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Soil Corrosivity Profile and Aquifer Protective Capacity in Dukpa, Gwagwalada Area, Crystalline Basement Complex, Nigeria

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Abstract : *Soils in Dukpa, Gwagwalada area, Crystalline Basement Complex were investigated to establish corrosivity profiles and aquifer protective capacity. Six vertical electrical soundings using Schlumberger electrode array were employed for data acquisition. Iteration and inversion processes of determining resistivities, curve types and thicknesses of the various layers were executed using WINRESIST software. Results show that the area is characterized by 4 to 5 geoelectric subsurface layers. Soils with resistivities between 50.6 and 111.8 Ωm in the upper layers between 8.8 and 11.2m depth respectively at VES 1 were characterized as "slightly to moderately corrosive", while soil with resistivity value of 37.2 Ωm in the clay layer at 8.4m depth at VES 2 is characterized as "moderately corrosive". Similarly, resistivity of 42.4 Ωm in the clay layer at 9.1 m depth at VES 3 is considered "moderately Corrosive", while resistivity of 1101.3 Ωm at depth greater than 37.2 m at VES 4 is characterized as "Non-Corrosive" except within 2.7 to 10.1m depth where clay materials with resistivities between 29.1 and 96.5 Ωm is classified as "slightly to moderately corrosive". Resistivity of 52.1 Ωm at a depth of 10.6 m due to 8.2 m thick clay material is categorized as "moderately Corrosive" at VES 5. Resistivity value of 56.3 Ωm at 11.1 m depth within 9.4 m thick clay material at VES 6 is characterized as "moderately corrosive" except within the top 1.7 m where resistivity of 139.7 Ωm is classified as "slightly corrosive". Two aquifer protective capacity zones: "weak", 0.18 mhos and "moderate", 0.20–0.30 mhos are delineated. The weak zone coincides with thin overburden sand column with high resistivity while the moderate zones coincide with appreciable overburden clay thicknesses with low resistivity. These findings suggest that underground metallic installations should be buried at depths away from these corrosive zones (8.4 to 11.1 m) in order to reduce the effect of corrosion and prolong the lifespan of such metallic facilities.*
Keywords: *Aquifer Protective Capacity, Basement Complex, Gwagwalada Area, Soil Corrosivity, Vertical Electrical Sounding*

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I. Introduction

The integrity of underground metallic installations such as civil engineering constructions; storage tanks; utility pipelines; fences; electricity powerlines, mobile communication cables and so on basically depends on the soil composition and environmental factors such as content of dissolved salts, optimum moisture content, organic percentage content, Triaxial and Uniaxial strengths, oxygen amount and pH value. These factors control the resistivity and consequently corrosivity and the aquifer protective capacity of the soil.

Determining the corrosive nature of soils that makes these metallic materials susceptible to failure leading to environmental pollution and economic loss is very essential in Gwagwalada metropolis with rapid industrialization and its environs with rapid urbanization due to influx of people. Dukpa, a satellite community in Gwagwalada Area Council, is witnessing a rapid population growth due to its proximity to the overpopulated city leading to increase in civil engineering constructions and infrastructural development to serve the teeming population.

Apart from the direct mechanical drilling by which soil samples are collected and tested in the laboratory, surface geophysical methods which involve taking measurements at or near the ground surface had also been employed to better investigate the properties of the soil underlying construction sites and determine the suitability of such soil prior to civil engineering constructions and installations of infrastructure. Electrical resistivity survey is one of the surface geophysical methods that has been very usefully employed in studying the properties of soils such as resistivity, corrosivity, aggressivity, longitudinal conductance, conductivity according to [1]; [2]; [3]; [4].

Most soils are usually assumed to be very suitable for civil engineering constructions and infrastructure installations but their corrosivity levels can reduce their suitability. Consequently, it is important to critically examine the characteristics and conditions of soils supposed to be suitable during the design and constructions of civil engineering structures. Therefore, this research determines the corrosivity properties of soils suitable for civil engineering constructions and the aquifer protective capacity of such soils in Dukpa, Gwagwalada Area, Nigeria. The thicknesses, resistivities, corrosivities and Longitudinal Conductance of different soil layers have been determined using the vertical electrical sounding method.

