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Geoelectric Investigation of Corrosivity and Competence Soils Using Geospatial Technology: A Case Study in Part of Yenagoa, Bayelsa State, Nigeria

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Abstract
The study established the use of Electrical Resistivity Method and Geospatial Technology to investigate soil corrosivity and competence in part of Yenagoa, Bayelsa State, Nigeria. A total of 22 Geoelectric was acquired using Abem Terrameter SAS1000 and Schlumberger configuration with a maximum half current electrode spacing of 160 m. Geoelectric layers were determined using IPI2win software and ArcGIS 10.4 for modeling. The results indicate a low elevation of 0.65 m and a high elevation of 29.09 m with an estimated land area of approximately 80 km2, geoelectrical sections of three layers are observed but our main interest is the Topsoil (first layer) and perhaps the second layer with respect to depth. The soil corrosivity of topsoil indicates five corrosivity class namely essentially non-corrosive with an estimated land area of 59%, moderately corrosive is 9%, mildly corrosive with 12%, and soil competent indicating moderately competent of 0.10% and 99% incompetent with geoelectric curve present H, K KH and AH, with a thickness range from 0.4 m to 1.5 m while layer 2 indicate the area contain incompetent with 4.98 km2 land area, moderately competent 28 km2 land area cover, competent 19 km2 and highly competent with a land area cover of 31.39 km2 and soil corrosivity indicate three class namely moderately corrosive with 6% land area, mildly corrosive contains 17% and essentially non-corrosive indicate 61.68 km2 with 77% land area present in layer 2 with thickness ranging from 1.2 m to 18.89 m. Therefore, corrosion-resistant pipes are strongly recommended to forestall challenges associate with rupture of corroded pipes with a depth of about 2 m depth as recommended and GIS techniques have shown to be a useful tool in mapping soil corrosivity and competence using geophysical data.

Keywords: Geoelectric, GIS Technology, Corrosivity, Competence

Introduction
The importance of soil corrosivity and competent can't be avoided because soil corrosion and competence is a geologic hazard that affects buried metals on the ground with concrete that's in direct contact with soil or bedrock yielding the fact, the area under investigation is an oil-producing local government within the Niger Delta region where NAOC/Agip, Shell Petroleum Development Company (SPDC) and Nigerian Liquified Natural Gas (NLNG), etc. are presently operating and pipeline network are already been done however the need for pipeline protection and maintenance is vital to the environment knowing that corrosion stems from material interaction with the surroundings and usually leads to material degradation method that risky the safety of human being which could result to serious challenge in materials and engineering [1]. The electrical resistivity measurement is a non-destructive testing technology and a very convenient tool for describing moisture content, porosity, saturation, type, and mineral compositions of soil and application prospects due to the good technical, continuous, fast, and economic benefits [2]. It's accustomed to predict the matrix suction of unsaturated soil, to evaluate the shear strength of complicated soil to assess the engineering quality their studies conjointly show that major facilities laid low with soil corrosion embody drink and sewer systems, road bridges and buildings, gas and liquid transmission pipelines and storage facilities. suggested for the correct protection of underground steel pipes for water distribution to stop the deterioration of water quality as a result of pipeline corrosion. Therefore, is important to delineate corrosive and competent soil using Geospatial technology for better visualization of result in other to model the thickness of layer and predict the competence, and corrosivity area to see the quality of soils within the study area for the development of infrastructure.

Materials and Methods
Study Area
The area under investigation is Tombia and its environs which is located in Yenagoa LGA and It is one of the rapidly growing urban in the South-South geopolitical region of Nigeria. Its major communities surrounding it are Agudama-Ekpetiama, Gbrainturo, Igbedi, and Akaibiri in Bayelsa state, Nigeria. The study area covers about 80 km2 with a good road network connecting different parts of the city of Yenagoa and its surroundings. This zone is located in longitudes 0060 14'30" and 0060 21'30" east of the first meridian and latitudes 040

55'0" and 050 0'30" north of the equator in the coastal zone of Niger Delta. (Figure 1). The area of study is Yenagoa City which is the capital of Bayelsa State. The study area which falls within the South-Western flank of the Niger Delta Region of Nigeria has been geologically described by Reyment [3]. The major social-economic activities of the locals are fishing, farming, and local sand dredging from and rivers. The study area which is in the southwestern flank of the Niger Delta and its geology has been described extensively by Short and Stauble amongst many others [4]. The Niger Delta Basin is formed by a failed rift triple unction during the separation of the South American Plate and the African plate, which opens into Atlantic. Rifting in the basin started late Jurassic and ended in the mid Cretaceous. Several faults occur although there are mainly thrust faults within the basin. The delta covers a land area over 105,000 km2 Reijers [5].

