Supported by
tetfund
TERTIARY EDUCATION TRUST FUND

GEOELECTRIC AND HYDROCHEMICAL INVESTIGATIONS OF THE AQUIFER AROUND THE AUTOMOBILE MECHANIC VILLAGE IN SAPELE, NIGERIA.

Harriet Obakpororo Isabu, Merrious Oviri Ofomola, Ezekiel Onoriode Abriku, Ochuko Anomohanran
Department of Physics, Delta State University, Abraka, Nigeria
Email: ofomola@delsu.edu.ng

Received: September 14, 2024 Accepted: November 28, 2024

Abstract: Vertical electrical sounding, 2-D resistivity imaging and hydrochemical analysis have been applied in the study of the aquifer around the automobile mechanic workshop in Sapele, Nigeria. Fifteen sounding points were done and six resistivity imaging employing dipole-dipole configuration around the automobile mechanic village. The geoelectric sections revealed four distinct layers namely topsoil, lateritic sand, fine sand, and medium coarse sand. The third and the fourth layers were identified as the aquiferous layers with resistivity values and depth ranged from 17.4 Ωm to 459 Ωm and 4.5 m to 10.0 m respectively. The low resistivity values of 19.1 Ωm to 454 Ωm obtained around the automobile mechanic workshop in the geoelectric sections is attributed to the effect of leachate from the activities of the workshop. The aquifer protective capacity was found to be predominantly weak. The results of the hydrochemical analysis of water samples from boreholes revealed that the concentration of cadmium, nickel and lead are greater than the Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO), implying that the groundwater is polluted by leachates. The results of the pollution load index (PLI) which is greater than one, revealed that the groundwater from the sampling sites is deteriorating and polluted due to the presence of heavy metals, and the water quality indices (WQI) is >300 which reveals that the water is unsafe for drinking. Based on these, the water in the study area was rated as unsuitable and thus need proper treatment before domestic use.

Keywords: Geoelectric, Hydrogeochemical, Aquifer, Leachate, Automobile Mechanic Village.

Introduction

Groundwater is a crucial resource for sustaining various socio-economic activities and fulfilling the water needs of communities globally (Atakpo and Ofomola, 2012; Gleeson et al., 2012). In Sapele, Delta State, Nigeria, groundwater significantly supports domestic, agricultural, and industrial activities. Specifically, the automobile mechanic village heavily depends on groundwater for its daily operations. However, the sustainability and quality of the aquifer system in the area remains poorly documented. The area is experiencing rapid urbanization and industrialization, leading to increased pressure on groundwater resources (Shafique et al., 2019). Over fifty (50) automobile repairs and maintenance workshops are operating in the area for more than four decades ago, and their activities involve the use of various chemicals, lubricants, and petroleum products, which pose substantial risks to the local aquifer system (Adelana & MacDonald, 2008). Understanding the hydrogeological characteristics and geochemical composition of the aquifer is essential for effective water resource management and pollution control strategies in the area. Previous studies in similar environments have demonstrated that industrial activities can significantly impact groundwater quality. Egbai et al., (2018) emphasized the importance of geochemical analysis in assessing groundwater quality around some open dumpsites in Sapele Delta State, Nigeria while investigating the aquifer protective capacity and groundwater quality.

Due to the industrial nature of the area and the potential risks it poses to groundwater quality, it is essential to conduct a comprehensive investigation using both geoelectric and hydrochemical methods. The study of aquifers around automobile mechanic villages is critical due to potential environmental impacts resulting from anthropogenic activities. These activities often lead to the contamination of soil and groundwater resources, primarily through the disposal of hydrocarbons, heavy metals, and other pollutants. Geoelectric and hydrochemical methods are frequently employed to investigate subsurface conditions and assess the extent of contamination (Ohwoghere-Asuma et. al., 2020; Anomohanran et. al., 2021). Anomohanran (2015) conducted a study in Delta State, employing geoelectric methods to identify aquifer characteristics and potential contamination. The study demonstrated the efficacy of resistivity methods in assessing aquifer properties and identifying contamination plumes. Anomohanran et. al., (2023) assessed the groundwater potential in Ughelli using vertical electrical sounding (VES). The study identified several aquiferous zones, providing essential data for groundwater exploration and management in the region. In Osubi, Ofomola (2015) conducted a combined geophysical and hydrochemical survey to evaluate groundwater contamination from nearby dumpsites. The study utilized vertical electrical sounding (VES) and revealed significant contamination, guiding remediation strategies and protecting water quality. Atakpo (2013) conducted a 2D resistivity survey using a dipole-dipole array to investigate oil spill contamination in Ogulaha, Delta State. The study identified high resistivity values associated with oil-contaminated soils, indicating significant infiltration of oil up to a depth of 10 meters. This survey was crucial for understanding the extent of environmental damage and planning remediation efforts.

Udom et al. (2002) conducted a comprehensive geochemical study in Khana and Gokhana areas of Rivers State, analyzing groundwater samples for heavy metals such as lead, cadmium, and zinc. The study revealed that concentrations of these metals exceeded WHO guidelines, indicating significant contamination from mechanic workshops. Nwankwoala and Moms (2007) conducted a comprehensive geochemical study in the Niger Delta, highlighting elevated levels of lead, cadmium, and nickel in groundwater samples from mechanic villages. The study attributed these levels to improper waste disposal practices prevalent in these areas.

1. Location and Geology of the Study Area

The study area, Sapele, is situated within longitudes 5°37′E to 5°44′E and latitudes 5°51′N to 5°52′N. The focus is on the Automobile Mechanic Village located at Shell Road in the Sapele Local Government Area of Delta State (Figure 2). This region lies within the Niger Delta basin and features a seaward-sloping flat terrain. The area experiences an equatorial climate, characterized by two main seasons: the wet season, which spans from April to September, and the dry season, which lasts from October to March. The area is an industrial hub known for its automotive repair and maintenance activities. The area is drained by several small streams and channels that eventually feed into larger rivers such as the River Ethiope, a significant water body in the region. These natural drainage systems are vital for managing storm water and runoff from the mechanic village. However, inadequate waste disposal and insufficient drainage infrastructure can result in localized flooding and potential groundwater contamination (Ekeocha, 2020). The topography of the area is characterized by a predominantly flat to gently undulating terrain, with elevations ranging from approximately 7 to 20 meters above sea level. The flat nature of the landscape influences drainage patterns and surface water flow, which are critical for managing industrial waste and preventing contamination. The soil composition in Sapele predominantly consists of sandy soils with clayey layers at varying depths. Sandy soils have high permeability, allowing rapid water infiltration, while clayey layers act as barriers, slowing down contaminant movement but potentially creating perched water tables. This composition affects both water infiltration and the movement of contaminants (Akinbile et al., 2019). The area consists of sedimentary rocks, as Delta State is predominantly underlain by sedimentary formations. These sedimentary rocks may include sandstone, shale, and possibly limestone. Additionally, given the location's proximity to the Niger Delta region, there could be significant presence of alluvial deposits, which are often rich in sand, clay, and gravel.

