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ASSESSMENT OF AQUIFER PROTECTIVE CAPACITY AND SOIL CORROSIVITY IN UMUNEDE, DELTA STATE, USING DEPTH PROBING RESISTIVITY INVERSION

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ABSTRACT

The essence of water and soil for domestic, industrial, and irrigation uses cannot be overemphasized, and hence the protective potential and soil corrosivity of the Umunede village in Ika North East, Delta State, were assessed, and the study area has been categorized recently among the oil-producing towns in the distinct Niger Delta. Ten (10) Vertical Electric Soundings (VES) were carried out with the assistance of an Abem Terrameter to delineate areas with low or poor (< 0.1 mho), moderate (0.2-0.69 mho), and also good (0.7-4.9 mho) protective capacities by utilizing geophysical techniques. Areas were identified by evaluating and ascertaining the area's longitudinal conductance. Aquifers in most areas are shielded (prevented) from oil spills in the event of pollution, according to the study, which rates the protective ability (capacity) of the majority of the just-discovered oil community as good and moderate. Conversely, areas with identified weak or poor protection capability (capacity) are vulnerable to groundwater taint (contamination) from observed surface spills and also from other nearby sources. VES data indicate soil corrosivity levels for VES 4 and 6 to be moderately corrosive (10-60 Ωm), VES 2, 5, 7, and 9 with a small degree of corrosivity, and VES 1, 3, 8, and 10 non-corrosive (values greater than 180 Ωm), and VES 4 and 6 risk pipeline failure. Environmental management initiatives are needed for storm-proofing and protecting the community's aquifer system. This study simplifies the location and distribution of subsurface aquifers, aiding in exploration projects planning for groundwater-producing wells in the study region.

Keywords: Aquifer, Assessment, Corrosivity, Resistivity, Vertical electrical sounding (VES)

INTRODUCTION

Water discovered and found in a saturated void below the earth's surface is known as groundwater. As stated by Okiotor et al. (2022), precipitation and humidity that seep into the subsoil are the principal sources of groundwater. This is only accessible if the saturated zone's rocks are sufficiently porous (permeable) to allow a lot or a huge amount of water to run off into wells, uncontaminated springs, or streams. Its porosity and permeability in the host and matured rock that contains it predict its availability, abundance, and exploitability. In the process of extracting groundwater, both characteristics are crucial (Oghenevovwero et al., 2025). One of the most vital and sustaining natural resources that keep life on earth possible is water. Because of this, the world has recognized the value and relevance of freshwater on March 22nd as World Water Day each year since 1993 (Okolie and Akpoyibo, 2012; Esi and Akpoyibo, 2024). Although there is a great need for groundwater mining and exploration, there is also a present social need to conserve these newly discovered groundwater resources. Leachate from tainted landfills, saltwater invasion (intrusion), oil adulteration, mining occurrences, and wastewater (from toilets and noticeable septic tanks) can all contaminate groundwater and make it unfit for human use (Ikegu et al., 2024). The construction of landfills and restrooms frequently disregards the hydrogeological conditions of the surrounding area, endangering groundwater resources (Ofomola et al., 2017).

Oil spills are a significant and noticeable environmental risk in the Niger basin Delta area brought on by crude oil probing in the area and are a big societal burden (issue) in Nigeria, particularly in the oil-producing villages. Damage of fixed pipelines and storage amenities, corrosion in pipelines, human related inaccuracy (error), equipment/facility failure, and sabotage, upgrades to continuous flow stations, tank reconstruction/rehabilitation, and natural events like thundering, engulf flooding, incessant lightening, heavy/large rain, and tree falls (deforestation) are the main causes of oil spills (Atakpo 2013; Esi et al., 2023; Oghenevovwero et al., 2025). The forfeiture of biodiversity, the poisoning and destruction of surface and the tapped groundwater resources, and the degradation of arable, productive land and soil fertility are all consequences (results) of oil spills on land. The research area (Umunede) in Delta State's Ika North East, reportedly an oil-manufacturing community in the bestow Niger Delta, is close to the teaching hospital and the Faculty of Law at the University of Delta. It has experienced its fair share of environmental deterioration and pollution due to continuing exploration and oil misappropriation (bunkering) activities. Some oil spills, whether they are purposefully disposed of or unintentionally leak to the ground, have the potential to eventually poison and endanger groundwater due to their relative stability there. This pollution can be extremely lethal for human health. The number of productive and abortive wells drilled by governments, people and non-governmental organizations is expanding. This demonstrates unequivocally that groundwater in the nation helps and serves as an efficient addition to other water sources. Therefore, the motive of this study is to evaluate the protective ability of aquifer units and the soil corrosivity of concrete and underground metal pipes in the study region using one-dimensional resistivity inversion. A geological risk known as "soil corrosivity" affects concrete that comes into close touch with soil and bedrock as well as buried discoverable metals. It causes subterranean oil and gas transmission lines to break, which is the fundamental and major way that hydrocarbon pollution in oil-producing regions is caused.

Drilling test holes and examining drill logs exclusively to check the protective layer's thickness and/or lateral spread are traditional techniques for describing a layer. Such inspections have the drawback of potentially being expensive and labour-intensive (Akpoyibo et al., 2023). A cheap and non invasive technique for determining an area's capacity for protection is surface geophysical measurement. Esi and Akpoyibo, (2023) discovered that aquifer protection scrutiny, studies and the assessment of aquifer hydrological qualities can directly employ the integration of layer/strata resistivity and also thickness of Dar Zarrouk calculated variables S (longitudinal conductance) and also T (transverse/lateral resistance).

Regarding and considering aquifer protection, the longitudinal conductance S of a clayey aquifer has an impermanent dimension (permeation time) that is proportionate to its ability to safeguard the load of overburden sediments. (Atakpo and Ayolabi, 2009; Atakpo, 2013; Esi and Akpoyibo, 2023) The protective capacity in Mho is describable as being proportionate and agreeable to the unit longitudinal conductivity. Due to the quick advancements and progress in numerical modelling modifiable software programs used to model large (huge) volumes of geophysical data, the application/use of surface geophysical measurements in groundwater valuable resource mapping and water ranking (quality) assessment has dramatically increased recently (Esi et al., 2023; Esi and Akpoyibo, 2024; Vwavware et al., 2024; Ogholaja et al., 2025). The 1D electrical method, often called VES, is a widely used methodology in groundwater conservation control studies because of its ease of use.