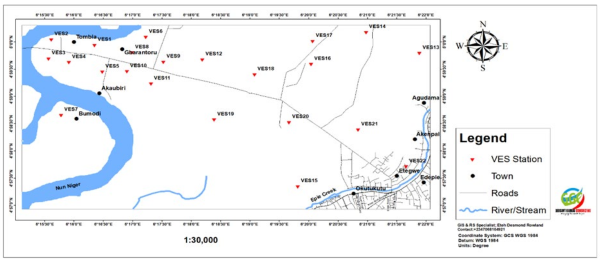

Figure 1: Sample location Map of the study area

Electrical Resistivity of Soil

In this study, the Schlumberger configuration was performed using the vertical electrical sounding field procedure to assess the electrical resistivity of the subsurface and the thickness of the aquifer.

The apparent resistivity (ρa) was calculated using:

$$\rho_a = \pi \left(\frac{(AB/2)^2 - (MN/2)^2}{MN} \right) R_a \qquad (1)$$

where AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and Ra is the apparent electrical resistance measured from the equipment.

The equation can be simplified to $\rho_a = K \times R_a$ (2)

where the geometric factor K is given as

$$\pi \left(\frac{(AB/2)^2 - (MN/2)^2}{MN} \right) R_a \qquad (3)$$

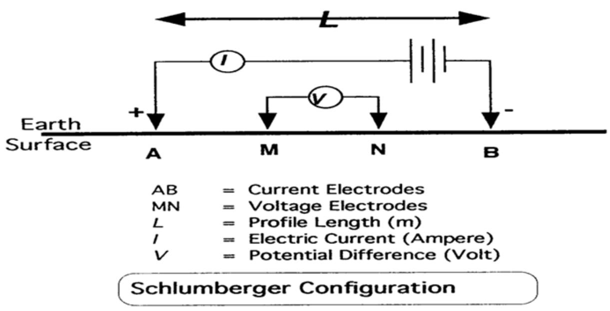

Figure 2: The Schlumberger Configuration

Data Collection

Schlumberger configuration was carried out within the same area in Yenagoa LGA, Bayelsa State in Twenty-two location. The data were collected using a handheld Global Positioning System (GPS) to obtain the coordinate and Altitude and Abem Terrameter SAS 1000, a sophisticated tool that automatically displays the resistance value of each VES point on a digital display screen, and these values were written down on a book provided during the fieldwork. four electrodes are usually required to measure electrical resistivity. To inject current, two electrodes called A and B are used (current electrodes). To record the resulting potential difference, two other electrodes called M and N are used (potential electrode). To record the resulting potential difference, two other electrodes called M and N are used (potential electrode). For field measurement of electrical resistivity, Hersir and Flovenz (2013) mentioned that the measured apparent resistivity will be transformed into a nod of the true resistivity structure since the apparent resistivity does not show the true resistivity structure of the Earth [6]. There are three types of modeling done which is 1D. The resistivity distribution changes only with depth and is assumed to resemble a horizontally layered Earth in the 1D modeling.

Data Processing

The obtain apparent resistivity, ρa, values were plotted against the electrode spacing (AB⁄2) on a log-log scale to obtain the VES sounding curves using a computer software IPI2win+IP.
The field curves were at first interpreted through partial curve matching techniques, using theoretically calculated master curves, in conjunction with the auxiliary curves of A, Q, K, and H types. This information (layer parameters) was then used to interpret the sounding data through a 1-D inversion technique (ipi2win).

GIS and Remote Sensing Processing

Step 1: Software
Arc GIS 10.6, TCX, DNR GPS, Google Earth Pro, and Microsoft Excel 2013 software for sample parameter spreadsheet preparation.

