Geophysical Characterisation of Native Clay Deposits in Some Parts of Niger State, Nigeria

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Abstract: Clay minerals are among the world's most important and useful industrial minerals. Conductance, transmissivity and corrosity are some physical parameters for determining quality clay. Four (4) clay deposit sites in Kaffin-Koro, Dutse, Dogon-Ruwa and Kushikoko were investigated to evaluate corrosivity, the longitudinal conductance and transmissivity to determine the clay quality. Electrical resistivity method employing Schlumberger electrode array was used to determine the thicknesses and depths of the subsurface strata while Interpex 1xD software was used to interpret the data. Three (3) to four (4) layer earth models were delineated. Kaffin-Koro and Dutse showed three layer models while Dogon-Ruwa and Kushikoko revealed four layers. Moderate clay content was found in Kaffin-Koro in the second layer with longitudinal conductance value of 0.4780 siemens and thickness 0.770m at depth of 1.17m Dogon-Ruwa also had moderate clay content in the third layer with conductance value of 0.237 siemens, depth of 2.43m and thickness 1.76m. Kushikoko had low clay deposit in the second layer with conductance 0.1810 siemens and thickness 2.73 m at 4.37 m while the clay deposit in Dutse appeared to be generally poor as the longitudinal conductance values of the top two layers were less than 0.1 siemens.

Keyword : Apparent resistivity, clay, corrosivity, longitudinal conductance, transmissivity

1. Introduction

Clay is among the earliest and most important minerals utilized by humans in industrial and other applications (Gina et al., 2020). Its records are preserved in buildings, on monuments, pottery and as inscriptions on clay tablets (Rozynek et al., 2013). Clay minerals are also globally recognized as one of the most important industrial minerals of great significance (Rozynek et al., 2013). For instance, they are a major constituent in construction as bricks and tiles. Therefore, the physical and chemical properties of clay minerals determine their potential for utilization for industrial purposes (Georges et al., 2018).

In domestic applications for example, clay is used extensively in pottery, earthenware, cooking ware, vases, plumbing fixtures, tiles, porcelain wares and ornaments (Gina et al., 2020). In the electricity industry, it is used for conduits, sockets insulators and switches (Faheem, 2008). It is also used on a large scale to make refractory wares such as fire bricks, furnace linings, chemical stone wares, crucibles and retorts (Gina et al., 2020). In addition, clay minerals are used in geological applications such as stratigraphic correlations, indicators in environments of mineral deposits and to measure temperature for generation of hydrocarbons (Obaje, 2013).

Data by the Nigeria Geological Survey Agency suggests that some 34 major clay mineral deposits are distributed across Nigeria that may be attractive to investors (Obaje, 2013). Deposits of clay in mineable commercial quantities have been documented to occur in most of the States in Nigeria, including Niger (Obaje, 2013). For practical industrial purposes, some of the most important properties to consider in selecting high quality clay include conductance, transmissivity, plasticity, corrosivity, shrinkage, fusibility and color (Totsche et al., 2018).

Electrical resistivity methods have been extensively used for evaluation of the transmissivity, conductance and corrosivity of the subsurface. The most common methods are the electrical profiling and vertical electrical sounding (VES) using four-electrode probes in Wenner or Schlumberger configurations. In this work, emphasis was placed on understanding the vertical stratification of the subsurface, hence the Schlumberger array which provides better resolution and takes less time to deploy, was used for the data collection. Some successful applications of the methods on accessing quality of forest soils have been reported in McBride *et al*., (1990), mapping water flow paths and finding perched water locations (Freeland *et al*., 1997), estimation of hydraulic conductivity (Mazac *et al*., 1990) and texture of the stratified soils and sediments (Banton *et al*., 1997). Barker (1990) also applied VES to a landfill outlining. The method has also been used by Kibria and Hossain (2019) to determine the electrical resistivity response of clay minerals and by Gingine *et al*.; (2016) to investigate the compaction control of clayey soils. The VES method was therefore, applied in this study for adequate evaluation of clay soil deposits with a view to determining the longitudinal conductance, transmissivity and clay overburden so as to determine the corrosivity or otherwise of the clay deposits.

