Evaluation of aquifer protective capacity of overburden unit and soil corrosivity in Makurdi, Benue state, Nigeria, using electrical resistivity method

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This paper presents result of 30 vertical electrical soundings carried out in Makurdi, Benue state capital, north-central Nigeria to evaluate aquifer protective capacity and soil corrosivity of overburden units in the study area. This was done using the Schlumberger electrode array to obtain the data and was modelled using computer iteration (Winresist software). The field data gives a resolution with 3–4 geoelectric layers and the observed frequencies in curve types include: 30% of KQ, 16.67% of QH, 6.67% of AA and K, 3.33% of HA, Q and A, 10% of H, KH and HK. Using the longitudinal unit conductance (S), the protective capacities of the study area were classified as 36.67% weak, 10% poor, 40% moderate, and 13.33% as good. The corrosivity ratings of the study area show that 10% is strongly corrosive, 23% moderately corrosive, 37% slightly corrosive, and 30% noncorrosive. The results reasonably provide information on areas where industries can be sited and iron pipes can be laid in order to safeguard the hydrological setting for resident's safety in the study area. Regions with moderate/good protective capacity are good sites for locating boreholes.

1. Introduction

The role of water cannot be over-emphasized as it plays a very important role in the existence of life (plant and animal). Groundwater is that water found within the saturated voids beneath the ground. The source of groundwater is chiefly from precipitating atmospheric moisture, which has percolated down into the soil and subsoil layers. 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 (Strahler 1973). 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 porosity of a geologic material is the amount of water (fluid) the material can hold. It is the volume ratio of the pore spaces to the total volume of soil, rock or sediment (Chernicoff and Whitney 2009).

However, the present social demands are not only to detect new groundwater resources but to protect them. The potability of groundwater can be contaminated by leachate from dumpsites, salt intrusion, oil spillage, mining activities, sewage (from latrines, underlined petroleum pipes and septic tanks) (Makeig 1982). Dumpsites and latrines are sited without considering the hydrogeological settings of the area, thereby rendering the future of groundwater at risk (Ugbaja and Edet 2004). The widespread use of chemical products, coupled with the disposal of large volumes of waste materials, poses the potential for widely distributed

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groundwater contamination. Hazardous chemicals, such as pesticides, herbicides, and solvents, are used ubiquitously in everyday life. These and a host of other chemicals are in widespread use in urban, industrial, and agricultural settings. Whether intentionally disposed of, accidentally spilled, or applied to the ground for agricultural reasons, some of these chemicals can eventually reach the groundwater and contaminate it. Because of the volumes of toxic wastes and because of their stability in groundwater, such contamination can pose a serious threat to public health. Almost every major

industrial and agricultural site has in the past disposed of its wastes on site, often in an inconspicuous location on the property. Every municipality has had to dispose of its waste at selected locations within its proximity. Past waste-disposal practices and dealing with spills have not always been considered as potential for groundwater contamination.

The rate of groundwater contamination depends on permeability, porosity, and overburden thickness of geologic formations. When the underlying geologic material is unconsolidated and uncompacted, such as coarse sand, the polluting influents are capable of escaping into the subsurface to contaminate groundwater, rendering the soil corrosive and forming a polluting plume that extends hundreds of meters (Keswick *et al.* 1982). Using electrical resistivity method and borehole lithologic logs, Dan-Hassan (2001) found out that the aquifers of the basement complex rocks of north-central Nigeria are predominantly weathered overburden aquifers. There is always a chance that pipelines could leak or rupture and a pipeline failure can constitute serious hazards to the environment, assets, and even humans due to explosion and leakage (Yahaya *et al.* 2009). Using geophysical studies, environment can be evaluated without interfering with the hydrogeologic system (Mogaji *et al.* 2007). Abiola *et al.* (2009) studied the groundwater potential and aquifer protective capacity of overburden units in Ado Ekiti and delineated

Figure 1. Geological map of Nigeria (Kogbe 1989).

Figure 2. Geological map of Benue State (British Geological Survey 2001).

three groundwater potential zones (high, medium, and low) and aquifer protective capacity (good, moderate, weak, and poor) in the study area. Some recent researchers had employed electrical resistivity method in investigating aquifer protective capacity and soil corrosivity in Nigeria (Adeniji *et al.* 2014; George *et al.* 2014). The use of geophysics for both groundwater resource mapping and for water quality evaluations has increased dramatically due to the rapid advances in microprocessors and associated numerical modelling solutions. The vertical electrical sounding (VES) has proved very popular with groundwater studies due to the simplicity of the technique. Traditional methods for characterizing protective layers include test hole drilling and analysis of log, with the objective being

to characterize thickness and/or lateral extent of the protective layer. Disadvantages of such investigations are that they can be labour-intensive and expensive (Kalinski *et al.* 1993).

