Standard Scientific Research and Essays Vol 12(8): 217-227, August, 2024 (ISSN: 2310-7502)
http://www.standresjournal.org/journals/SSRE
DOI: 1015413/ssre.2024.0181

Research Article

Evaluation of Aquifer Protective Capacity and Soil Corrosivity Using Vertical Electrical Sounding Data in Umuahia North L.G.A., Abia, South-Eastern Nigeria

***Terhemba Emberga and Epuerie Emeka**

Department of Physics/Electronics, Federal Polytechnic Nekede, Owerri

*Corresponding author: terhemba4sure@yahoo.com; Phone: 08037513494

Received 29 April, 2024 *Accepted 15 August 2024* *Published 30 August, 2024*

Abstract

A Geoelectric survey was carried out in Umuahia North Local Government Area of Abia State in South-Eastern Nigeria, with the aim of evaluating the aquifer protective capacity and soil corrosivity of overburden units in the study area using Vertical Electrical Sounding (VES) method. A resistivity meter (terrameter) was employed to obtain the field data of thirty (30) VES points within the study area. The information obtained from software modeling of the field data was used to evaluate longitudinal conductance and transmissivities of the layers. From the modeled VES data, it was observed that all the thirty VES points were having an average of ten layers. The minimum and maximum resistivity obtained in the study area ranges from 1.20Ωm to 42,300Ωm, representing shale and sandstone intercalated with gravel. There exists resistivity overlapping values between moderately resistive and highly conductive geo-materials. The apparent depths of the geo-electric layers ranged from 0.3 to 269 Metres, while thicknesses of the geo-electric layers varied between 0.3 to approximately 107 meters. The study area was deduced to be 35.7% essentially non-corrosive, 20% slightly corrosive, 3.3% moderately corrosive, 20% corrosive, 16.7% highly corrosive and 3.3% extremely corrosive. Also, the evaluation of the longitudinal conductance of the study area showed that it is characterized by poor aquifer protective capacity at 56.7%, weak aquifer protective capacity at 13.3%, moderate aquifer protective capacity at 16.7% and good aquifer protective capacity at 13.3%. These evaluations help to deduce suitable locations for the siting of boreholes as well as adequate measures to be taken in the process.

Keywords: Aquifer, Protective Capacity, Soil Corrosivity, Vertical Electrical Sounding

INTRODUCTION

Water is a gift of nature, and it is in a bounteous proportion, noticeable by its presence (surface, rain, and underground), with a quality of transformation through recurrent hydrological evaporation, condensation, and precipitation (Abdullahi et al., 2017). Water resources are one of the most important materials in community development. Understanding the hydro-geological and hydro-chemical characteristics of an area is crucial for groundwater planning and development.

Groundwater had immensely become important water supply in urban and rural areas in both developed and developing nations for domestic, industrial and agricultural purpose (Durowaye et al., 2014). Potable or safe drinking water is a necessary requirement for the health and productive life of humans in any society. Ground water is a valuable source of potable water in most of our urban and rural communities, and for industrial and agricultural applications. However, maintaining a potable groundwater supply that is free from microbial and chemical contaminants is far from reality in most of our urban centers, due to poor waste disposal and management practices (Chernicoff and Whitney, 2009).

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. The availability, quantity and exploitability of groundwater depend on the porosity and permeability of the host rocks (Obiora et al., 2015). Both parameters play important roles in ground water movement and recovery. The porosity of a geologic material is the amount of water (fluid) the material can hold (Abdullahi et al., 2017). It is the volume ratio of the pore spaces to the total volume of soil, rock or sediment (Obiora et al., 2015).

Generally, corrosive soils contain large concentrations of soluble salts, especially in the form of sulphates, chlorides and bicarbonates and may thus be characterized by high acidity (low pH) or high alkalinity (high pH) (Ahmad et al., 2016). Soils with high clay and silt contents are usually characterised by fine texture, high water-holding capacity and consequently, are usually poorly aerated and drained (Bullard et al., 2004). Thus, they are also prone to be potentially more corrosion than coarse-textured soils like sands and gravels where there is greater circulation of air (Bullard et al., 2004). Some recent researchers had employed electrical resistivity method in investigating aquifer protective capacity and soil corrosivity in Nigeria (Adeniji et al., 2014). Corrosive soils contain chemical constituents that can react with construction materials, such as concrete and ferrous metals, which may damage foundations and buried pipelines (George et al., 2014). The electrochemical corrosion processes that take place on metal surfaces in soils occur in the groundwater that is in contact with the corroding structure (Muraina et al., 2012).

Despite this seemingly important relief, there could be threats of contamination to groundwater occasioned by soil corrosivity and infiltration of contaminants from the surface through the migration paths into the aquifers. It is in trying to monitor the quality of groundwater that we used the VES method to decipher the structural layering of the subsurface in Umuahia North Local Government Area of Abia State, Nigeria; with a view to finding the depth to water-bearing formations.

Geology of the Study area

Nigeria is situated in the West African sub-region and located between latitude 4º and14º N and longitudes 3º to 15º E (Obaje, 2009). It is bounded by Niger Republic to the north and the Atlantic Ocean to the south. Benin Republic and Cameroun flank it to the west and east respectively. A small strip borders the Chad Republic to the northeast. It has a landmass of 923,768 sq. km. The geology of Nigeria is made up of three major litho-petrological components, namely, the Basement Complex, Younger Granites, and Sedimentary Basins. The Basement Complex, which is Precambrian in age (Pan-African and older, greater than 600 million years), is made up of the Migmatite-Gneiss Complex, the Schist Belts and the Older Granites. The Younger Granites comprise several Jurassic (200 – 145 million years) magmatic ring complexes centered around Jos and other parts of north-central Nigeria. They are structurally and petrologically distinct from the Older Granites. The Sedimentary Basins, containing sediment fill of Cretaceous to Tertiary ages (less than 145 million years), comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Dahomey Basin (Obaje, 2009).