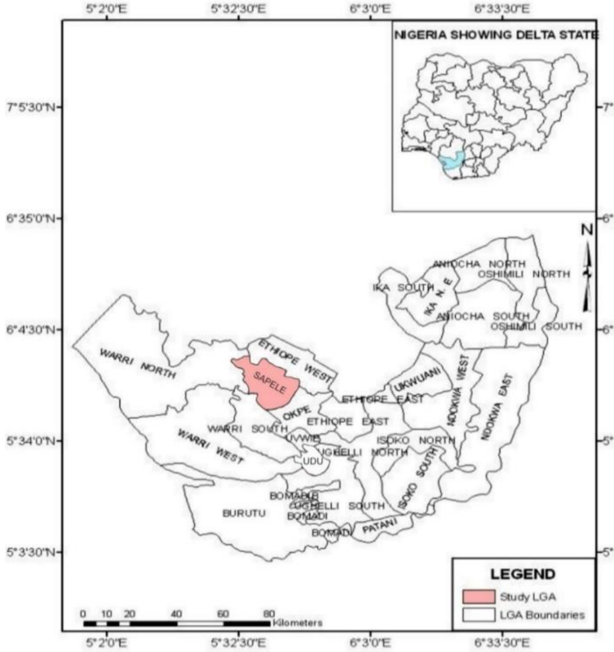

Figure 1: Map of Delta State showing the study area.

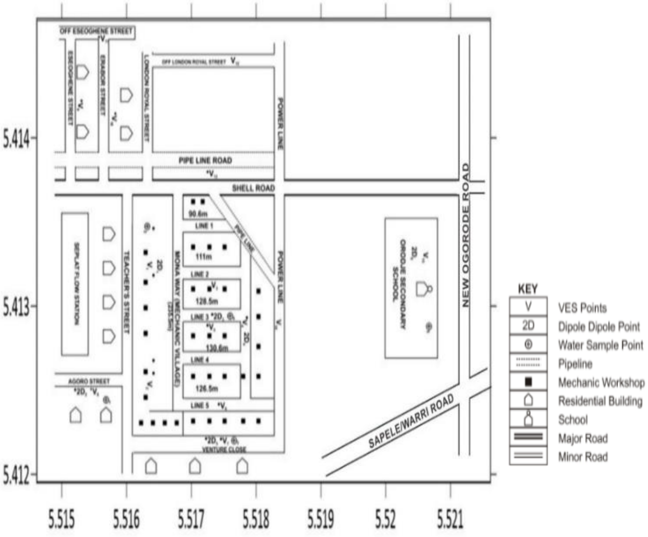

Figure 2: Base Map of the study area.

Methodology

Fifteen vertical electrical soundings and six dipole – dipole array profiling was administered using the ABEM SAS 1000 Terrameter. In the Schlumberger array of the vertical electrical sounding, the electrodes were placed symmetrically around a central point. The two current electrodes (C1 and C2) are placed symmetrically at increasing distances from the center with an initial spacing of 1 meter. The potential electrodes (P1 and P2) are placed closer to the center with a small spacing of 0.25 meters between them. Current was injected into the ground using the current electrodes (C1 and C2). The electrode spacing, current, and potential difference were logged into the Terrameter.

The spacing between the current electrodes (C1 and C2) was gradually increased while keeping the potential electrodes (P1 and P2) fixed near the center. After several steps, the spacing between the potential electrodes was increased. This process was repeated, expanding the spacing of the current electrodes and adjusting the potential electrode spacing as necessary, while recording the resistivity measurements. For the Schlumberger configuration, a maximum current electrode separation (AB) of 200 meters was adopted, allowing for a depth penetration of 100 meters (AB/2).

In the 2D data acquisition, the electrodes were arranged in a line along the survey direction. The first current dipole (C1 and C2) electrodes are position at the starting point of the survey line with a fixed separation distance. The potential dipole (P1 and P2) electrodes are position at a distance from the current dipole (where n=5). Current was injected into the ground using the current electrodes (C1 and C2). The electrode spacing, current, and potential difference were logged into the Terrameter. Keeping the current electrodes fixed, the potential electrodes is move further along the line to increase the separation factor. This increases the depth of investigation. The measurements were repeated for several values of n (typically n = 5, 10…). Once all measurements for the initial current dipole position are completed, the current dipole is move further along the line, and the procedure is repeated. The process is continued along the survey line until the entire area of interest is covered. The resistivity measurement is therefore recorded from the Terrameter.

The VES data and the obtained parameters were inputted into the computer for iteration using the Win resist version 1.0 software, which in turn show the resulting theoretical curves. The parameters were subsequently varied until a best fit between the field and theoretical curves were obtained for each VES station. The parameters of the ultimate models gave the layer resistivity and thickness for the VES point. These geoelectric parameters (resistivity and layer thickness) obtained from the iteration were used for the creation of geoelectric sections. Also, a specialized software called Dipro is used for the dipole-dipole data inversion to generate the 2D resistivity model. Interpretation of the processed data helped identify subsurface features and potential groundwater contamination zones.

For hydrochemical analysis, five water samples were collected from boreholes and one sample from a control site located approximately 200 m from the study area. Water sampling involves collecting water samples in sterilized bottles and sending them to the Delta State University Advanced Research Laboratory, Abraka for a standard water test. The elements tested are cadmium, chromium, copper, iron, lead, nickel, magnesium and zinc.

Results and Discussion

Results of geo-electric investigations

From the sounding curves which revealed four geo-electric layers which is composed of topsoil, lateritic sand, fine sand and medium to coarse grain sand. The first layer is the topsoil and has resistivity of 19.1 Ωm to129 Ωm in VES 1 to 7 which is around the automobile mechanic workshop, while VES 8 to 15 have high resistivity values of between 169 Ωm to 417 Ωm at the topsoil with an average thickness of 1.2 m. The second layer has resistivity of 20.6 Ωm to 302 Ωm with an average thickness of 5.1 m which indicate lateritic sand. The third has resistivity value of 17.4 Ωm to 136 Ωm and an average thickness of 16.4 m showing fine sand formation while the fourth layer has medium coarse sand formation with resistivity of 214 Ωm to 454 Ωm and the thickness cannot be ascertained as the current terminated at this point. In VES 8 to 15 which is outside the automobile mechanic village shows high resistivity across the different layers. The second layer in VES 8 to 15 has a resistivity value of 21.5 Ωm to 1143 Ωm and thickness of 6.4, with mostly lateritic sand formation. The third layer has a resistivity value of 121 Ωm to 459.3 Ωm and average thickness of 17.4 m which has fine sand formation. The fourth layer resistivity ranges from 41.9 Ωm to 1409 Ωm and the average thickness is not determined and have medium coarse sand or coarse sand in some VES location. The aquifer zone lies within the third and fourth layer at a depth of about 4.5 m to 10.0 m below the surface.

The result of the computer-based model containing the layer resistivity, thickness and depth is presented as shown in Table 1. Table 1 also contain the inferred lithology obtained by correlating the geo-electric data with the borehole log from the study area. The interpreted VES results are shown in Table 1.

The protective capacity of the aquifer layer due to the low resistivity values obtained from the geo-electric survey, the overburden protective capacity of the subsurface was determined by estimating the total longitudinal conductance using the relations (Ofomola, 2014).

$$S = \sum_i^n \frac{h_i}{\ell_i} \qquad \text{(Equation 1)}$$

where h is the layer thickness, ℓ is the resistivity of layers and S is the longitudinal conductance.

The values obtained for each layer was compared with the longitudinal conductance (mhos)/protective capacity ratings given by Ofomola (2014). Conductance values of >1 is for excellent), 0.5–1 very good, 0.1–0.49 good, 0.06–0.09 (moderate), 0.01–0.05 (weak) and <0.01 (poor). This was used for the interpretation of the protective capacity in this study and the values and classifications is also shown in Table 1. The protective capacity in study area shows that VES 1,7,9,10,11,12 and 14 have a weak protective capacity, VES 2,4 and 13 shows moderate protective capacity, while VES 15 shows poor protective capacity making the aquifer in these VES location prone to contaminations from the waste in the automobile mechanic workshop. The high value of the protective capacity in VES 5,6 and 8 is because of clay as an overburden impermeable material in the study area, thereby not enhancing the percolation of contaminants into the aquifer.

The columnar sections in and around Sapele automobile mechanic village shows four geo-electric layers as seen in figure 3.

