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Geoelectric Sounding and Soil Physico-chemical Tests for Subsurface Layers CorrosivityInvestigationsat Ilaramokin, near Akure, Southwestern Nigeria

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Abstract:*The study is aimed at investigating the subsurface corrosivity at Ilaramokin near Akure, southwestern Nigeria. Thirty (30) geoelectric Sounding data were acquired using Schlumberger array. The geoelectric sounding results delineated 3 - 5 geoelectric layers across the study area. The top soil resistivity values range from 48 - 721 Ωm indicating possible clay, sandy clay, clayey sand and lateritic clay lithologies. The weathered layer resistivity varies from 21 - 1800 Ωm, while the resistivity value of the weathered/fractured basement ranges from 15 - 435 Ωm. The presumed bedrock resistivity values range from 382 - 7557 Ωm. The results were also presented as iso-resistivity maps at different depth slices (1, 2 and 3 m). The iso-resistivity depth slice map at 1 m indicates that the northeastern part of the area is strongly corrosive (60 - 150 Ωm). The iso-resistivity depth slice map at 2 m shows that the central part of the area is strongly corrosive (60 - 150 Ωm) to very strongly corrosive (less than 60 Ωm). The iso-resistivity depth slice map at 3 m indicates that the southwestern part of the area are strongly corrosive (60 - 150 Ωm) to very strongly corrosive (less than 60 Ωm). The depth slice iso-resistivity at 2 m was considered the most appropriate for generating the corrosivity model map of the area.Soil samples utilized for physico-chemical tests (pH and conductivity) were also collected at the same 2 m depth. The corrosivity model map shows that the central part of the area is strongly corrosive to very strongly corrosive, while the western and southern flanks of the area are considered to be moderately to slightly corrosive (250 - 350 Ωm). About 65% of the study area are either strongly corrosive or very strongly corrosive, while only about 10% of the study area are considered to be slightly or non corrosive zones.The physico-chemical tests carried out on the soil samples indicated that the subsurface materials at the 2 m depth slice are slightly acidic and moderately conductive. The conductivity values show a consistent increase with decrease in resistivity; at non corrosive/slighthly corrosive zones (250 Ωm and above) conductivity values varies from 26.4 - 27.1 mhos, while at moderately corrosive zones (150 - 250 Ωm) conductivity values range from 32.3 - 33.0 and at strongly corrosive and very strongly corrosive zones (less than 60 - 160 Ωm) corrosivity values vary from 36.7 - 37.2 mhos. The pH and conductivity test results validated the corrosivity model map, since there was a strong correlation between the corrosivity model map and the physico-chemical tests (conductivity test).*

Keywords:*Geoelectric, subsurface, physic-chemical, iso-resistivity, depth-slices and corrosivity.*

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I. Introduction

Corrosion is the degradation of metallic materials due to their reaction with the environment (Owate et al, 2002). Effects of corrosion on engineering structures are many such as loss of strength, fatigue, reduced bond strength, limited ductility and reduced shear capacity among others (Gebremedhin et al, 2013). A corroded surface when mild or of low concentration is regarded as an irritant(Adeyemo et al, 2018). Soil corrosivity is caused by several soil properties such as; resistivity, pH, redox potential, sulfides concentrations (Najjaran et al, 2004 and Chesnokova, et al. 2015), percentage clay content (Adeyemo et al, 2018) and moisture content (Najjaran et al, 2004 and Idornigie et al, 2006).

Several approaches have been used to investigate and predict corrosivity. Fuzzy logic have been used in predicting deterioration of cast/ductile iron water mains using soil properties such as resistivity, pH, redox potential, sulfides, percentage clay content and moisture content (Najjaran et al, 2004).Electrical resistivity method have also been used to classified subsurce layers into different corrosivity zones (Idornigie et al, 2006; Oyedele et al, 2012 and Adeyemo et al, 2018). AAS-UV spectrophotometer-generated hydro-geochemical data obtained from surface water, hand dug wells and boreholes have been used (Gebremedhin et al,2013) in determining corrosivity aggressiveness. Microbiological indicators (number of sulfur cycle bacteria) have also been utilized (Chesnokova, et al. 2015) to determine the effect of sulfate-reducing bacteria and to revealed the contribution of thiobacteria in the corrosion development of underground metal pipelines. Electron scanning microscopy was also used (Chesnokova, et al. 2016) to detect defects on oil pipeline surface by identifying soil thionic and sulfate-reducing bacteria quantity. The effect of clay minerals and clay plasticity on corrosivity of buried metallic utilitieshave also been researched (Adeyemo et al, 2018).

Integrated geoelectricsoundingsurvey and soil physico-chemical tests was adopted for this work. The geoelectric sounding method and soil physico-chemical tests have been used succesfully in subsurface corrosivity mapping (Idornigie et al, 2006; Oyedele et al, 2012 and Adeyemo et al, 2018).

II. The Study Area

The study area is Ilaramokinnear Akure Southwestern Nigeria (Figure 1). Thearea lies between the geographic co-ordinates of 811500 - 814500 mN(Northing) and 732500 - 733500 mE(Easthing)in the Universal Traverse Mercator (UTM) WGS 84. The surface elevation ranges from 325-401 m above mean sea level and the area generally slopes downward from the east tothe west (Figure 2).

The study area lies within the basement complex area of Southwestern Nigeria. The study area is underlain by rocks of the Precambrian BasementComplex of Nigeria (Rahaman, 1988), while the lithological units recognized in the area includes;migmatite-gneiss, quartzite, migmatised biotite-hornblende-gneissand undifferentiated older granite suite (Figure 3).In the study area, weathering process create superficial layers with varying degree of porosity and permeability. The regolith and fractured bedrock generally occur in typical basement terrain (Odunsanya and Amadi, 1990). Studies have shown that the unconsolidated overburden could constitute reliable aquifer, if significantly thick (Satpathy and Kanugo, 1976; Dan-Hassan and Olorunfemi, 1999; Bala and Ike, 2001). Presence of groundwater within the weathered layer and the clay contents of the layer may increase the threat posed by corrosion to buried metallic utilities in the study area.

