/2) and potential electrode (MN/2) separation, and resistivity curve were plotted on the field for quality assurance purposes.

VES data were subjected to manual and automated processing to invert different geo-electric parameters. The field data were input to IX1D—a computer iterative curve-matching software for final interpretation. The software matches the curve from field data to a computer defined curve and output the estimated number of layers, resistivity, thickness and depth of each geo-electric layers, and the inversion uncertainties (RMS error).

2.3. Aquifer Vulnerability Assessment from VES Data

By the above approach, the observed HR results will be equivalent to the integrated electrical conductivity (IEC) or geophysical-based protective index (GPI) parameter. The geophysical-based Integrated Electrical Conductivities (IECs) were computed from the observed layer parameters (thickness and resistivity) using equation 1:

$$\text{IEC}=\sum_{i=1}^{n}\frac{hi}{\rho i}=\sum_{i=1}^{n}hi\times\sigma i \qquad \text{...eq. 1}$$

Where h_i and ρ_i are thickness and electrical resistivity of the vadose layer above the aquifer respectively.

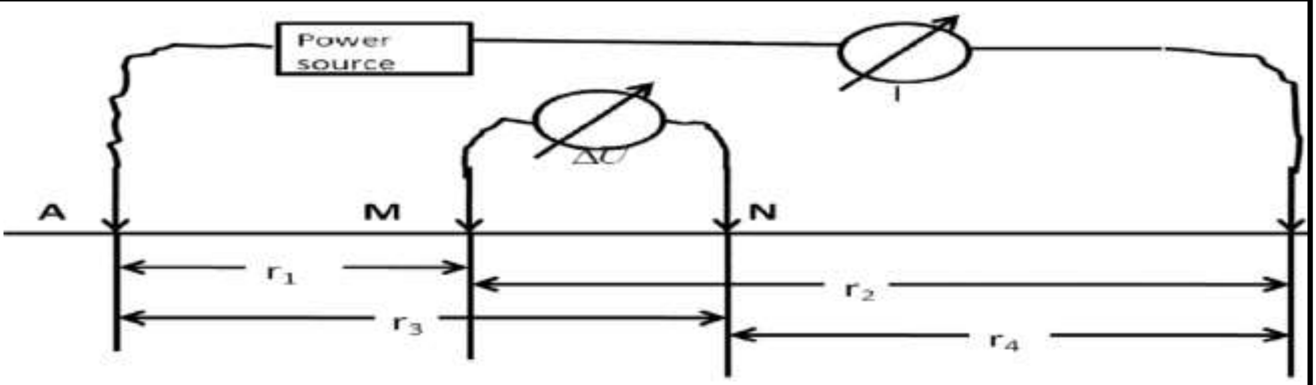
GOD value was also determined. The letter G expresses the level of groundwater hydraulic confinement and it measures the extent of hydraulic confinement of the water circulating within the aquifers. The letter O in the acronym represents the bulk nature of the overlying strata. Finally, the letter D in the acronym represents the depth to the groundwater table. The spatial distribution map of IEC values and GOD indices were then plotted.

2.4. Data analysis

In order to conduct this investigation, 25 Vertical Electrical Sounding surveys using the Schlumberger electrode array and a DDR3 Sensor Earth Resistivity Meter were conducted in various study area locations. Using the WIN-RESIST software, the acquired data was submitted to iterative interpretation with computer assistance. The field curves' quantitative analysis and interpretation were done using this program. In order to use the software, the user must enter the apparent resistivity values, the matching electrode spacing, and the number of subsurface layers. A comparison is made between the measured data and the theoretical curve for the initial input values. The program changes, improves, or modifies the initial model and its accompanying resistivity to get the best fit to the field data. [14]