Location and Geology of Umunede Area

The Umunede community is traceably found in Delta State's, precisely Ika North East (Ika ethnic group). Umunede is identifiably located between 6°14'55"N and 6°16'20"N in latitude and within 6°18'15"E and 6°19'35"N in longitude. It is bordered by the rivers Namomah and Orogodo. Akumazi, Mbiri, Owa, and Emuhu are bounded by the study area (Figure 1a). The aforementioned rivers travel southwest toward the shore and forest reserves are unique characteristics of vegetation. The local government of Ika North East, where Umunede is located, claims to have proven gas and oil reserves in blessed Delta State (Niger Delta). Numerous thorough studies have carefully examined the geology of the Umunede area in Ika North East, which position is situated in Niger Delta region (Akpoyibo et al., 2022, Anomohanran et al., 2023; Egheneji et al., 2023; Omajene et al., 2024; Vwavware et al., 2024; Akpoyibo and Vwavware, 2024; Akpoyibo et al., 2025; Ogholaja et al., 2025). Benin, distinct Agbada, and uniquely Akata formations are the described stratigraphic formations that make up (constitute) the Niger Delta basin (Anomohanran et al., 2023) and other researchers such (Akpoyibo et al., 2023, Molua et al., 2024), provide obvious summaries of typical parts of these formations. The Akata Formation is primarily and basically composed of marine shale and quantifiable sand layers, with dark gray sand and shale making up its subsurface. It is anticipated that this Formation (division) is more than 7,000 meters thick (Esi et al., 2023). Atakpo and Ayolabi (2009) described the upper or top Agbada Formation as a sequence of basically sandstone and numerous shale deposits. Its bottom end contains shale, whereas the higher section is mostly composed of sand with a tiny amount of shale and more than 3,700 m of thickness exist. Though much more exposed near the coast, the upper division of Benin is wrapped in several places by thin strata of laterite of different varying thicknesses (Figure 1b)

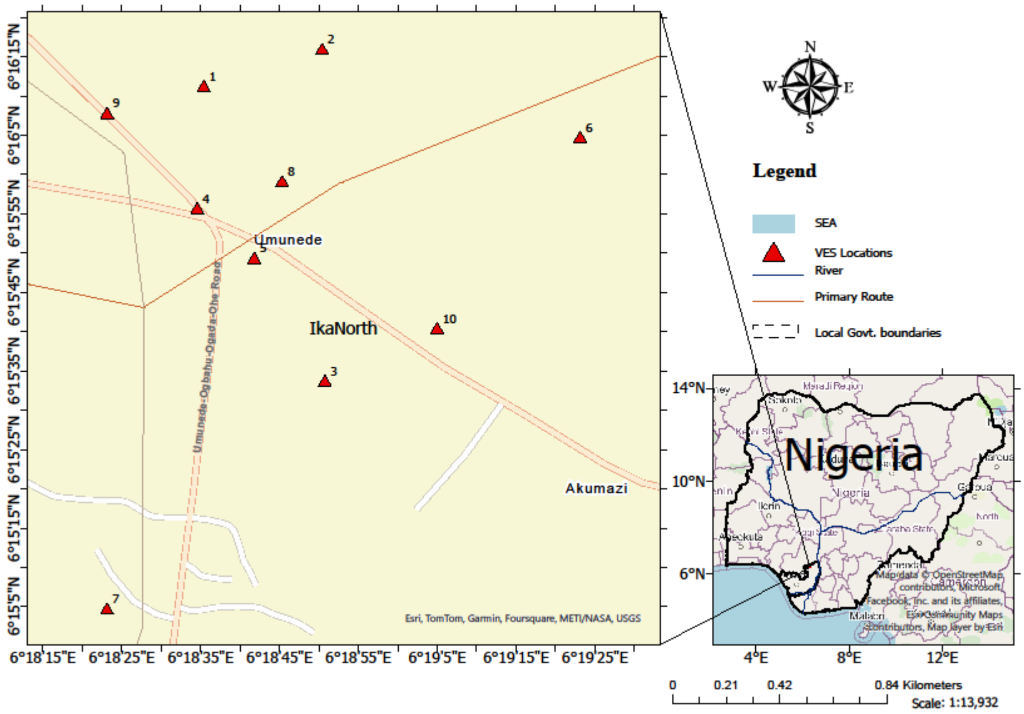

Figure 1a: Map of the study area unveiling the VES locations

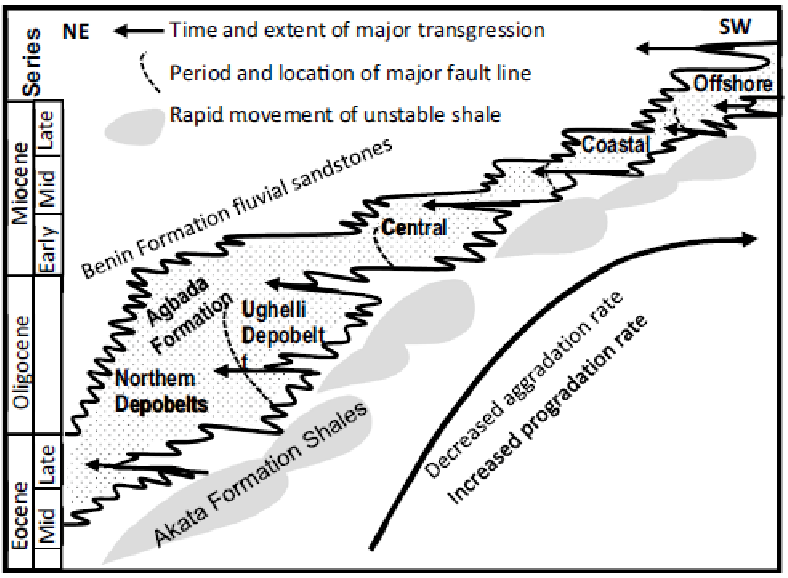

Figure 1b: Geology map of the Niger Delta Units with Umunede inclusive (Anomohanran et al., 2023)

MATERIALS AND METHODS

This study put into practice the one-dimensional resistivity method as part of the electrical resistivity methods to detect depth function and calculates vertical variations in resistivity. Data collection in the field was conducted, taking advantage of the SAS ABEM 1000 Terrameter resistivity meter. According to Okolie and Akpoyibo (2012) and Afolabi et al. (2004), the Schlumberger sounding technique was chosen for data collection because of its vulnerability to close surface variations. This technique can accurately identify subsurface structures based on their occurring resistivity and thickness, with a profound depth of penetration, while requiring less labor. It also delineates contaminated zones of groundwater. This investigation produced shallow and deep layers by varying the spacing of the maximum current electrode from 450 to 500 m. A precise total of ten (10) VES were undertaken in the studied community. In each occurrence, the GPS (global positioning system) of every sounding location was documented and converted to degrees.