II. Location and Geology of the Study Area

The study area is Dukpa community in Gwagwalada Area Council (Figure 1), Federal Capital Territory (FCT), Abuja. Gwagwalada is located along Abuja-Lokoja road, about 55km South-west of the Abuja City Centre. It is delimited by Latitudes 80° 55′ N and 90° 77′ N and Longitude 70° 04 E and 120° 07 E. The FCT is underlain by basement complex which comprises predominantly high grade metamorphic and igneous rocks of the Precambrian age [5]; [6]; [7]; [8]; [9] (Figure 2). Review by [10]; [11] suggested that the Nigerian Basement Complex is intruded by many Pan-African syn- to post collisional plutons, which are voluminous in the eastern region than the west and are known as Older Granites. The emplacement of the Older Granite suites was typically controlled by regional NE-SW shear zones. Generally, the North North East (NNE) and South South West (SSW) of the FCT are made of gneiss, migmatites and granites which characterize the Northern Nigeria. The outcrop of schist belt is found along the Eastern margin of the FCT [12]; [13]. This belt broadens as one moves southwards and maximum size is found to the South Eastern region of the FCT. The rocks found in Gwagwalada consist of granite, gneiss, diorites, horn blende schist, mica schist, feldspathic quartz schist and migmatites [14]. These Crystalline Basement rocks lack primary porosity and permeability when fresh but can store and transmit fluids after the development of regolith and discontinuities in their rock mass due to weathering and fracturing.