3. RESULTS AND DISCUSSION

Results obtained from the 1D and 2D modelling of resistivity data were used in assessing the vertical continuity of the various lithological units. Out of the twenty-five (25) VES station, four VES (VES 15, 16, 17 and 18) were within the Sedimentary Basin and the remaining VES are within the Basement Complex (figure 2). VES station 5, 9 and 24 has five (5) layers and the aquiferous zone is found in the fourth layer while the remaining VES stations has four (4) layers and the aquiferous zone is found in the third layer (table 1). The Aquifers in the study area which are major source of water for the people are shallow and are less than 40m deep (≤ 40m) (fig. 4). Therefore the level of protection offered by the vadose zone materials needed to be established quantitatively. IEC values range from 0.02-0.54 S (table 2 and figure 4). IEC values show strong dependence on depth to the aquifer, which in turn depends on the paleotectonic disturbances in the area [9]. The GOD indices were averaged and the value ranges from 0.59-0.705 (Table 2). The values of the GOD indices show that the aquifers in Lokoja metropolis have moderate-high vulnerability to contamination because the aquifer protective capacity is fairly weak. Observed values of the IEC and the GOD indices were compared (Table 3) and both correlate with geology. In some isolated areas where the vadose zone materials are reasonably thick, the vertical flow of contaminants can be impeded by mechanical, physico- chemical, microbiological and other natural processes. The impermeable and thick clay overburden materials which



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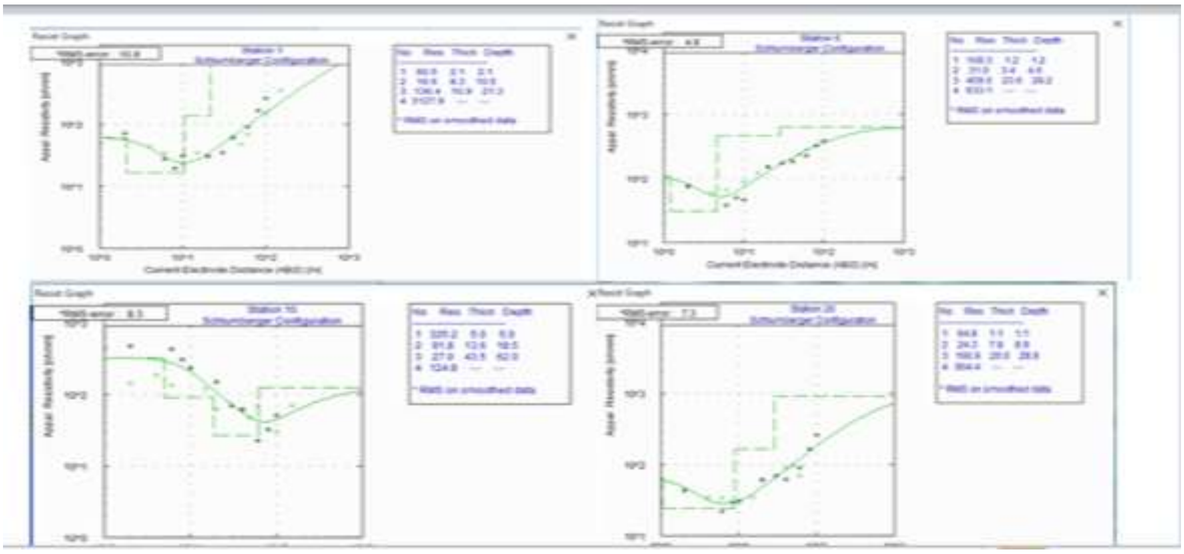