Geophysical data procedural and inversion processes

The resistivity model curves generated and produced from processing the VES data manually were partially curve-fitted with the assistance/aid of the auxiliary and master curves. The obtained (valid) layer parameters were then entered into the Win-Resist computer program (Esi et al., 2023) and assessed quantitatively to find the single-dimensional (1D) resistivity simulation parameters (i.e., thickness and layer resistivity). From these curves, the unique four (4) standard curves the Acategory curve ($P_1 < P_2 < P_3$), the Q- kind curve ($P_1 > P_2 > P_3$), the K-curve ($P_1 < P_2 > P_3$), and the Hgroup curve ($P_1 > P_2 < P_3$) were used to find and determine the curve type for each VES point. Quantitative evaluation of VES data created the layer parameters or variables (thickness, depth, and strata resistivity) also referred as the first-kind geoelectric variables (the thickness value layer hi and the strata resistivity (Pi) for the assigned ith layer.

The longitudinal unit conductance (Si) of each geoelectric layer also referred to as a second-order geoelectric parameter was obtained by applying these first-order geoelectric parameters (Atakpo and Ayolabi, 2009). The following deduced expression (Oghenevovwero et al., 2025) was used to calculate the total longitudinal conductance:

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

The protective capacity of Umunede was measured utilizing Atakpo and Ayolabi, 2009 echelon (in Table 1), which allows the categorization of aquifer protective structural capacity into poor (impoverished), weak, also moderate (mild), good, very or really good, or excellent. Areas in the Umunede community evaluated and rated from poor to moderate are prone and liable to contamination risk from nearby surface pollution incidents. The overburden protective (shielding) capacity of the stretch area was calculated deploying the total longitudinal unit conductance estimated values created in Equation 1 for every single VES point (Atakpo, 2013).

Table 1: Grading (Rating) of Longitudinal Conductance and Protective Capacity (Okiotor et al., 2022).

Total Longitudinal Section (unit) Conductance (mhos)	Classification of Overburden Protective (safeguarding) Capacity
Less than (<) 0.10	Poor (Pathetic condition)
0.10-0.19	Weak (deficient condition)
0.20-0.69	Moderate (Temperate condition)
0.70-4.9	Good (Acceptable condition)
5.0-10.0	Very good (Very satisfactorily)
>10.0	Excellent (Distinctive condition)

Using the topsoil first layer resistivity readings and an analysis based on the Table 2 classification scheme proposed by Okiotor et al. (2022), the corrosivity of the examined soil in the research region was also ascertained by echelon using resistivity value disparities. (Ogheneovovwero et al., 2025).

Table 2: Soil resistivity classification (categorization) based on corrosivity (Okiotor et al., 2022; Ogheneovovwero et al., 2025)

Soil Resistivity in the First Layer (Ω-m)	Ranking of soil Corrosivity
< 10	Very strongly (potently) corrosive (VSC)
10-60	Moderately (averagely) corrosive (MC)
60-180	Slightly (slimly) corrosive (SC)
≥ 180	Practically (almost) non-corrosive (PNC)

RESULTS AND DISCUSSION

Table 3 presents a summary of the findings related to the interpretation of VES, soil corrosivity, curve type, and longitudinal conductance of Unmunede of the overburden aquifer unit, as determined for VES 1–10. The primary and main curve types are AKH and KQH (Table 3). Using SURFER terrain and 3-D surface program software and the sophisticated contour level option, a protective capacity map was created using the longitudinal conductance values in Table 3. The contour lines in Table 1's advanced contour level option of the SURFER application are filled with diagnostic colors and made visible to help differentiate between the different longitudinal conductance/protective capacity ratings based on Atakpo and Ayolabi (2009). The longitudinal conductance values estimated for the Umunede area are distributed as a map in Figure 12. To differentiate between locations with strong (0.7-4.9 Mho), moderate (0.2-0.69 Mho), and poor protective capacity (< 0.1 Mho) for VES 1 to 10 (Table 3), the longitudinal conductance image map was color-coded and viewable in Figure 12. The VES locations 2, 4, 6, 7, and 10 fall within the moderate (within reasonable) protective capacity zone as represented by blue and green colors in Figure 12. VES 3 and 5 locations are located in the area of good protective capacity (Table 3) and are revealed in the yellow and red color zones. Parts of the neighborhood that fall under the previously said VES areas are moderately, favorably, and averagely protected from oil spills, such as leachate taint from landfills, sewage tanks, chemical runoff, and wasteland (lethal) materials released from agriculture or other nearby hazards, according to the longitudinal conductance map of Umunede (Figure 12).

Percolating fluid is naturally permeated and filtered by the earth's medium. A measure of the earth's protective capacity is its power to repress, accelerate, and filter percolating liquids into the subsurface (Okolie and Akpoyibo, 2012). VES location 1, 8 and 9, falls within low protective capacity as represented by purple colors in Figure 12, and indicates that these regions in Umunede metropolis are unprotected and absolutely prone to aquifer pollution due to wastes pollution or other near surface occurrences. The survey also showed that zones of significant overburden thickness with quantifiable clayey columns, which are thick enough to shield the local aquifer from surface pollution, are associated with aquifer protective capability from good to moderate.

Table 3: Concise Version of the VES Interpretations Showing the Computed Longitudinal Conductance Values, Soil Corrosivity Class, Curve Type, and Model Resistivity Parameters (Numerical Layers Resistivity and Thickness)

VES	Layer resistivity (Ω-m)	Layer thickness (m)	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$ (Mho)	Protective Capacity Assessment	Soil Corrosivity	Curve type
VES 1	197.0	1.7				
	599.3	10.1				
	702.5	17.5	0.0846	Poor	Practically non-corrosive	AKH
	555.5	19.0				
	1177.9	----				
VES 2	99.6	2.5				
	241.0	14.4				
	478.8	24.9	0.3487	Moderate	Slightly corrosive	AKH
	167.1	35.4				
	1357.9	----				
VES 3	851.1	2.8				
	584.8	13.1				
	331.1	46.2	1.5218	Good	Practically non-corrosive	QQQH
	151.8	25.1				
	27.2	32.4				
	1131.0	----				
VES 4	55.8	1.6				
	282.8	18.8				
	372.1	20.1	0.2755	Moderate	Moderately corrosive	AKHA
	268.8	23.1				
	358.8	14.5				
	1252.4	----				

VES 5	66.5	1.9				
	191.8	28.2				
	106.7	30.3	0.7872	Good	Slightly corrosive	KQH
	58.6	19.2				
	1007.3	----				
VES 6	38.2	1.8				
	254.9	21.8				
	289.1	33.1	0.4162	Moderate	Moderately corrosive	AKH
	137.2	23.2				
	2789.1	-----				
VES 7	104.2	2.1				
	259.0	42.1				
	244.5	42.9	0.4819	Moderate	Slightly corrosive	KQH
	229.5	28.4				
	2977.6	----				
VES 8	220.0	1.3				
	474.2	10.7				
	989.7	10.5	0.0617	Poor	Practically non-corrosive	AKHK
	566.8	7.6				
	1062.9	9.8				
	678.4	----				
VES 9	168.9	1.3				
	614.6	10.5				
	632.1	15.9	0.0686	Poor	Slightly corrosive	AAA
	827.3	15.4				
	1059.9	-----				
VES 10	195.5	1.4				
	74.9	5.3				
	389.0	31.3	0.4251	Moderate	Practically non –corrosive	HKH
	149.6	39.9				
	2029.5	----				