Today, we are witnessing an increasing number of boreholes drilled by government, nongovernmental organizations, and individuals. This shows clearly that groundwater is effectively complementing other sources of water supply in the area. This is due to the rate of contamination of surface water through the effect of inordinate quest for development. Surface water is found to be grossly degraded in quality because of its physical, biological, or chemical contaminants (Edet and Worden 2009). Design of appropriate groundwater management strategies in any geologic environment

Figure 3. Sketch map of Makurdi showing the road network and drainage pattern (Amadi *et al.* 2010).

Figure 4. Google Earth map showing VES stations.

No	Res	Thick	Depth
1	490.2	1.2	1.2
2	47.3	16.1	17.3
3	95.1	40.1	57.4
4	91.7	--	--

Figure 5. VES 5 geoelectric curve.

No	Res	Thick	Depth
1	144.5	1.2	1.2
2	31.1	18.4	19.7
3	121.0	--	--

Figure 7. VES 15 geoelectric curve.

No	Res	Thick	Depth
1	207.2	1.0	1.0
2	75.4	15.3	16.3
3	520.4	--	--

Figure 6. VES 10 geoelectric curve.

No	Res	Thick	Depth
1	1516.0	5.3	5.3
2	168.4	9.6	14.9
3	60.5	26.3	41.2
4	117.3	--	--

Figure 8. VES 19 geoelectric curve.

Table 1. Summary of the interpretation of longitudinal conductance, aquifer protective capacity and soil corrosivity.

VES station	Location name	Longitudinal										VES point		Curve type	
		Layer resistivity(Ω -m)					Layer thickness (m)					Soil corrosivity	Longitude (°)		Latitude (°)
		ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3	S (mhos)	Protective capacity					
1	Judges' Qtrs	905	111	82	275	2	6	62	0.11	Weak	Noncorrosive	N07.71225	E008.57804	QH	
2	Judges' Qtrs	327	184	109	150	3	12	45	0.33	Moderate	Noncorrosive	N07.71121	E008.58002	QH	
3	Owner's occupier	81	535	135	56	1	7	22	0.06	Poor	Slightly corrosive	N07.69639	E008.54855	KQ	
4	Owner's occupier	50	406	296	109	1	5	2	0.19	Weak	Moderately corrosive	N07.69639	E008.56032	KQ	
5	Nyíman Layout	88	353	72	63	1	2	5	0.22	Moderate	Slightly corrosive	N07.69633	E008.54484	KQ	
6	Nyíman Layout	45	311	333	800	1	4	65	0.11	Weak	Moderately corrosive	N07.70640	E008.51637	AA	
7	Nyíman Layout	35	428	273	251	1	2	3	0.11	Weak	Moderately corrosive	N07.70531	E008.51527	KQ	
8	High level	10	421	219	61	1	2	17	0.18	Weak	Moderately corrosive	N07.71994	E008.51964	KQ	
9	High level	86	110	131	300	1	4	35	0.16	Weak	Slightly corrosive	N07.71837	E008.52250	AA	
10	Mission ward	200	81	117	285	3	7	30	0.10	Weak	Noncorrosive	N07.75541	E008.54739	HA	
11	Industrial estate	133	10	46		2	6		0.62	Moderate	Slightly corrosive	N07.70197	E008.49008	H	
12	Lafia road	60	468	84	133	1	7	52	0.13	Weak	Moderately corrosive	N07.79809	E008.56592	KH	
13	UniAgric road	73	19	31	17	2	8	30	1.51	Good	Slightly corrosive	N07.76310	E008.57532	HK	
14	72 Battalion barrack	69	245	218	88	1	4	15	0.15	Weak	Slightly corrosive	N07.78555	E008.54099	KQ	
15	CAPS Staff Qtrs	13	39	58		1	7	17	0.55	Moderate	Strongly corrosive	N07.77264	E008.59575	A	
16	CAPS Boys' hostel	54	86	24	40	1	2	5	0.83	Moderate	Moderately corrosive	N07.77159	E008.59867	QH	
17	Shamija village	500	1276	304	149	1	4	10	0.07	Poor	Noncorrosive	N07.76231	E008.61812	KQ	
18	North bank (INEC)	200	583	56		1	5		0.44	Moderate	Noncorrosive	N07.98390	E008.56564	K	
19	Uchonu village	50	1190	271	81	1	7	33	0.11	Weak	Moderately corrosive	N07.77061	E008.55995	KQ	
20	Mission ward	182	157	185	66	2	8	30	0.20	Moderate	Noncorrosive	N07.76229	E008.55364	HK	
21	Wadata	5	90	39	87	1	5	54	1.13	Good	Strongly corrosive	N07.74444	E008.51550	QH	
22	Naval School	100	60	122		2	18		0.22	Moderate	Slightly corrosive	N07.71837	E008.54222	H	
23	Ankpa Qtrs	219	48	46		5	45		0.96	Good	Noncorrosive	N07.70963	E008.50399	Q	
24	New G.R.A	65	223	184	250	1	5	44	0.22	Moderate	Slightly corrosive	N07.68977	E008.53838	KH	
25	New G.R.A	69	702	543		1	5		0.07	Poor	Slightly corrosive	N07.68717	E008.53881	K	
26	Naka road	69	33	26	43	1	5	20	0.28	Moderate	Slightly corrosive	N07.68336	E008.48886	KH	
27	Kanshio	1659	1272	150	500	5	5	50	3.17	Good	Noncorrosive	N07.68336	E008.53665	QH	
28	Wurukum	228	124	150		2	23		0.19	Weak	Noncorrosive	N07.72420	E008.53853	H	
29	Lower staff Qtrs	154	141	160	121	2	8	30	0.26	Moderate	Slightly corrosive	N07.66061	E008.55924	HK	
30	Kanshio	5	1063	686	141	1	8	40	0.21	Moderate	Strongly corrosive	N07.68476	E008.53820	KQ	