1.1. Geology of Niger State

Niger State is covered by two major rock formations: the sedimentary rocks to the south characterised by sandstones and alluvial deposits, particularly along the Niger valley and in most parts of Borgu, Bida, Agaie, part of Lapai, Mokwa, Lavun, Gbako and Wushishi LGAs.

The basement complex area falls within the general geology of the basement complex of Nigeria where three major petro-lithological units are distinguishable, namely:

Migmatite – Gneisses, Schists, and Older Granites. The Migmatite – Gneiss Complex is generally considered as the basement complex *sensu stricto* (Rahaman, 1988) and it is the most widespread of the component units in the Nigerian basement. Kaffin-Koro, Dogon-Ruwa, Kashikoko and Dutse where data was collected belong to the basement complex. Schistose rocks are also very abundant in the areas which also show some dominance of older Granites in the bedrock cover.

2. Materials and Methods

2.1. Materials

The materials used for the collection of data included Geotron resistivity meter (G41), Cable reels, non-polarizable electrodes, measuring tapes, Hammers, recording materials, Ground Positioning System Device and Interpex 1D Sounding Inversion Software (1D-SIS).

2.2. Methods

Clay deposit sites in four (4) locations (Kaffin-Koro, Dutse, Dogon-Ruwa & Kushikoko) were studied for adequate evaluation of clay deposits, with a view to determining the longitudinal conductance, transverse resistivity and clay overburden so as to determine the corrosivity of the deposits. The information would lead to determining the quality and grade of the clay under study.

The four electrode arrangement (Figure 1), where current *I* is applied on electrodes A and B and the potential drop ΔU is measured between the potential electrodes M and N, was used. The apparent soil resistivity (ρ_a) was calculated using:

$$\rho_a = K\frac{\Delta U}{I} \tag{1}$$

where *K* is the geometric factor

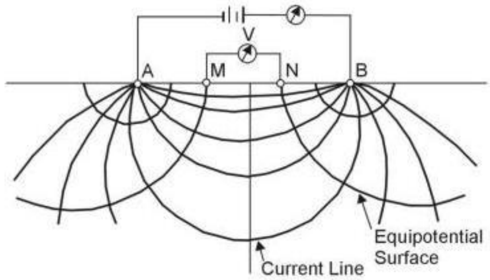

Figure 1. Transmission of current in the ground

In the Schlumberger Array, the current electrodes are placed much further apart than the potential electrodes and spread out symmetrically about the sounding point. If S is mid-point and M, N are symmetrical about *S* so that the distance MN is $2r$ and AS = BS = L then

$$\rho_a = \frac{2\pi\Delta U}{I}\left(\frac{4r}{L_{2-r_2}}\right)^{-1} \tag{2}$$

$$\text{For } L \gg r,\ \rho_a = \left(\frac{\pi r^2}{2I}\right)\frac{\Delta U}{L} \quad (3)$$

where: $\frac{\pi r^2}{2I} =$ Array constant (4)

2.3. Clay Soil Protective capacity and Transmissivity

The protective capacity and *transmissivity* of the clay soil was determined based on the first and second order geoelectric parameters. According to Nwankwo and Ehirim (2010), for n-1 layers overlying a semi-infinite substratum of resistivity ρ_n, the longitudinal conductance (S) is given as:

$$S_i = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \text{(siemens)} \quad (5)$$

where ρ_i and h_i are the layer resistivity and thickness of the ith layer respectively.

Transmissivity T was determined according to Nwankwo and Ehirim (2010) to know the level of permeability of an overburden soil using:

$$T_i = \sum_{i=1}^{n} \rho_i \,.\, h_i (\text{ohm}.m^2) \quad (6)$$

where p_i is the layer resistivity and h_i is the thickness of the ith layer.

If T values are >400 Ωm^2 and correspond to zones where the thickness and resistivities of the clay material are large, the clay materials is classified as poor.

2.4. Soil Corrosivity

Corrosion is the gradual chemical attack and degradation that results in the conversion of metallic materials into oxides, salts or other compounds (Elarabi and Elkhawad, 2014). It is usually accompanied by high degrees of environmental, human, agricultural and economic consequences. Areas characterized by relatively low resistivity values are considered corrosive while areas with high resistivity values are considered non corrosive. Sandy soils are high up on the resistivity scale and therefore, considered the least corrosive. Clay soils on the other hand have low resistivities and hence more corrosive. Table 1 shows soil corrosivity severity rating in terms of soil resistivity.