Step 2: Method of analysis for Geographical Information Systems

The data collected were open data of Shuttle radar topographic mission from NASA and Geoelectric coordinate in degree, minute, second and imported into Microsoft Excel and the data was converted to degree decimal and transferred to Geographical Information System environment in DataBase in Arc GIS 10.6 using Arc map tools and add various layers such as road, community, River to generate sample location map. Spatial analyst extension tools in Arc GIS 10.6 using hydrological tools to generate the height information from altitude value to produce Digital Terrain Model and Contour.

Step 3: Method of analysis
The spatial distribution maps for assessment of corrosivity and competent soil using Arc GIS 10.6 software in Arc toolbox to generate surfaces in spatial analysis tool using kinging method for Soil corrosivity, Competent and thickness map of the study area.

Results and Discussion

The subsurface results show the relationship between Apparent Resistivity, Corrosivity, and competent soil using Geospatial technology with aid of the following proposed guidelines by Robinson, Escalante, Idornigie et al., Gopal, Bhattarai, Ojo et al., and Oki et al. [7-14].

Table 1: Topsoil and layer 2 parameters of the study area

VES Station	Long	Lat	Apparent Resistivity (Ωm)	Thickness (m)	Depth(m)	Lithology	Curve Type	Competent Status	Corrosivity status
VES1	6.272584	4.999251	40	0.7	0.7	Topsoil	KH	Incompetent	Corrosive
			809	11.7	12.4	Sand		Highly competent	Essentially non-corrosive
VES2	6.260354	5.000956	93	0.7	0.7	Topsoil	K	Incompetent	Moderately corrosive
			1960	13.2	13.9	Sand		Highly competent	Essentially non-corrosive
VES3	6.259519	4.995108	68	0.4	0.4	Topsoil	K	Incompetent	Moderately corrosive
			1530	8.9	9.3	Sand		Highly competent	Essentially non-corrosive
VES4	6.265367	4.993994	55	1.2	1.2	Topsoil	K	Incompetent	Moderately corrosive
			5281	2.2	3.4	Sand		Highly competent	Essentially non-corrosive
VES5	6.274836	4.99107	75	0.7	0.7	Topsoil	K	Incompetent	Moderately corrosive
			5285	14.2	14.9	Sand		Highly competent	Essentially non-corrosive
VES6	6.287179	5.001709	91	0.8	0.8	Topsoil	K	Incompetent	Moderately corrosive
			1763	18.9	19.7	Sand		Highly competent	Essentially non-corrosive
VES7	6.263139	4.977841	57	1.1	1.1	Topsoil	H	Incompetent	Moderately corrosive
			475	15	16.1	Clayey sand		Competent	Essentially non-corrosive
VES8	6.283233	4.996992	109	1.5	1.5	Topsoil	H	Moderately competent	Mildly corrosive
			492	3.5	5	Clayey sand		Competent	Essentially non-corrosive
VES9	6.292154	4.994111	91	1	1	Topsoil	K	Incompetent	Moderately corrosive
			1763	18.9	19.9	Sand		Highly competent	Essentially non-corrosive
VES10	6.281798	4.991209	89	0.9	0.9	Topsoil	K	Incompetent	Moderately corrosive
			1530	8.9	9.8	Sand		Highly competent	Essentially non-corrosive
VES11	6.28868	4.987455	79	1.1	1.1	Topsoil	H	Incompetent	Moderately corrosive
			10	5.3	6.4	Clay		Incompetent	Highly corrosive
VES12	6.303242	4.994829	97	1.2	1.2	Topsoil	HA	Incompetent	Moderately corrosive
			482	3.2	4.4	Clayey sand		Competent	Essentially non-corrosive
VES13	6.364928	4.996779	32	0.7	0.7	Topsoil	K	Incompetent	Corrosive
			1663	18.2	18.9	Sand		Highly competent	Essentially non-corrosive
VES14	6.34975	5.003184	30	1.1	1.1	Topsoil	H	Incompetent	Highly corrosive
			10	4.3	5.4	Clay		Incompetent	Highly corrosive
VES15	6.330395	4.95598	30	1	1	Topsoil	H	Incompetent	Highly corrosive
			12	2	3	Clay		Incompetent	Highly corrosive
VES16	6.334155	4.993437	33	0.8	0.8	Topsoil	H	Incompetent	Corrosive
			19	5	5.8	Sandy clay		Incompetent	Highly corrosive
VES17	6.334567	5.000459	32	0.6	0.6	Topsoil	H	Incompetent	Corrosive
			11	2	2.6	Sandy clay		Incompetent	Highly corrosive
VES18	6.318055	4.990259	63	0.5	0.5	Topsoil	H	Incompetent	Moderately corrosive
			13	1.7	2.2	Sandy clay		Incompetent	Highly corrosive
VES19	6.306584	4.976449	46	1	1	Topsoil	H	Incompetent	Corrosive
			12	3	4	Clay		Incompetent	Highly corrosive
VES20	6.327889	4.975613	39	1	1	Topsoil	H	Incompetent	Corrosive
			11	7.5	8.5	Clay		Incompetent	Highly corrosive
VES21	6.347523	4.973385	31	0.7	0.7	Topsoil	H	Incompetent	Corrosive
			10	4.4	5.1	Sandy clay		Incompetent	Highly corrosive
VES22	6.361169	4.962106	24	0.4	0.4	Topsoil	H	Incompetent	Highly corrosive
			12	1.2	1.6	Sandy clay		Incompetent	Highly corrosive