depends to a reasonable extent on the nature of subsurface materials, whose properties (physical and chemical) and spatial distribution constitutes the goal of all hydrogeological and hydrogeophysical investigations (George *et al.* 2014). Omoyoloye *et al.* (2008) defined overburden protective capacity as the ratio of the overburden thickness to its resistivity. The higher the overburden longitudinal conductance, the higher its protective capacity.

Schlumberger resistivity soundings have been used in this study to evaluate the aquifer protective capacity, longitudinal conductance, and corrosivity of overburden units in the study area. The result of this study will help identify areas where groundwater is or could be contaminated by leachates.

2. Physiographic, geological and hydrogeological settings of the study area

The study area is Makurdi, the Benue State capital, north-central, Nigeria (figure 1). Makurdi is known for its agricultural activities. It lies between latitudes 7°40' and 7°50'N of the Equator and between longitude 8°20' and 8°40'E of the Greenwich Meridian, covering a total area of about 670 km² (figure 2). Makurdi lies within the Guinea savannah vegetation zone with a few patches of forests. The annual rainfall ranges between 1500 and 2000 mm with its peak rainfall in the months of July and September. Temperatures in March and April are about 38°C and 48°C, respectively, while in December/January, the temperature is 27°C (Benue State Water Supply and Sanitation Agency 2008). The area is accessible through Nasarawa, Taraba, Obudu, Enugu, and Ankpa road. Also, a good road network exists within Makurdi metropolis and a railway line runs through the town from Enugu to Jos and Kaduna. The area can also be accessible through the Benue River which flows through from the Cameroon Mountain to the Niger-Benue confluence at Lokoja. Makurdi, the Benue State capital falls in the Makurdi Formation (figure 3). The formation overlies the Albian Shale. It consists of thick current bedded coarse grained deposits. The Makurdi sandstone has a thickness of about 900 m (Offodile 1976). The southern part of the Benue valley is generally gently undulating and punctuated by a few low hills. But towards the northeast, the relief is exaggerated by hills like the Lammuder and Ligri hills, which rise up to 600 m above sea level. The drainage consists of rivers which meander into the River Benue from the north and south directions.

Geologically, the Benue valley consists of a linear stretch of sedimentary basin running from about the present confluence of the Niger and the Benue rivers to the northeast, and is bounded roughly

by the Basement Complex areas in the north and south of the river Benue. The elongated trough-like basin is continuous with the coastal basin, and in fact, has been correctly described as the longest arm of the Nigerian coastal basin (Offodile 2002).