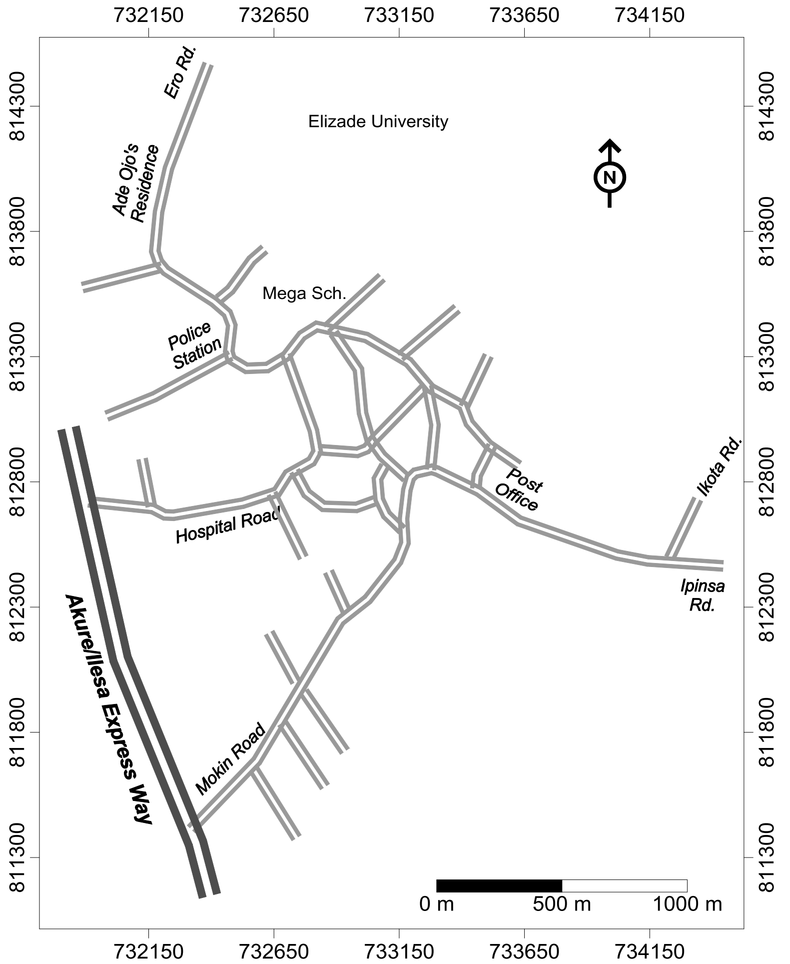


Figure 1: Base map of Ilaramokin

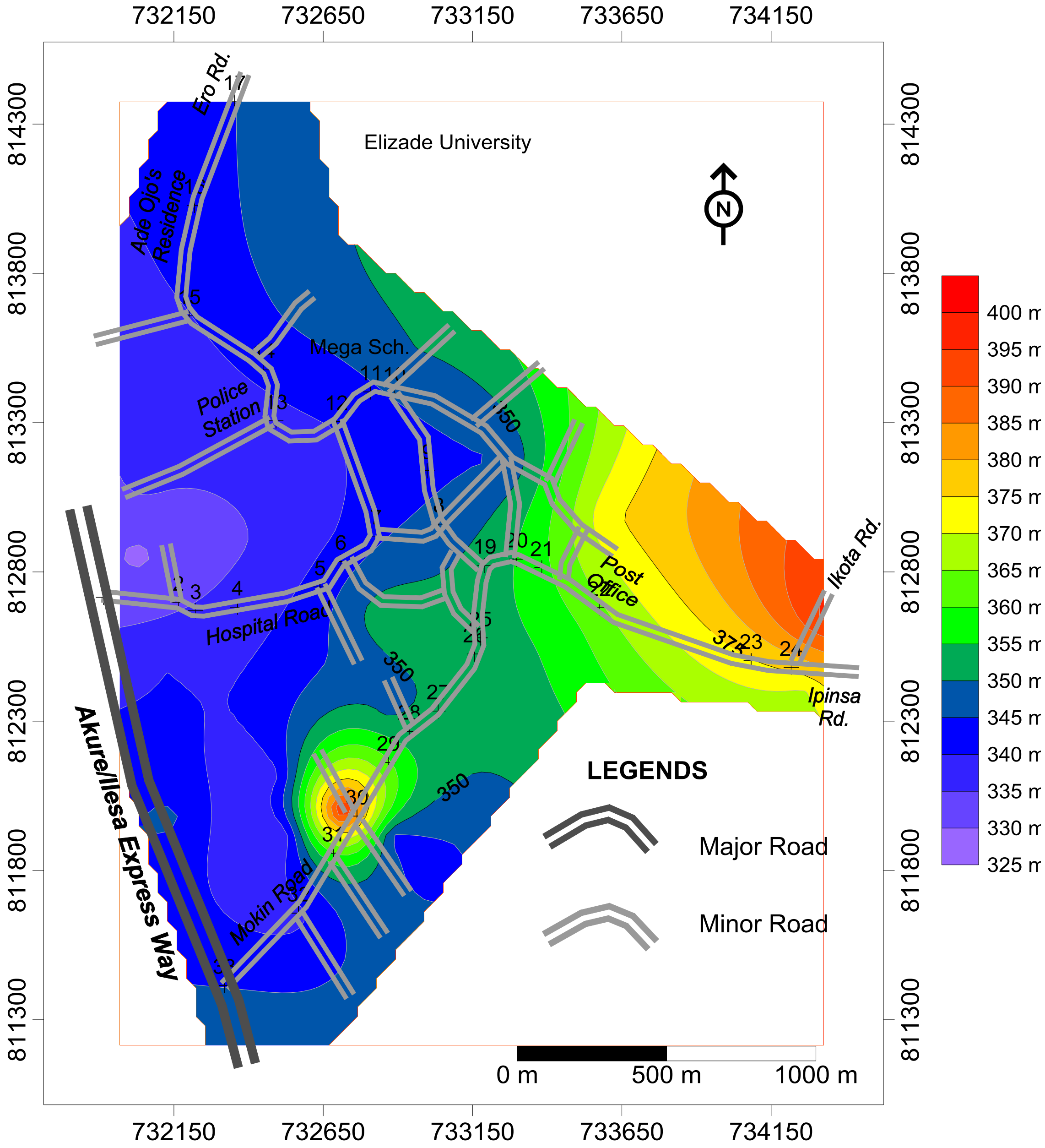


Figure 2: Topographic map of Ilaramokin

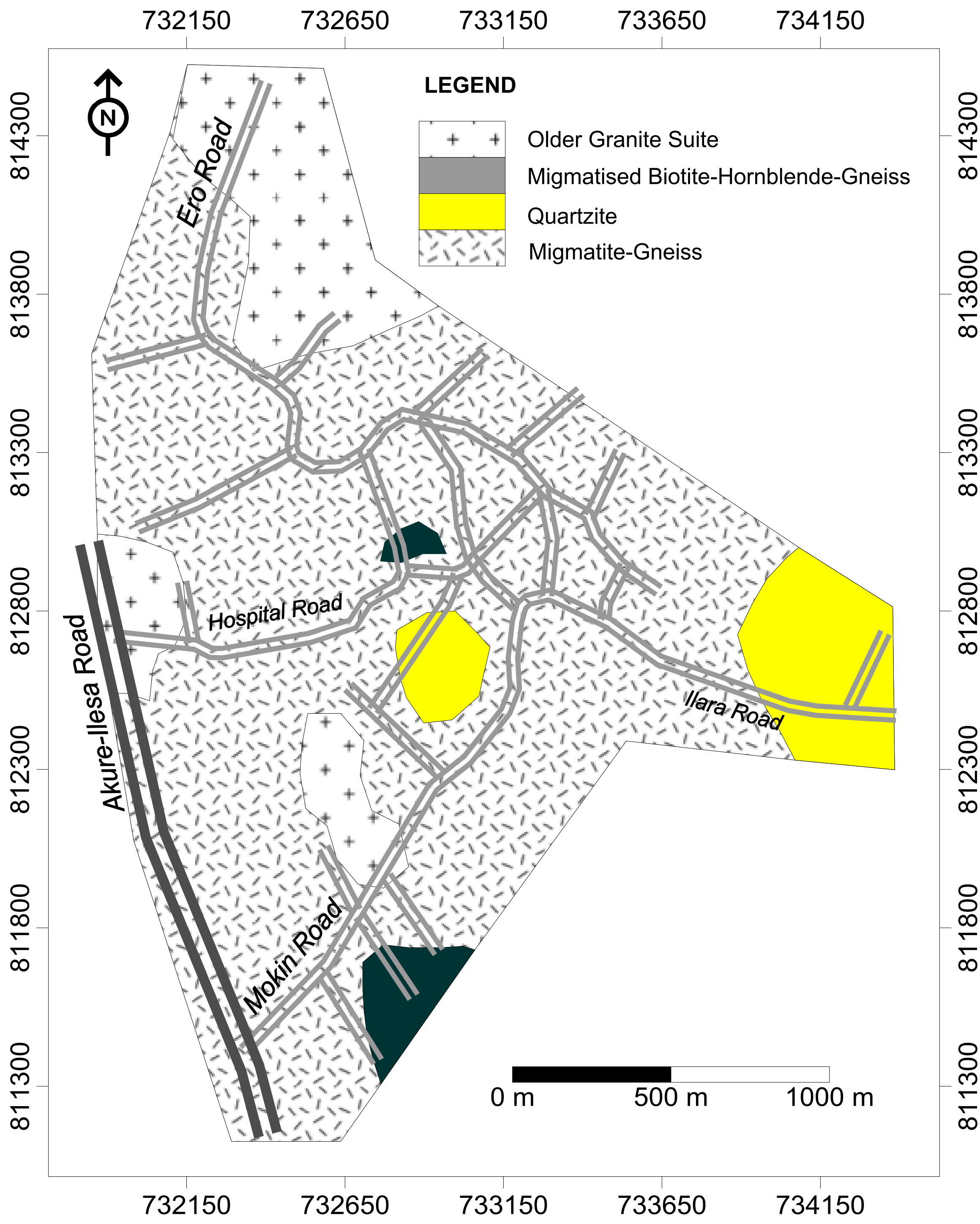


Figure 3: Simplified Geological Map of Ilaramokin

III Research Methodology

Thirty (30) geoelectric sounding data was acquired across the study area (Figure 4). The data were interpreted using partial curve matching method involving the use of 2-layer Schlumberger master curve and auxiliary curves (Zohdy, 1965 and Koefoed, 1979).Subsequently a 1-D computer forward modeling programme, Window Resist version 1.0 (Vander Velpen, 1989) was used to enhance the resultant geoelectric parameters (layer thickness and resistivity). The geoelectric sounding results were presented as sounding curves and iso-resistivity depth slice maps at three (3) different depth surfaces (1, 2 and 3 m). Soil samples were collected at six (6) different loocations coresponding to slightly corrosive, moderately corrosive, strongly and very strongly corrosive zones. Two samples (2) were collected at each corrosive zones. The corrosivity model map of the study area was generated based on the isoresistivty values at 2 m depth slice and the corrosivity model map was validated using pH and conductivity values obtained from the physico-chemical tests conducted on the collected soil samples.