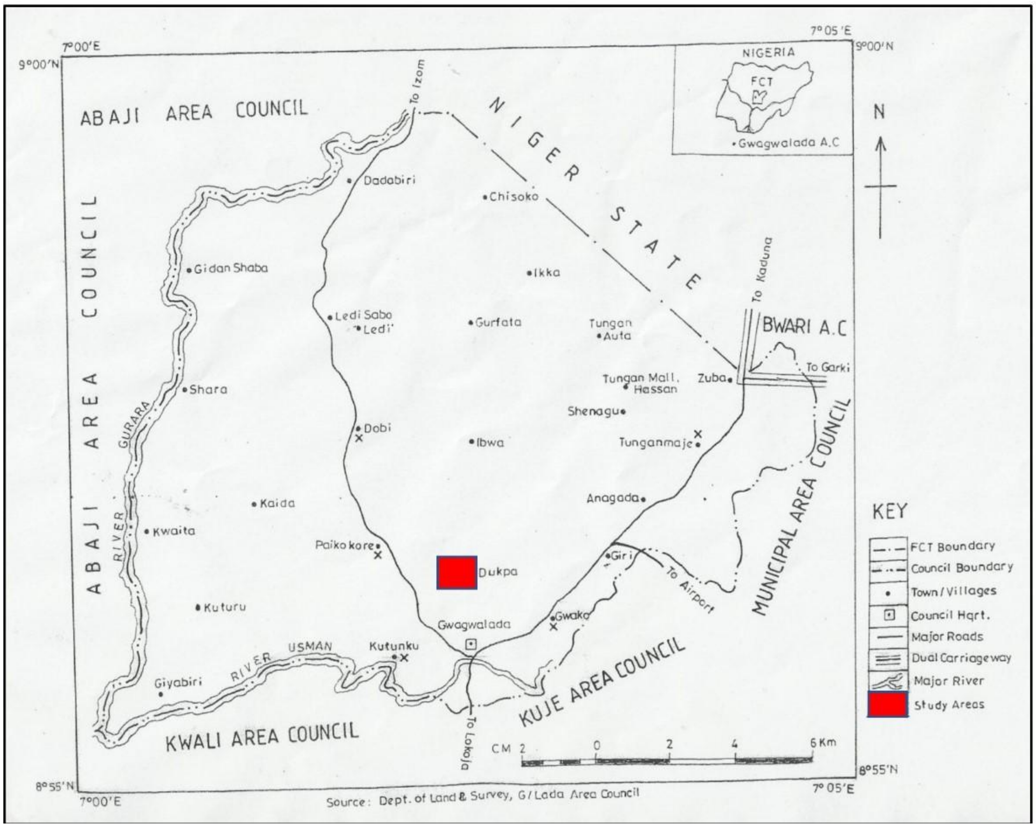

Figure 1: Map of Gwagwalada Area Council showing Dukpa Community

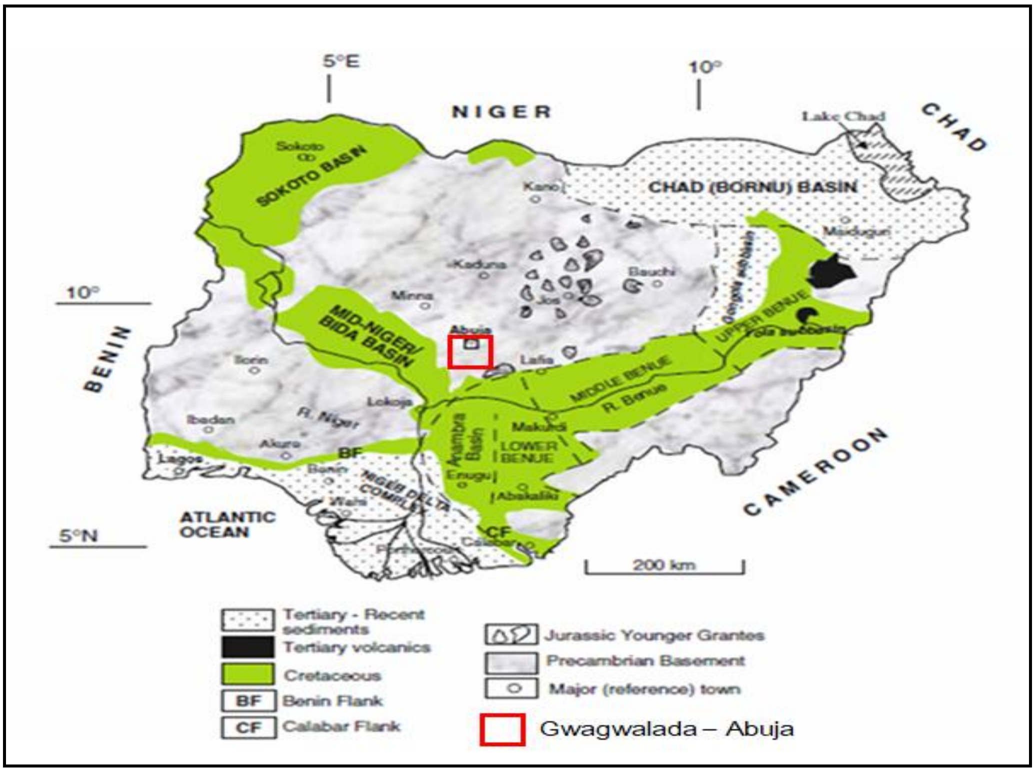

Figure 2: Geologic map of Nigeria, showing Gwagwalada, Abuja [9]

This regolith includes both the residual soil and the saprolite. Preliminary assessment of geophysical and borehole drilling data collected in the study area so far indicate that the weathered regolith varies in thickness from 2m or less to as deep as about 45m in places [15].

Much of the land surface have a well-developed clay soil and lateritic cover, and bedrock is not generally exposed except along the bank of streams. Granite and quartzite cobbles and gravels can be observed on the land surfaces which are compacted into the soil in some places [16]; [17]. The quartzite is dirty white to milky in colour but highly fractured [12]. The fractures are in the form of conjugate joint and cracks.

III. Methodology

Field Data Acquisition

The electrical resistivity data were acquired using Ohmega 1000 Resistivity Meter with its accessories along 6 traverses. The Schlumberger array (Figure 3) with a maximum half current electrodes separation of 90 m was employed. Following similar setup by [18], two current electrodes and two potential electrodes were placed in line, but not equidistant from one another and centered on the same location. The current electrodes were equidistant from the centre of the sounding, **s**. The potential electrodes were also equidistant from the centre of the sounding, but at a distance, a/2 lesser than the distance, **s.** Different spreads of current electrodes, AB were achieved, thereby resulting in different probe depths (Table 1).