Table 1. Soil corrosivity severity rating (Roberge, 2000)

S/N	Soil Resistivity(ohm.m)	Corrosivity Rating
1	>200	Essentially noncorrosive
2	100 - 200	Mildly corrosive
3	50 - 100	Moderately corrosive
4	30 - 50	Corrosive
5	10 - 30	Highly corrosive
6	<10	Extremely corrosive

3. Results and Discussion

Results of the apparent resistivity data collected from various clay deposit sites are shown in Tables 2, 3, 4 and 5 for Kaffin-Koro, Dogon-Ruwa, Kashikoko and Dutse sites respectively.

Table 2. Schlumberger Sounding data sheet for Kaffin-Koro Site

S/N	AB/2 (m)	MN (m)	ρ_a (ohm-m) (Clay deposit) (Lat. 9°37.522; Long. 7°04.202	ρ_a (ohm-m) (Control) (Lat. 9°31.609; Long. 7°04.300
1	2	1	7.40	342.62
2	3	1	6.29	203.78
3	5	1	8.50	2160.50
4	8	1	14.66	910.85
5	10	1	21.73	1576.50
6	20	1	55.41	10847.24

Table 3. Schlumberger Sounding data sheet for Dogon-Ruwa (Along Minna-Bida Road)

S/N	AB/2 (m)	MN (m)	ρ_a (ohm-m) (Clay deposit) Lat. 9°27.149N; Long. 06°22.789E	ρ_a (ohm-m) (Control) Lat. 9°27.074N; Long. 06°22.681E
1	3	1	38.61	25.58
2	4	1	33.35	32.12
3	6	1	25.53	49.49
4	10	1	34.28	80.24
5	10	2	35.04	84.85
6	14	2	46.80	3161.68
7	20	2	81.15	590.12
8	20	6	84.91	582.38
9	30	6	122.65	237.34
10	40	6	160.55	
11	50	6	205.06	
12	60	6	249.53	

Table 4: Schlumberger Sounding data sheet for Kushikoko (Bida LGA)

S/N	AB/2 (m)	MN (m)	ρ_a (ohm-m) (Clay deposit) Lat. 8°92.587N; Long. 6°07.754E	ρ_a (ohm-m) (Control) Lat. 8°92.545N; Long. 6°07.794E
1	3	1.0	27.53	842. 00
2	4	1.0	26.35	663.58
3	6	1.0	28.61	920.50
4	8	1.0	34.23	990.88
5	10	2.0	40.56	1076.56
6	20	2.0	84.44	1419.84

Table 5. Schlumberger Sounding data sheet for Dutse in Mariga LGA (Along Kontagora –Mariga Road)

S/N	AB/2 (m)	MN/2(m)	ρ_a (ohm-m) (Clay deposit) Lat. 10°23.54N; Long. 5°28.35E	ρ_a(ohm-m) (Control) Lat. 10°23.50N; Long. 5°28.20E
1	3	1.0	80.01	19303.00
2	5	1.0	121.63	54214.33
3	8	1.0	206.36	75612.56
4	8	2.0	216.97	75472.52
5	10	2.0	283.82	115961.75
6	20	2.0	718.86	123460.00
7	25	2.0	905.44	126760.20

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These data were subjected to multiple iterations using interpex 1D interpretation software to generate layered earth models and depth logs at each of the clay sites as well as the control points. Figures 2, 3, 4 and 5 show the graphs of apparent resistivity (ohm.m) versus AB/2 (m) on the clay sites placed side by side with the depth logs for Kafin-Koro, Dogon-Ruwa, Kushikoko and Dutse sites respectively. Figure 6 is a graph of apparent resistivity (ohm.m) versus AB/2 (m) at one of the control points (the Kafin-Koro site).