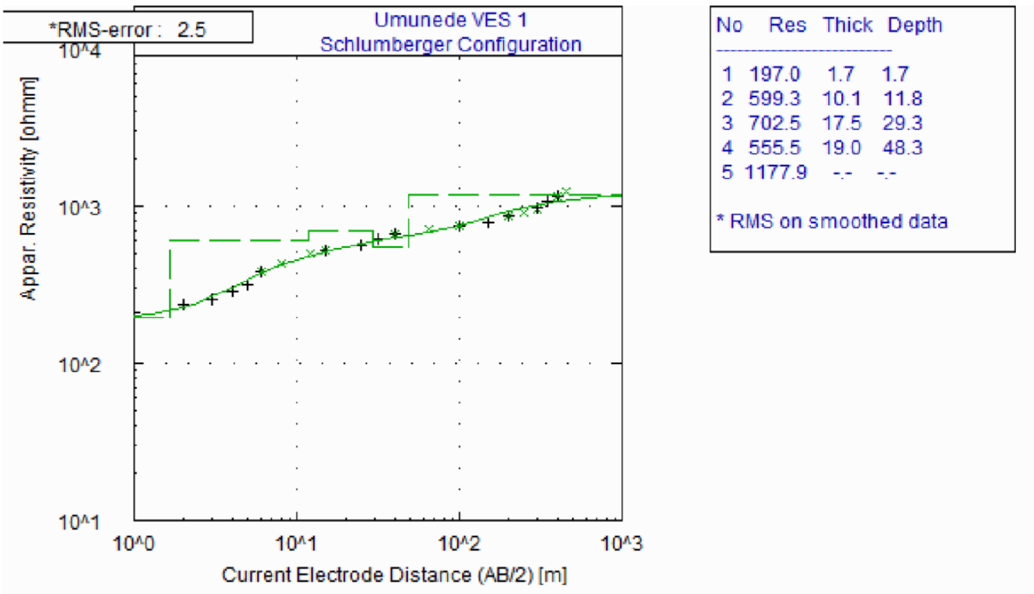

Figure 2: Typical AKH curve type (VES 1)

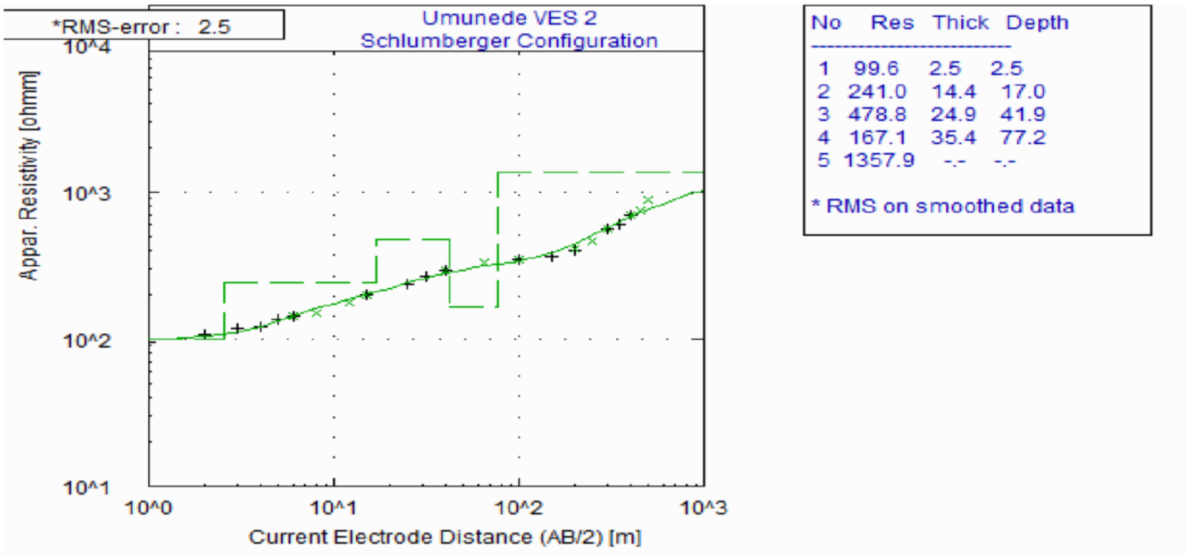

Figure 3: Identify AKH curve kind (VES 2)

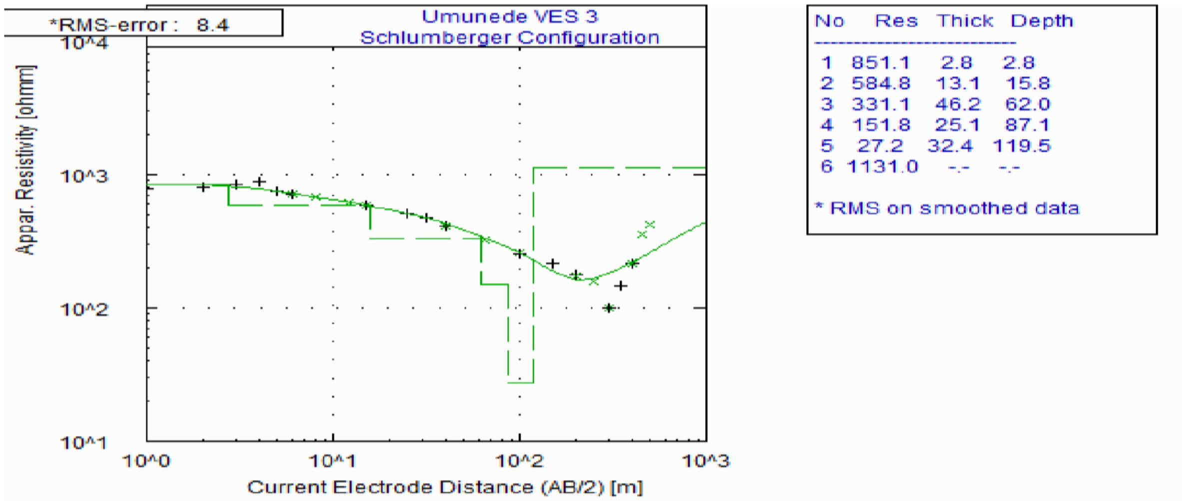

Figure 4: Typical form of QQQH curve type (VES 3)