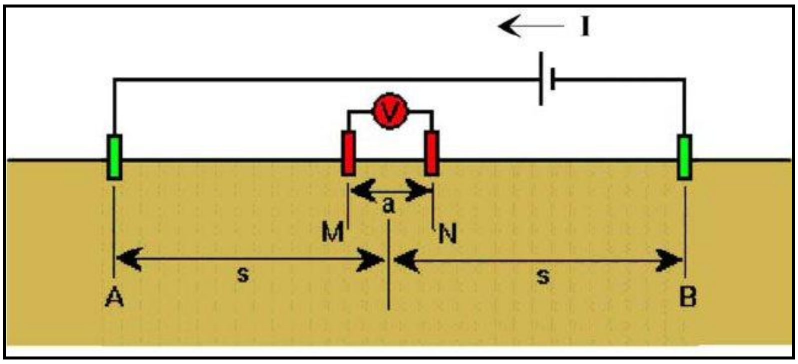

Figure 3: Schlumberger Array for Data Acquisition

Table 1: Vertical Electrical Sounding Data Acquired in Dukpa, Gwagwalada Area, Abuja, Nigeria

ELECTRODE CONFIGURATION		TRAVERSE 1		TRAVERSE 2		TRAVERSE 3		TRAVERSE 4		TRAVERSE 5		TRAVERSE 6	
AB/2 (m)	MN/2 (m)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)
1	0.2	37.91	285.962712	42.14	317.8704	97.66	736.668912	30.17	227.578344	39.22	295.844304	17.29	130.421928
2	0.2	9.87	307.111959	10.76	334.8049	23.63	735.263991	7.87	244.880559	10.86	337.916502	3.99	124.151643
3	0.2	4.133	290.9764256	4.214	296.6791	7.87	554.073184	2.873	202.2683936	4.244	298.7911808	1.614	113.6307648
6	0.2	0.5646	159.5309482	0.4518	127.6587	0.6985	197.3651565	0.317	89.5701569	0.527	148.9068539	0.2972	83.97555404
6	0.6	1.685	157.2898635	1.655	154.4895	1.959	182.8669689	0.9119	85.12322049	1.797	167.7447387	0.8926	83.32162146
9	0.6	0.4102	86.63817792	0.3517	74.28242	0.4285	90.5033136	0.2493	52.65455328	0.4884	103.1547686	0.331	69.9103776
12	0.6	0.2193	82.50441003	0.1797	67.60621	0.1777	66.85377867	0.135	50.7893085	0.2386	89.76540006	0.1766	66.43993986
16	0.6	0.1411	94.47544748	0.1238	82.89199	0.1035	69.29984985	0.0857	57.3816148	0.136	91.06067227	0.1127	75.4598365
20	0.6	0.1066	111.5807535	0.09992	104.5886	0.08032	84.07285294	0.06123	64.09089623	0.09698	101.5112709	0.08966	93.84925292
20	2	0.3452	107.4113964	0.334	103.9264	0.2884	89.7376788	0.2312	71.9394984	0.3379	105.1399503	0.328	102.059496
25	2	0.267	130.2828503	0.2691	131.3075	0.2274	110.9600006	0.1574	76.80344805	0.2333	113.83891	0.2528	123.3539496
30	2	0.2193	154.3942176	0.2234	157.2807	0.1868	131.5131776	0.132	92.932224	0.19	133.76608	0.198	139.398336
35	2	0.1868	179.2160601	0.1878	180.1755	0.1594	152.9284796	0.1096	105.1503222	0.1528	146.5964346	0.1634	156.7660826
40	2	0.1655	207.5464335	0.1655	207.5464	0.137	171.805809	0.09596	120.3393097	0.1388	174.0631116	0.136	170.551752
45	2	0.1482	235.341711	0.1462	232.165	0.1198	190.242489	0.0859	136.425144	0.1237	196.435692	0.1188	188.654489
50	2	0.1309	256.7252688	0.1279	250.8416	0.1056	207.1060992	0.07849	153.9370997	0.1025	201.02628	0.1045	204.948744
55	2	0.1177	279.3904633	0.1137	269.8955	0.09525	226.0997589	0.0721	171.1474291	0.09504	225.6012713	0.09241	219.3583068
60	2	0.1045	295.2707065	0.1035	292.4451	0.08601	243.0261576	0.06621	187.080129	0.08388	237.0077212	0.08276	233.8430973
65	2	0.09769	324.0036118	0.09667	320.6206	0.079	262.0154093	0.06143	203.7418556	0.08056	267.1893844	0.07545	250.2412991
70	2	0.08926	343.3860763	0.08855	340.6547	0.07331	282.0259159	0.05717	219.9348194	0.07503	288.642811	0.06996	269.1383587
75	2	0.08124	358.8127689	0.08621	380.7638	0.06874	303.6040096	0.0529	233.6434697	0.0695	306.9607021	0.06397	282.536347
80	2	0.07504	377.1253013	0.07788	391.3982	-	-	0.04915	247.0110416	0.06738	338.6287687	0.05412	271.9885568
85	2	0.06946	394.1091461	0.07301	414.2515	-	-	0.04447	252.3183664	-	-	0.05341	303.0430391
90	2	0.06509	414.0656089	0.06803	432.7682	-		0.04305	273.8596476	-		0.05097	324.242189

