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GEOPHYSICAL INVESTIGATION FOR ENVIRONMENTAL HYDRO-HAZARD ANALYSES IN MAKARFI TOWN, NORTH-WESTERN NIGERIA.

Ahmed A. L[1]., Adukwu G. O[2]., Abubakar A[3]. and Dewu B. B. M[4]

[1]Department of Physics, Ahmadu Bello University, Zaria;
[2]Dept. of Physics & Astronomy, University of Nigeria, Nsukka;
[3]Department of Physics, University of Maiduguri, Maiduguri, Nigeria;
[4]Centre for Energy Research & Training, Ahmadu Bello University, Zaria.

Abstract

Geophysical investigation for hydro-hazard studies was undertaken at Makarfi town which falls within the Basement Complex of North-Western Nigeria. The study was aimed at assisting in the planning and developmental process of the undeveloped part of a College site in Makarfi town. Vertical Electrical Sounding (VES) using Schlumberger Array was conducted at 55 sounding stations. The data obtained were subjected to IP12Win software to determine the layer parameters from which the Dar-Zarrouk Parameter for each sounding point was calculated. The Longitudinal Unit Conductance values were contoured using Surfer-8 which revealed that the Overburden Protective Capacity of the superficial deposits in the environment is generally poor, constituting about 25%, and varied from less than 0.100mhos (good) on the north-west and south-west flank of the study area. Thus, the hydrogeologic system at the College site is vulnerable to contamination. Hence, the result reasonably provides a basis for which groundwater potential zones are appraised for safety in case potential sources of contamination sites such as septic tanks, sewage channels, waste landfills et cetera are planned for the area under study. Likewise, the Soil Corrosivity map shows that the southern to eastern portion of the area are characterized by slightly corrosive to strongly corrosive overburden. corrosion-prevention system ought to be considered at engineering design stages of metal-fortified structures to be used within the College site. This study presents soil corrosion and overburden protection as environmental hazard-prone factors that need be considered at the planning stages of civil engineering structures within the study area.

***Keywords*: *Environmental Hazards, Longitudinal Unit Conductance, Overburden Protective Capacity, Soil Corrosivity, Metal-fortified Structures*.**

1.0 Introduction

The development of new towns as well as new college site generally require a detailed subsurface survey of the site so proposed with respect to evaluating the environmental hazards associated with the hydro-geologic system in the area. The derivatives of such subsurface information usually assist Civil engineers, builders and town planners in the design and siting of metal-fortified civil engineering structures. The survey may actually involve the evaluation of the existing hydro-geologic setting, surface water resources, existing geotechnical parameters and geological setting [1].

As population in Makarfi town increases with the attendant difficulty inherent in non-availability and purification of surface water in the area, excessive pressure will be mounted on the existing borehole. Therefore, it becomes imperative to locate other viable areas suitable for tapping groundwater to augment the existing borehole.

However, delineating the aquifer units viable for future groundwater abstraction alone is not on its own satisfactory. The need to ascertain the degree of the Overburden Protective Capacity which overlies the aquifer units is paramount. The protective capacity of the overburden materials enables scientists to establish the level of safety of the hydro-geologic system in the study area vis-à-vis contaminating structures such as septic tanks, waste landfills, and sewage channels if they are not far-detached from the promising areas that are viable for future groundwater development.

Corresponding Author**:** Ahmed A.L., Email: aminuahmed777@gmail.com, Tel: +2348037051464

Similarly, overburden corrosivity as another environmental hazard can lead to severe corrosion failure of metal-fortified structures and these failures are known to be linked with low resistivity. Low resistivity values and corrosion are enhanced by moisture. Therefore, evaluating the corrosivity of the subsurface materials is necessary in making recommendations for the nature of engineering materials to be used for subsurface structures in the study area which formed the main goal of this study.