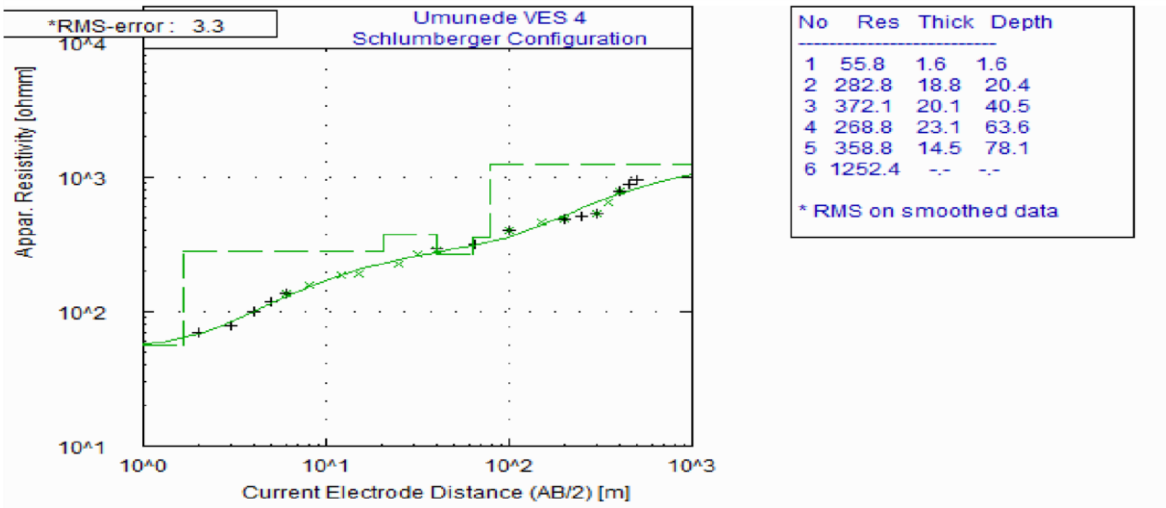

Figure 5: True AKHA curve category (VES 4)

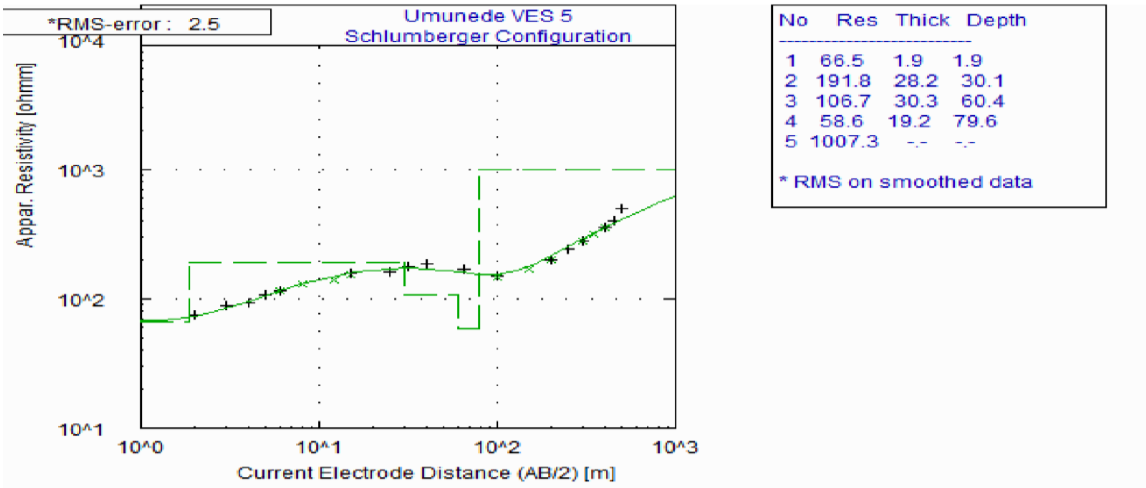

Figure 6: Typical KQH curve type (VES 5)

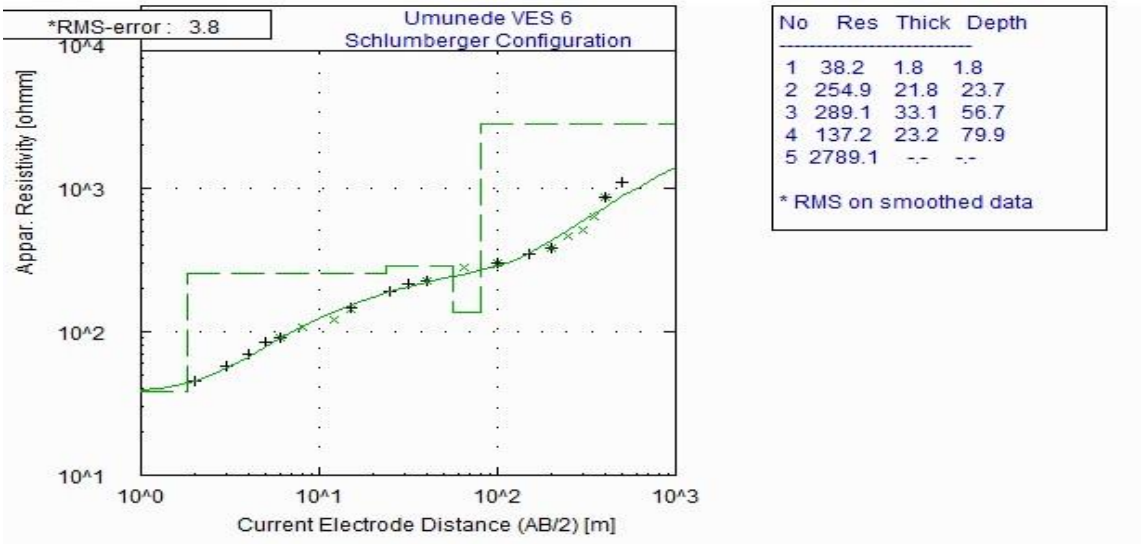

Figure 7: Representative AKH curve type (VES 6)