Computation of Soil Apparent Resistivity, ρ_a

The apparent resistivity was computed using the equation:

$$\rho_a = \frac{2\pi \Delta V}{I\left[\frac{1}{A_M} - \frac{1}{A_N} - \frac{1}{B_M} + \frac{1}{B_N}\right]} \quad (1)$$

Where ρ_a is apparent resistivity, $\frac{\Delta V}{I}$ is the resistance, R and $\left[\frac{1}{A_M} - \frac{1}{A_N} - \frac{1}{B_M} + \frac{1}{B_N}\right]$ is the geometric factor.

Evaluation of Soil Corrosivity

The soil resistivity values obtained from the interpretations of the VES results were utilized in evaluating the corrosivity of the subsoils.

Table 2: Resistivity-Corrosivity Classification based on [19]

SOIL RESISTIVITY (Ωm)	SOIL CORROSIVITY
< 10	Very strongly corrosive (VSC)
10 – 60	Moderately corrosive (MC)
60 – 180	Slightly corrosive (SC)
> 180	Practically non-corrosive

Computation of Longitudinal Conductance

The total longitudinal conductance (S_T) of the overburden unit at each vertical electrical sounding station was obtained from the mathematical relation [20]:

$$S_T = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (2)$$

Where S_T = Total Longitudinal Conductance of the overburden layer; ρ_i = Layer Resistivity; h_i = Layer Thickness and n = Number of Layers

Evaluation of Aquifer Protective Capacity

Aquifer protective capacity (APC) is inferred from longitudinal conductance. According to [2], highly impervious materials such as clay and shale usually have high longitudinal conductance values (resulting from their low resistivity values) while pervious materials such as sand and gravels have low longitudinal conductance values (resulting from their high resistivity values). While high longitudinal conductance value corresponds to excellent and good APC, low longitudinal conductance values are associated with poor and weak APC. Table 3 shows the classification of Aquifer Protective Capacity based on Longitudinal Conductance [21].

Table 3: Longitudinal Conductance and Aquifer Protective Capacity [21]

LONGITUDINAL CONDUCTANCE, S (mhos)	AQUIFER PROTECTIVE CAPACITY
> 10	Excellent
5 – 10	Very Good
0.7 – 4.49	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
< 0.1	Poor

IV. Data Interpretation

The apparent resistivity values obtained from equation (1) were plotted against half current electrode separation spacing. From these plots, qualitative deductions, such as the resistivity of the layer, the depth to each layer, and the curve types were made. The WINRESIST software was employed in executing the iteration and inversion processes of determining the resistivities and thicknesses of the various layers. The iteration process was conducted for each sounding station until the root mean square (RMS) error of lower than or equal to 2.5% was obtained.

V. Results and Discussion

Figures 4(a – f) show the geoelectric sections for the six traverses. Generally, the QHA type curve was observed in the study area.