2.0 Location and Brief Geographic Description of the Area

The study area hosts the Shehu Idris College of Health Science and Technology, Makarfi. It lies between Latitudes 11^0 21′ 08.9″N - 11^0 21’ 37.5” N and Longitudes7^0 53’07.1″ E - 7^0 53’ 46.0” E. The site is situated along the Zaria-Kano expressway, at about 16 km northeast of Zaria (Fig 1). The topography is that of high plain (flat terrain) of Hausa land. The site is located within the tropical climatic belt with Sudan Savannah Vegetation (SSV). The environment is Savannah type with distinct wet and dry season. The rainfall regime is simple but with slight variation which consists of wet season lasting from May to September. Temperature ranges between 24^0C to 31^0C reaching a maximum of about 36^0C around April [2].
Makarfi is within the area underlain by the crystalline rock of the basement complex of Nigeria. The basement complex of Nigeria forms part of the African Crystalline Shield in Northwest Nigeria. The major crystalline rocks are porphyritic granite, biotite granites, charnockite, quartizite and gneiss migmatite. Makarfi area is within the northern Nigeria basement complex (Fig. 1).The rocks typically found within the basement complex include gneisses, migmatites, metasediments and some intercalation of amphibolites. Exposures are scanty and highly weathered. The rock types are biotite, gneisses, granite gneisses and are in parts with subordinate migmatites [3].

2.1 ***Accessibility*****:** Accessibility is generally very good via a network of motorable (main) roads and few minor foot-paths.

2.2 ***Drainage*****:** Laminar drainage patterns predominate the area. This pattern is enhanced by the resistance of the underlying crystalline basement rocks.

2.3 ***Vegetation*****:** The vegetation is predominantly grassland savannah with sparse and scattered stunted trees that survive dry conditions. The area has trees of low and middle height with shrubs and herbs being absent.

2.4 ***Weathering*****:** Physical and mechanical weathering predominates. The mineral composition of the crystalline material first gives lateritic weathering leading to a gradual change to silt and clay materials.

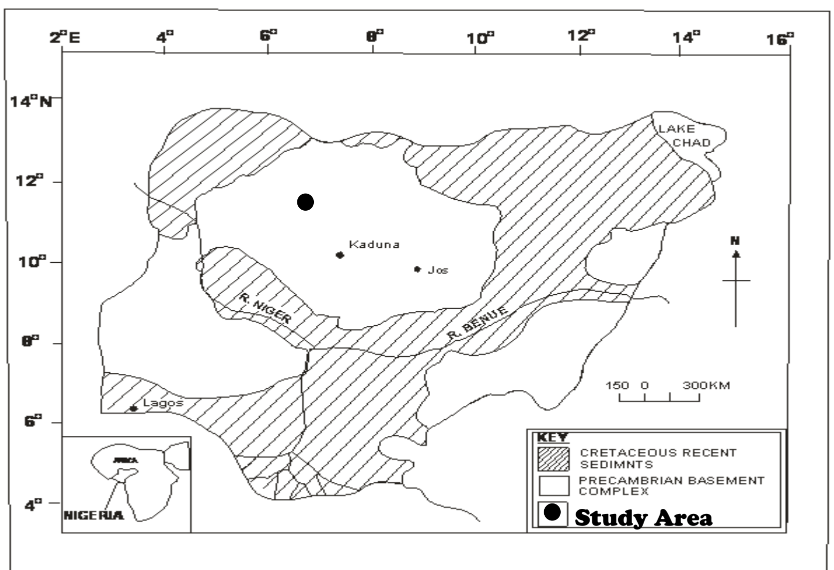

Figure 1: Location of Makarfi on the Basement Complex [4]

3.0 Methods and Materials

Vertical Electrical Sounding (VES) using Schlumberger Array were carried out at 55 stations along profiles as shown in figure 2. Overburden in the Basement is not as thick as to warrant large current electrode spacing for deeper penetration, therefore the largest current electrode spacing AB used was 200m. That is ½(AB) =100m. The principal instrument used for the survey is ABEM (Signal Average System, SAS300) Terrameter.