Earth Material	Resistivity, Average or Range (Ohm-m)	Earth Material	Resistivity, Average or Range (Ohm-m)
Granite	10^2-10^6	Sandstone	1-10^8
Diorite	10^4-10^5	Limestone	50-10^7
Gabbro	10^3-10^6	Dolomite	10^2-10^4
Andesite	10^2-10^4	Sand	1-10^3
Basalt	10-10^7	Clay	1-10^2
Peridotite	10^2-10^3	Brackish water	0.3-1
Air	~0	Seawater	0.2

Figure 3: Resistivities of some common rocks, minerals, and chemicals [15].

Interpretation of results from the twenty-two vertical electrical soundings conducted in the study area to delineate Corrosivity and competent soil zone in the area. The study area shows geo-electric curve types of H, K, and KH with VES 7,11, 14, 15, 16, 17, 18, 19, 20, 21, and 22 contain H curve, with topsoil (first layer) vary from 0.4 – 1.5 m in thickness, Apparent resistivity varies from 24 – 109 Ωm in Table 1, layer 2 contain lithologies of clayed and clayed sand with a thickness ranging from 1.2 – 1.5 m and apparent resistivity of 10 to 492 Ωm when compared with Figure 3 and VES 2,3,4,5,6,9,10, and 13 contain K type curve with topsoil vary from 0.4 – 1.2 m in thickness, Apparent resistivity ranged from 55 – 93 Ωm in Table 1, layer 2 which is the second layer contain sand with Apparent resistivity ranging from 1530 – 5281 Ωm in Table 1 when compared with Figure 3, with thickness varying from 2.2 to 18.9 m. VES 1 has curve type of KH with topsoil (first layer) contain resistivity of 40 Ωm, the thickness of 0.7 m and second layer contain Apparent resistivity of 809 Ωm with a thickness of 12.4 m while VES 12 contain curve type of HA with topsoil Apparent resistivity of 97 Ωm with a thickness of 1.2 m and the second layer contain Apparent resistivity 482 Ωm which is represented as clayed sand in Table 1 with a thickness of 3.2 m.

Digital Terrain Model

The area under investigation has a low altitude which in turn gives a better view of the general information of the terrain in the area. Figure 4. The Digital Terrain Model of the study area varies from 0.65 – 29.09 m (Figure 4) beside it is used to determine the area that is prone to flood during the rainy season [15]. Also, the area contains a total estimated land area of 79.98 km2 with 7.96 km2 is blue contain 10%, 17.97 km2 with 22 % is ash, 33.26 km2 is yellow with 42%,20.79 km2 is a brown colour with 26% and it can be used for research for site suitability for flood relief center and other projects apart from that it can be used for rice farming due to the terrain from