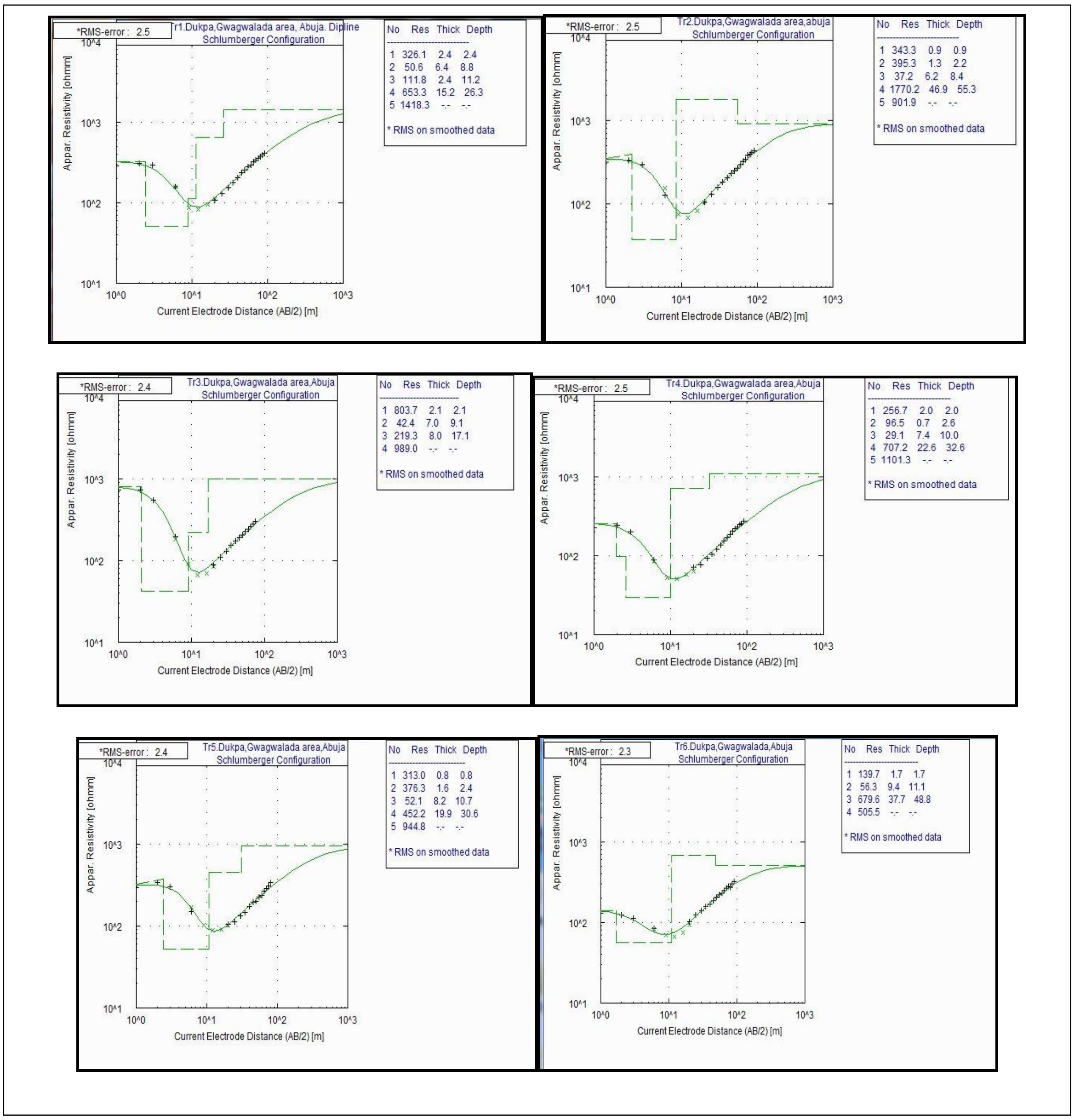

Table 4 is a summary of the interpretation of the results of the Vertical Electrical Sounding in the study area. The results show that the area is characterized by 4 to 5 geoelectric subsurface layers.