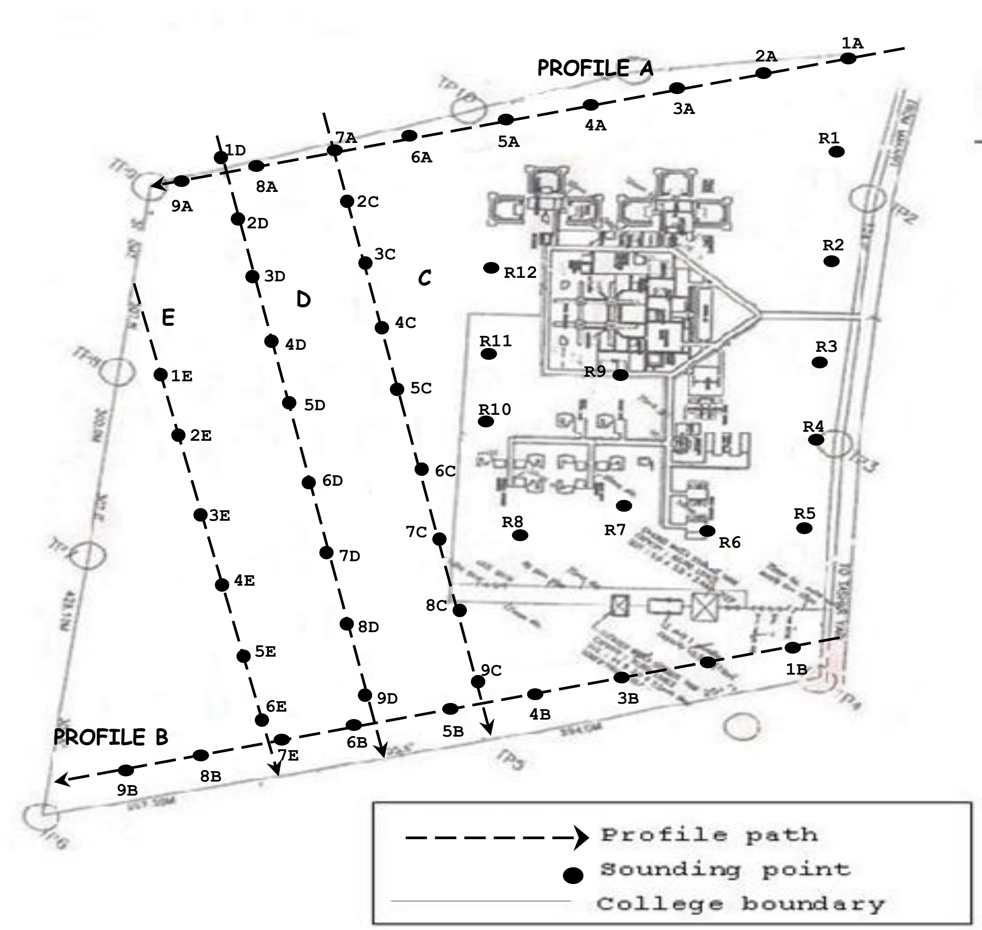

Figure 2: The site plan of the survey area showing the profiles and the VES sounding points.

The resistance reading at every VES point was automatically displayed on the device screen and then written down on paper. The GARMIN 12 channel personal navigation Global Positioning System (GPS) receiver unit was used to take the coordinate of the location of the electrical sounding points and the boundary of the survey area. The plan map of the survey area showing the survey profiles and sounding points is as shown in figure 2. The geometric factor, K, was calculated using the formula;

$$K_{(\text{Geometric Factor})} = \pi\left(\frac{L^2}{2b} - \frac{b}{2}\right) \qquad (1)$$

for Schlumbereger array with MN =2b and ½ AB =L. The Values obtained were the multiplied with the resistance values to obtain the apparent resistivity, ρa values. Then the apparent resistivity ρa values were plotted against the electrode spacings (1/2 AB) on a log-log scale to obtain the VES Sounding curves using IP12 Win software.

4.0 Results and Discussion

The VES results gave the layer parameters which were used to calculate the Dar-Zarrouk Parameter (Tables 1a-e).