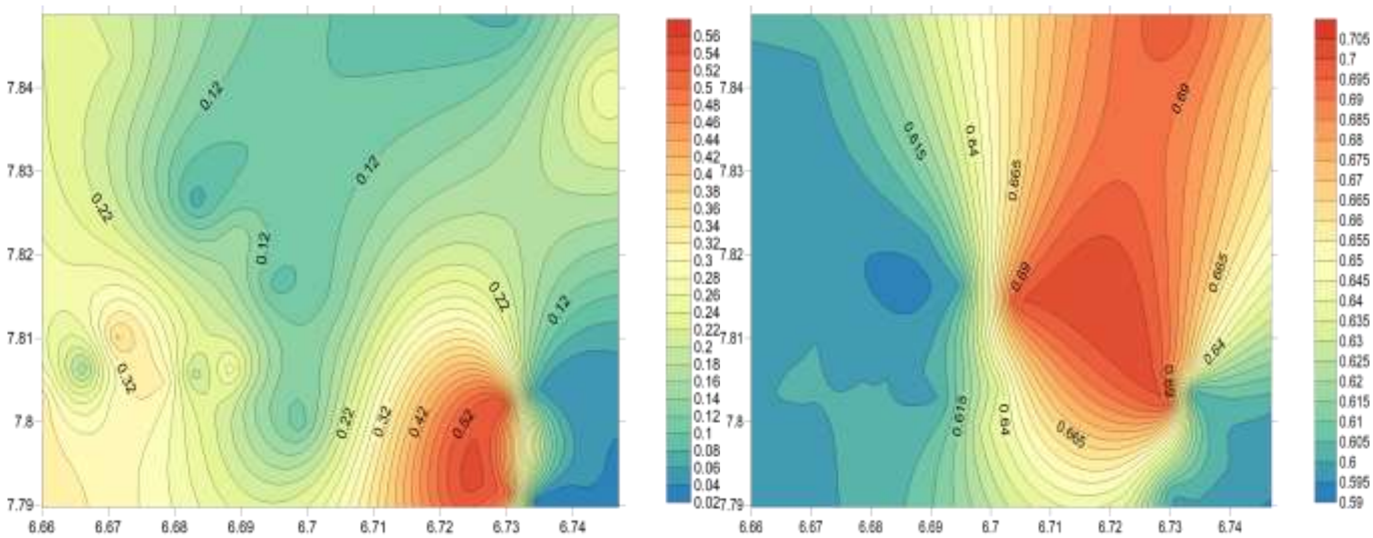
Figure 3: Model VES curves observed at Station 1, 6, 15 and 20

Table 1. Summary of layer parameters generated from the inversion of VES data

S\no.	Location coordinates			Layer resistivity (Ωm)					Estimated thickness to bottom(m)			
	Longitude	Latitude	VES Points	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4
1	6.730056	7.791389	VES1	60.6	16.9	134.6	3133.9	-	2.1	8.5	10.8	-
2	6.734528	7.790389	VES2	70.8	137	1773.4	377.6	-	5.1	3	33.3	-
3	6.746889	7.801139	VES3	10.4	176.2	63.8	4827.3	-	1.5	8.1	16.3	-
4	6.723167	7.78975	VES4	134.1	7.2	2145.5	15468.1	-	0.8	3.8	12	-
5	6.700917	7.804278	VES5	1298	34	340	495.5	248.8	0.4	4.4	27.8	31
6	6.698917	7.7995	VES6	109.3	31	459	633.1	-	1.2	3.4	23.6	-
7	6.691611	7.802639	VES7	79.2	84.1	445.2	2939.2	-	3.2	13.7	10.8	-
8	6.6885	7.806222	VES8	80.8	18.5	123.4	110.9	-	1.1	5.1	48	-
9	6.683	7.805694	VES9	111.5	41.9	539.6	818.8	2035.2	1.8	7.8	10.1	12
10	6.704306	7.8145	VES10	823.1	64.1	193.3	792	-	2.5	8.2	30.4	-
11	6.695056	7.816306	VES11	18.4	52.7	267.8	2434.2	-	6.6	4.9	13.4	-
12	6.689583	7.822306	VES12	262.1	57.6	405.6	1545.5	-	4.6	8.9	11.5	-
13	6.683139	7.826306	VES13	355.8	139.1	91.2	1835.1	-	4.8	9.6	15	-
14	6.671167	7.843389	VES14	94.5	16.9	549	650.5	-	1.7	3.7	24.8	-
15	6.733278	7.806722	VES15	325.2	91.8	27	124.8	-	5	13.6	43.5	-
16	6.729611	7.802361	VES16	243.7	7.4	20.3	953.7	-	1.9	4	7.4	-
17	6.744833	7.839444	VES17	19.5	13.7	2.7	251.5	-	5.3	3.6	12.8	-
18	6.730889	7.848778	VES18	161.6	77.8	3.5	238	-	1.4	5.4	12.8	-
19	6.742028	7.793639	VES19	45	108.9	121.4	632.4	-	6.5	5.5	25.5	-
20	6.678667	7.804972	VES20	64.8	24.3	166.9	904.4	-	1.1	7.8	20	-
21	6.66	7.802944	VES21	106	41.5	509.1	2108.6	-	1.9	14	18.3	-
22	6.666222	7.806361	VES22	717.6	42.7	428.6	364.5	-	1.7	6.6	18.8	-
23	6.734	7.803444	VES23	47.9	58.9	412.9	118.6	-	6.5	4	15.7	-
24	6.671167	7.810167	VES24	876.9	18.2	91.4	114	482.2	0.4	6.7	9.7	12
25	6.670583	7.802361	VES25	152	21.2	245.5	104.2	-	1.4	6.5	9.7	-