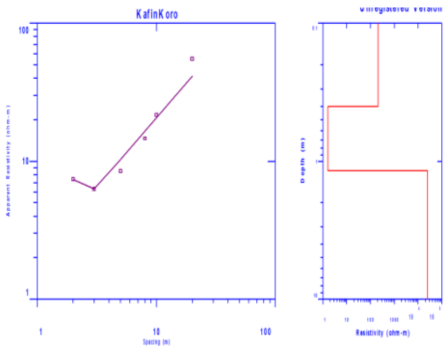

Figure 2. Kaffin-Koro clay site

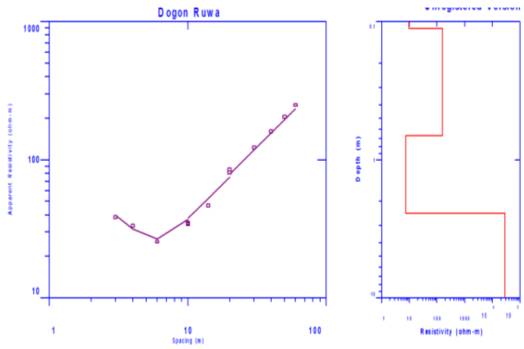

Figure 3. Dogon-Ruwa clay site

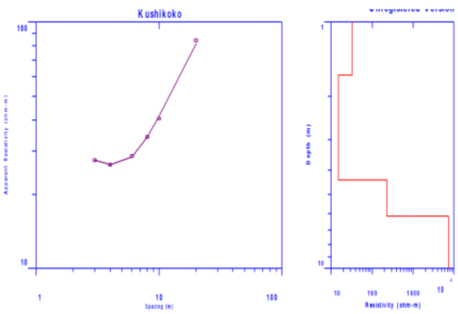

Figure 4: Kushikoko clay site

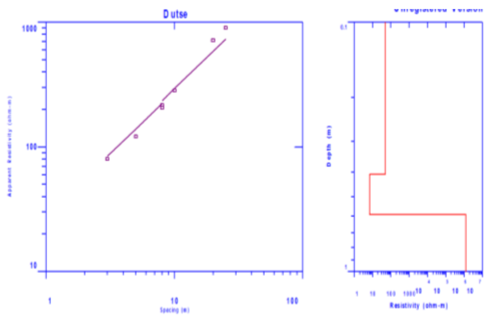

Figure 5: Dutse clay site

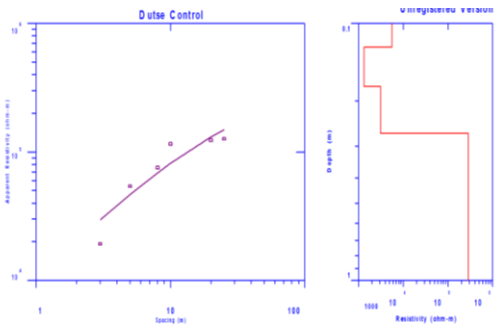

Figure 6: Dutse control point

The result of the iteration process revealed the average resistivity, the thickness and the depth of each layer. This information was then used to compute the longitudinal conductance and transmissivity of the layers using equations (5) and (6) respectively, with the intent of deciphering the quality of the clay deposits present at the sites. Tables 6 and 7 show the layered earth models showing the clay parameters on clay deposit sites and at the control stations respectively while Table 8 shows the corrosivity ratings.

Longitudinal conductance values less than 0.1 Siemens are established indicators that the overburden soil materials have no significant quantity of impermeable clay overlying strata which demonstrates high infiltration rates of surface contaminants or leachate, making the clay a low quality one.

Table 6. Characteristics of the layered earth model on clay sites

S/N	Site Des.	Layer	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Longitudinal Conductance (mhos)	Transmissivity (ohm.m^2)	Lithology	Rating of Clay composition	Corrosivity rating
1	Kaffin-KoroKafinkoro	1	207.60	0.401	0.401	0.0019	83.43	Sandy clay	Poor	Essentially noncorrosive
		2	1.60	0.770	1.17	0.4780	1.23	Clay	moderate	Extremely corrosive
		3	24671.50	-	-	-	-	Basement Rock	-	
2	Dogon-Ruwa	1	9.69	0.111	0.111	0.0115	1.08	Sandy clay	poor	Extremely corrosive
		2	155.40	0.558	0.670	0.0036	86.76	Clay	poor	Mildly corrosive
		3	7.46	1.76	2.43	0.2370	13.20	Fractured Basement	moderate	Extremely corrosive
		4	28810.70	-	-	-	-	Fresh Basement	-	
3	Kushikoko	1	32.56	1.64	1.64	0.0505	53.59	Sandy clay	poor	Corrosive
		2	15.02	2.73	4.37	0.1810	41.06	Clay	low	Highly corrosive
		3	228.30	1.76	6.14	0.0077	403.80	Fractured Basement	poor	Essentially noncorrosive
		4	7400.00	-	-	-	-	Fresh Basement	-	
4	Dutse	1	48.72	0.408	0.408	0.0084	19.90	Sandy clay	poor	Corrosive
		2	8.24	0.217	0.625	0.0263	1.79	Clay	poor	Extremely corrosive
		3	1.545 E+06	-	-	-	-	Basement Rock	-	