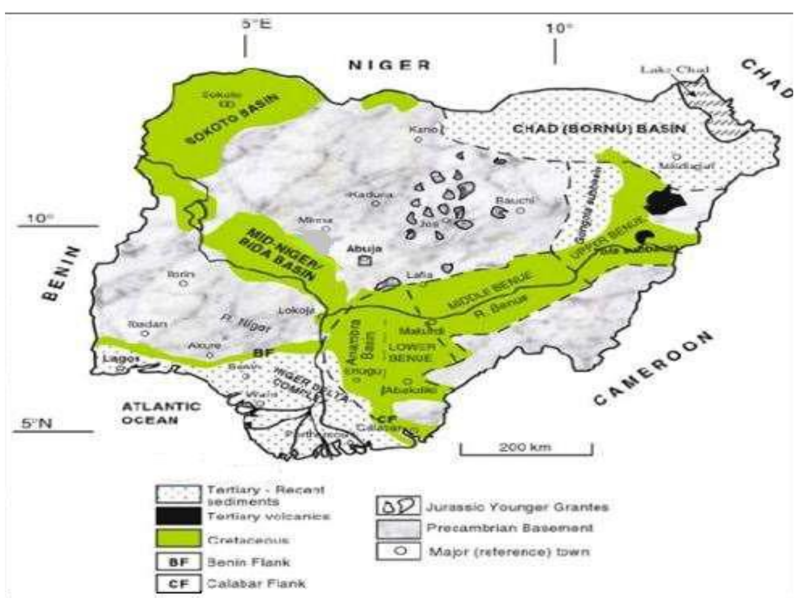

Figure 1. Geologic Map of Nigeria

Umuahia, which happens to be the capital city of Abia State, is in South-eastern Nigeria and is part of the Benin Basin.

The geographical coordinates are within longitude 7.4922º E and latitude 5.5250º N. The climatic conditions are 70% relative humidity and an average temperature of 29ºC to 31ºC, with an annual rainfall of about 4000mm per annum (Amos-Uhegbu *et al*., 2012). It has an area of about 245 sq. km, a population of about 220,660 people [as of 2006 census] and an average elevation of 99 m. (*www.en.wikipedia.org*).

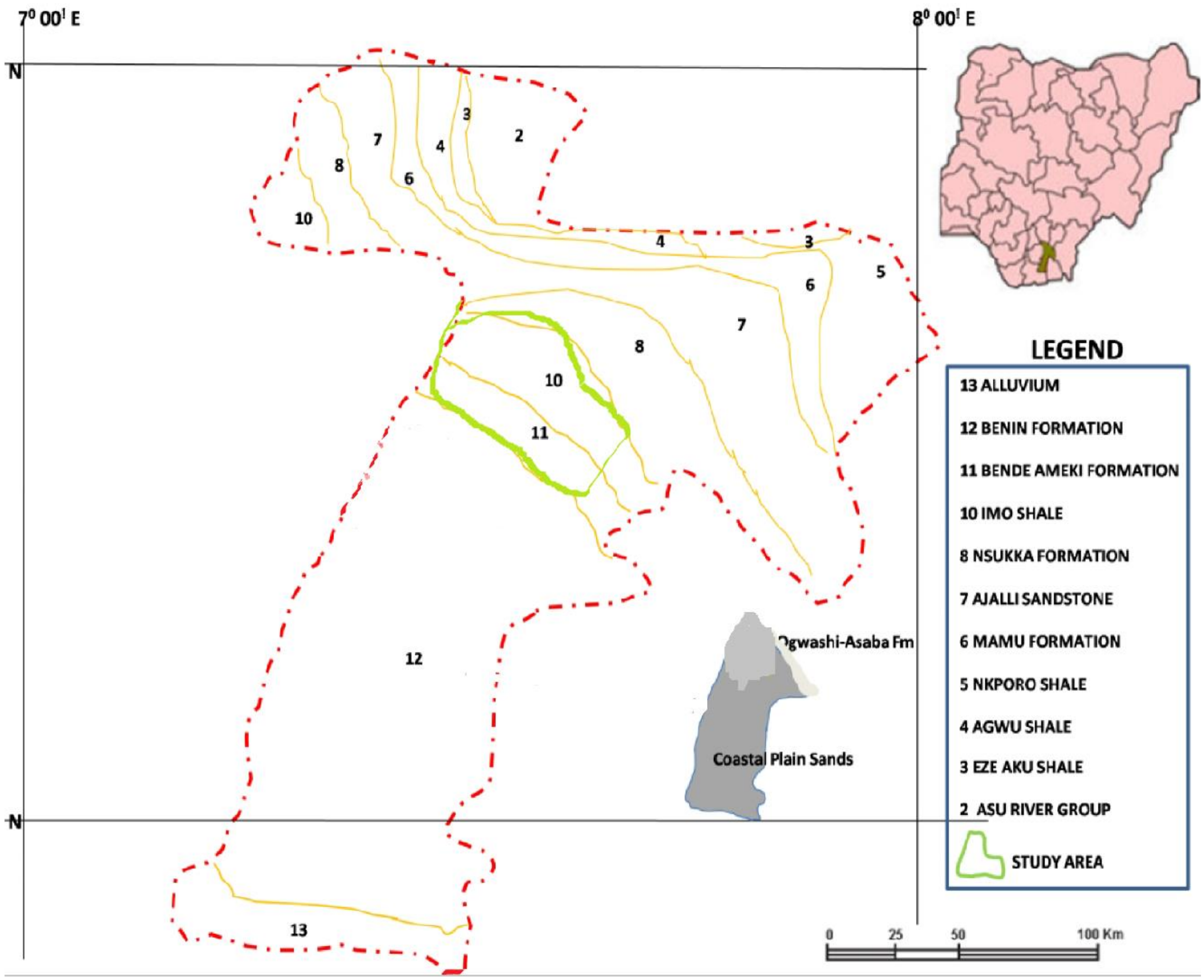

Figure 2. Geologic Map of Abia State showing the study Area

MATERIALS AND METHODS

Thirty vertical electrical soundings were made on thirty random locations within the study area using a terrameter and its accessories. Schlumberger array electrode configuration pattern with half inter-current electrode spacing (AB/2) varying from 1 to 100m was adopted.