Table 4: VES Data Interpretation Results in the Study Area

Sounding Locations	Layers	Resistivity, ρ(Ωm)	Corrosivity (Aggressivity)	Thickness, h(m)	Depth, D(m)	Longitudinal Conductance, S (mhos)	Aquifer Protective Capacity (APC)	Soil lithology
VES 1	I	326.1	Non-Corrosive	2.4	2.4	0.00736		Topsoil
	II	50.6	Moderately corrosive	6.4	8.8	0.126482		Clay
	III	111.8	Slightly Corrosive	2.4	11.2	0.021467		Clayey Sand
	IV	653.3	Non-Corrosive	15.2	26.4	0.023266		Sandy Clay
	V	1418.3	Non-Corrosive	-	-	-		Sand
						S_T = 0.18	Weak	

VES 2	**I**	343.3	Non-Corrosive	0.9	0.9	0.002622		Topsoil
	II	395.3	Non-Corrosive	1.3	2.2	0.003289		Clayey Sand
	III	37.2	Moderately corrosive	6.2	8.4	0.166667		Clay
	IV	1770.2	Non-Corrosive	46.9	55.3	0.026494		Sand
	V	901.9	Non-Corrosive	-	-	-		Sandy Clay
						S_T = 0.20	**Moderate**	
VES 3	**I**	803.7	Non-Corrosive	2.1	2.1	0.002613		Top Soil
	II	42.4	Moderately corrosive	7.0	9.1	0.165094		Clay
	III	219.3	Non-Corrosive	8.0	17.1	0.03648		Clayey Sand
	IV	989.0	Non-Corrosive	-	-	-		Sand
						S_T = 0.20	**Moderate**	
VES 4	**I**	256.7	Non-Corrosive	2.0	2.0	0.007791		Topsoil
	II	96.5	Slightly Corrosive	0.7	2.7	0.007254		Clayey Sand
	III	29.1	Moderately corrosive	7.4	10.1	0.254296		Clay
	IV	707.2	Non-Corrosive	22.6	32.7	0.031957		Coarse sand
	V	1101.3	Non-Corrosive	-	-	-		Fine sand
						S_T = 0.30	**Moderate**	
VES 5	**I**	313.0	Non-Corrosive	0.8	0.8	0.002556		Top soil
	II	376.3	Non-Corrosive	1.6	2.4	0.004252		Clayey Sand
	III	52.1	Moderately corrosive	8.2	10.6	0.15739		Clay
	IV	452.2	Non-Corrosive	19.9	30.5	0.044007		Sandy Clay
	V	944.8	Non-Corrosive	-	-	-		Sand
						S_T = 0.21	**Moderate**	
VES 6	**I**	139.7	Slightly Corrosive	1.7	1.7	0.012169		Top soil
	II	56.3	Moderately corrosive	9.4	11.1	0.166963		Clay
	III	679.6	Non-Corrosive	37.7	48.8	0.055474		Sand
	IV	505.5	Non-Corrosive	-	-	-		Sandy Clay
						S_T = 0.24	**Moderate**	

VES 1: This station is located at Latitude 08°55'25.7" N and Longitude 007°04'16.3" E at an elevation of 213m. Five geoelectric layers are delineated at this zone. Soil deposits are characterized by clayey sand, sandy clay, sand and clay. The lowest resistivity value between 50.6 and 111.8 Ωm was observed in the upper layers between the depth of 8.8 and 11.2m respectively. This is as a result of clay materials observed within this layer. Soils within this layer are characterized as "slightly to moderately corrosive". While above and below this layer, the soils are characterized as 'non-corrosive' since the resistivity values here are from 326.1 to 1418.3 Ωm. The total longitudinal conductance in this zone is computed as 0.18 mhos which classifies the soil as having "weak" aquifer protective capacity.

VES 2: This station is located at Latitude 08°58'24.8" N and Longitude 007°04'15.4" E at an elevation of 212m. Five geoelectric layers are delineated at this zone. Uppermost sediments (less than 1.5m thick) are characterized by top soil materials which are mostly porous and permeable with high resistivity. The lowest resistivity value was 37.2 Ωm was observed in the clay layers at a depth of 8.4m. Soil within this layer is characterized as "Moderately Corrosive". Above and below this layer, the soils are characterized as 'non-corrosive' since the resistivity values here are from 343.3 to 1770.2 Ωm. The total longitudinal conductance in this zone is computed as 0.20 mhos which classifies the soil here as having "moderate" aquifer protective capacity.