The columnar sections show four geo-electric layers as seen in figure 3. The result indicates the resistivity values of the various layers within and around the Sapele automobile workshop. For layer 1, VES 10,11,12,13, and 14 has resistivity values which have the same ranged as the control. For layer 2, VES 1 to 14 has resistivity values lower than that of the control. For layer 3, VES 8, 10,11,12 and 13 are within the value obtain from the control while VES 1,2,3,4,5,6,7,9 and 14 are lower than that of the control. For layer 4, VES 1 to 14 have resistivity values lower than the value obtained from the control. The above analysis showed that the resistivity values of the geo-electric layers obtained in this study were found to be lower than those obtained from the control, especially in VES 1,2,3,4,5,6,7 which is the area within the automobile mechanic workshop indicate potential contamination from the nearby automobile workshop. Correlating this with the borehole log shows that the third and the fourth layers constitute the aquifer which is situated at a depth range of 4.5 m to 10.0 m below the surface.

The resistivity contour map in figure 4 highlights that regions with lower resistivity are indicative of significant contamination, while higher resistivity areas show minimal contamination, possibly due to protective geological formations.

Table 1: Layer resistivity, thicknesses, depth and inferred lithology obtained from VES

VES	Number	Resistivity value(Ωm)	Thickness (m)	Depth (m)	Curve Type	Longitudinal Conductance (Ω^{-1})	Protecting Rating	Reflection coefficient (RC)	Lithology
	1	129.5	0.8	0.9	QH	0.043	Weak	0.67	Topsoil
		90.3	3.3	4.1					Lateritic sand
		46.5	18.9	23.1					Fine sand
		233.9							Medium coarse sand
	2	35.8	1.1	1.1	KH	0.079	Moderate	0.79	Topsoil
		108.1	5.2	6.3					Lateritic sand
		40.9	20.7	27.0					Fine sand
		349.3							Medium coarse sand
	3	61.2	1.2	1.2	KH	0.05	Weak	0.63	Topsoil
		152.0	4.7	5.9					Lateritic sand
		48.5	15.9	21.8					Fine sand
		214.0							Medium coarse sand
	4	19.1	1.0	1.0	KH	0.084	Moderate	0.86	Topsoil
		191.0	6.1	7.1					Lateritic sand
		21.8	17.8	24.9					Fine sand
		307.0							Medium coarse sand
	5	61.0	1.0	1.0	HA	0.34	Good	0.32	Topsoil
		20.6	6.6	7.7					Lateritic sand
		136.0	13.3	21.0					Fine sand
		264.0							Medium coarse sand
	6	126.4	1.8	1.8	HH	0.13	Good	0.92	Topsoil
		44.1	5.2	7.0					Lateritic sand
		18.9	14.6	21.5					Fine sand
		445.9							Medium coarse sand
	7	57.6	1.0	1.0	KH	0.033	Weak	0.93	Topsoil
		302.0	4.8	5.8					Lateritic sand
		17.4	13.7	19.5					Fine sand
		454.0							Medium coarse sand
	8	169.5	1.8	1.8	HK	0.267	Good	-0.83	Topsoil
		21.5	5.5	7.3					Lateritic sand
		459.3	16.8	24.1					Fine sand
		41.9							Fine sand
	9	193.0	1.1	1.1	KH	0.028	Weak	0.60	Topsoil
		247.0	5.6	6.8					Lateritic sand
		128.0	16.5	23.3					Fine sand
		514.0							Medium coarse sand
	10	417.0	1.0	1.0	HA	0.033	Weak	0.27	Topsoil
		264.0	8.0	9.0					Lateritic sand
		294.0	15.9	24.9					Fine sand
		509.0							Medium coarse sand
	11	316.0	1.2	1.2	HK	0.045	Weak	-0.35	Topsoil
		151.0	6.2	7.4					Lateritic sand
		351.0	14.6	22.0					Fine sand
		216.0							Medium coarse sand
	12	231.0	1.1	1.1	KH	0.026	Weak	0.21	Topsoil

	358.0	7.6	8.8					Lateritic sand
	227.0	18.1	26.9					Fine sand
	351.0							Medium coarse sand
13	313.0	1.1	1.1	HA	0.055	Moderate	0.44	Topsoil
	132.0	6.8	7.9					Lateritic sand
	354.0	17.5	25.4					Fine sand
	918.0							Coarse sand
14	233.0	1.0	1.0	QH	0.05	Weak	0.62	Topsoil
	126.0	5.7	6.6					Lateritic sand
	121.0	16.9	23.5					Fine sand
	519.0							Medium coarse sand
15	417.0	1.2	1.7	KH	0.079	Poor	0.61	Topsoil
	1143.0	5.7	7.0					Lateritic sand
	332.0	22.6	29.6					Fine sand
	1409.0							Medium coarse sand

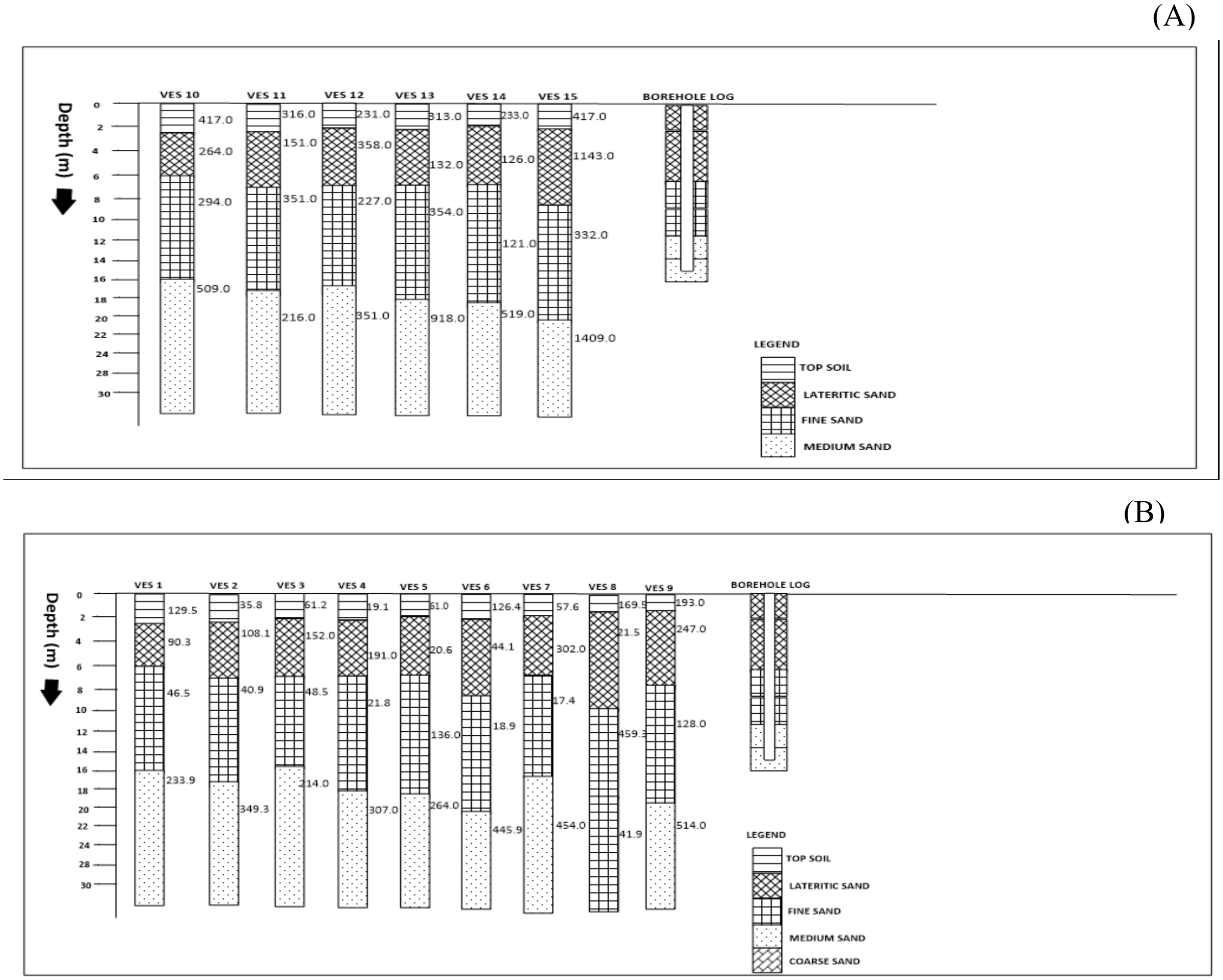

Figure 3: The columnar sections VES 1 – 15 around the Sapele automobile mechanic workshop