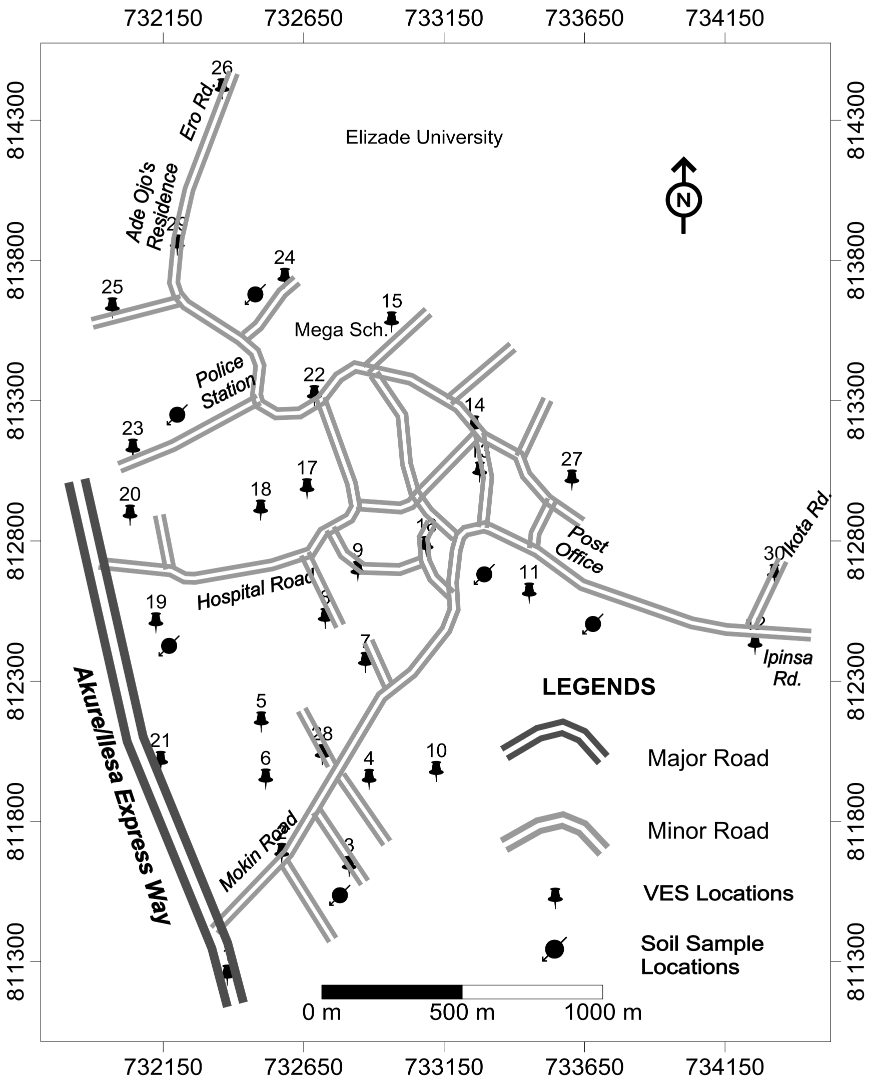


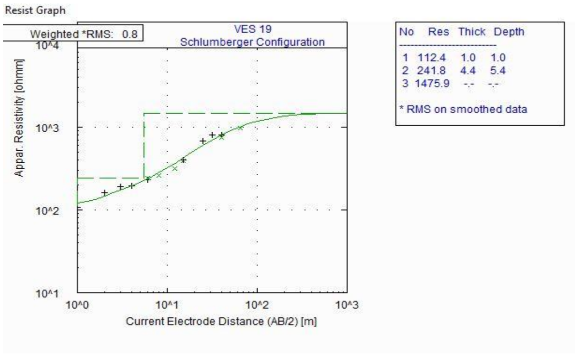
Figure 4: Base map of Ilaramokin showing geolecric and soil sampling locations

IV Results and Discussion

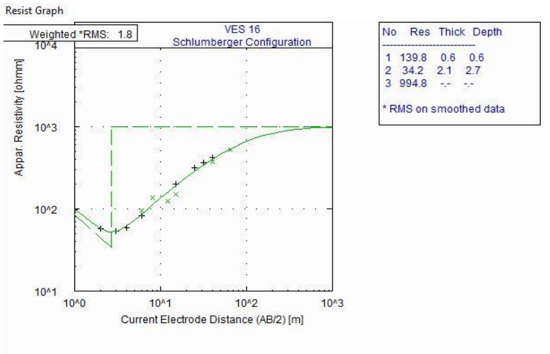
Geoelectric Sounding Results: The summary of the geoelectric sounding results is as presented in table 1. The geoelectric sounding results delineated 3-5 geoelectric layers across the study area. The 3-layers curves include the A, Hand K types, while the 4-layers curves are HA, KA, KH and KA and the 5-layer curve type isthe HKH curve (Figures $5_{(a-g)}$). The top soil resistivity values range from 48 - 721 **Ω**m and the layer thickness varies from 0.6 - 2.5m. Based on this range of resistivity values, the top soil layer is probably consisting of clay, sandy clay, clayey sand and lateritic clay, topsoil layer with these materials will probably be corrosive. The weathered layer resistivity varies from 21 - 1800 **Ω**m, this range of resistivity also suggest possible corrosivity within the weathered layer and this is not surprising because this layer constitute the aquifer layer in most part of the study area. The resistivity value of the weathered/fractured basement ranges from 15 - 435 **Ω**m and the resistivity between 150 - 250 **Ω**m is characterized as moderately corrosive (Adeyemo et al, 2018). The resistivity value of the presumed bedrock ranges from 382 - 7557 **Ω**m and based on this resistivity the layer is considerd non-corrosive (Adeyemo et al, 2018).The geoelectric sounding results were also presented as iso-resistivity maps at different depth slices (1, 2 and 3 m). The corrosivity at these depth surfaces can be inferred from their resistivity values which depends on their constituent geologic materials and fluid's content.