Table 1(a): Profile A

VES Station	**Station coordinate**	**Layer**	**Layer Resistivity (Ωm)**	**Thickness (m)**	**Depth (m)**	Dar Zarrouk Parameter(mhos) $S = \sum_{i=1}^{n-1} \frac{h_i}{\rho_i}$	**Inferred/possible lithology**
1A	$11^0$21'45.8"N $07^0$53'45.0"E	1	152	1.23	1.23	0.010	Top soil
		2	113	0.70	1.93		Weathered layer
		3	426	9.69	11.6		Fractured basement
		4	1329	-	∞		Fresh basement
2A	$11^0$21'45.2"N $07^0$53'41.8"E	1	45	2.28	2.28	0.123	Top soil
		2	171	12.3	14.5		Weathered layer
		3	1765	-	∞		Fresh basement
3A	$11^0$21'44.4"N $07^0$53'38.6"E	1	48	1.71	1.71	0.073	Top soil
		2	298	11.2	12.9		Weathered layer
		3	2643	-	∞		Fresh basement
4A	$11^0$21'44.0"N $07^0$53'35.6"E	1	48	1.13	1.13	0.042	Top soil
		2	326	5.96	7.09		Weathered layer
		3	433	11.6	18.7		Fractured basement
		4	2112	-	∞		Fresh basement
5A	$11^0$21'43.4"N $07^0$53'32.4"E	1	196	1.33	1.33	0.012	Top soil
		2	152	0.78	2.11		Weathered layer
		3	245	10.2	12.3		Fractured basement
		4	1960	-	∞		Fresh basement
6A	$11^0$21'42.8"N $07^0$53'29.2"E	1	257	2.64	2.64	0.338	Top soil
		2	114	37.36	40.0		Weathered layer
		3	1410	-	∞		Fresh basement
7A	$11^0$21'42.2"N $07^0$53'26.2"E	1	249	1.2	1.2	0.076	Top soil
		2	169	12.1	13.3		Weathered layer
		3	1309	-	∞		Fresh basement
8A	$11^0$21'41.6"N $07^0$53'23.0"E	1	154	1.37	1.37	0.020	Top soil
		2	199	2.14	8.51		Weathered layer
		3	152	15.2	18.70		Fractured basement
		4	1289	-	∞		Fresh basement
9A	$11^0$21'41.0"N $07^0$53'20.0"E	1	53.5	2.09	2.09	0.317	Top soil
		2	20.6	5.73	7.82		Weathered layer
		3	153	26.4	34.2		Fractured basement
		4	1144	-	∞		Fresh basement

Table 1(b): Profile B

VES Station	Station coordinate	Layer	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Dar Zarrouk Parameter(mhos) $S=\sum_{i=1}^{n-1}\frac{h_i}{\rho_i}$	Inferred/possible lithology
1B	11^{0}21'18.7"N 07^{0}53'38.4"E	1	373	1.43	1.43	0.035	Top soil
		2	221	6.8	8.23		Weathered layer
		3	473	17.0	25.30		Fractured basement
		4	1251	-	∞		Fresh basement
2B	11^{0}21'17.2"N 07^{0}53'34.9"E	1	370	1.65	1.65	0.208	Top soil
		2	77.6	15.7	17.4		Weathered layer
		3	503	20.4	37.8		Fractured basement
		4	1161	-	∞		Fresh basement
3B	11^{0}21'16.5"N 07^{0}53'31.6"E	1	276	1.06	1.06	0.040	Top soil
		2	351	12.8	13.9		Weathered layer
		3	522	11.0	24.9		Fractured basement
		4	1197	-	∞		Fresh basement
4B	11^{0}21'16.0"N 07^{0}53'28.1"E	1	304	2.02	2.02	0.016	Top soil
		2	593	5.51	7.53		Weathered layer
		3	834	17.4	25.00		Fractured basement
		4	2019	-	∞		Fresh basement
5B	11^{0}21'15.4"N 07^{0}53'24.7"E	1	257	2.64	2.64	0.235	Top soil
		2	144	32.36	35.00		Weathered layer
		3	1410	-	∞		Fresh basement
6B	11^{0}21'14.9"N 07^{0}53'21.2"E	1	256	2.96	2.96	0.096	Top soil
		2	391	33.04	36.00		Weathered layer
		3	1450	-	∞		Fresh basement
7B	11^{0}21'14.6"N 07^{0}53'18.0"E	1	272	1.87	1.87	0.082	Top soil
		2	228	17.13	19.00		Weathered layer
		3	1362	-	∞		Fresh basement
8B	11^{0}21'13.9"N 07^{0}53'14.4"E	1	367	4.14	4.14	0.024	Top soil
		2	298	3.85	7.99		Weathered layer
		3	1765	-	∞		Fresh basement
9B	11^{0}21'13.2"N 07^{0}53'11.0"E	1	353	1.54	1.54	0.014	Top soil
		2	708	6.58	8.13		Weathered layer
		3	3115	-	∞		Fresh basement