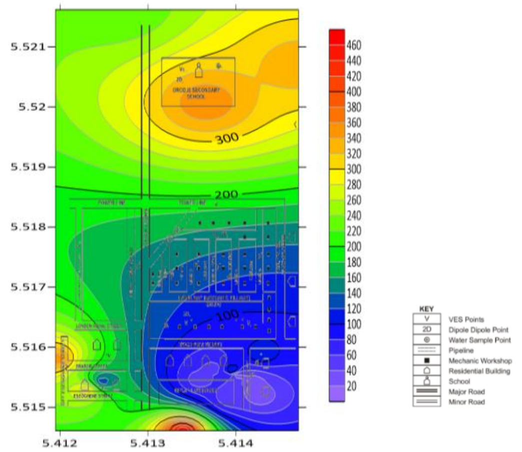

Figure 4: Aquifer resistivity map of the study area

The Aquifer depth contour map for the geoelectric investigation of the aquifer around the automobile mechanic village in Sapele is shown in figure 5. The depth to the aquifer ranges from 4.1 meters at VES 1 to 9.0 meters at VES 10. This variation in depth is crucial for understanding the potential impact of contamination from surface activities, particularly in areas like mechanic villages where oil spills, heavy metals, and other pollutants are common. The result of this work is in line with the work done by Anomohanran et. al., (2021) in an open dumpsite in Sapele, which is not too far from the study location.

The longitudinal conductance contour map is shown in figure 6, which reveals values ranging from 0.026 to 0.34 Ω^{-1} , with the highest conductance at VES 5 and the lowest at VES 12. Longitudinal conductance (S) is a parameter used to assess the protective capacity of the subsurface layers in shielding the aquifer from surface contamination. At VES 5, the high longitudinal conductance value of 0.34 Ω^{-1} suggests the presence of conductive materials such as clay or fine-grained sediments in the subsurface. The high conductance at VES 5 indicates that the aquifer in this region is well protected from surface contamination, as the overlying layers provide significant protection against the infiltration of pollutants from activities at the mechanic village. In contrast, VES 12, with the lowest conductance value of 0.026 S, points to the presence of less conductive materials, such as sand or gravel, which are more permeable and allow for easier migration of contaminants. Low longitudinal conductance indicates poor protective capacity, meaning the aquifer in this area is more vulnerable to contamination. Given the proximity to the automobile mechanic village, areas with low conductance, such as VES 12, are at higher risk of being impacted by contaminants from surface activities, such as oil spills, heavy metals, and other pollutants. General, areas with high longitudinal conductance, like VES 5, have a lower risk of contamination due to the protective nature of the subsurface materials. On the other hand, areas with low conductance, such as VES 12, are more susceptible to contamination, as the subsurface provides less resistance to the downward migration of pollutants.

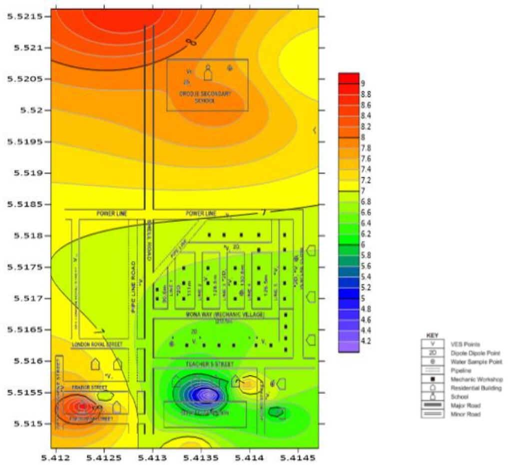

Figure 5: Aquifer depth map of the study area

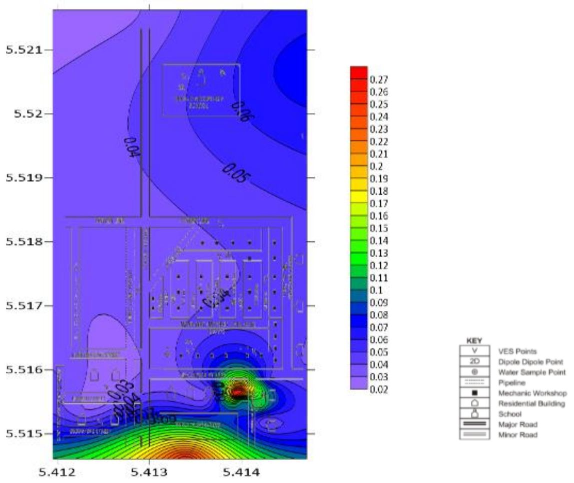

Figure 6: Longitudinal conductance map of the study area

This makes low-conductance zones more critical for monitoring in terms of potential groundwater contamination.

The reflection coefficient (RC) value of the study area is shown in Table 1 which provides insights into subsurface layering and potential contaminant presence. The contour map in figure 7 reveals that the area near VES 6 (with the highest RC of 0.93) is likely to have the most intact aquifer, with good geological separation protecting it from contaminants. The region around VES 8 (with the lowest RC of -0.83) shows the presence of highly conductive materials, possibly pointing to significant groundwater contamination from the automobile mechanic village. Other areas such as VES 1, 2, 3, and 9 show moderate contrasts, suggesting some degree of protection but with a potential for contamination. This interpretation suggests that contamination from the automobile mechanic village is likely localized, with the highest risks near **VES 8** and better protected areas near **VES 6**. This result is in line with the work done by Yohanna et.

al., (2022) in Bauchi to investigate the geoelectric characterization of the aquifer.

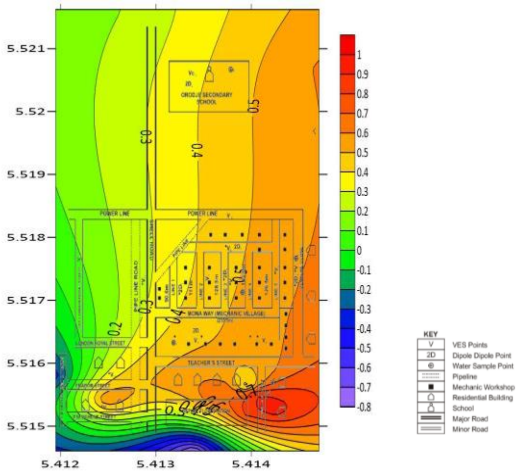

Figure 7: Reflection co-efficient map of the study area

The Groundwater/Contaminant Flow Direction map with arrows superimposed on the elevation contour map in Figure 8 illustrates the groundwater flow direction across the study area, showing how water moves from higher to lower elevation, moving contaminants along the flow path.