VES 3: This station is located at Latitude 08°58'23.9" N and Longitude 007°04'4" E at an elevation of 213m. Four geoelectric layers are delineated at this zone. Soil layers at this zone are characterized by porous and permeable top soil materials and clay minerals. The clay material is observed to be the cause of the low resistivity. Low resistivity value of 42.4 Ωm was observed at the clay layer at 9.1 m depth. Soil layers here are characterized as "moderately Corrosive". Above and below this layer, the soils are characterized as 'non-corrosive' since the resistivity values here are from 219.3 to 989.0 Ωm. The total longitudinal conductance in this zone is computed as 0.20 mhos which classifies the soil here as having "moderate" aquifer protective capacity.

VES 4: This station is located at Latitude 08°58'15.9" N and Longitude 007°04'5.1" E at an elevation of 213m. Five geoelectric layers are delineated at this zone. This zone showed high resistivity values up to 1101.3 Ωm at a depth greater than 37.2 m. Soil layers in this zone are characterized as "Non-Corrosive" except within 2.7 to 10.1m depth where clay minerals with resistivity values are observed to be between 29.1 and 96.5 Ωm and classified as "slightly to moderately corrosive". The total longitudinal conductance in this zone is computed as 0.30 mhos which classifies the soil here as having "moderate" aquifer protective capacity.

VES 5: This station is located at Latitude 08°58'22.4" N and Longitude 007°03'59.1" E at an elevation of 213m. Five geoelectric layers are delineated at this zone. Low resistivity value of 52.1 Ωm was observed at a depth of 10.6 m due to 8.2 m thick clay material. The soil in this layer is characterized as "moderately Corrosive". Other soil layers above or below this layer with high resistivities ranging from 313.0 to 944.8 Ωm are classified as "Non-corrosive". The total longitudinal conductance in this zone is computed as 0.21 mhos classifying the soil here as having "moderate" aquifer protective capacity.

VES 6: This station is located at Latitude 08°58'24.1" N and Longitude 007°04'16.8" E at an elevation of 212m. Four geoelectric layers are delineated at this zone. This zone showed low resistivity value of 56.3 Ωm at a depth of 11.1 m within the clay material of 9.4 m thickness. Soil layers in this layer are characterized as "Moderately Corrosive" except within the top 1.7 m depth where resistivity value of 139.7 Ωm was observed and classified as "slightly corrosive". From the depth of 48.8 m and below, the soil layers are classified as "Non-corrosive". The total longitudinal conductance in this zone is computed as 0.24 mhos which classifies the soil here as having "moderate" aquifer protective capacity.

VI. Conclusion and Recommendation

The study reveals that resistivity values vary within different soil layers at the various VES stations due to the mineralogical composition of the different rock types which weathered to constitute the soil. Very low resistivity values are observed to be prevalent in zones with high clay rock forming minerals and these mainly contributed to the "slight to moderate" corrosivity of the soils. Different soil layers have different degrees of corrosivity. Soils are "moderately corrosive" in the clay layer within the depths of 8.8, 8.4, 9.1, 10.1, 10.6 and 11.1 m respectively at the VES stations and "slightly corrosive" at VES 1 at a depth of 11.2 m, VES 4 at 2.7 m and VES 6 at 1.7 m.

Two aquifer protective capacity zones, deduced from the longitudinal conductance: weak, 0.18 mhos and moderate 0.20–0.30 mhos are delineated. The weak aquifer protective capacity zones coincide with zones of shallow or thin overburden with sand column and high resistivity while the moderate zones coincide with zones of appreciable overburden thicknesses and low electrical resistivity with clay column. The results reveal that the weak aquifer protective capacity zones are vulnerable to anthropogenic pollution sources (mines waste disposal, acid deposition, sewage sludge, municipal wastes, water sludge, urban composts, atmospheric deposits and other industrial chemicals and wastes) in the area. The moderate aquifer protective capacity zones have higher tendency of resisting the permeation of contaminant fluids such that in any event of contamination such zones are apparently safe.

Consequent upon the findings of this study, it is recommenced that underground metallic installations such as civil engineering constructions; storage tanks; utility pipelines; fences; electricity powerlines, mobile communication cables should be buried at depths away from these corrosive zones (8.4 to 11.1 m) in order to reduce the effect of corrosion and prolong the lifespan of such metallic facilities.

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