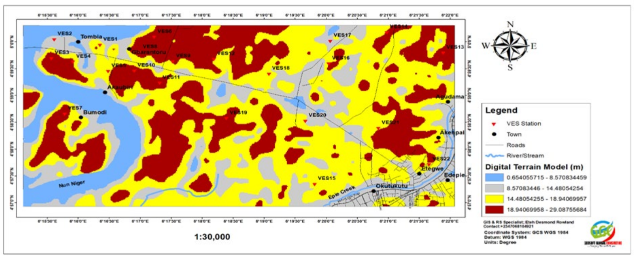

Figure 4: Digital Elevation of the Study area

Table 2: Digital Elevation range in the Study area from SRTM data

S/N	Area (km^2)	Percentage
1	7.96	10
2	17.97	22
3	33.26	42
4	20.79	26
	79.98	

Contour

The area under investigation is characterized by low lands with a topography that is part of the surface and it shows the altitude nature of the terrain. Contour lines (Figure 5) connects areas of equal elevation were generated at 2 m intervals. The spot height tells the direction in which water flows through. The areas are drained mainly by the Epie creeks and tend to slope gently into River Nun which in turn drains into the Atlantic Ocean. Due to the poor drainage of the area, it tends to flood during the rainy season.

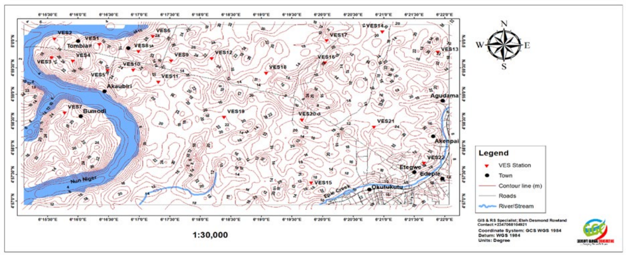

Figure 5: Contour map of the Study area

GIS Analysis using Reclassification Tool

For the final prediction of the soil corrosivity map, soil competent map, the criteria under evaluation are required to be expanded. The GIS application using reclassify method provided a set of map classes occurring on each input. These maps have been assigned to different value range from Table 2 and 3 using guidelines proposed by Idornigie et al. and Ojo et al., Robinson, Escalante, Gopal, Bhattarai, Oki et al. [8-14].

Table 3: Rating of subsoil competence using resistivity values. Sources: Idornigie et al. and Ojo et al.

Soil resistivity	Lithology	Competence rating
<100	Clay	Incompetent
100-350	Sandy clay	Moderately competent
350-750	Clayey sand	Competent
>750	Sand/Laterite	Highly competent

Table 4: Soil Corrosivity rating. Sources: Robinson, Escalante, Gopal, Bhattarai, Oki et al.

Soil resistivity	Corrosivity rating
>200	Essentially non-corrosive
100-200	Mildly corrosive
50-100	Moderately corrosive
30-50	Corrosive
10-30	Highly corrosive
<10	Extremely corrosive

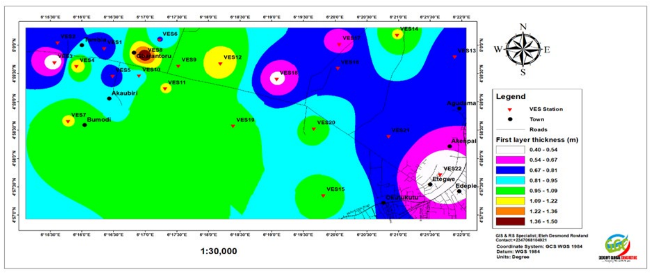

Figure 6: Spatial distribution map of the thickness of the first layer (Topsoil) in the study area

Table 5: Estimated area of the thickness of the first layer (Topsoil) in the study area

S/N	Area (km2)	Percentage (%)
1	2.48	1.98
2	4.97	3.97
3	18.8	15.11
4	19.75	15.80
5	32.14	25.71
6	1.56	1.25
7	0.16	0.13
8	0.10	0.08
	80.00	