Table 7: Characteristics of the layered earth model at the control stations

S/N	Site Des.	Layer	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Longitudinal Conductance (mhos)	Transmissivity (ohm.m^2)	Lithology	Rating of Clay composition	Corrosivity rating
1	Kaffin-KoroKafinkoro	1	4604.10	0.407	0.407	0.00000885	1875.90	Top soil	very poor	Essentially noncorrosive
		2	48.15	0.380	0.787	0.000790	18.30	Clayey sand	very poor	Corrosive
		3	4463.40	0.320	1.10	0.00000717	1428.60	Sand	very poor	Essentially noncorrosive
		4	979831.50	-	-	-	-	Fresh Basement	-	
2	Dogon-Ruwa	1	4622.20	0.171	0.171	0.00000371	792.90	Top soil	very poor	Essentially noncorrosive
		2	8.32	0.522	0.694	0.0627	4.35	Clayey sand	very poor	Extremely corrosive
		3	2564.60	0.215	0.909	0.00000840	552.30	Sand	very poor	Essentially noncorrosive
		4	920981.10	-	-	-	-	Fresh Basement	-	
3	Kushikoko	1	26971.10	0.572	0.572	0.00000212	15451.70	Top soil	very poor	Essentially noncorrosive
		2	90.53	0.298	0.871	0.00330	27.03	Clayey sand	very poor	Moderately corrosive
		3	409.90	0.320	1.190	0.0000781	131.30	Sand	very poor	Essentially noncorrosive
		4	1715.40					Fresh Basement		
4	Dutse	1	5595.00	0.123	0.123	0.00000221	692.80	Top soil	very poor	Essentially noncorrosive
		2	1328.00	0.052	0.175	0.00000392	69.15	Clayey sand	very poor	Essentially noncorrosive

S/N	Site Des.	Layer	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Longitudinal Conductance (mhos)	Transmissivity (ohm.m^2)	Lithology	Rating of Clay composition	Corrosivity rating
		3	3097.30	0.910	0.266	0.00000294	282.00	Sand	very poor	Essentially noncorrosive
		4	283009.80	-	-	-	-	Fresh Basement	-	

Table 8: Clay resistivity values of the present study with corrosivity ratings based (Roberge, 2000)

S/N	Site Description	Layer	Resistivity (ohm-m)	Corrosivity Rating
1	Kaffin-Koro	1	207.60	Extremely corrosive
		2	1.60	Extremely corrosive
		3	24671.50	Essentially corrosive
2	Dogon- Ruwa	1	9.69	Extremely corrosive
		2	155.40	Extremely corrosive
		3	7.46	Extremely corrosive
		4	28810.70	Essentially corrosive
3	Kushikoko	1	32.56	Extremely corrosive
		2	15.02	Extremely corrosive
		3	228.30	Extremely corrosive
		4	7400.00	Moderately corrosive
4	Dutse	1	48.72	Extremely corrosive
		2	8.24	Extremely corrosive
		3	1.545E+06	Essentially non-corrosive

A profile of clay soil is strongly differentiated in morphology, texture, and chemical properties; therefore, in electrical resistivity the top clay layer would have a relatively high humus (Organic matter, loam, saline, silt and clay) content and cation exchange capacity, hence, a high density of mobile electrical charges, relatively low resistivity and extremely high corrosivity (Mosuro *et al.,* (2012). The underlying layer mostly consists of bleached sand grains with much lower density of mobile electric charges than the first layer. Therefore, the resistivity might be lower in the second or third layer, a characteristic that could be attributed to enrichment in fine clay material.