Table 1(c): Profile C

VES Station	Station coordinate	Layer	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Dar Zarrouk Parameter(mhos) $S=\sum_{i=1}^{n-1}\frac{h_i}{\rho_i}$	Inferred/possible lithology
1C	11^{0}21'39.4"N 07^{0}53'23.2"E	1	72.8	1.67	1.67	0.038	Top soil
		2	219	3.33	5.00		Weathered layer
		3	2045	-	∞		Fresh basement
2C	11^{0}21'36.0"N 07^{0}53'23.6"E	1	83.6	1.99	1.99	0.116	Top soil
		2	218	20.1	22.1		Weathered layer
		3	396	12.90	35.0		Fractured basement
		4	1396	-	∞		Fresh basement
3C	11^{0}21'32.6"N 07^{0}53'24.0"E	1	245	1.25	1.25	0.036	Top soil
		2	196	6.05	7.31		Weathered layer
		3	526	26.3	33.6		Fractured basement
		4	1215	-	∞		Fresh basement

4C	11^{0}21'29.2"N 07^{0}53'24.4"E	1	245	1.24	1.24	0.016	Top soil
		2	190	2.02	3.26		Weathered layer
		3	1931	-	∞		Fresh basement
5C	11^{0}21'25.8"N 07^{0}53'24.8"E	1	211	5.49	5.49	0.063	Top soil
		2	408	15.00	20.5		Weathered layer
		3	1520	-	∞		Fresh basement
6C	11^{0}21'22.4"N 07^{0}53'25.2"E	1	38	1.25	1.25	0.053	Top soil
		2	520	10.6	11.8		Weathered layer
		3	1520	-	∞		Fresh basement
7C	11^{0}21'19.0"N 07^{0}53'25.6"E	1	39	1.26	1.26	0.044	Top soil
		2	114	1.37	2.62		Weathered layer
		3	1287	-	∞		Fresh basement
8C	11^{0}21'15.6"N 07^{0}53'26.0"E	1	452	1.31	1.31	0.013	Top soil
		2	133	1.37	2.68		Weathered layer
		3	1233	-	∞		Fresh basement
9C	11^{0}21'12.2"N 07^{0}53'26.4"E	1	55	0.25	0.25	0.019	Top soil
		2	120	4.77	5.03		Weathered layer
		3	1329	-	∞		Fresh basement