With the location of the sounding point, the GPS was used to determine the coordinates in longitude, latitude and elevation height above mean sea level. Then, the terrameter used in the data acquisition was deployed to the position where direct current (DC) from the terrameter was passed into the ground using two metal stakes (current electrodes 'AB/2') linked by insulated cables. The current developed a ground potential difference whose voltage was determined using two other electrodes 'MN/2' kept in line with the pair of current electrodes.

The observed field data which is the ratio of the resulting voltage to the imposed current was only a measure of resistance of the subsurface (ground resistance). This was read off directly from the terrameter and was used to compute the corresponding apparent resistivity in Ohmmeters by multiplying with the geometric factor 'values as functions of electrode spacing', which then gave the required apparent resistivity results as functions of depths of individual layers.

$$\rho\alpha = \pi R\left(\frac{L2-l2}{2l}\right) \quad (1)$$

Where, $\rho\alpha$ = Apparent resistivity
R = Resistance (in Ohms)
L = AB/2 (half current electrode spacing in metres)
l = MN/2 (half potential electrode spacing in metres)

$\pi\left(\frac{L2-l2}{2l}\right)$ = Geometric factor (K)

The apparent resistivity values obtained was plotted against the AB/2 using the IP2Win software. From the plots, layer resistivity, depth and thickness; number of layers and curve types were deduced; also, geologic cross-sections and iso-resistivity maps were made.

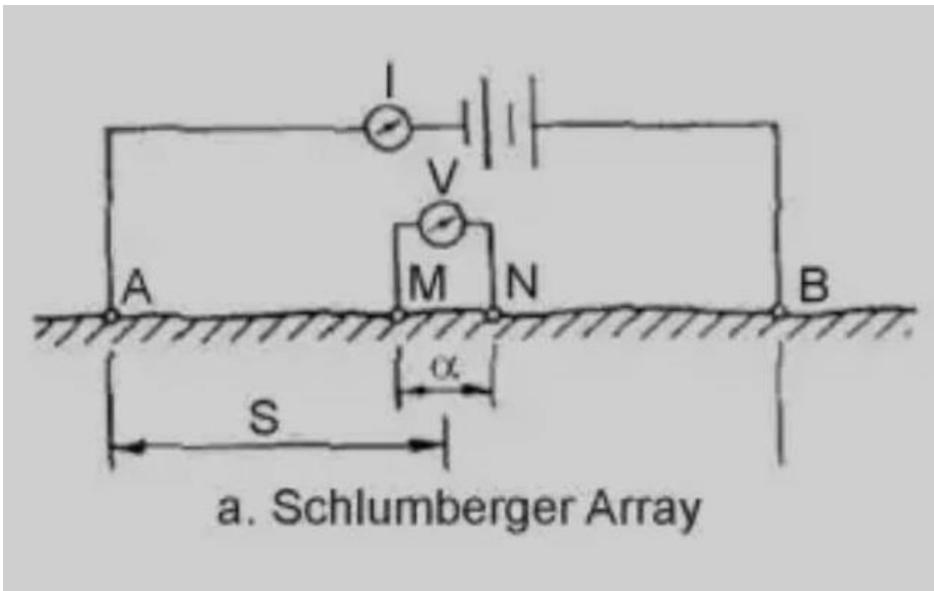

Figure 3. Schlumberger Array electrode configuration

Resistivity survey investigates horizontal and vertical variations of electrical resistance (or conductivity, the inverse of resistivity) of the subsurface by causing an electrical current to flow through the ground, using wires connected to it. The procedure is to measure potentials at other electrodes in the vicinity of the current as shown in (figure 3). Since the current is also measured, the apparent resistivity of the subsurface can be effectively determined (Telford et al., 2011).
Electrical resistivity surveys are based on Ohm's law which holds for simple circuits as well as earth materials. Resistivity, by definition, is the product of the resistance, R and the unit cross-sectional area of a material divided by a unit length of the material through which the current passes, i.e.:

$$\rho = \frac{RA}{L} \quad (2)$$

$$\sigma = \frac{I}{\rho} = \frac{L}{RA} \quad (3)$$

But $V = IR$ (Ohm's law)
Where, V = potential difference, L = current electrode separation, A = cross-sectional area,
I = current &R = resistance

$$\frac{1}{R} = \frac{I}{V} \quad (4)$$

Therefore, $\sigma = \frac{I}{\rho} = \frac{LI}{VA}$ (5)

$$\sigma = \frac{I}{\rho} = \frac{L}{V}J \quad (6)$$

$$J = \frac{V}{L}\sigma \quad (7)$$

$$J = \frac{I}{A} = \frac{\sigma dv}{dl}; \text{ but} \frac{V}{L} = E; \ \frac{I}{A} = J \quad (8)$$

Where, *J* is the current density (current divided by area). Three-dimensional in electrical resistivity in the direction of *J*.

$$E = -\nabla V \quad (9)$$

This implies that:

$$J = -\sigma\left(i\frac{\partial v}{\partial x} + j\frac{\partial v}{\partial y} + k\frac{\partial v}{\partial z}\right) = -\sigma\nabla V \quad (10)$$

The electrical resistivity method is an active geophysical method that employs an artificial source which is introduced into the ground through a pair of electrodes. The procedure involves measurement of potential difference between other two electrodes in the vicinity of current flow.

Apparent resistivity ($\rho\alpha$) is defined as the resistivity of an electrically homogeneous and isotropic half-space that would yield the measured relationship between the applied current and the potential deference for a particular arrangement and spacing of electrodes (Stummer, et al., 2004). An equation giving the apparent resistivity in terms of applied current, distribution of potential and arrangement of electrodes can be arrived at through an examination of the potential distribution due to a single current electrode. The effect of an electrode pair (or any other combination) can be found by superposition.