3. Data acquisition and interpretation

The electrical resistivity survey involved VES, which is based on measuring the potentials between one electrode pair while transmitting direct current (dc) between another electrode pair. The depth of penetration is proportional to the separation between the electrodes in homogeneous ground, and varying the electrodes separation provides information about the stratification of the ground (Dahlin 2001). This method can be used in groundwater to determine depth, thickness, and boundary of an aquifer (Zohdy 1969). In this study, the Schlumberger array was performed using the vertical electrical sounding field procedure to assess the electrical resistivity of the subsurface and the thickness of the aquifer. The apparent resistivity (ρ_a) was calculated using (Ibuot *et al.* 2013):

$$\rho_a = \pi \cdot \left[\frac{(AB/2)^2 - (MN/2)^2}{MN} \right] \cdot R_a \quad (1)$$

Figure 9. Bar chart showing frequency of curve type distribution in the study area.

Table 2. Modified longitudinal conductance/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

where AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and R_a is the apparent electrical resistance measured from the equipment. The equation can be simplified to (Ibuot *et al.* 2013)

$$\rho_a = K \cdot R_a \quad (2)$$

where the geometric factor

$$K = \pi \left[\frac{(AB/2)^2 - (MN/2)^2}{MN} \right]$$

Thirty vertical electrical soundings (VES) were carried out in the study area (figure 4). PZ-02 resistivity meter was used with maximum current electrodes spacing ($AB/2$) of 100.0 m, ($MN/2$) of 15.0 m. Using the conventional partial curve matching technique with two-layer master curves in conjunction with auxiliary point diagrams

(Orellana and Mooney 1966), the initial estimates of VES data was achieved. From this, estimates of layer resistivities and thicknesses were obtained, which served as starting points for computer-assisted interpretation. The conventional curves and auxiliary point diagrams (theoretical curves) used in the interpretation helped in obtaining a good fit between the observed field curves and the theoretical curves during total and partial matching. The computer software program WinResist was used and the datasets obtained from the manual interpretation stage were keyed as inputs into the computer modelling software (WinResist) to generate data for the estimated model. Figures 5–8 show examples of modelled VES curves obtained within the study area. From the interpreted data, it was possible to compute for every VES station the longitudinal conductance using equation (3) (Zohdy *et al.* 1974):

$$S = \sum_{i=1}^n \frac{h_i}{\rho_i} \quad (3)$$

Figure 10. (a) Map of distribution of longitudinal conductance. (b) 3D distribution map of the longitudinal conductance of the study area.

where h_i is the saturated thickness of each layer, ρ_i is the true resistivity of each layer. Soil corrosivity was evaluated using the resistivity value of the first layer on each VES point in the study area by comparing with the corrosivity rating (table 3).

4. Results and discussion

The information obtained from geophysical investigation (table 1) reveals that the study area geoelectric parameter shows three to four geoelectric layers with different curve types across the research area, and was characterized by varying resistivity values. The thickness of the topsoil ranges between 1.0 and 5.0 m and the layer resistivity varies from 5.0 to 1659 Ωm . The partially/weathered layer thickness ranges from 1.0 to 63.7m with resistivity varying from 10.0 to 1276 Ωm , indicating

that the material composition is largely clay, laterite, sandy clay, and clayey sand. The partially/fractured sandstone resistivity values range between 109.0 and 800.0 Ωm which indicate high degree of fracture and/or water saturation. It is of infinite thickness where it is the last observable layer. Thirty VES points, which cut across the study area were selected and used to evaluate the protective capacity of the aquifer in the study area. The curves were grouped into 10 types as 16.67% of QH, 30% of KQ, 6.67% of AA and K, 3.33% of HA, Q and A, 10% of H, KH and HK. The dominant curve type is KQ with 30% each. The frequency distribution of the curve types is shown in figure 9.

Using the inferred layer resistivities and thicknesses, longitudinal conductance (a Dar Zarrouk parameter) was used as a criterion for the aquifer protective capacity rating according to the rating

Figure 11. (a) 2D distribution of aquifer thickness in the study area and (b) 3D map showing the distribution of aquifer thickness in the study area.

in table 2. The four distinct zones defined are weak, poor, moderate, and good aquifer protective capacity, based on the numerical values assigned to each point. VES 1, 4, 6, 7, 8, 9, 10, 12, 14, 19 and 28 have weak aquifer protective capacity covering 36.67% of the mapped area. 10% poor protective capacity was obtained in VES 3, 17, and 25; 40% moderate protective capacity in VES 2, 5, 11, 15, 16, 18, 20, 22, 24 and 26; 13.33% good aquifer protective capacity in VES 13, 21, 23, and 27.

The earth's medium acts as a natural filter to percolating fluid. The ability of the earth to retard or accelerate and filter percolating fluid is a measure of its protective capacity (Barker *et al.* 2001) Figure 10(a and b) shows the distribution of longitudinal conductance in the study area.