Table 1(d): Profile D

VES Station	**Station coordinate**	**Layer**	**Layer Resistivity (Ωm)**	**Thickness (m)**	**Depth (m)**	Dar Zarrouk Parameter(mhos) $S = \sum_{i=1}^{n-1} \frac{h_i}{\rho_i}$	**Inferred/possible lithology**
1D	11^{0}21'40.3"N 07^{0}53'16.3"E	1	26	1.13	1.13	0.051	Top soil
		2	316	2.33	3.46		Weathered layer
		3	1270	-	∞		Fresh basement
2D	11^{0}21'36.7"N 07^{0}53'17.0"E	1	28	2.64	2.64	0.124	Top soil
		2	302	8.84	11.50		Weathered layer
		3	1410	-	∞		Fresh basement
3D	11^{0}21'33.1"N 07^{0}53'17.7"E	1	28	0.38	0.38	0.045	Top soil
		2	162	5.10	5.48		Weathered layer
		3	3699	-	∞		Fresh basement
4D	11^{0}21'29.5"N 07^{0}53'18.4"E	1	199	6.58	6.58	0.033	Top soil
		2	2935	-	∞		Fresh basement
5D	11^{0}21'25.9"N 07^{0}53'19.1"E	1	347	2.64	2.64	0.008	Top soil
		2	2593	-	∞		Fresh basement
6D	11^{0}21'22.3"N 07^{0}53'19.8"E	1	261	6.08	6.08	0.023	Top soil
		2	3307	-	∞		Fresh basement
7D	11^{0}21'18.7"N 07^{0}53'20.5"E	1	254	1.5	1.5	0.009	Top soil
		2	358	1.1	2.6		Weathered layer
		3	519	5.86	8.46		Fractured basement
		4	1519	-	∞		Fresh basement
8D	11^{0}21'15.1"N 07^{0}53'21.2"E	1	281	1.59	1.59	0.020	Top soil
		2	356	5.09	6.68		Weathered layer
		3	658	30.6	37.3		Fractured basement
		4	1614	-	∞		Fresh basement
9D	11^{0}21'11.5"N 07^{0}53'21.9"E	1	256	0.90	0.90	0.053	Top soil
		2	694	34.1	35.00		Weathered layer
		3	3511	-	∞		Fresh basement

Table 1(e): Profile E

VES Station	**Station coordinate**	**Layer**	**Layer Resistivity (Ωm)**	**Thickness (m)**	**Depth (m)**	Dar Zarrouk Parameter(mhos) $S = \sum_{i=1}^{n-1} \frac{h_i}{\rho_i}$	**Inferred/possible lithology**
1E	$11^0$21'31.3" N $07^0$53'13.8" E	1 2 3	200 14.1 1200	1.0 2.75 -	1.0 3.75 ∞	0.200	Top soil Weathered layer Fresh basement
2E	$11^0$21'27.8" N $07^0$53'14.3" E	1 2 3	350 27 1560	3.0 9.5 -	3.0 12.5 ∞	0.350	Top soil Weathered layer Fresh basement
3E	$11^0$21'24.3" N $07^0$53'14.9" E	1 2 3	180 31 2150	1.25 4.75 -	1.25 6.00 ∞	0.160	Top soil Weathered layer Fresh basement
4E	$11^0$21'20.9" N $07^0$53'15.3" E	1 2	750 1875	7.5 -	7.5 ∞	0.010	Top soil Fresh basement
5E	$11^0$21'17.4" N $07^0$53'15.8" E	1 2	277.7 1870	2.5 -	2.5 ∞	0.009	Top soil Fresh basement
6E	$11^0$21'14.1" N $07^0$53'16.4" E	1 2	600 1540	6.0 -	6.0 ∞	0.010	Top soil Fresh basement

The Overburden Protective Capacity in all areas of the school premises enabled the establishment of the level of safety of the hydrogeologic system for safety appraisal of groundwater consumption in the area. To achieve this, the total Longitudinal Unit Conductance was utilized in evaluating the overburden protective capacity in the area. This is because, the earth medium acts as a natural filter to percolating fluid like sewage from septic tanks, decaying matter from waste landfills, and hydrocarbon spills etc. Its ability to retard and filter percolating fluid is a measure of its Protective Capacity. The protective capacity of an overburden material, overlying an aquifer unit is proportional to the hydraulic conductivity, [5]. Hence, the protective capacity of the overburden can be considered as being proportional to the longitudinal unit conductance(S) defined as the ratio of the overburden thickness to its resistivity. The higher the overburden longitudinal conductance, the higher is the protective capacity [1]. According to [6] the second order parameter (Dar Zarrouk Parameter) is derived thus; for n-layers of earth model, the total longitudinal unit conductance (S) is given by;