Table 2. Vulnerability and Protective Capacity of the Vadose zone

Layer	IEC (s)	G	O	D	GOD
2	0.502959	0.4	0.6	0.8	0.6
2	0.021898	0.4	0.6	0.8	0.6
2	0.04597	0.5	0.5	0.8	0.6
2	0.527778	0.4	0.6	0.9	0.633333333
2	0.129412	0.4	0.6	0.9	0.633333333
2	0.109677	0.4	0.6	0.9	0.633333333
2	0.162901	0.4	0.6	0.8	0.6
2	0.275676	0.4	0.6	0.8	0.6
2	0.186158	0.4	0.6	0.8	0.6
2	0.127925	0.6	0.7	0.8	0.7
2	0.092979	0.4	0.6	0.8	0.6
2	0.154514	0.4	0.6	0.8	0.6
2	0.069015	0.4	0.6	0.8	0.6
2	0.218935	0.4	0.6	0.8	0.6
2	0.148148	0.6	0.6	0.8	0.666666667
2	0.540541	0.6	0.7	0.8	0.7
2	0.262774	0.6	0.6	0.8	0.666666667
2	0.069409	0.6	0.7	0.8	0.7
2	0.050505	0.5	0.5	0.8	0.6
2	0.320988	0.4	0.6	0.8	0.6
2	0.337349	0.4	0.6	0.8	0.6
2	0.154567	0.4	0.6	0.8	0.6
2	0.067912	0.4	0.6	0.8	0.6
3	0.368132	0.4	0.6	0.8	0.6
2	0.306604	0.4	0.6	0.8	0.6



A

B

Figure 4. A) Spatial distribution map of IEC values: B) Spatial distribution map of GOD indices

Table 3. General Vulnerability and Protective Capacity Classes [3]

IEC (S)	Protective capacity	GOD	Vulnerability rating
>2.0	Strong	< 0.3	Low
1.1-2.0	Moderate	0.3-0.5	Moderate
0.1-1.0	Fair	0.5-0.7	High
<0.1	Weak	>0.7	Extreme

are characterized by low hydraulic conductance serve as natural filters to any percolating fluid [10-12]. These materials reduce the rate of movement of the fluid through them hence, increasing their residence time and offering better protection to the underlying aquifers. From the result of twenty five VES, the level of aquifer confinement is site dependent due to the abundance of subsurface structural discontinuities such as fractures appearing to exert the influence on them.

4. CONCLUSION

This study was embarked upon to test the vulnerability of aquifer and to detect how prone they are to contamination using the IECs and GOD techniques. The IECs indices for lithologies that overlie the aquifers were computed using the interpreted layer resistivity and thicknesses. The aquifers exist under unconfined to partially confined conditions. The composition of the overlying materials varies from argillaceous materials to consolidated sandstones materials. Thus, the protection capacity offered by the overlying materials to the aquifer varies from weak to fair depending on the composition of the overlying materials that in many cases, depends on the paleotectonic events of the area. Vulnerability mapping based on IEC and GOD techniques are cost effective and efficient techniques for exploratory assessment of aquifer protection and management as these two are suited for regional investigations. Groundwater monitoring, assessment and management must be instituted within the area and its environs with an effort to synergize with the relevant developers and government to reduce the careless dumping of anthropogenic wastes, which finally degrade groundwater resources at large. Regularly monitoring of the level of ingress of contamination reflected by the severity of contaminated water in boreholes must be upheld while efforts should be intensified to measure, treat/disinfect the known contaminated water before consumption.

5. ACKNOWLEDGEMENT

NA

6. SOURCE/S OF FUNDING

NA

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