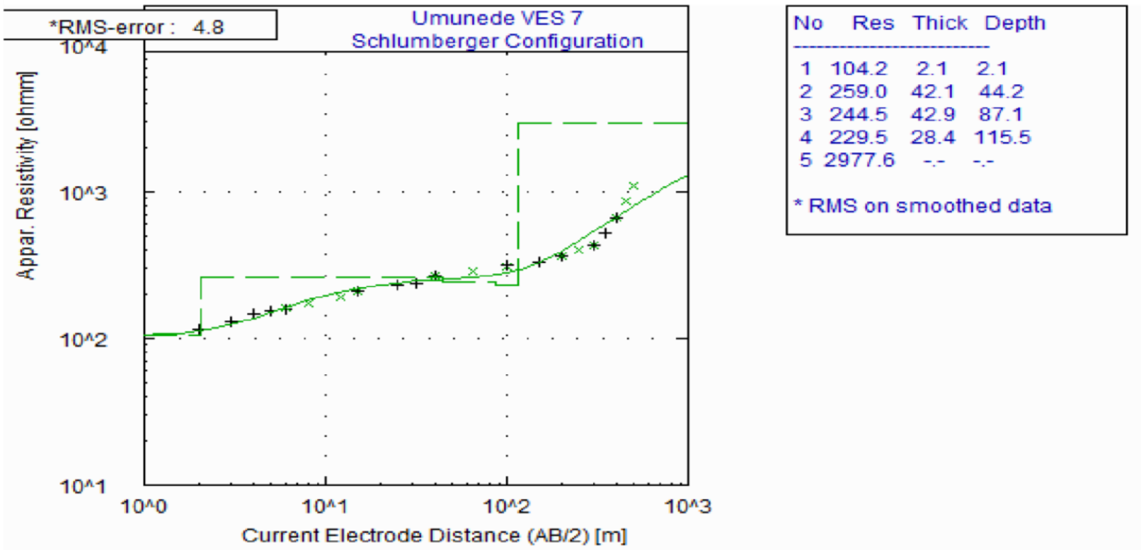

Figure 8: Typical KQH shape type (VES 7)

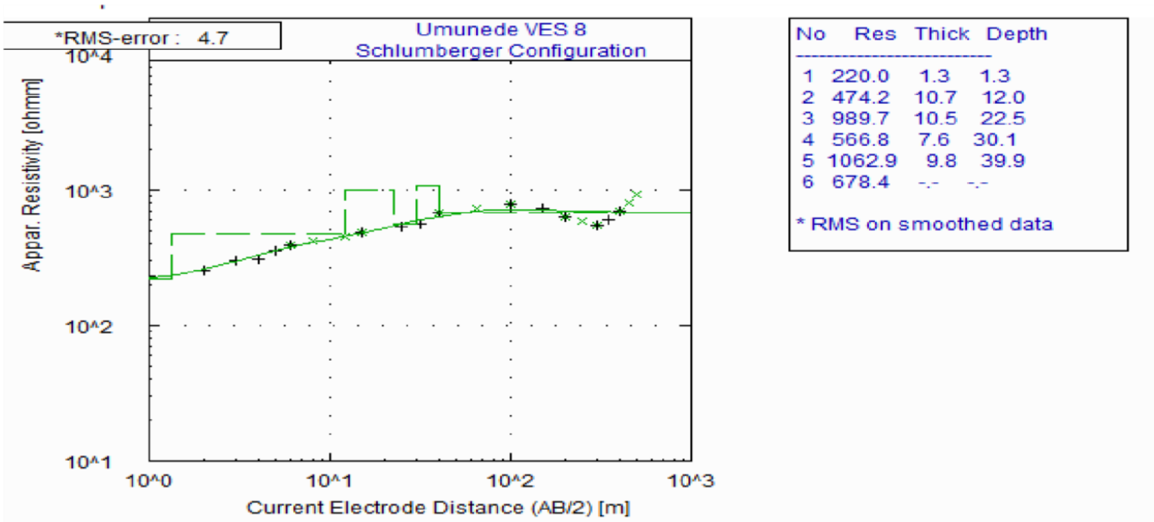

Figure 9: Typical AKHK curve specification (type) (VES 8)

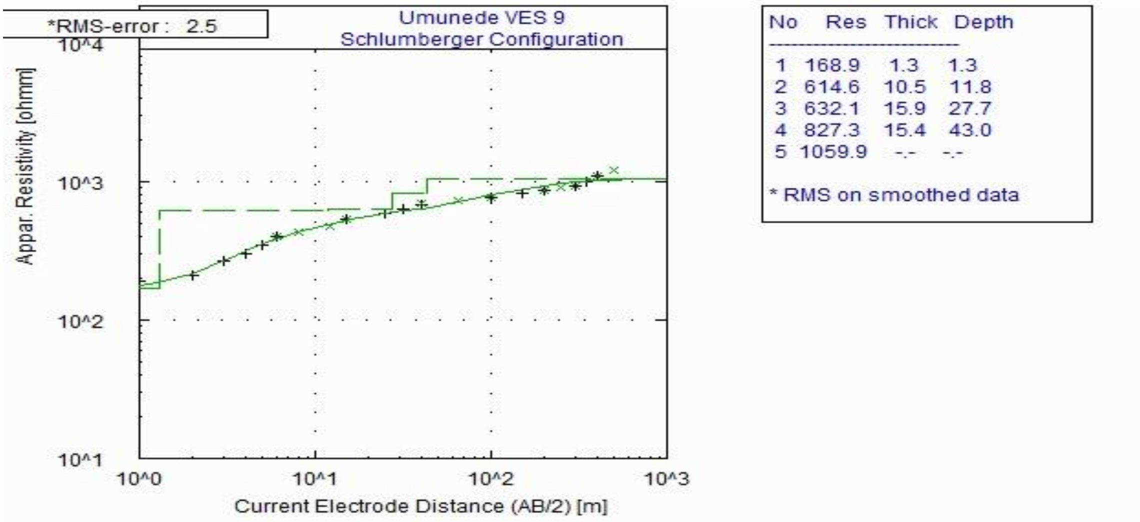

Figure 10: Typical AAA shape category (VES 9)

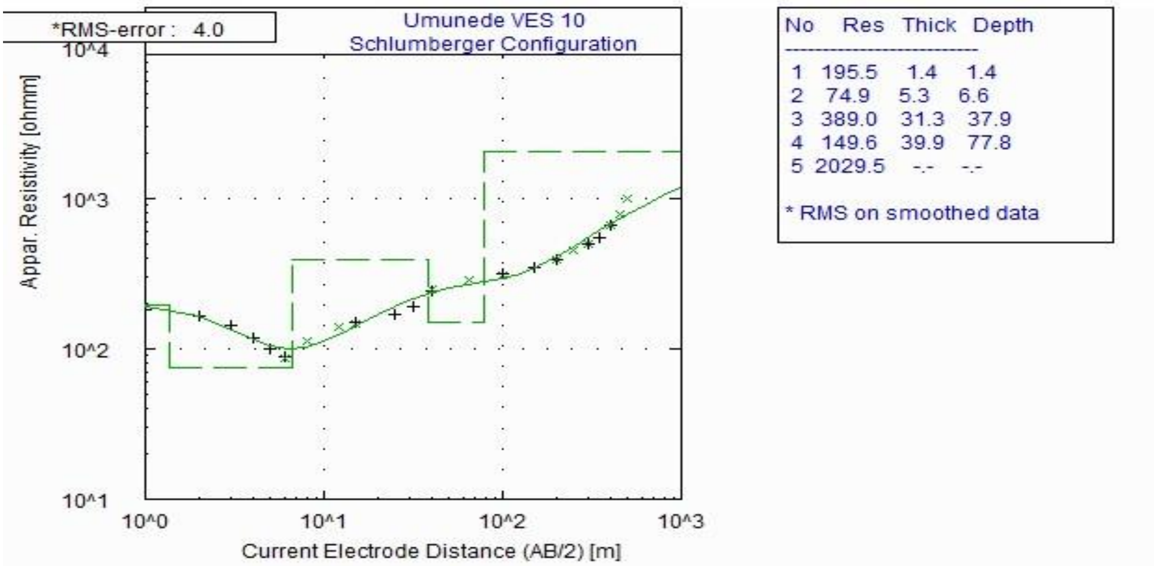

Figure 11: Typical HKH curve formation (VES 10)

The overburden studied thickness map of the first (foremost), subsequent second, and third geoelectric layers is provided in the 3D surface map displayed in Figure 14a, b, and c.