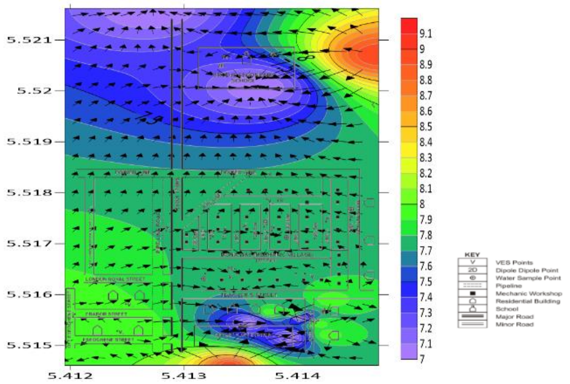

Figure 8: Groundwater flow direction of the study area

Higher elevation which are areas outside the automobile mechanic village suggests a likely recharge zone. Groundwater appears to flow from this high zone down towards the central and lower areas, specifically toward the automobile mechanic village. This flow pattern could facilitate the migration of contaminants from the mechanic village toward other lower-elevation areas, potentially affecting nearby aquifers. The area surrounding the mechanic village is marked by relatively lower elevations and a concentration of arrows pointing toward it. This implies a risk of contamination spreading within the aquifer as pollutants from the mechanic village flow outward. The lower right side of the contour map, which are arears close to the mechanic village shows an area with a clustering of low-elevation contour lines, suggesting groundwater may pool or flow more slowly here, allowing contaminants to potentially accumulate. The groundwater flow pattern indicates that areas around and downstream of the mechanic village are at higher risk of contamination.

3.2 Dipole – dipole pseudo-sections

The dipole – dipole measurements results are presented as pseudo-sections shown in figures 9-14. The 2D resistivity structures are presented in terms of resistivity and depth. The results of the six profiles near and around the study area offers valuable insights into the subsurface conditions, particularly regarding the aquifer and potential contamination.

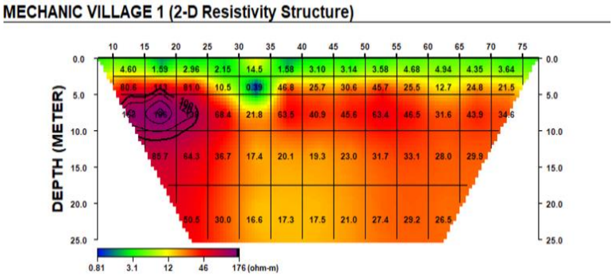

Figure 9: Inverted 2D resistivity structure along profile 1

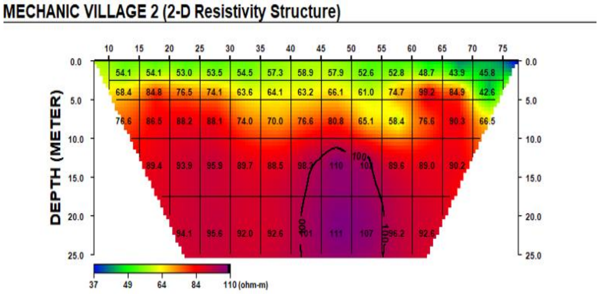

Figure 10: Inverted 2D resistivity structure along profile 2

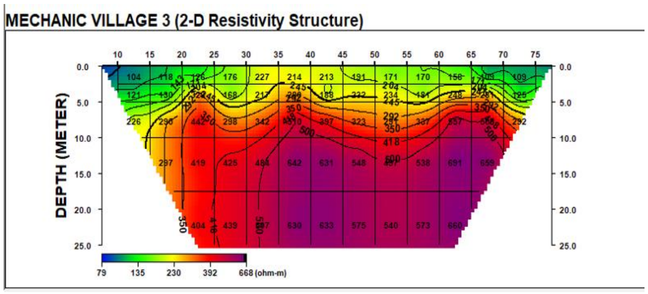

Figure 11: Inverted 2D resistivity structure along profile 3

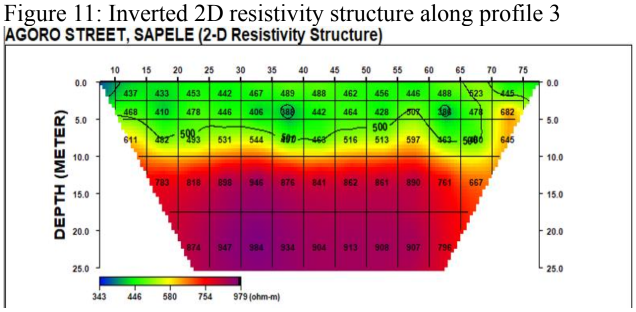

Figure 12: Inverted 2D resistivity structure along profile 4

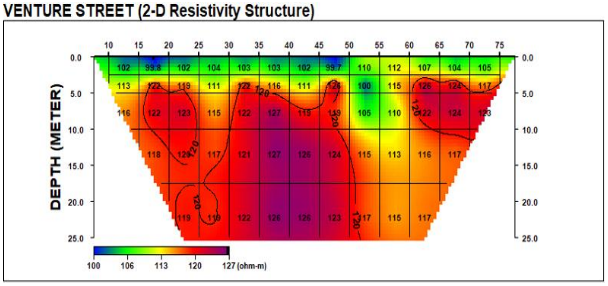

Figure 13: Inverted 2D resistivity structure along profile 5

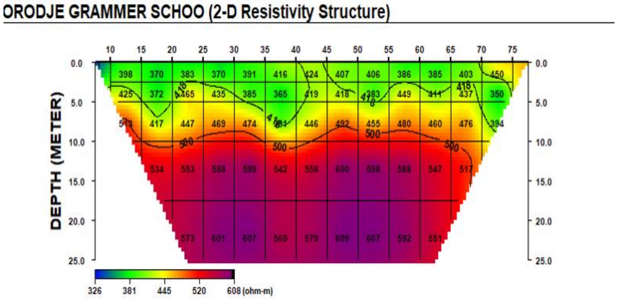

Figure 14: Inverted 2D resistivity structure along profile 6

Variations in resistivity values are observed at different locations in the 2D image suggesting leachate plume in the aquifer at various depth. In profile 1, the topsoil has a low resistivity ranging from 1.59 to 4.97 Ωm, which suggest the presence of conductive contaminants, such as engine oil or chemical waste from the automobile mechanic activities. This layer represents the zone of greatest vulnerability to surface contaminants. The second layer resistivity ranges from 0.39 to 143 Ωm, the wide range of resistivity in this layer may indicate heterogeneous materials. Lower resistivity close to 0.39 Ωm at station 30 and 34 which can be seen as blue indication could correspond to contaminated zones, while higher values towards 143 Ωm may indicate sandy or gravelly materials, which are more resistive. The third layer resistivity ranges from 21.8 to 196 Ωm, the higher resistivity at this depth is an indication of more resistive materials such as sands or gravel, potentially indicating clean aquifer zones. However, the resistivity values above 100 Ωm suggest a more permeable, uncontaminated aquifer, whereas the lower range could still indicate areas of residual contamination, especially in regions closer to the study area where waste runoff may have penetrated. The fourth layer resistivity ranges from 17.4 to 85.7 Ωm, this layer with moderate resistivity, is likely a transition zone between contaminated areas and more intact aquifer sections. The presence of lower resistivity around 17.4 Ωm indicates some leaching or lateral movement of contaminants, while the higher resistivity suggests cleaner sections of the aquifer. The fifth layer resistivity ranges from 16.6 to 50.5 Ωm, at this depth, the resistivity generally indicates a cleaner, more resistive aquifer. However, the presence of resistivity as low as 16.6 Ωm suggests some potential for contamination.