In granular and unconfined aquifers, the main natural protection against the contamination is related to the presence of overlapping clay layers, whose protection capability comes down to the infiltration time lag of solutions, due to their low permeability (Braga et al., 2006) demonstrated that the protection degree of an aquifer may be considered directly proportional to the ratio between the thickness and resistivity. Determining the geo-electric characteristics of the aquifers and using this information to determine the soil corrosivity and aquifer protective capacity. Clay soils, especially those contaminated with saline water are on the opposite end of the spectrum. Classification of soil resistivity in terms of corrosivity is presented in Table 1. While high longitudinal conductance value corresponds to excellent, very good and good aquifer protective capacity, low longitudinal conductance values are associated with poor and weak aquifer protective capacity are presented in Table 1

Table 1. Classification of soil resistivity in terms of corrosivity

Soil Resistivity (*ohm-m*^{2})	**Soil Corrosivity**
> 20,000	Essentially Non – Corrosive (ENC)
10,000 – 20,000	Slightly Corrosive (SC)
5,000 – 10,000	Moderately Corrosive (MC)
3,000 – 5,000	Corrosive (C)
1,000 – 3,000	Highly Corrosive (HC)
< 1000	Extremely Corrosive (EC)

Table 2. Longitudinal conductance/aquifer protective capacity rating

Longitudinal conductance (*mhos*)	Aquifer 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

The Longitudinal Conductance (S), which enables us to define the protection degree of ground waterfront of contaminants migrating vertically. However, it was necessary to modify the term degree of protection for vulnerability, in order to fit this new method to the terminology used by those already existing. In this manner, an overlying layer with high longitudinal conductance (generally greater than 1.0) offers a high protection degree to contamination, therefore the bigger the thickness of this layer, the greater the infiltration time of the contaminants (large filter) and the lower the resistivity, the more clayey and less permeable the material is less than 1.0 (Braga et al., 2006). To establish the vulnerability classes of the (S) method (table 1 and 2), which correspond to the value ranges of longitudinal conductance, it sought relationships between thickness and resistivity that could be considered representative of each class, in terms of hydraulic accessibility to the saturated zone and pollutant attenuation capacity of the unsaturated zone.

RESULTS AND DISCUSSION

The VES modeling was carried out on a total of thirty (30) VES stations within an area covering about 1000km^2. The elevation of the area above sea level ranges from 107m to above 190m, which indicates that the area is generally a hilly terrain which, although challenging, can support growth of various agricultural produce with proper land management techniques such as terracing and contour plowing, if water is made available all year round.

The VES is limited to the vertical distribution of electrical resistivity within the subsurface of the study area. Representative VES curve from the research area is displayed in the appendices. This was made possible by geophysical software called IP2Win which involves a forward and inverse modeling approach to generate a computer modeled curve as shown. The layer parameters, resistivity and thickness for each VES points were obtained after a series of iteration to match the field curve with theoretical curves. This iteration activity continued until the RMS error between the field data and the model data is reduced to the maximum percentage, showing different geo-electric curve type.

From the modeled VES data, it was observed that all the thirty VES points were having an average of ten layers. The minimum and maximum resistivities obtained in the study area ranges from 1.20Ωm to 42,300Ωm, representing clayey soil, silty-sand, sandstone and sandstone intercalated with gravel. There exists a resistivity overlapping values between moderately resistive and highly conductive geo-materials. The apparent thickness and depths of the geo-electric layer were established with the depth of the first geo-electric layer ranging between 0.3m and 2.4m, the second layer depth ranges from 1.4m to 9.9m, the third layer depth ranges from 2.6m to 31m, the fourth layer depth ranges from 7.7m to 52.5m, the fifth layer depth ranges from 11.6m to 83.6m, the sixth layer depth ranges from 18.1m to 131m, the seventh layer depth ranges from 25.3m to 180m, while the eighth and ninth layer depths range from 40.2m to 219m and 64.9m to 269m, respectively. The thickness of the geoelectric layers also varies as the first geo-electric layer expresses a thickness range of 0.3m to 2.4m, the second layer thickness ranges from 0.5m to 9.5m, the third layer ranges from 0.9m to 23.2m, the fourth layer ranges from 2.9m to 31.9m, the fifth layer ranges from 3.5m to 45.5m, the sixth layer ranges from 6.5m to 68.8m, the seventh layer ranges from 7.2m to 106.4m, the eighth layer ranges from 13.8m to 66.2m while the thickness of the ninth layer ranges between 16.6m to 82m. The depth and thickness of the tenth geo-electric layer extends beyond the probe depth of this investigation. Hence, the depth and thickness of the tenth layer are proposed to be infinite in extent.