The research area's overburden thickness varies greatly, with parts with significant overburden thickness and others with low overburden thickness, as demonstrated by the maps' vertical and lateral extents. The maps in Figures 12, 13, and 14 as well as Table 3, are helpful in locating subsurface aquifers and determining the distribution of their protection capacity across the whole research region. Planning exploration projects for the location of groundwater-producing wells in the region should be done in VES 3, 5, and 10 with no trace of corrosivity and moderate to good protective capacity. Considering the first stratum resistivity results and in comparison with Table 2 following Okiotor et al.'s (2022) study, the soil corrosivity in the research region was also deduced, as shown in Table 3. According to VES 2, 5, 7, and 9, it indicates that the topsoil (soil) is quite and slightly corrosive since the first layer (stratum) resistivity falls within 60-180 Ωm. The topsoil is practically uncontaminated and noncorrosive in VES 1, 3, 8, and 10, with ascertained first (foremost) layer resistivity in the range of $\rho > 180$ Ωm. However, VES 4 and 6 show that the materials are moderately (somewhat) corrosive (first layer resistivity within (between) 10-60 Ωm). The study area's contour map of soil corrosivity distributions is displayed in Figure 13 and Table 3.

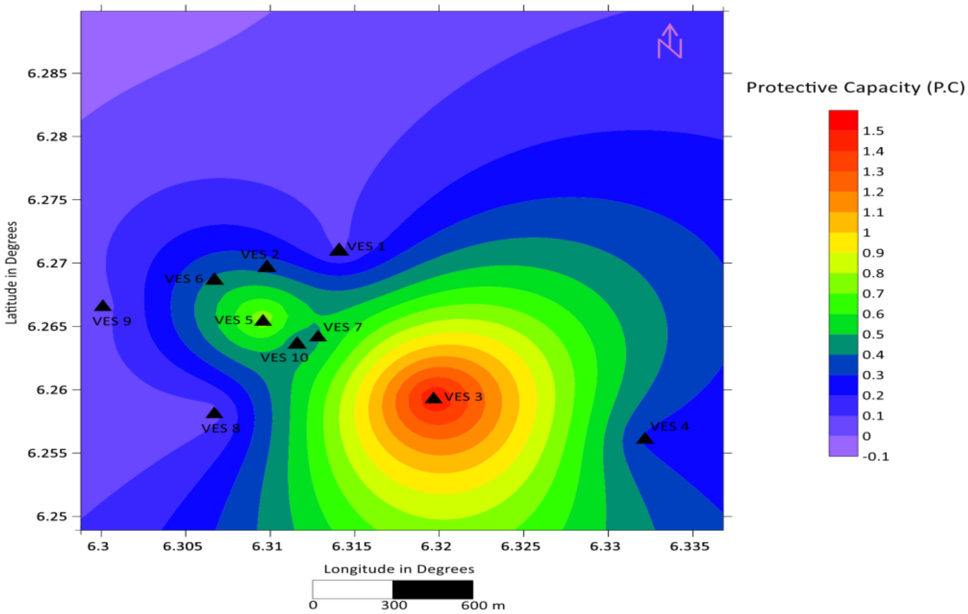

Figure 12: Protective capacity (PC) map (shape) of the examined area

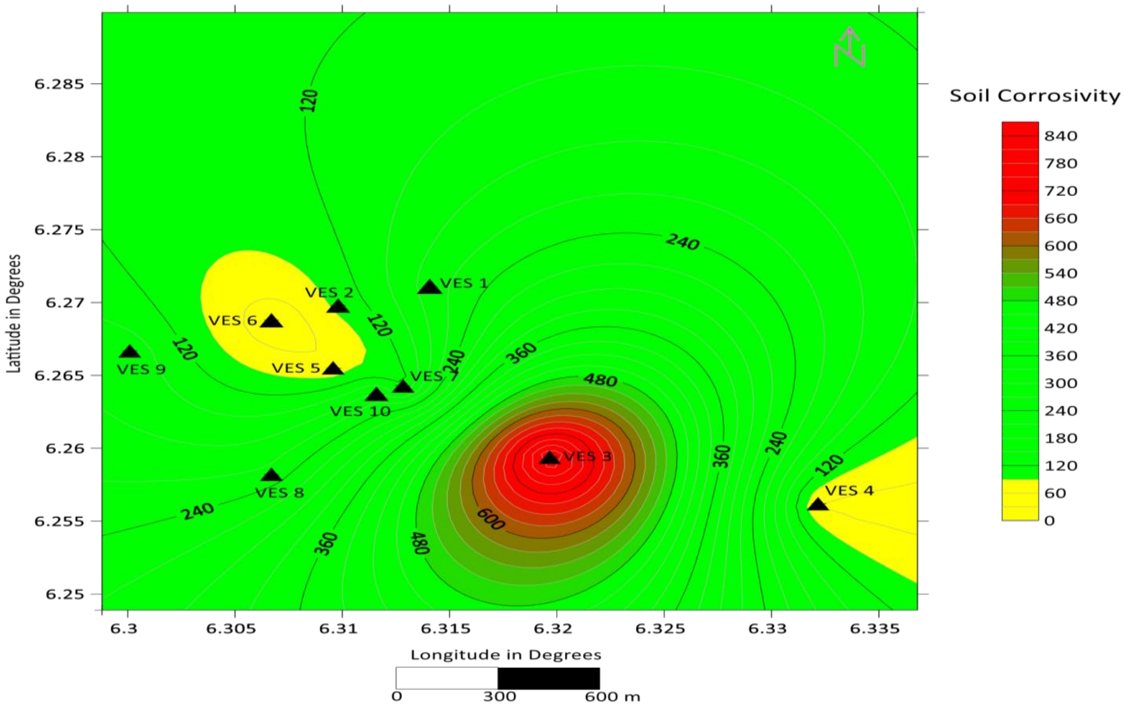

Figure 13: Map of the soil corrosivity of the inspected (survey) area

The contour lines in Figure 13 were successfully made visible and filled in with various marked colours in order to identify regions with materials that are almost noncorrosive (green to red), slightly (mildly) corrosive (green), and moderately (substantially) corrosive (yellow). The map shows that most of the research region is composed of materials that are virtually noncorrosive, whereas portions with moderate to mild corrosivity are susceptible to water pollution and pipeline failures. This explains why continuing oil leaks and tainted ground water have been observed often at different locations across the research region.