In profile 2, the first layer resistivity ranged from 43.9 to 58.9 Ωm. This range suggests a mix of sandy or silty materials, which could be indicative of a near-surface unsaturated zone or a water-bearing layer with moderate permeability. This also suggests the presence of contaminants across the topsoil. The second layer resistivity ranges from 42.6 to 99.2 Ωm. The wider resistivity range here suggests heterogeneity in subsurface materials, possibly reflecting areas of contamination or varying lithological units such as sands and clays. The lower resistivity values around 42.6 Ωm could point to regions with a higher degree of contamination or conductive materials like clays, while higher resistivity approaching 99.2 Ωm may represent clean, uncontaminated sandy or gravelly aquifer zones. The third layer resistivity ranges from 58.4 to 86.5 Ω, at this depth, the relatively consistent moderate resistivity indicates a more homogeneous aquifer layer, likely composed of sands or gravels, which are typically more resistive. The resistivity here suggests that this layer might be less affected by contamination compared to shallower layers, as the values are consistent with materials that facilitate water flow but do not contain significant pollutants. This could represent a productive part of the aquifer system, though the lower end of the resistivity range could still indicate some minor contamination. The fourth layer resistivity ranges from 88.5 to 110 Ωm, the higher resistivity values in this layer indicate more resistive materials, which could be clean, permeable sands or gravels. This is likely a deeper, uncontaminated section of the aquifer, acting as a stable, productive water-bearing layer. Given the higher resistivity, this layer is less likely to be impacted by surface contaminants from the mechanic village. However, the presence of resistivity closer to 88.5 Ωm could suggest early signs of contamination. The fifth layer resistivity ranges from 92 to 111 Ωm, this layer, with the highest resistivity values, likely represents the most stable and cleanest part of the aquifer. These values are typical of clean, coarse-grained materials such as sands and gravels with low clay content. This layer probably lies below the influence of contamination and could be the target zone for clean groundwater extraction. The high resistivity indicates that this layer is likely free from significant pollution, acting as the deeper part of the aquifer system with minimal contamination.

In profile 3, the first layer resistivity ranges from 104 to 227 Ωm. The resistivity values in this range suggest the presence of silt, clay, or fine-grained materials, which are often more conductive. These lower resistivity values may also indicate the potential for contamination, possibly from surface activities related to the automobile mechanic village. Pollutants such as engine oils, heavy metals, or other contaminants may have infiltrated this layer. The second layer resistivity ranges from 121 to 234 Ωm, this is like the first layer, the resistivity values suggest conductive materials, possibly retaining water or contaminants. The fact that this layer has slightly higher resistivity compared to the first layer may indicate a mix of materials, including some finer sands or gravel that may act as a barrier to further infiltration. The third layer resistivity ranges from 226 to 442 Ωm, the resistivity in this layer indicates a shift to more resistive materials, which may include coarse sands or gravels. The higher resistivity suggests less influence from contaminants, possibly representing a transition zone where the materials become less conductive and more suitable for aquifer development. This layer may provide a better-quality water source compared to the shallow layers. The fourth layer resistivity ranges from 297 to 659 Ωm, this layer shows a significant increase in resistivity, indicating the presence of cleaner, coarser materials. The higher resistivity suggests minimal contamination, and this layer could serve as a crucial water-bearing formation. The fifth layer resistivity ranges from 404 to 630 Ωm, the resistivity values continue to indicate a highly resistive layer, suggesting good quality aquifer material. The relatively high resistivity values indicate that this layer may also be a suitable source of groundwater, with minimal risk of contamination from surface activities.

In profile 4, the first layer resistivity ranges from 433 to 488 Ωm, the resistivity values indicate a relatively resistive layer, suggesting the presence of coarse sands or gravels. These materials are often less susceptible to contamination and may provide good drainage, allowing for the infiltration of surface water. However, the proximity to the mechanic village indicates the need for monitoring to ensure no contaminants infiltrate this layer. The second layer resistivity ranges from 386 to 682 Ωm, the resistivity values show a broad range, indicating variability within this layer. The lower end which has a resistivity value of 386 Ωm may represent finer materials, potentially retaining moisture and contaminants. However, the upper end which has a resistivity value of 682 Ωm suggests the presence of coarser materials or less saturated zones. The third Layer resistivity ranges from 482 to 645 Ω, the resistivity in this layer continues to indicate coarse materials. The relatively high resistivity values suggest a solid formation, potentially composed of well-sorted sands or gravel, making it suitable for groundwater storage. This layer may also exhibit good water quality, particularly if it is well separated from the shallow layers that might be affected by contamination. The fourth layer resistivity ranges from 667 to 949 Ωm, the resistivity values in this layer suggest very resistive materials, likely indicating clean aquifer formations. This layer likely contains high-quality groundwater, as the resistivity suggests minimal interaction with contaminants. Its high resistivity is indicative of good groundwater potential and minimal contamination risks. Fifth layer resistivity ranges from 796 to 984 Ωm, the highest resistivity values in this layer suggest the presence of very coarse and consolidated materials, likely indicating excellent aquifer conditions. These values point towards a high-quality groundwater source with minimal risks of contamination, making this layer an optimal target for groundwater extraction.

In profile 5, the first layer resistivity ranges from 99.6 to 112 Ωm, the low resistivity values in this layer suggest the presence of fine-grained materials such as silt or clay. These materials tend to retain water and can be more susceptible to contamination, especially from surface activities associated with the study area. The second layer resistivity ranges from 100 to 126 Ωm, the resistivity values remain low, indicating a similar composition to the first layer. This layer may consist of moisture-retaining materials that could contribute to higher conductivity. The potential for contamination is significant here, especially given the activities around the mechanic village. Third Layer resistivity value ranges from 105 to 132 Ωm, the resistivity is slightly higher compared to the first two layers but still indicates the presence of fine-grained materials. This layer could represent a transitional zone, where materials are still saturated with water, but with slightly improved drainage compared to the shallow layer. The fourth layer resistivity value ranges from 113 to 127 Ωm, the resistivity values show a minor increase, suggesting a possible change in composition. This layer may contain mixed materials that could include fine sands or slightly coarser materials, but overall, it remains low in resistivity. This could imply that the potential for contamination still exists. Fifth Layer resistivity ranges from 115 to 126 Ωm, which is similar to the fourth layer, the resistivity values indicate a continuity of fine-grained materials. The low resistivity suggests that this layer may not be significantly different in terms of geological composition and potential contamination risks.

In profile 6 which is the control location, the first layer resistivity value ranges from 370 to 450 Ωm, the relatively high resistivity indicates the presence of coarse-grained materials, such as sands or gravels, which are generally more permeable and less prone to saturation. These materials are typically associated with better drainage, reducing the risk of contamination from surface activities. The second layer resistivity value ranges from 350 to 465 Ωm, the resistivity in this layer remains high, this indicates a consistent geological profile that favors good drainage and reduced water retention. Third Layer resistivity value ranges from 394 to 480 Ωm, the resistivity values continue to indicate coarse materials, possibly representing a well-drained sandy formation. This layer may also serve as an effective aquifer zone, providing a good source of groundwater, with minimal contamination risks. The fourth layer resistivity value ranges from 534 to 600 Ωm, the increased resistivity in this layer suggests a transition to even more consolidated or coarse materials, possibly indicating the presence of gravel or sandstone. This is likely to be a solid aquifer layer, contributing positively to groundwater quality and availability. Fifth Layer resistivity value ranges from 569 to 607 Ωm, the highest resistivity values indicate very consolidated materials, which are generally favorable for groundwater storage. This layer may represent a significant aquifer, capable of sustaining higher yields with minimal risk of contamination due to its depth and geological composition.

3.3 Hydrochemical Results Analysis

The results of the hydrochemical analysis of water samples are presented in Table 2. These were compared with World Health Organization (2017) guidelines for drinking – water quality and Nigerian Standard for Drinking Water Quality (NSDWQ 2017) permissible limits.