Table 1: Geoelectric Sounding Results

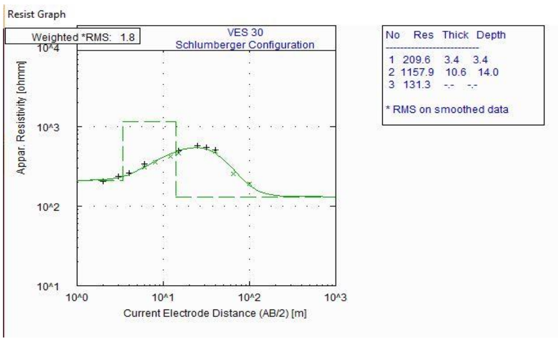
VES NO	Layer Resistivity (Ωm) $\rho_1/\rho_2/\rho_3......h_n$	Layer Thickness (m) $h_1/h_2/h_3......h_n$	No of Layer	Curve Type
1	86/ 119/ 15/ 679	1/ 2.4/ 4.4	4	KH
2	76/ 143/ 588	1.5/ 11.6	3	A
3	190/ 323/ 116/ 515	1/ 1.2/ 7.6	4	KA
4	74/ 98/ 3362	0.9/ 12.0	3	A
5	221/ 53/ 1103	1.4/ 5.5	3	H
6	131/ 39/ 111/ 791	0.6/ 2.5/ 5.4	4	HA
7	92/ 41/ 2317	1.5/ 2.7	3	H
8	261/ 202/ 994	1.2/ 7.9	3	H
9	57/ 80/ 900	1.3/ 1.9	3	A
10	141/ 167/ 7557	1.6/ 11.3	4	A
11	54/ 42/ 5714	1.7/ 1.5	3	A
12	150/ 71/ 123/ 80/ 332	0.9/ 0.6/ 1.8/ 21.4	5	HKH
13	80/ 42/ 2750	1.1/ 7.2	3	H
14	87/ 21/ 993	1.0/ 2.2	3	A
15	86/ 129/ 6729	1.4/ 6.3	3	A
16	140/ 34/ 995	0.6/ 2.1	3	A
17	287/ 94/ 270/ 342	0.8/ 0.5/ 0.9	4	HA
18	92/ 55/ 164/ 919	1.0/ 0.4/ 20.2	4	HA
19	112/ 242/ 1476	1.0/ 4.4	3	A
20	114/ 249/ 1304	1.2/ 3.7	3	A
21	113/ 172/ 1800/ 36/ 377	0.8/ 1.0/ 0.9/ 39.0	4	HKH
22	133/ 175/ 1141	1.2/ 4.2	3	A
23	98/ 435/ 14/ 383	1.7/ 3.1/ 10.5	4	KH
24	397/ 253/ 999	0.8/ 2.3	3	H
25	111/ 147/ 382	1.0/ 6.0	3	H
26	111/ 165/ 4034	1.6/ 5.4	3	A
27	48/ 63/ 3244	1.7/ 3.0	3	A
28	721/ 142/ 323/ 1286	0.7/ 0.8/ 23.5	4	HA
29	109/ 158/ 4413	2.5/ 2.3	3	A
30	210/ 1158/ 131	3.4/ 10.6	3	K



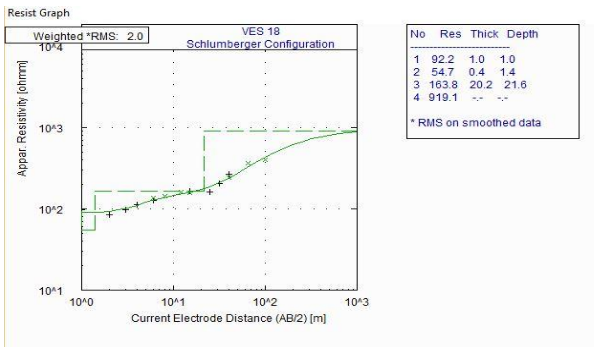
(a) A Curve type



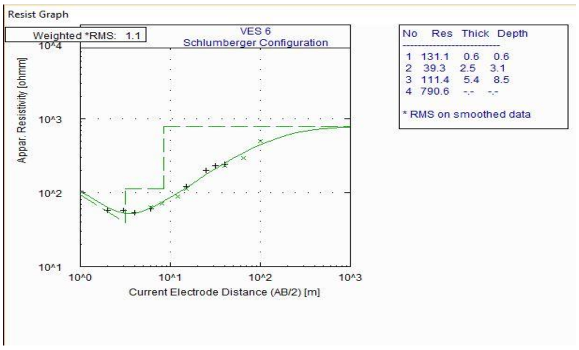
(b) H curve



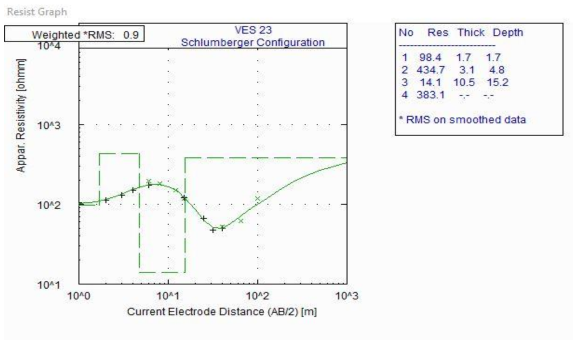
(c) K Curve type



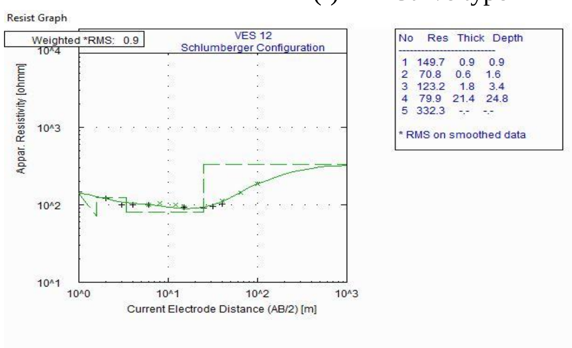
(d) AA Curve type



(e) HA Curve type



(f) KH Curve type



(g) HKH Curve type

Figures $5_{(a-g)}$: Typical curve types obtained from the study area

The iso-resistivity depth slice map at 1 m (Figure 6) indicates that the western and eastern parts of the area is strongly corrosive (60 - 150 Ωm), while the central and northwestern and southwestern part of the area are moderately corrosive (150 - 250 Ωm) to slightly corrosive (250 - 350 Ωm). It is obvious that the largest percentage of the surface along this 1 m depth slice is strongly corrosive.

The iso-resistivity depth slice map at 2 m (Figure 7) shows that the central part of the area is strongly corrosive (60 - 150 Ωm) to very strongly corrosive (less than 60 Ωm), while the western and southern flanks of the area are considered to be moderately corrosive (150 - 250 Ωm) to slightly corrosive (250 - 350 Ωm). It is of note that about 15% and 50 % of the 2 m depth slice surface area are either strongly corrosive (60 - 150 Ωm) or very strongly corrosive (less than 60 Ωm).