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

However, considering the overburden materials alone (i.e. Neglecting the underlying infinite bedrock of infinite thickness and resistivity), the Longitudinal Unit Conductance (S) becomes;

$$S = \sum_{i=1}^{n-1} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \ldots + \frac{h_{n-1}}{\rho_{n-1}} \quad (3)$$

Where S = the total longitudinal unit conductance
h_i = the thickness of the i-th layer
ρ_i= the resistivity of the i-th layer
The protective capacity ratings (Table 2) adopted in this investigation is based on modified [7]. The modified rating table enables the zoning of the study area into good, moderate, weak and poor protective capacity zones. The modification involves the increase in protective capacity rating owing to the geologic and geoelectric complexity characterizing the basement rocks [8]. The longitudinal unit conductance map (Figure 3) therefore presents the protective capacity distribution of the study area. The underlying aquifer isoverlain by moderately thick overburden whose longitudinal conductance is presented in Table 2.

Table 2: Modified Longitudinal Conductance/Protective Capacity Rating [7]

Total Longitudinal Unit Conductance (mhos)	Soil Protective Capacity Classification
< 0.1	Poor
0.1 – 0.19	Weak
0.2 – 0.69	Moderate
0.7 – 4.9	Good
5 – 10	Very Good
> 10	Excellent

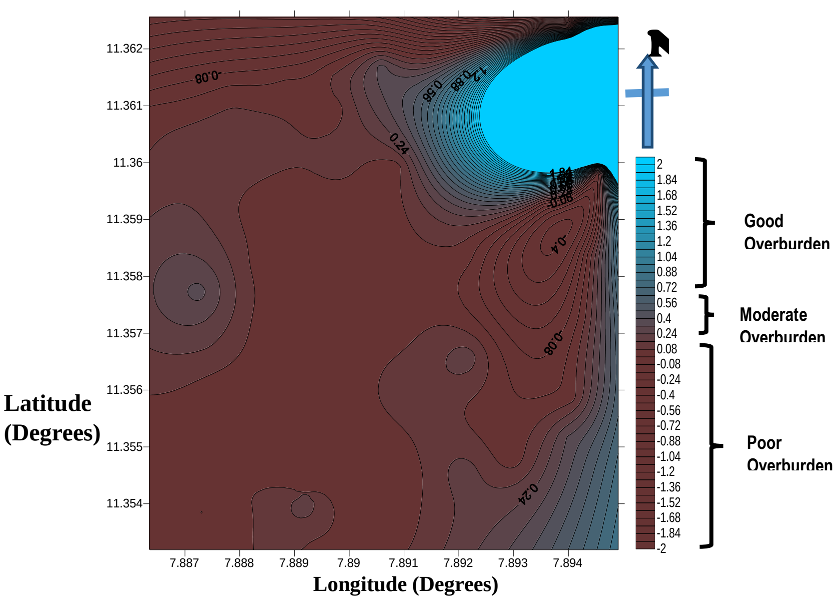

Figure. 3: Overburden Protective Capacity Map

Overburden protection capacity of the superficial deposits in the environment varies from 2.000mhos (good) on the northeastern flank of the area to less than 0.100mhos (poor) on the northwest and southwest flank. Generally, the map shows that the aquifer protective capacity within the study area is rated poor (< 0.1mhos), moderate (0.2 – 0.69mhos) and good (0.7 – 4.9mhos), though the area with poor protection capacity predominates (figure 3). This implies that nearly all the overburden material overlying the aquifer in the area have poor protective capacity with the exception of small areas underlying the northeastern part of the area which are characterized by materials of good protective capacity. Fresh groundwater protection in the environment is envisaged to be vulnerable to contamination while very deep aquifer units with thick overlying overburden column are also less likely to meet protection requirement from the result analysis.