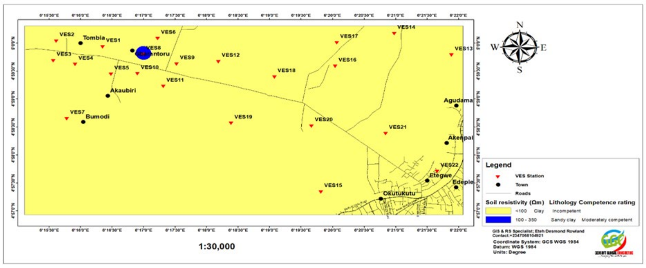

Figure 7: Soil competence map of layer 1 in the Study area

Table 6: Estimated area of the Soil competence layer 1 in the study area

S/N	Area (km2)	Percentage (%)
1	79.75	99.90
2	0.16	0.10
	79.91	

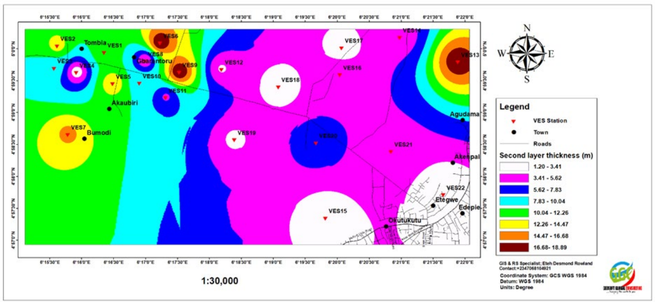

Figure 8: Spatial distribution map of the thickness of the second layer in the study area

Table 7: Estimated area of the thickness of the second layer in the study area

S/N	Area (km2)	Percentage (%)
1	9.72	12.17
2	26.84	33.58
3	11.69	14.63
4	11.73	14.68
5	14.09	17.68
6	3.75	4.70
7	1.30	1.63
8	0.74	0.93
Total	79.87	

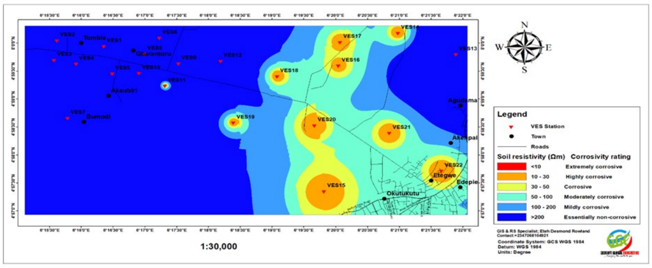

Figure 9: Soil Corrosivity map of layer 1 of the Study area

Table 8: Estimated area of the Soil Corrosivity map layer 1 in the study area

S/N	Area (km2)	Percentage (%)
1	0.001	0
2	2.993	4
3	4.943	6
4	14.964	19
5	9.591	12
6	47.467	59
	79.958	