Table 2: Hydrochemical analysis of the borehole water samples.

Parameter (mg/l)	Borehole 1	Borehole 2	Borehole 3	Borehole 4	Borehole 5 control	NSDWQ	WHO
Cd	0.02	0.06	0.02	0.01	ND	0.003	0.003
Cr	ND	0.01	ND	0.01	ND	0.05	0.05
Cu	0.07	0.09	0.10	0.12	0.05	1.0	2.0
Fe	0.05	0.07	0.06	0.08	0.04	0.3	0.3
Pb	0.02	0.01	0.02	0.01	0.03	0.01	0.01
Ni	0.04	0.07	0.04	0.09	0.02	0.02	0.07
Mn	0.17	0.19	0.14	0.11	0.14	0.2	0.4
Zn	0.04	0.06	0.05	0.11	0.05	3.0	3.0

ND = No Detectable level; NSDWQ = Nigerian Standard for drinking water Quality; WHO = World Health Organization

The results indicate significant contamination of the aquifer by heavy metals such as cadmium, lead, and nickel, all of which exceeded the safe drinking water limits set by the NSDWQ and WHO. This contamination is likely linked to the activities of the automobile mechanic workshops, which could be releasing industrial waste into the groundwater, particularly from battery disposal, metal parts, and oil spills.

Given the high levels of certain heavy metals, particularly cadmium, lead, and nickel, there is a significant risk to public health and the environment. Drinking water contaminated with lead, cadmium, and nickel poses significant health risks, including neurological, kidney, cardiovascular, reproductive, and carcinogenic effects. Long-term exposure to these metals, especially at the elevated levels found in the aquifer around the automobile mechanic village in Sapele, can lead to chronic health conditions that may not present immediately but can be severe over time. Reducing exposure through the regulation of industrial activities and treatment of contaminated water is essential to protect public health.

3.3.1 *Contamination Factor (CF) from the water samples*

The Contamination Factor (CF) was calculated for each metal in each sample using the formula proposed by Hakanson (1980): To calculate the **Contamination Factor (CF)** for each sample, using the following metals: Cd, Cr, Cu, Fe, Pb, Ni, Mn, and Zn. It is by comparing the concentration in each sample to the concentration in the control sample.

If the control sample has no detectable level (ND), the CF for that metal cannot be calculated.

$$CF = \frac{C_i}{C_{control}} \quad \text{(Equation 2)}$$

Where:

C_i is the concentration of the metal in the sample.
$C_{control}$ is the concentration of the metal in the control sample.

CF values are interpreted as:

$CF<1$ = Low contamination
$1<CF<3$ = Moderate contamination
$3<CF<6$ = Considerable contamination
$CF>6$ = High contamination

Samples 1 to 3 show moderate contamination for Cu, Fe, Mn and Zn, which indicates some level of contaminant presence likely due to automobile mechanic-related activities. There is also a considerable contamination from Ni in samples 2 and 3 and this could be associated with vehicle batteries and other parts. Pb and Zn show low contamination, suggesting minor contributions to overall contamination.

In Sample 4, Cu, Fe, and Zn show moderate contamination, while Ni again registers as considerable contamination. This suggests persistent Ni pollution across samples, potentially indicative of specific contaminants from automotive materials or waste. The presence of metals like Cu and Fe in moderate amounts also suggests that the activities in the area are contributing to potential pollution risks for the local groundwater, and thus, the aquifer system.

3.3.2. Pollution Load Index (PLI):

The PLI is a useful tool that provides valuable information about metal toxicity in representative samples (Yang et al., 2011). The Pollution Load Index for a given location was calculated using the formula (Harikumar & Nasir, 2010):

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \ldots . CF_n} \quad \text{(Equation 3)}$$

Where:
CF_1, CF_2 ..... Cn are the Contamination Factors for each metal, and n is the number of metals analyzed.
PLI values are interpreted as: PLI < 1 Unpolluted
PLI = 1 Baseline level of pollution. 1 > PLI ≤ 2 Moderately polluted
2 > PLI ≤ 4 Highly polluted. PLI > 4 Very highly polluted

The results of the PLI are shown in Table 4, the Pollution Load Index (PLI) values for all the samples are greater than 1, indicating that the water quality around the Sapele automobile mechanic village is deteriorated and polluted due to the presence of contaminants. These results agree with the works of Bhutian et al., 2017 and Gopinath et al., 2016. Sample 4 has the highest PLI, indicating it is the most polluted among the samples.

3.3.3 Water Quality Index (WQI)

Water quality index is a tool used in ranking to enable easy classification of water into categories. The water quality index in this study was determined for all the samples and the results is presented in Table 3. This index helps in the classification of the water samples to know its status, and the rating was done according to Akakuru et al. (2021).

Water quality index (WQI) was calculated by adopting the weighted arithmetic index method. The quality rating scale (q_i) for each parameter was obtained by dividing the sample concentration (C_i) in each groundwater sample by its respective standard (S_i). The result was then multiplied by 100 (Akakuru & Akudinobi, 2018; Gopinath et al., 2016).

$$q_i = \frac{C_i}{S_i} \times \frac{100}{1} \qquad \text{(Equation 4)}$$

Relative weight (W_i) was obtained from the inversely proportional of the value to the WHO standard (S_i) of the corresponding parameter:

$$W_i = \frac{1}{S_i} \qquad \text{(Equation 5)}$$

$$WQI = \sum q_i W_i \qquad \text{(Equation 6)}$$

Where q_i is the ith parameter quality and W_i is the weight of the unit i^{th} parameter.

Table 3: WQI rating

S/N	WQI Values	Water Quality Status
1	< 50	Excellent
2	50 – 100	Good
3	100 – 200	Poor
4	200 -300	Very poor
5	> 300	Unsuitable for drinking

The results are presented in Table 4. All the water samples analyzed have values greater than 300 except for sample 1 which is 183, indicating poor water quality. Based on this, the water in the study area was rated as unsuitable and thus need proper treatment before any use. Water quality decreases as you move closer to the mechanic workshop. The control location has a good water quality when compared with the water quality around the automobile mechanic workshop. The result of the WQI is not in line with the work done by Akakuru & Akudinobi, (2017), due to the difference in the study location and other environmental factors. These findings suggest that the mechanic workshop activities are impacting the surrounding water quality.

Table 4: Results of CF, PLI and WQI of groundwater samples in the study area

Sample	Metal	Concentration (Sample)	Concentration (Control)	CF (CF1,CF2,CF3,CF4)	PLI	WQI
1	Cd	0.02 mg/L	ND	Undefined	1.20	183
	Cr	ND	ND	Undefined		
	Cu	0.07 mg/L	0.05 mg/L	1.4		
	Fe	0.05 mg/L	0.04 mg/L	1.25		
	Pb	0.02 mg/L	0.03 mg/L	0.67		
	Ni	0.04 mg/L	0.02 mg/L	2.0		
	Mn	0.17 mg/L	0.14 mg/L	1.21		
	Zn	0.04 mg/L	0.05 mg/L	0.8		
2	Cd	0.06 mg/L	ND	Undefined	1.47	777
	Cr	0.01mg/L	ND	Undefined		
	Cu	0.09 mg/L	0.05 mg/L	1.8		
	Fe	0.07 mg/L	0.04 mg/L	1.75		
	Pb	0.01 mg/L	0.03 mg/L	0.33		