The iso-resistivity depth slice map at 3 m (Figure 8) indicates that the northeastern part of the area is non-corrosive (above 350 Ωm) to slightly corrosive (250 - 350 Ωm), while the central and northwestern parts of the area are moderately corrosive (150 - 250 Ωm). The southwestern part of the area are considered to be strongly corrosive (60 - 150 Ωm) to very strongly corrosive (less than 60 Ωm). The non-corrosive nature of the eastern half of the study area shows that depth to bedrock in this part of the area is very shallow (less than 3 m).

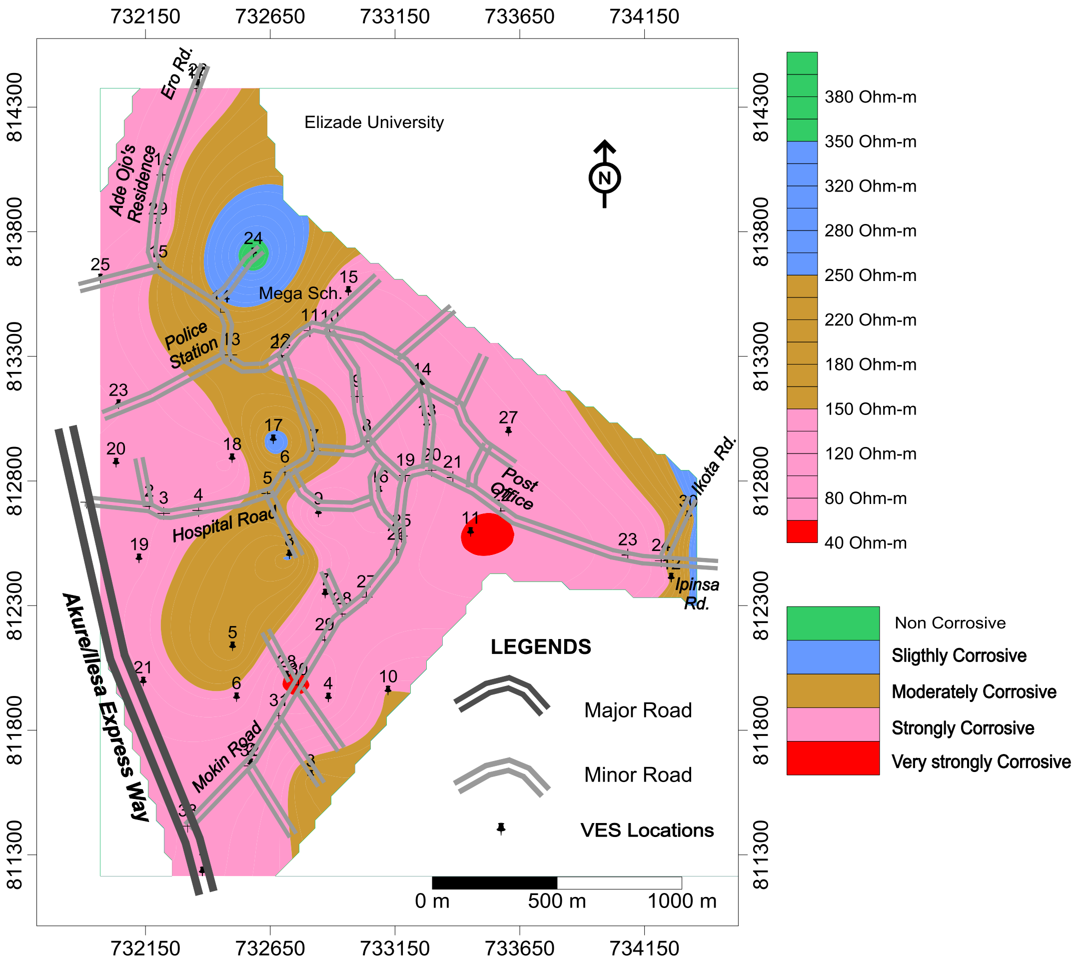


Figure 6: Iso-resistivity map of Ilaramokin at 1 m depth slice

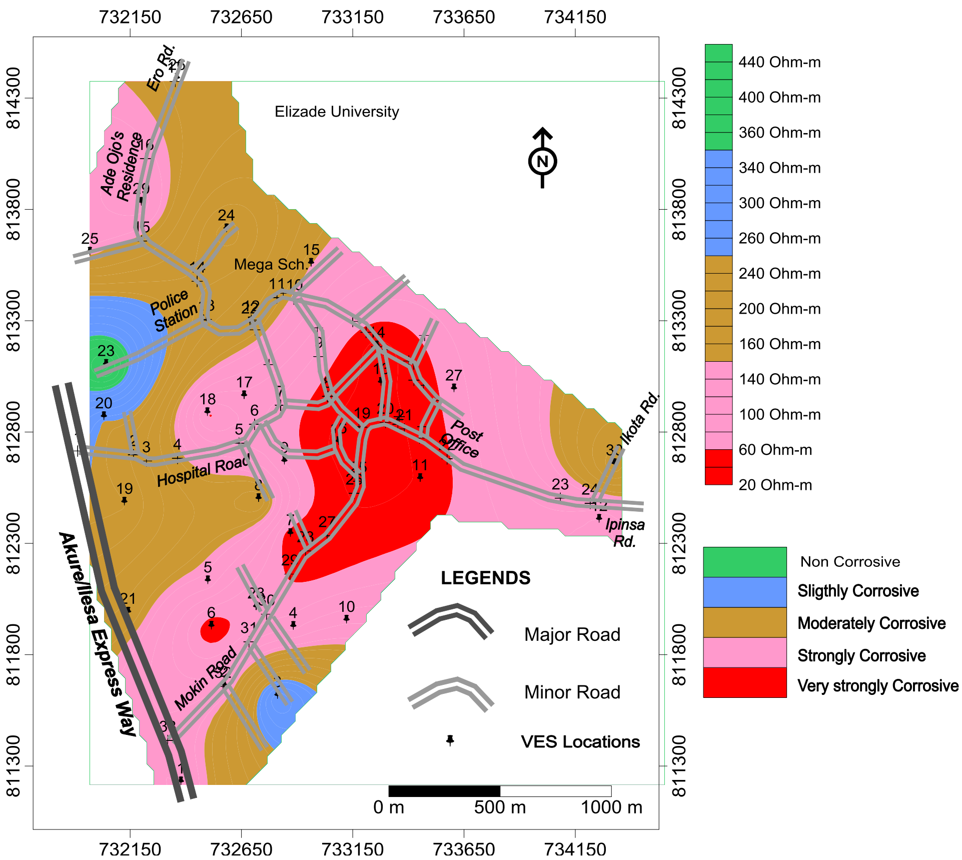


Figure 7: Iso-resistivity map of Ilaramokin at 2 m depth slice

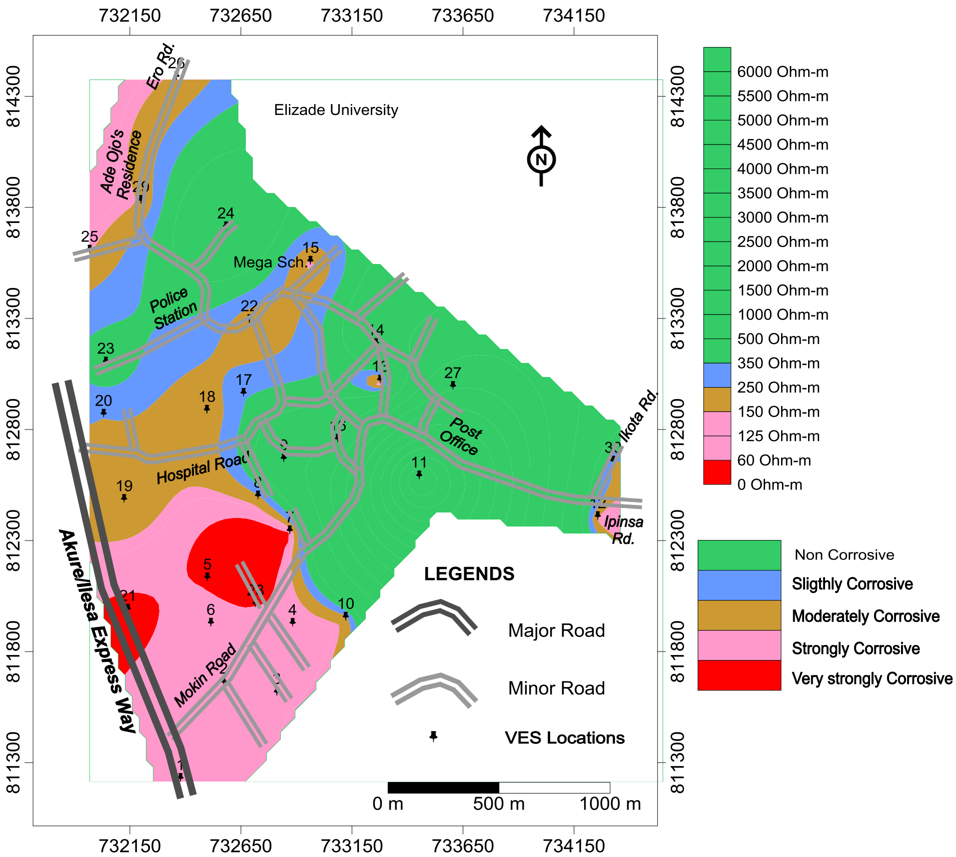


Figure 8: Iso-resistivity map of Ilaramokin at 3 m depth slice

Corrosivity Model Map: The depth slice iso-resistivity of 2 m (Figure 7) was used generate the corrosivity model map of the study area. The depth slice iso-resistivity of 2 m was considered the most appropriate for a number of reasons; most metallic utilities were buried at this depth (storage tanks, pipes and others), the depth slice have the largest corrosive surface area (about 65 %) and also most locations at the eastern part of the study area have shallow depth to the bedrock (generally below 3 m). The Corrosivity Model Map (Figure 9) shows that the central part of the area is strongly corrosive to very strongly corrosive, while the western and southern flanks of the area are considered to be moderately to slightly corrosive (250 - 350 Ωm). About 65% of the study area are either strongly corrosive or very strongly corrosive, while only about 10% of the study area are considered to be slightly or non corrosive zones. Soil samples utilized for physico-chemical tests (pH and conductivity test) were also collected at the same 2 m depth. The corrosivity model map of the area was validated using the obtained pH and conductivity values from the physico-chemical analysis of soil samples.