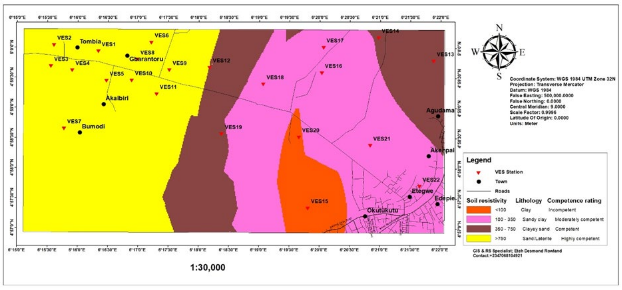

Figure 10: Soil competence map of layer 2 in the Study area

Table 9: Estimated area of the Soil competence second layer in the study area

S/N	Area (km2)	Percentage (%)
1	4.98	6
2	28.20	36
3	15.24	19
4	31.39	39
	79.81	

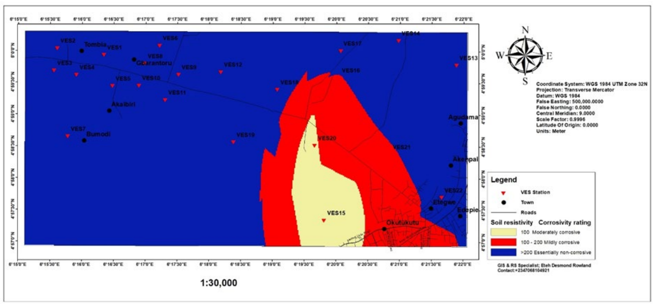

Figure 11: Soil Corrosivity map of layer 2 in the Study area

Table 10: Estimated area of the Soil Corrosivity map layer 2 in the study area

S/N	Area (km2)	Percentage (%)
1	4.98	6
2	13.15	17
3	61.68	77
4	79.81	

The spatial distribution map in Figure 6 shows the spatial pattern of the Topsoil (first layer) thickness map ranging from 0.40 m to 1.50 m and is estimated land area and the percentage is shown in Table 5 and the spatial pattern of the distribution map in Figure 8 indicates the second layer thickness map varies from 1.2 m to 18.89 m with estimated area and percentage shown in Table 7. From Figure 7 the soil competence map of layer 1 (topsoil) in the study area under investigation contain blue colour and is represented as moderately competent when compared with Table 3 signifying sandy clay in VES 8 in Figure 1 and its estimated land area is 0.16 km2 with 0.1% in Table 6, The yellow colour in Figure 7 is incompetent and is clay when compared with Table 3, the estimated land area of soil competence is 79.75 km2 with 99.99% in Table 6. The area contains VES 1 to 7 and VES 9 to 22, Signifying the area is incompetent base on the analyse results for layer 1, for layer 2 in Figure 10, red colour represents clay and is incompetent when compared with Table 3, it also contains estimated land area of 4% in Table 9 of VES 15. The pink colour in Figure 10 is moderately competent and is sandy clay when compared with Table 3, the estimated land area of soil competence is 28.20 km2 with 36% in Table 9. The area contains VES 18,17,16,21, and 22, brown colour indicates competent in Figure 10 and is clayey sandy with an estimated land area of 19% and yellow colour indicate sand/laterite and is highly competent in Figure 10 with an estimated land area of 39%, Signifying the area is competent base on the analyse results for layer 2. The soil corrosivity map shows the area contains six class in Figure 9 and Table 8 in topsoil (layer 1) namely, red reflecting extremely corrosive with an estimated land area of 0.001km2, orange colour indicated highly corrosive with 4%, yellow colour indicates corrosive with an estimated land area of 6%, light blue showing mildly corrosive with an estimated land area of 9.59 km2 and dark blue signifying non-corrosive with 49.57 km2 with 59% present and layer 2 the soil corrosivity map shows the area contains three class in Figure 11 and Table 10 in namely, yellow indicates moderately corrosive with estimated land area of 4.9 8km2, red colour indicated mildly corrosive with 17% and dark blue signifying Essentially non-corrosive with 61.68 km2 with 77% present.

Conclusion

The results obtained show that the area is a low land terrain and its estimated land area is approximately 80 km2, the geoelectrical sections delineated 3 distinct layers but we may interest in the Topsoil (first layer) and perhaps the second layer concerning depth. The soil corrosivity of topsoil (layer 1) in the study area indicate five different corrosivity rating ranging from extremely corrosivity, highly corrosive, corrosive, moderately corrosive, mildly corrosive and essentially non-corrosive with estimated land area of 59%, moderately corrosive is 9%, mildly corrosive with 12% and soil competent indicating moderately competent of 0.10% and 99% incompetent with geoelectric curve present H,K KH and AH, with Topsoil (first layer) range from 0.4 m to 1.5 m while layer 2 (second layer) reveal the area contain four class of competence ranging from incompetent with 4.98 km2 land area ,moderately competent 28 km2 land area cover, competent 19 km2 and highly competent with land area cover 31.39 km2 and is the highest among other class and soil corrosivity indicate three class namely moderately corrosive with 6% land area , mildly corrosive contain 17% and essentially non-corrosive indicate 61.68 km2 with 77% land area present in layer 2 with thickness ranging from 1.2 m to 18.89 m. Therefore, because pipe network in Yenagoa is made to be at a depth of about 2 m from ground level (layer 1) the area signifying the soil corrosivity of topsoil essentially non-corrosive due to it occupies 59% of the estimated land area and soil competent indicate 99% of the estimated area are incompetent in layer 1 while layer 2 is highly competent with estimate land area 31.39 km2 with essentially non-corrosive indicate 61.68 km2 with 77% land area and corrosion resistant pipes are strongly recommended to forestall challenges associated with rupture of corroded pipes.

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