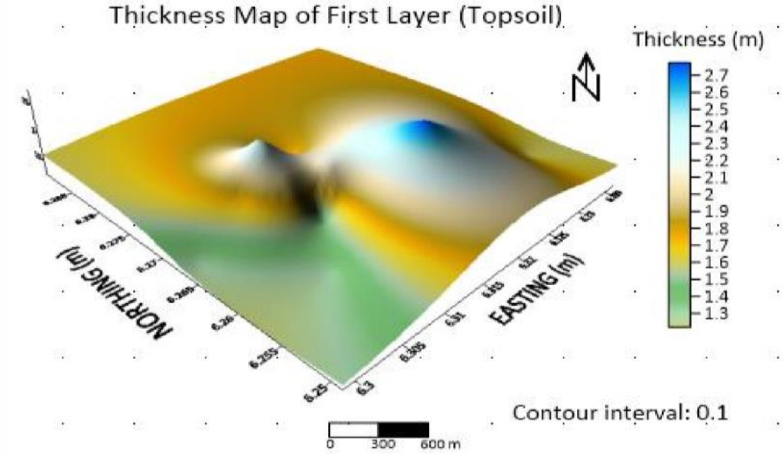

Figure 14(a): Overburden sketched thickness map of first stratum (layer) top soil

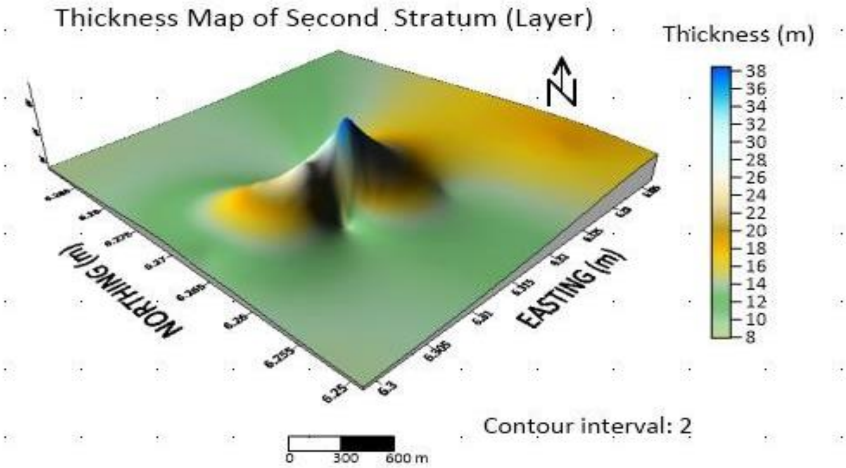

Figure 14(b): Overburden plotted thickness detailed map of second (2nd) layer

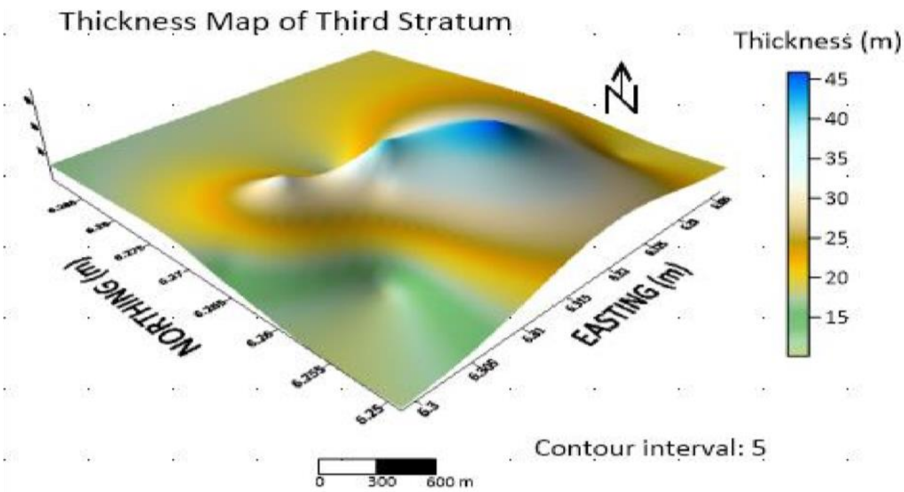

Figure 14(c): Overburden formation thickness map of third division layer

CONCLUSION

The Umunede town in Delta State has overburden protective capability; soil corrosivity and overburden ascertained thickness were assessed using the electrical resistivity sounding (VES) technique. Ten (10) vertical electrical soundings (VES) applying the Schlumberger electrode array were employed in this survey, and they were dispersed across the town in three different places. The electrode separation in this investigation ranged from 400 to 500 meters for deeper subsurface soil investigation, and to determine the first-category geo-electric variables (the stratum resistivity and the layer thickness), the VES data derived were quantitatively and carefully evaluated using partial curve matching and further inputted into the Win-Resist software. The prevalence of K and Q curves is indicated by the frequency of the curve types. The longitudinal unit conductance (S) was calculated with usage of the first-order geo-electric variables, and the total longitudinal unit/division conductance values were then used to assess the area's overburden protection capability. Areas with weak (< 0.1 mho), moderate (0.2-0.69 mho), and good (0.7-4.9 mho) shielding capacity were identified using the longitudinal conductance map. Areas with weak or poor protection ability are vulnerable to groundwater befouling and contamination. VES 3 and 5 of the community surveyed had good (0.7–4.9 mho) protective capacity as indicated by the VES interpretation (1.5218 and 0.7872, respectively), meaning that the aquifers in these identified areas are protected and free from hydrocarbon tainting in the eventuality (phenomenon) of pollution. The examination of soil corrosivity based on VES data revealed that the subsurface contained components that were practically noncorrosive, moderately corrosive, and somewhat corrosive. Pipeline failure is more likely to occur in areas with mild to severe corrosivity. Since there are constant spills in various parts of the community, water quality management needs to be given top and adequate priority. The following measures are therefore advised for the community's aquifer system protection in light of the study's findings: drilling deep boreholes and raising awareness to prevent residents from drinking water from manually (hand) dug wells, which are sensitive and open to contamination. Petroleum pipelines should be regularly (at fixed intervals) checked for corrosion, and if a spill occurs due to sabotage, pipeline disorder/failure, or other causes. Remediation efforts should be right away to avoid further contamination of the community's quality aquifer.

Regular water quality analyses and community groundwater well monitoring should also be carried out adequately.

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