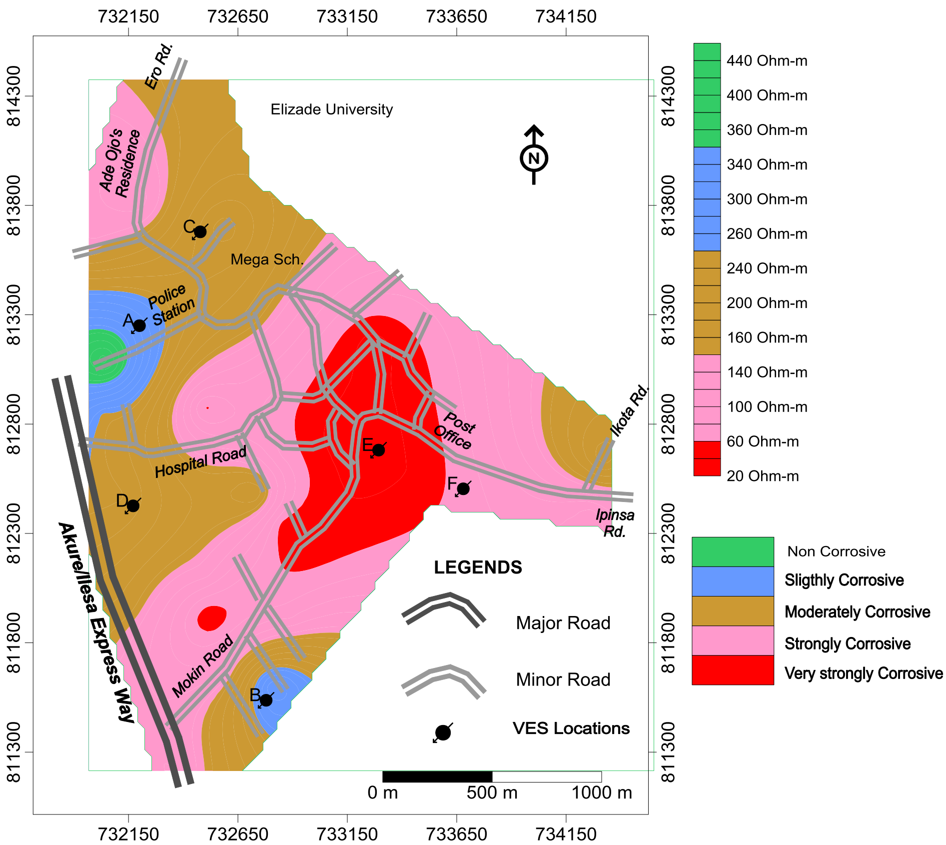


Figure 9: Corrosivity model map of Ilaramokin showing soil sample locations

pH and Conductivity: The pH and conductivity tests were conducted on the soil samples collected from the study area (Table 2) purposely to validate the generated corrosivity model of the area. samples A and B were taken at the non corrosive and slightly corrosive zones and conductivityvalues at these zones vary from 26.4 - 27.1 mhos. Two samples C and D were taken at moderately corrosive zones and the conductivity values at these zones range from 32.3 - 33.0 mhos. The two samples (E and F) collected from the strongly and very strongly corrosive zones yields 36.7 - 37.2 mhos. The pH values measured from the six (6) collected soil samples from the study area range from 5.774 - 7.393. The physico-chemical tests carried out on the soil samples indicated that the subsurface materials at the 2 m depth slice are slightly acidic and moderately conductive. The conductivity values are more useful since they show a consistent increase with decrease in resistivity; at non corrosive/slighthly corrosive zones (250 Ωmand above) conductivity values varies from 26.4 - 27.1 mhos, while at moderately corrosive zones (150 - 250 Ωm) conductivity values range from 32.3 - 33.0 and at strongly corrosive and very strongly corrosive zones (less than 60 - 160 Ωm) corrosivity values vary from 36.7- 37.2 mhos. The pH and conductivity test results validated the corrosivity model map, since there was a strong correlation between the corrosivity model map and the physico-chemical tests (conductivity values).

Table 2: pH and Conductivity Soil Test Results

Samples	pH	Conductivity (mhos)
A	5.774	26.4
B	6.427	27.1
C	5.872	32.3
D	7.242	33.0
E	7.393	37.2
F	6.829	36.7

V Conclusion

Thirty (30) geoelectric sounding data was acquired across Ilaramokin near Akure, Southwestern Nigeria. The data were interpreted manually and the resulting geoelectric parameters were iterated to generate final layer parameters (resistivities and thicknesses). Six soil samples were collected across the area for physico-chemical tests (pH and conductivity). The corrosivity model map of the study area was generated based on the isoresistivty values at 2 m depth slice. The corrosivity model map was validated using pH and conductivity values obtained from the pysico-chemical tests conducted on the collected soil samples.Three (3) to five (5) geoelectric layers were delineated across the study area namely the A, H, K, AA, KA, HA, KH and HKH types. The top soil resistivity values range from 48 - 721 Ωm. The weathered layer resistivity varies from 21 - 1800 Ωm, while the weathered/fractured basement resistivity varies from 15 - 435 Ωm. The presumed bedrock resistivity ranges from 382 - 7557 Ωm.

The geoelectric sounding results were also presented as iso-resistivity maps at different depth slices (1, 2 and 3 m). The iso-resistivity depth slice map at 1 m indicates that the northeastern part of the area is strongly corrosive (60 - 150 Ωm), while the central and northwestern areas are moderately corrosive (150 - 250 Ωm) to slightly corrosive (250 - 350 Ωm). The southwestern part of the area is strongly corrosive (60 - 150 Ωm) to moderately corrosive (150 - 250 Ωm). The iso-resistivity depth slice map at 2 m shows that the central part of the area is strongly corrosive (60 - 150 Ωm) to very strongly corrosive (less than 60 Ωm), while the western and southern flanks of the area are considered to be moderately corrosive (150 - 250 Ωm) to slightly corrosive (250 - 350 Ωm). It is of note that about 15% and 50 % of the 2 m depth slice surface area are either strongly corrosive (60 - 150 Ωm) or very strongly corrosive (less than 60 Ωm). The iso-resistivity depth slice map at 3 m indicates that the northeastern part of the area is non-corrosive (above 350 Ωm) to slightly corrosive (250 - 350 Ωm), while the central and northwestern part of the area are moderately corrosive (150 - 250 Ωm) and southwestern part of the area are strongly corrosive (60 - 150 Ωm) to very strongly corrosive (less than 60 Ωm). The non-corrosive nature of the eastern half of the study area shows that depth to bedrock in this part of the area is very shallow (less than 3 m).

The depth slice iso-resistivity of 2 m was utilizedfor generating the corrosivity model map of the study area. The corrosivity model map shows that the central part of the area is strongly corrosive to very strongly corrosive, while the western and southern flanks of the area are considered to be moderately to slightly corrosive (250 - 350 Ωm). About 65% of the study area are either strongly corrosive or very strongly corrosive, while only about 10% of the study area are considered to be slightly or non corrosive zones.Six (6) soil samples utilized for physico-chemical tests (pH and conductivity test) were collected at the same 2 m depth. The pH and conductivity values were used to validate the corrosivity model map. The conductivity values are more useful because of its consistent increase with decrease in resistivity; at non corrosive/slighthly corrosive zones (250 Ωm and above) conductivity values varies from 26.4 - 27.1 mhos, while at moderately corrosive zones (150 - 250 Ωm) conductivity values range from 32.3 - 33.0 and at strongly corrosive and very strongly corrosive zones (less than 60 - 160 Ωm) corrosivity values vary from 36.7 - 37.2 mhos. The pH and conductivity test results validated the corrosivity model map, since there was a strong correlation between the corrosivity model map and the physico-chemical tests (conductivity values).

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