Table 3. Tabulation of Geoelectrical Parameters

VES Points	Latitude	Longitude	No. of Layers	Layer resistivity, ρ (Ωm)					Layer depth, *d* (m)					Layer thickness, *h* (m)				
				ρ1	*ρ2*	*ρ3*	*p4*	*p5*	*d1*	*d2*	*d3*	*d4*	*d5*	*h1*	*h2*	*h3*	*h4*	*h5*
1	N5°33.002	E7°29.747	10	73.4	1980	222	1070	224	0.5	2	6.1	16.6	32.1	0.5	1.5	4.1	10.5	15.5
2	N5°31.760	E7°30.157	9	69.4	2070	1630	610	768	1.1	5.2	12.8	30.5	70.3	1.1	4.1	7.6	17.7	39.8
3	N5°31.616	E7°30.011	10	31.2	1570	245	19.3	78.3	0.6	3.6	6.5	17.3	24.8	0.6	3	2.9	10.8	7.5
4	N5°31.840	E7°27.727	10	166	830	709	2750	1320	0.7	3.3	7.5	15.5	28	0.7	2.6	4.2	8	12.5
5	N5°32.940	E7°30.294	10	532	76.1	3410	26600	6440	0.5	1.4	3.5	14	21.9	0.5	0.9	2.1	10.5	7.9
6	N5°32.312	E7°30.449	10	158	23	8700	18100	5620	0.9	1.9	6	17.2	28.4	0.9	1	4.1	11.2	11.2
7	N5°30.884	E7°29.634	9	176	270	355	9800	2100	0.9	10.2	21.4	52.5	80.3	0.9	9.3	11.2	31.1	27.8
8	N5°30.607	E7°30.736	10	268	75.9	675	75	810	2.4	5.5	13.4	30.5	48.2	2.4	3.1	7.9	17.1	17.7
9	N5°33.014	E7°30.683	10	387	33900	5860	2940	2180	0.4	3.2	11.7	21.5	39.9	0.4	2.8	8.5	9.8	18.4
10	N5°35.404	E7°30.000	10	940	86	5.5	38.4	85	1	3.4	9	17.1	24.1	1	2.4	5.6	8.1	7
11	N5°32.262	E7°29.211	10	134	3540	1630	314	97	0.4	2.8	15.4	22.2	38.6	0.4	2.4	12.6	6.8	16.4
12	N5°33.644	E7°30.657	10	756	5600	457	118	1060	0.5	1.6	9.5	19.2	34.7	0.5	1.1	7.9	9.7	15.5
13	N5°33.562	E7°29.912	10	30.7	279	14	234	145	0.5	2.3	13.3	39.8	72.7	0.5	1.8	11	26.5	32.9
14	N5°33.603	E7°29.883	10	158	10.2	1.2	45	152	1.1	2.6	6.4	11.8	22.1	1.1	1.5	3.8	5.4	10.3
15	N5°35.626	E7°30.259	10	372	870	129	9.2	23.6	0.8	2.7	4.5	9.5	13.9	0.8	1.9	1.8	5	4.4
16	N5°29.806	E7°29.672	10	175	432	9700	790	5800	1.2	1.7	6.1	15.4	24.4	1.2	0.5	4.4	9.3	9
17	N5°34.429	E7°29.009	10	57.1	40.9	100	11.7	4.5	0.8	1.7	4.6	8.4	18.3	0.8	0.9	2.9	3.8	9.9
18	N5°32.623	E7°31.265	10	109	19.2	168	3870	373	0.6	1.7	2.6	11	17.9	0.6	1.1	0.9	8.4	6.9
19	N5°39.455	E7°26.332	10	365	246	4.1	10.7	1.9	0.9	1.9	5.6	15	23.4	0.9	1	3.7	9.4	8.4
20	N5°33.052	E7°29.516	10	404	1670	1260	12500	1600	0.8	3.2	6.7	17.5	26.1	0.8	2.4	3.5	10.8	8.6
21	N5°34.500	E7°26.994	10	488	2270	263	970	2540	0.7	4	10	18.1	36	0.7	3.3	6	8.1	17.9
22	N5°33.020	E7°29.795	10	155	371	33	484	9000	0.8	2	4.9	7.8	20.5	0.8	1.2	2.9	2.9	12.7
23	N5°30.381	E7°30.441	10	376	201	90	13.1	13.5	0.8	7.8	31	43.1	64.3	0.8	7	23.2	12.1	21.2
24	N5°30.525	E7°29.490	10	545	129	761	55.4	9.9	0.8	2.3	5.9	10.2	23	0.8	1.5	3.6	4.3	12.8
25	N5°31.889	E7°29.784	9	49.1	52.1	557	1500	60	0.8	6.4	9.7	22.8	67	0.8	5.6	3.3	13.1	44.2
26	N5°32.976	E7°31.339	10	870	1510	212	5.5	36.4	0.8	1.8	8.7	22.5	33	0.8	1	6.9	13.8	10.5
27	N5°30.504	E7°29.966	10	93	110	1710	171	2920	1	1.8	7.8	23.6	56.3	1	0.8	6	15.8	32.7
28	N5°33.106	E7°31.154	10	134	604	5.5	5	7.3	0.4	9.9	29	42.8	59	0.4	9.5	19.1	13.8	16.2
29	N5°32.566	E7°28.586	10	97	15	221	1030	143	0.5	1.5	2.9	10.2	21.1	0.5	1	1.4	7.3	10.9
30	N5°31.193	E7°31.400	10	134	8300	578	129	1030	0.3	1.4	2.6	7.7	24.9	0.3	1.1	1.2	5.1	17.2

Table 4. Summary of Soil Corrosivity and Aquifer Protective Capacity Characteristics

VES Points	Average Transverse Resistance Per VES Points (Ωm^2)	Soil Corrosivity	Average Longitudinal Conductance Per VES Points (mhos)	Aquifer Protective Capacity
1	417,427.47	Essentially Non-Corrosive	0.013	Poor
2	11,319.45	Slightly Corrosive	0.054	Poor
3	16,745.85	Slightly Corrosive	0.075	Poor
4	12,821.58	Slightly Corrosive	0.018	Poor
5	39,660.32	Essentially Non-Corrosive	0.014	Poor
6	50,585.82	Essentially Non-Corrosive	0.017	Poor
7	49,332.93	Essentially Non-Corrosive	0.024	Poor
8	79,772.65	Essentially Non-Corrosive	0.039	Poor
9	145,285.48	Essentially Non-Corrosive	0.005	Poor
10	45,555.32	Essentially Non-Corrosive	0.162	Weak
11	34,401.58	Essentially Non-Corrosive	0.029	Poor
12	10,748.93	Slightly Corrosive	0.037	Poor
13	2,735.45	Highly Corrosive	0.326	Moderate
14	1,765.38	Highly Corrosive	0.498	Moderate
15	3,711.55	Corrosive	0.117	Weak
16	367,838.3	Essentially Non-Corrosive	0.003	Poor
17	463.95	Extremely Corrosive	1.012	Good
18	4,001.64	Corrosive	0.816	Good
19	3,678.03	Corrosive	0.974	Good
20	25,367.03	Essentially Non-Corrosive	0.063	Poor
21	11,092.24	Slightly Corrosive	0.037	Poor
22	77,657.55	Essentially Non-Corrosive	0.017	Poor
23	4,995.14	Corrosive	0.349	Moderate
24	2,286.33	Highly Corrosive	0.173	Weak
25	4,360.02	Corrosive	0.191	Weak
26	4,882.97	Corrosive	0.379	Moderate
27	14,566.14	Slightly Corrosive	0.061	Poor
28	1,517.42	Highly Corrosive	1.136	Good
29	2,126.94	Highly Corrosive	0.361	Moderate
30	9,098.68	Moderately Corrosive	0.052	Poor