4.1 Soil Corrosivity

Similarly, Soil corrosivity as environmental hydro-hazard can lead to severe corrosion failure and is known to be associated with low resistivity which is enhanced by moisture content. Low electrical resistivities are indicative of good electrical conducting paths arising from reduced aeration, increased electrolyte saturation or high concentration of dissolved salts or ions in the soil. [9]. According to [10], soil resistivity classified in terms of the degree of soil corrosivity is as shown in

Table 3.For medium-to-massive civil engineering structures, the depth of foundation ranges from the weathered layer to bedrock respectively [1]. The areas considered to be of high corrosivity with resistivity values being of the order of 180 and less are at the central portion of the area extending between southern to the eastern part (Figure 4). A small portion on the southern flank is also prone to corrosion. These areas are characterized by low resistivity and high moisture content.

Table 3: Classification of soil resistivity in terms of the corrosivity [10]

Soil Resistivity (Ωm)	**Soil Corrosivity**
< 10	Very strongly corrosive (VSC)
10 – 60	Moderately corrosive (MC)
60 – 80	Slightly corrosive (SC)
> 180	Practically non-corrosive (PNC)

The degree of soil corrosivity within the study site varies from slightly corrosive (>200Ωm) to very strongly corrosive (<0.200Ωm) on the south-eastern part (Figure 4). Engineering use of metal-fortified structures in the Shehu Idris College of HealthScience and Technology project implementation should consider the incorporation of corrosion prevention system in these areas. For underground piping facilities, plastic pipes may be considered in the areas that are prone to corrosion.

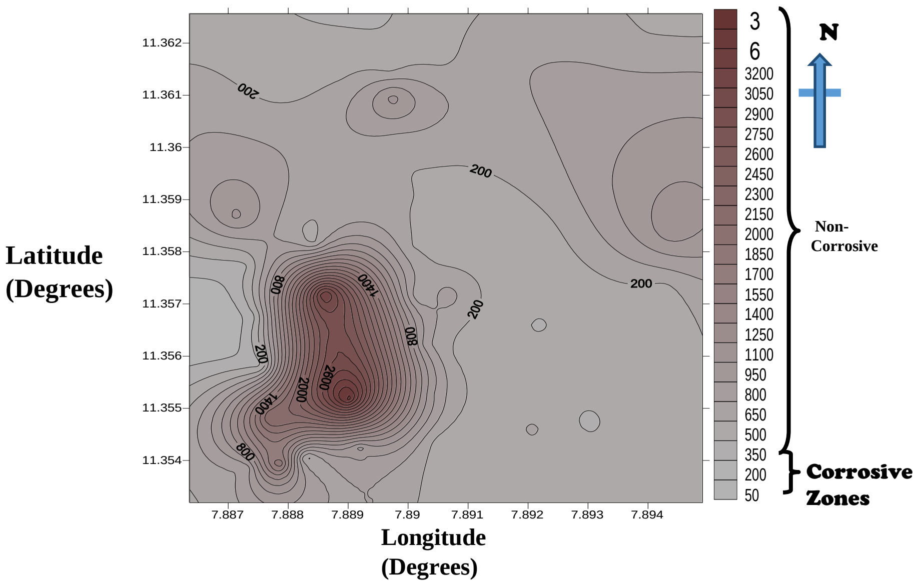

Fig. 4: **Soil Corrosivity Map**

5.0 Conclusion

The Longitudinal Conductance map has shown that the generality of the entire study area is underlain by materials of poor to moderate protective capacity. This suggests the vulnerability of the groundwater in the area if there is leakage of buried underground sewage tanks or an infiltration of leachates from decomposing refuse dumps in any region within the studied area. The study of the Overburden Protective Capacity in the area revealed that the aquifer is largely poorly protected. Hence, there is need to site potential sources of aquifer contamination site such as sewage tank and waste disposal sites away from the promising aquifer units to enhance safety appraisal of groundwater consumption in the area. Civil engineering structures involving underground piping utilities should be coated with corrosion prevention system to prevent corrosion as some of the areas are liable to corrosion. As an alternative, the piping utilities should be made of plastics instead of metals.These results so far, have highlighted a set of environmental hydro-hazard factors which are failure of metal-fortified structures and Overburden Protective Capacity.

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