From the clay deposit sites investigated, three to four layer earth models were delineated. Kaffin-Koro and Dutse showed three layer models comprising top soil, clay deposit and basement rocks, Dogon- Ruwa and Kushikoko revealed four layers: top soil, silty/clay layers and the basement layer. Resistivity values in the range of 207.60-228.30 ohm.m has been ascribed to the presence of silt soil, which were within the range of 200-1000 ohm.m reported by Faheem, (2008) on soil fractions. The characteristics of the layered earth model on clay sites revealed resistivity values in the range of 1.60-48.72 ohm.m, which are within the standard established report on the resistivity values of clayey mineral in the range of 1-100 ohm.m according to Arul (2004).

In the Kaffin-Koro clay deposit site, the top soil had poor longitudinal conductance of 0.0019 siemens which could be attributed to the presence of relatively high humus content and cation exchange capacity leading to high density of mobile electrical charges which produce relatively high conductivity and hence low resistivity values. This layer is followed by a layer of longitudinal conductance 0.4780 siemens and thickness 0.770 m at a depth of 1.17 m, which might be due to lightened sand grains with much lower density of mobile electric charges resulting in relatively lower resistivity values than the first layer. This, according to Oladapo and Akintorinwa, (2007), could be interpreted as moderate enrichment in fine clay material. The conductance of the basement rocks could not be determined because of its infinite thickness.

At the Dogon-Ruwa site, the clay deposit is suspected to be distributed in the third layer which has an average conductance value of 0.237 siemens and situated at a depth of 2.43 m and of thickness 1.76 m. This layer could be adjudged as moderate clay composition based on Oladapo and Akintorinwa, (2007) ratings. The two thin layers overlying the third one had conductance values less than 0.01siemens which is indicative of lesser clay content due to the presence of lower density of mobile electrical charges.

Kushikoko has presented an intriguing scenario where the clay deposit layer could be described as low as it has conductance value of 0.1810 siemens, thickness 2.73 m and is situated at a depth of 4.37 m. This layer is sandwiched by two layers suspected to be of poor clay content on account of their having latitudinal conductance values of 0.0505 siemens overlay and 0.0077 siemens underlay, which are both less than 0.1 siemens. The low value of the upper layer, as in other cases could be attributed to the presence of relatively high humus content and cation exchange capacity while the third layer is suspected to be laterite with some degree of charged particles circulating within the liquid content, thus resulting in low conductance values. The transmissivity value of the third layer is observed to be >400 ohm.m^2, an indication, based on Nwankwo and Ehirim, (2010), that the layer is porous and with very little or no clay content.

The clay deposit in Dutse appears to be generally poor as the longitudinal conductance values of the top two layers are both <0.1 siemens. However, the second layer which is situated at about 62.5 m and of thickness 21.7 m and conductance 0.0263 appears to have poor clay content. The very low transmissivity value of 1.79 ohm.m^2 indicates that the layer is not porous and might contain some clay cementation.

Table 6 has revealed the longitudinal conductance values for all the layers to be far less than 0.1siemens which is an indication of little or no clay composition. Generally, low conductance values have been linked to the availability of free ionic species within the pores, moisture content, particle size and texture (Arul, 2004). The conductance values determined at the various clay sites are low while resistivity values are high. These have been attributed to the low moisture content of clayey material, probably due to the dry season sampling of the clay being studied.

4. Conclusion

Electrical resistivity method using Schlumberger array was employed in data acquisition at some clay sites in Niger State to determine the longitudinal conductance, transmissivity and corrosivity of clay deposits. Three to four layer models were identified from the clay sites based on resistivity values. A three-layer model (Top soil, clay deposit and basement rocks) was inferred for the Kaffin-Koro and Dutse clay sites whereas Dogon-Ruwa and Kushikoko revealed four layers (Top soil, silty/clay layers and the basement). The longitudinal conductance values of the ranged from 0.0019 to 0.4780 mhos. Conductance values of 0.237- 0.478 mhos at a depth of 2.43 m and 1.76 m thickness evidenced the presence of moderate clay content in the study areas while values <0.1 mhos showed poor clay content. Conductance values >0.7 mhos indicated high clay content while portions where conductance value range from 0.2 and 0.69 mhos are classified as zones of moderate clay content and protective capacity. The results revealed areas of moderate, low and poor clay content in the study area while the corrosivity level of the clay range from extremely corrosive to essentially non-corrosive. These results were matched with the controls for comparison.

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