To ascertain the aquifer protectivity, transmissivity and soil corrosivity of the area under consideration, the transverse resistance and longitudinal conductance values were evaluated from the measured resistivity values and the thickness of the layers (using tables 1 and 2 respectively as shown in table 4). The longitudinal conductance also shows a variation from 0.003 Siemens in VES 16 to 1.136 Siemens in VES 28. On average, almost all the VES points show values of longitudinal conductance that are less than 1.0 Siemens, suggesting that the overburden rock materials have no significant quantity of impermeable clay overlying strata which demonstrates high infiltration rates of surface contaminants into the aquifer. The resistivity values as obtained from the measurements show that overburden resistivity values are relatively low in almost all the VES points. This indicates that the areas are generally corrosive, having weak conductance and aquifer protective capacity. This corrosivity could be attributed to the chemical constituents of the area and may cause disease if any form of agricultural activities is done and consumed. The information obtained from geophysical investigation (table 4) reveals that the study area with geoelectric parameter shows nine or more subsurface geoelectric units delineated beneath the VES sections. The lithological variability of the subsurface lithology of the study area is characterized by the variability in the geoelectric properties of these geomaterials. The resistivities obtained in the study area ranges from 1.2Ωm to 42,300Ωm, typically corresponds to sedimentary rocks, which can include formations like sandstone and shale.

From table 4, the four distinct zones defined are poor, weak, moderate and good aquifer protective capacity zones, based on the numerical values assigned to each point. VES points 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 16, 20, 21, 22, 27 and 30 represent the areas with poor aquifer protective capacity covering 56.7% of the study area, while VES points 10, 15, 24 and 25 show weak aquifer protective capacity and covered 13.3% of the study area. Moderate protective capacity at VES points 13, 14, 23, 26 and 29; which constitute 16.7% of the study area and good aquifer protective capacity at VES points 17, 18, 19 and 28 covers the remaining 13.3%. Using the inferred layer resistivities and thicknesses, longitudinal conductance (a Dar Zarrouk parameter) was used as a criterion for the aquifer protective capacity rating. The soil corrosivity in the study area was also determined from table 4, using the average transverse resistance and comparing with that of table 1. VES points1, 5, 6, 7, 8, 9, 10, 11, 16, 20 and 22 suggest that the subsurface (soil) is essentially non-corrosive. VES points 2, 3, 4, 12, 21 and 27 suggest slightly corrosive material. VES points 15, 18, 19, 23, 25 and 26 suggest corrosive material. VES points 13, 14, 24, 28 and 29 suggest highly corrosive material, while VES points 30 and 17 suggest moderately corrosive and extremely corrosive material, respectively.
Figure 4 shows the protective capacity chart of the study area.

The geo-electric sections show that the depth to the different lithologies varies across the sounding stations. The sandstone and shale which occur in different parts of the study area has relatively low to moderate resistivity values ranging from 1Ωm to 300Ωm, while lithologic formations with resistivity ranges over a thousand ohm-metres are often associated with non-conductive rocks (such as evaporites). Evaporite rocks like rock salt (halite) or gypsum can exhibit high resistivity due to their low conductivity. The resistivity values for such formations can exceed a thousand ohm-metres and even go much higher.

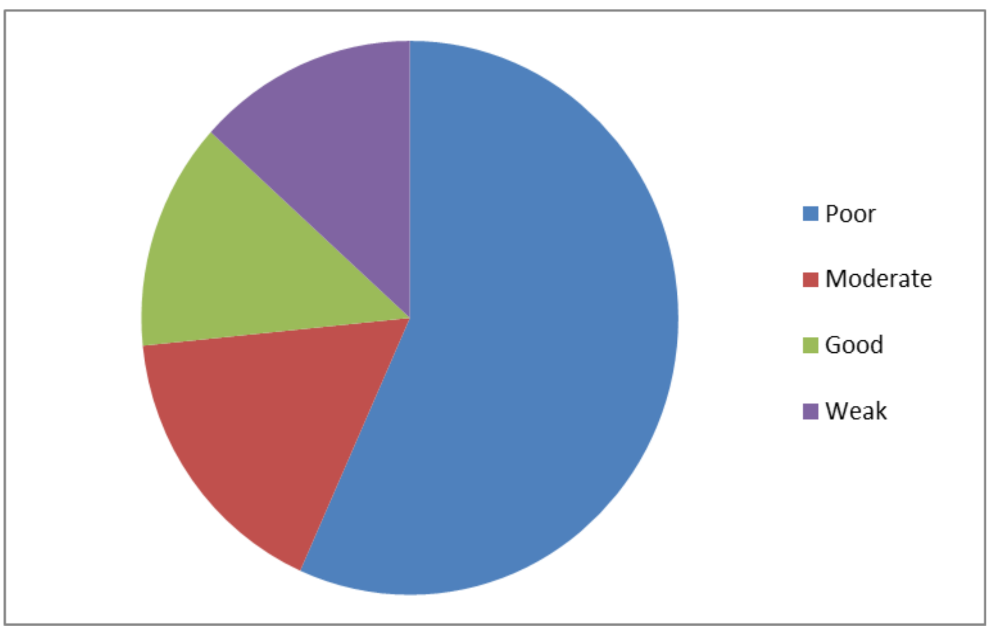

Figure 4. Aquifer Protective Capacity of Study Area

Figure 5. Soil Corrosivity of Study Area

CONCLUSION

Water is key to daily human activities hence, without water, there cannot be human, animal or plant life. It is in view of this that the geo-electric investigation for the evaluation of the subsurface for optimal groundwater production was undertaken in the study area.