The poor and weak zones are zones which are vulnerable to surface contaminant materials, which have less protective capacity. The study also revealed that areas with aquifer protective capacity ranging from moderate to good coincide with zones of appreciable overburden thickness with clayey columns, which are thick enough to protect the aquifer in the area from surface polluting fluid. A 2D and 3D thickness map of the aquiferous layer (figure 11a and b) shows that the aquifer thickness is highly variable in the study

area. From the vertical and lateral extents of the map, it is seen that the thickness in the eastern part of the study area is thinnest in a continuum. The maps and table serve as guides to the locations of aquifers, aquifers protective capacity, and their distributions throughout the entire study area.

The result from pumping tests shows that the study area has static water level (SWL) of 4.68 m, maximum draw down of 32.32 m, average draw down of 1.47 m, dynamic water level (DWL) of 37.0 m, average pumping rate of 0.82 I/s and transmissivity (T) as 1.30 m/day.

The soil corrosivity in the study area was also determined from table 1, using the first layer resistivity and comparing with that of table 3. VES 1, 2, 10, 17, 18, 20, 23, 27 and 28 suggest that the subsurface (soil) is practically noncorrosive. VES 3, 5, 9, 11, 13, 14, 22, 24, 25, 26, and 29 indicate slightly corrosive material. VES 4, 6, 7, 8, 12, 16, and 19 suggest moderately corrosive material. VES 15, 21, and 30 indicate strongly corrosive material. Figure 12 shows the corrosivity rating of the study area.

5. Conclusion

The electrical resistivity (Vertical Electrical Sounding) method is an efficient tool for most groundwater studies. It was used in this study to investigate the protective capacity and corrosivity of overburden units in the study area. The frequency of the curve types indicates regular presence of K and H curves. This indicates the translation of layers with limited hydrologic significance into prolific units in which the selection of the best near surface and economic groundwater aquifer repository is, based on aquifer thickness and its degree of exposure to surface contaminants. Areas of thick overburden units and low resistivity values constitute zones of high longitudinal conductance. Regions with poor protective capacity (Shamija Village and New G.R.A.) are vulnerable to pollution and contamination if there is oil spillage, leakage in buried storage tank, petroleum pipelines, and infiltration of leachate from decomposed dump or waste site. Regions of weak protective capacity (Judges Quarters, Owners Occupier, Nyiman Layout, High level, Mission ward, Lafia road, 72 Battalion barracks, Uchonu village, and Wurukum) are less vulnerable to groundwater pollutant or contaminant but can be more vulnerable with time as pollutant persists. Moderate protective capacity regions (Industrial estate, CAPS Staff Quarters, INEC Office, Naval School, Naka Road, Lower Benue Staff Quarters and Kanshio) and good protective capacity (UniAgric road, Wadata, Ankpa Quarters) will forever serve as a sealing potential

Table 3. Classification of soil resistivity in terms of corrosivity (Baeckmann and Schwenk 1975; Agunloye 1984; Oladapo *et al.* 2004).

Soil resistivity (Ω -m)	Soil corrosivity
<10	Very strongly corrosive (VSC)
10–60	Moderately corrosive (MC)
60–180	Slightly corrosive (SC)
≥ 180	Practically noncorrosive (PNC)

Figure 12. Soil corrosivity rating of study area.

for the underlying hydrogeological system. This makes the contamination of groundwater in such regions almost impossible. Laboratory checks can be conducted from time to time in order to access the protective capacity of aquifers within regions described as poor and weak. Areas that are very strongly corrosive (CAPS Staff Quarters, Wadata and Kansio) and moderately corrosive (Owner Occupier, Nyiman layout, High level, Lafia road and Uchonu village) are characterized by low resistivity values and high moisture content of the soil. Underground iron storage tanks are not to be buried in these areas. Reticulation of water, transmission of oil and gas using galvanized pipes could deteriorate, rupture or leak due to the reactions of corrosive materials with buried pipes, which can cause serious hazards to mankind and its environment. Plastic pipes are more preferable in these areas. In slightly corrosive areas (Industrial estate, Naval School, New G.R.A, Naka Road, Lower Benue Staff Quarters), concrete underground reservoirs can be constructed for water storage and steel pipes could be used for piling oil and gas. Practically noncorrosive areas (Judges Quarters, Mission ward, UniAgric road, 72 Battalion barrack, Shamija village, Mission ward, Ankpa Quarters, and Wurukum) are absolutely good for burying of iron underground tanks without deterioration.

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