	Ni	0.07 mg/L	0.02 mg/L	3.5		
	Mn	0.19 mg/L	0.14 mg/L	1.36		
	Zn	0.06 mg/L	0.05 mg/L	1.2		
3	Cd	0.02 mg/L	ND	Undefined	1.31	635
	Cr	ND	ND	Undefined		
	Cu	0.10 mg/L	0.05 mg/L	2.0		
	Fe	0.06 mg/L	0.04 mg/L	1.5		
	Pb	0.02 mg/L	0.03 mg/L	0.67		
	Ni	0.04 mg/L	0.02 mg/L	2.0		
	Mn	0.14 mg/L	0.14 mg/L	1.0		
	Zn	0.05 mg/L	0.05 mg/L	1.0		
4	Cd	0.01 mg/L	ND	Undefined	1.57	468
	Cr	0.01mg/L	ND	Undefined		
	Cu	0.12 mg/L	0.05 mg/L	2.4		
	Fe	0.08 mg/L	0.04 mg/L	2.0		
	Pb	0.01 mg/L	0.03 mg/L	0.33		
	Ni	0.09 mg/L	0.02 mg/L	4.5		
	Mn	0.11 mg/L	0.14 mg/L	0.79		
	Zn	0.11 mg/L	0.05 mg/L	2.2		

4. Conclusion

The integration of geophysical and hydrochemical investigations at the automobile mechanic village in Sapele indicates that the aquifer system has been polluted, mainly because of contaminants from automotive activities. The VES data, and the dipole-dipole analysis show that contamination affects both the vertical and horizontal extents of the aquifer extensively. The study determined that the aquifer in the study area is shallow, with a depth ranging from 4.5 to 10 meters. It was discovered that the aquifer in the study area is poorly protected, with varying levels of vulnerability to contamination, which is crucial information for implementing protective measures for the aquifer and strategic remediation plans. The research also revealed that the groundwater in the area has been contaminated with heavy metals such as Cd, Ni, and Pb because of the automobile mechanic village activities, making it unsafe for consumption without treatment. It is recommended that immediate and long-term remediation strategies, including on-site treatment methods, be implemented to mitigate contamination throughout the entire vertical and horizontal extent of the aquifer. Additionally, strict environmental regulations and best practices should be enforced within the mechanic village to prevent further contamination. This should include proper hazardous waste disposal and regular monitoring of environmental compliance. Public awareness campaigns should be conducted to educate the local population about the risks associated with using contaminated groundwater. Safe alternative water sources should be provided until the aquifer meets acceptable quality standards. Lastly, the automobile mechanic village should be situated away from residential areas.

REFERENCE

Adelana, S. M. A., & MacDonald, A. M. (2008). Groundwater and Climate in Africa - A Review. *Hydrological Sciences Journal*, 53(4), 612-625.

Akakuru, O. C., Akudinobi, B. E., Nwankwoala, H. O. (2021). Compendious evaluation of groundwater in parts of Asaba, Nigeria for agricultural sustainability. *Geosci J. 145(6)*, 56-67

Akakuru, O.C. and Akudinobi, B.E.B. (2018) Determination of water quality index and irrigation suitability of groundwater sources in parts of coastal aquifers of eastern Niger Delta, Nigeria. International Journal of Applied and Natural Sciences, 7, 1–6.

Akinbile, C. O., Ogunbode, E. B., & Ajibade, F. O. (2019). Soil and Groundwater Pollution by Open Refuse Dumps in Ibadan, Southwest Nigeria. *Journal of Environmental Science and Technology, 12*(1), 45-53.

Anomohanran, O., Nakireru, O.F., Ofomola, M.O., Anomohanran, E.E and Abrika, E.O (2023) Assessment of groundwater potential of Somebreiro-Warri plain sand of Ughelli, Nigeria. *Sustain. Water Resour. Manag.* **9**, 26. https://doi.org/10.1007/s40899-022-00797-9

Anomohanran, O., Utieyin, B.S. and **Ofomola, M.O.** (2021) Delineation of groundwater vulnerability to pollution around dumpsites in Sapele, Nigeria. International Journal of Hydrology Science and Technology 12(1), 59-76 https://doi.org/10.1504/IJHST.2021.116240

Anomohanran, O. (2015). Geophysical investigation of groundwater potential and aquifer vulnerability in Delta State, Nigeria. *Journal of Environmental and Earth Sciences, 5*(2), 105-112.

Atakpo, E. A. (2013). Resistivity imaging of crude oil spill in Ogulaha Coastal Community, Burutu LGA, Delta State, Nigeria. *International Journal of Research and Reviews in Applied Sciences, 15*(1), 97–101.

Atakpo, E., & Ofomola, M. O. (2012). Hydro geologic investigation using vertical Electrical sounding method in Agbacha Otor, Delta State Nigeria. *Nig. J. Sci. Environ*, *11*(1), 95-103

Bhutian, R., Dipali, B. Ki, Khanna, D. R., Ashutosh, G. (2017). Geochemical distribution and environmental risk assessment of heavy metals in groundwater of an industrial area and its surrounding, Haridwar, India. *Energy Ecol. Environ. 2(2),* 155 – 167.

Egbai, J. C., Okolie, E. C., Oseji, J. O., & Ese, E. C. (2018). Geoelectric and geochemical investigation of groundwater quality: A case study from Sapele, Delta State, Nigeria. *Journal of Applied Geophysics, 12*(3), 45-60.

Ekeocha, A. E. (2020). The Impact of Industrial Effluents on the Quality of Groundwater in Industrial Areas of Enugu State, Nigeria. *Journal of Environmental Hydrology, 28*, 1-11.

Gleeson, T., Wada, Y., Bierkens, M. F. P., & van Beek, L. P. H. (2012). Water Balance of Global Aquifers Revealed by Groundwater Footprint. *Nature*, 488(7410), 197-200.

Gopinath, S., Srinivasamoorthy, K., Saravanah, K. (2016). Modelling saline water intrusion in Nagapattinam coastal aquifer Tamilnadu, India. *Modeling Earth Systems and Environ,* 34(14), 1-10.

Hakanson, L. (1980). An Ecological Risk Index for Aquatic Pollution Control. A Sedimentological Approach. Water Res., 14, 975-1001. https://doi.org/10.1016/0043-1354(80)90143-8

Harikumar, P. S., & Nasir, U. P. (2010). Ecotoxicological impact assessment of heavy metals in core sediments of a tropical estuary. *Ecotoxicology and Environmental Safety,73*(7), 1742–1747.

Nwankwoala, H. O., & Moms, P. C. (2007). Groundwater chemistry and quality assessment in the Niger Delta: implications for groundwater management. *Journal of Environmental Hydrology, 15(3)*, 1-10.

Ofomola, M. O. (2015). Integrated geophysical and hydrogeochemical studies of shallow aquifer contamination in Osubi, Near Warri, Southern Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, *5*(4), 79-102.

Ofomola, M. O. (2014). Aquifer characterization and groundwater quality studies in part of Niger Delta area using geoelectric and hydrogeochemical methods, *Nigerian Journal of Physics*. 25 (2), pp 96 – 106.

Ohwoghere-Asuma, O., Iserhien-Emekeme, R., Aweto, K.E. Ofomola, M.O (2020) Geophysical investigation of resistivity and groundwater quality in Ogbe-Ijoh coastal area of the western Niger Delta of Nigeria. *Appl Water Sci* **10**, 70. https://doi.org/10.1007/s13201-020-1144-0

Shafique, M., Kim, S., & Kim, S. (2019). Groundwater Pollution Sources and Vulnerability Assessment: A Review. Science of the Total Environment, 684, 136-147.

Udom, G. J., Esu, E. O., & Ekwere, S. J. (2002). A geochemical survey of groundwater. *Environmental Geology, 42*(7), 784-789.

World Health Organization (WHO). (2017). *Guidelines for Drinking-water Quality*. WHO Publication (4th ed.), 1(96), pp 47 – 55.