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. Areas of thick depth units and low resistivity values constitute zones of high longitudinal conductance. Regions with poor protective capacity (VES points 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 16, 20, 21, 22, 27 and 30) 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 (VES points 10, 15, 24 and 25) are less vulnerable to groundwater pollutant or contaminant but can be more vulnerable with time as pollutants persist. Moderate protective capacity regions (VES points 13, 14, 23, 26 and 29) and good protective capacity regions (VES points 17, 18, 19 and 28) will forever serve as a sealing potential for the underlying hydrogeological system. This makes the contamination of groundwater in such regions almost impossible. Areas that are slightly corrosive, moderately corrosive, corrosive, highly corrosive and extremely corrosive (VES points 2, 3, 4, 12, 13, 14, 15, 17, 18, 19, 21, 23, 24, 25, 26, 27, 28, 29 and 30) 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, and 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. Essentially non-corrosive areas (VES points 1, 5, 6, 7, 8, 9, 10, 11, 16, 20 and 22) are absolutely good for burying of iron underground tanks without deterioration which has a good groundwater potential as revealed by the geoelectric parameters. The geoelectrical properties of the subsurface lithologies was used to classify the area into low, medium and high groundwater potential zones and safe for drinking with no effect to humans and animals and also safe for any form of agricultural activities within the study area.

Five subsurface geoelectric units were delineated beneath the VES sections. The lithological variability of the subsurface lithology of the study area is sponsored by the variability in the geoelectric properties of these geomaterials.

RECOMMENDATION

i) Government, individuals or estate developers who wish to site boreholes within the study area are strongly advised to consider VES points 13, 14, 17, 18, 19, 23, 26, 28 and 29.
ii) Plastic pipes and storage tanks are more preferable in these areas due to their corrosivity levels.
iii) Areas with poor and weak aquifer protective capacity should be avoided for sinking borehole to reduce leachate infiltration to the groundwater.
iv) Laboratory checks can be conducted in order to access the protective capacity of aquifers within regions described as poor and weak before carrying out any form of activity there.

Acknowledgement

The Authors are grateful to the Management of Tertiary Education Trust Fund (TETFUND) for supporting the Research and sponsoring it 100% through the 2024 Institution Based Research (IBR).

References

Abdullahi A, Shehu AD, Muhammad AU (2017). Evaluation of Soil Corrosivity and Aquifer Protective Capacity Using Secondary Geoelectric Parameters Across Gombe Metropolis in North-Eastern Nigeria. Nigerian Agric. Business and Technol. 15: 29-51.

Abiola O, Enikanselu PA, Oladapo MI (2009). Groundwater Potential and Aquifer Protective Capacity of Overburden Units in Ado-Ekiti, South-Western Nigeria. Int. J.Physics Sci. 4(3): 120–132.

Ahmad DS, Abdullahi A, Victor EG (2016). Assessment of the Extent of Soil Corrosivity Using Vertical Electrical Sounding: A Case Study of Mbat-Odukpani, Cross River, Nigeria. *JOLORN* VOL. 17 No. 1, 2016.

Ajibade OM, Ogungbesan GO (2013). Prospects and Quality Indices for Groundwater Development in Ibadan Metropolis, Southwestern, Nigeria, Int. J. Development and Sustainability. 2(1): 398 – 414.

Amos-Uhegbu C, Igboekwe MU, Eke KT, Adindu RU (2012). Groundwater Modelling, an Effective Tool in the Assessment of Groundwater Contamination: A Case Study of Umunwanwa in Umuahia-South, Abia State, Nigeria. British J. Appl. Sci. Technol. 2(4): 334-355.

Arabi A, Nur A, Dewu B (2009). Hydro Geo-Electrical Investigation in Gombe Town and Environs, North-Eastern Nigeria. J. Appl. Sci. Environ. Manag. Vol. 13, No. 3.

Ayolabi EA, Adeoti L, Oshinlaja N, Adeosuni IO, Idowu OI (2009). Seismic Refraction and Resistivity Studies of Part of Igbogbo Township, South-west Nigeria: J. Sci. Res. Development. 11: 42–61.

Ayuk MA, Adelusi AO, Adiat KAN (2013). Evaluation Of Groundwater Potential and Aquifer Protective Capacity Assessment at Tutugbua-Olugboyega Area, Off Ondo Road, Akure, South-Western Nigeria. Int. J. Physical Sci. 8(1): 37-50.

Belmonte SJ, Enrigueze JO, Zamora MA (2004). Groundwater Resource Evaluation in the Western Part of Kushtia District of Bangladesh Using Vertical Electrical Sounding Technique. J. Hydraulic Eng. 21(1):97-110.

Braga ACO (2008). Estimation of the Natural Vulnerability of Aquifers: A Contribution from the Resistivity and Longitudinal Conductance. Brazilian J. Geophysics. 26(1): 61-68.

Braga ACO, Dourado JC, Malagutti FW (2006). Resistivity (DC) Method Applied to Aquifer Protection Studies. Brazilian J. Geophysics. 24(4): 573-581.

Bullard SJ, Covino JRBS, Cramer SD, Holcomb GR, Ziomek-Moroz M, Locke ML, Warthen MN, Kane RD, Eden DA, Eden DC (2004). Electrochemical Noise Monitoring of Corrosion in Soil Near A Pipeline Under Cathodic Protection. Albany Research Center (ARC), Albany.

Chernicoff AE, Whitney IK (2009). An Introduction to Physical Planning; Houghton Mifflin Company, New York. Dahlin T 2001 The Development of DC Resistivity Imaging Techniques*;* Computer Geosciences. 27(9): 1019-1029.

Durowaye SI, Alabi AGF, Sekunowo OI, Bolasodun B, Rufai IO (2014). Effects of pH Variation on Corrosion of Mild Steel in Bore-hole Water using 1M Sodium Hydroxide Solution*. Int. J. Engineering and Technol.* 4: 3*.*

Edet A, Worden RH (2009). Monitoring of the Physical Parameters and Evaluation of the Chemical Composition of Rivers and Groundwater in Calabar (South-Eastern Nigeria). Environmental Monitoring Assessment. 213(1–3): 243–258.

Ekpo A, Orakwe L, Ekpo F, Eyeneka, F (2016). Evaluating the Protective Capacity of Aquifers in Uyo, Akwa Ibom State, Southern Nigeria, Using the Vertical Electrical Sounding (VES) Technique. Int. Advanced Res. J. Sci. Engineering and Technol. 3: 4-8.

Emmanuel O, Joshua OO, Odeyemi A, Oladotun OF (2011). Geoelectric Investigation of the Groundwater Potential of Moniya Area, Ibadan. *J. Geol. Min. Res.* 3(3): 5462.

Henriet JP (1975). Direct Applications of the Dar Zarrouk Parameters in Ground Water Surveys. *Geophysical Prospecting*, 24 (3): 44–353.

Keller G, Frischknecht FC (1996). Electrical Methods in Geophysical Prospecting Toronto, Sydeney, Braunsckweig*. Int. J. Geosci.* Vol. 4, No. 10.

Keswick BH, Wang D, Gerba CP (1982). The Use Of Micro-Organisms As Groundwater Tracers – A Review; Groundwater 20(2) 142–149. Kogbe A. C. 1989 Geology of Nigeria. Elizabethan Publishing Company, Lagos-Nigeria.

Maillet R (1947). The Fundamental Equations of Electrical Prospecting. *Geophysics*. 12: 529-556.

Makeig KS (1982). National Buffers for Sludge Leachate Stabilization of Groundwater. G*eophysics,* 20(4): 420–429.

Mogaji KA, Adiat KAN, Oladapo MI (2007). Geoelectric Investigation of the Dape Phase III Housing Estate F.C.T Abuja, North–Central Nigeria. J. Earth Sci. 1(2): 76–84.

Mohammed G, Ibrahim A, Hassan AA, Ibrahim SH, Mahdy AM, Ibrahim MG, Bektas S(2014). Geo-Electrical Data Analysis to Demarcate Groundwater Pocket Zones in Kaltungo and Environs, North-Eastern Nigeria. Int. J. Engineering, 4: 8269.

Muraina Z, Isaac R (2014). Geoelectric Evaluation of Subsoil for Optimum Cocoa Yield in Parts of Ondo State, South-Western Nigeria. Civiland Environmental Research; Vol.6, No.1, 2014.

Muraina ZM, Martins OO, Alex II (2012). Geoelectric Sounding for Evaluating Soil Corrosivity and the Vulnerability of Porous Media Aquifers in Parts of the Chad Basin Fadama Floodplain, North-Eastern Nigeria. J. Sustainable Development; Vol. 5, No. 7.

Obaje N G(2009). Geology and Mineral Resources of Nigeria, Lecture Notes in Earth Sciences 120, DOI 10.1007/978-3-540-92685-6_1.

Obiora DN, Ajala AE, Ibuot JC (2015). Evaluation of Aquifer Protective Capacity of Overburden Unit and Soil Corrosivity in Makurdi, Benue state, Nigeria; Using Electrical Resistivity Method. J. Earth System Sci. 124:125-135.

Oladapo MI, Adeoye-Oladapo OO, Mogaji KA (2009). Hydrogeophysical Study of the Groundwater Potential of Ilara-Mokin South-Western Nigeria. Global J. Pure and Appl. Sci. 15(2): 195 – 204.

Olorunfemi M.O., Ojo J.S. & Akintunde O.M. (1999). Hydrogeophysical Evaluation of the Groundwater Potential of the Akure Metropolis, South-Western Nigeria. J, Mining and Geol, 35(2):207-228.

Oyedele AA, Olayanju GM, Talabi AO, Ogunyebi SN, Ojo OF (2017). Soil Corrosivity and Aquifer Protective Capacity of Overburden Units in Ado-Ekiti, South-Western. Nigeria Original Scientific Paper. 64: 045-058.

Rahaman MA (1988). Recent Advances in the Study of the Basement Complex of Nigeria: Precambrian Geology of Nigeria, G.S.N. Pp. 11-41.

Revie RW, Uhlig HH (2008). Corrosion And Corrosion Control: An Introduction To Corrosion Science And Engineering, Hoboken New Jersey. John Wiley & Sons Inc.

Salako KA, Adetona AA, Rafiu AA, Ofor NP, Alhassan UD, Udensi EE (2009). Vertical Electrical Sounding Investigation for Groundwater at the South-Western Part (Site A) of Nigeria Mobile Police Barracks (MOPOL 12), David Mark Road, Maitumbi, Minna. J. Sci. Educational Technol. 2:350-362.

Stummer P, Maurer H, Green AG (2004). Experimental design: electrical resistivity data set that provide optimum subsurface information. Geophysics. vol. 69, no. 1 pp. 120-139.

Telford WM, Geldart LP, Sheriff RE (2011). Applied Geophysics, 2nd ed. Cambridge University.

Tsepav MT, Adamu Y, Umar MA (2015). Evaluation of Aquifer Protective Capacity and Soil Corrosivity Using Geoelectrical Method. World Academy of Science, Engineering and Technology. Int. J. Mathematical, Computational, Physical, Electrical and Computer Engineering. Vol:9, No:11.

Tsepav MT, Bello A, Gbedako AA (2014). Geoelectric Investigation of Some Parts of Ibrahim Badamasi Babangida University, Lapai. Nigeria Physical Sci. Int. J. 4(4): 623-635.

Ugbaja AN, Edet MO (2004). Groundwater Pollution Near Shallow Waste Dumps in Southern Calabar, Nigeria. Global J. Sci. 2(2) 199–206.

Zohdy AA (1973). A Computer Program for Automatic Interpretation of Schlumberger Sounding Curves Over Horizontal Stratified Media. PB-232703, National Technical Information Service, Spring Field, Virginia. Pp. 25.

Scan Me