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Full Length Research Paper

Geophysical and hydrochemistry methods for mapping groundwater contamination around Aule area, Akure, Southwestern Nigeria

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An integrated geophysical investigation involving 2D-Wenner profiling, very low frequency electromagnetic, vertical electrical sounding (VES) and water quality analysis was conducted around Aule area within Akure the capital city of Ondo state southwestern Nigeria where there have been reported cases of groundwater contamination. Also hydrochemical analysis was carried out on five water samples in the area; two from boreholes and others from hand dug wells. Results of the investigation showed that the groundwater had been contaminated by hydrocarbon arising from a filling station in the area. The hydrocarbon contaminant plumes are characterized by relatively high resistivity values (> 200 Ω-m) and were delineated to a depth of about 10 m. Hydrochemical results showed that three of the sampled water have higher total dissolved solids (TDS) (>240 ppm) compared to the remaining water samples. The major ions identified includes (Na^+, K^+,Cl^-,Mg^{2+},Ca^{2+} and NO_3^-). The total dissolved solid (TDS) and electrical conductivity shows values not in agreement with WHO standards. Twelve (12) Vertical Electrical Sounding (VES) stations were occupied along three traverse lines trending NW-SE and N–S direction. The vertical electrical sounding results indicate maximum of four subsurface layers-Top soil, hydrocarbon contaminated clay, weathered layer and the fresh basement. The VLF-EM results assist in the delineation of non conductive zones which in most cases coincides with the hydrocarbon contaminated plumes delineated by the 2D-pseudo section obtained from modeling the results obtained from Wenner profiling. The contaminant plume has migrated to a significant depth thus posing an inherent danger to the inhabitant of the area.

Key words: Hydrochemical analysis, contaminant plumes, Wenner profiling.

INTRODUCTION

The earth's sub-surface has become the safest and most abundant source of potable water in comparison to the earth's surface as it is often shielded from direct human activities. However, any undetected contamination of this resource poses a threat to the well-being and continuous existence of man in the environment. Contamination is the pollution involving constituents that are hazardous to health because of their nature or quality (Enikanselu, 2008). Groundwater is transmitted through a deep aquifer comprising unconsolidated weathered materials that form the overlying mantle or regolith (Morris et al., 2003). The inhabitants of the study area, in Aule, Akure South local Government (Figure 1) depend majorly on groundwater as their source of water consumption. Groundwater contamination occur in the area due to human activities such as waste disposal (private sewage disposal systems, land disposal of solid waste, municipal wastewater, wastewater impoundments, land spreading

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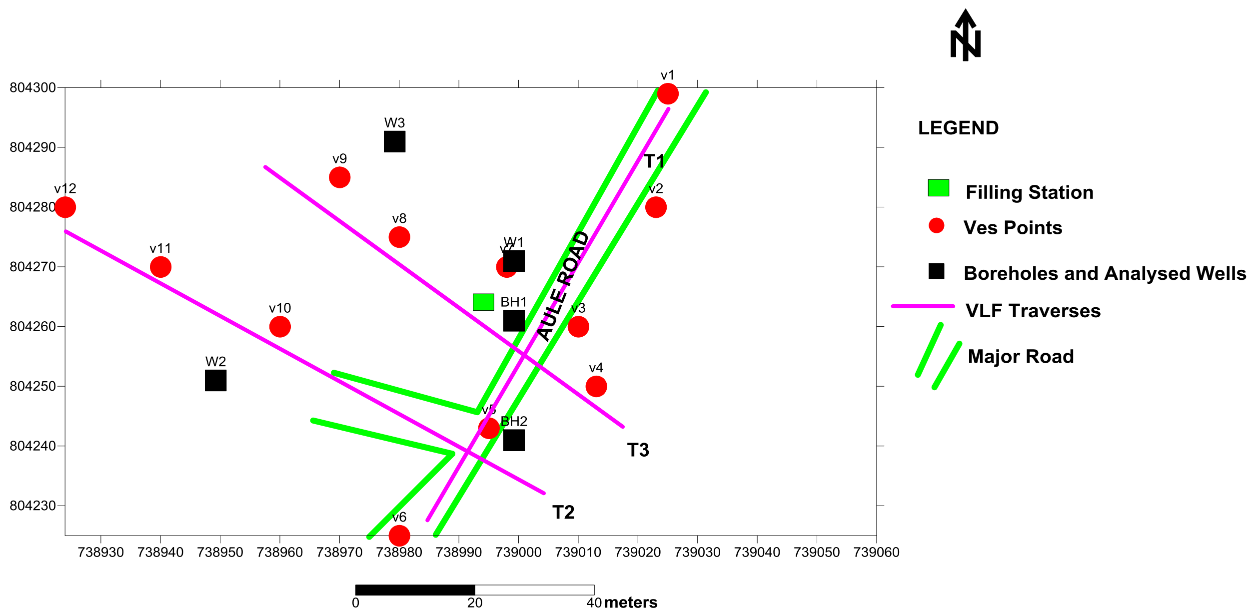

Figure 1. Location map of the study area showing Wells, VES points and VLF Traverses.

of sludge, brine disposal from the petroleum industry, mine wastes, deep-well disposal of liquid wastes, animal feed wastes, radioactive wastes), road salt and leakage from underground storage tank for petroleum products. The aquifer system around Aule area is typical of the basement complex terrain with the aquifer types consisting of weathered layer aquifer and weathered/fractured (unconfined) aquifer. The water table shows the level of saturation in an unconfined aquifer (Freeze and Cherry, 1979). Recently, cases of hydrocarbon contamination has been reported and this has led to the use of very low frequency electromagnetic and electrical resistivity methods to map the hydrocarbon contaminants within the subsurface since geophysical methods have been found useful in mapping area(s) of contaminated soil and groundwater based on their ability to measure certain physical properties of the subsurface structures that can harbor groundwater and its contaminants (Kelly, 1976; Urish, 1993; Telford et al., 1990).

Geology of the study area

Aule area is underlain by crystalline rock of the Precambrian basement complex of the southwestern Nigeria (Rahaman, 1989). The lithological units include migmatite gneiss complex, granitic gneiss and charnokites. Outcrops of biotite gneiss and granitic gneiss occur in some locations around the western part of the study area (Figure 2). Likewise some other boulders of granite and charnokites occur at the western part of the study area. The hydrogeological setting of the area is such that various rock types of both igneous and metamorphic origin occur but in general, they are impermeable except in cleaved, sheared, jointed and fissured areas (Olayinka, 1972) as in the case of the study area where the fractured basement of granite gneiss and charnokite serves as aquifers for the boreholes and the wells in the area tap their water from the clay overburden.

METHODOLOGY

Integrated geophysical approach involving geophysical and hydrochemical investigations were adopted for the study. The geophysical methods used include the 2D- Wenner profiling, the vertical electrical sounding (VES) and the very low frequency electromagnetic method (VLF-EM). Vertical electrical sounding (VES) survey is a measure of variation of electrical resistivity with depth. This is achieved by a gradual increase in the electrode spacing about a fixed center of electrode spread. Twelve (12) vertical electrical sounding locations were obtained along three traverses previously occupied by the 2D-Wenner profiling and the very low frequency electromagnetic method. The vertical electricity sounding data and the Wenner profiling were obtained using DC resistivity meter R-50. The Wenner electrode configuration were occupied with constant electrode spacing of a = 5, 10 and 15 m for n = 1, 2 and 3 respectively. RES 2D inversion software was used to generate pseudo sections from the resistivity data. The very low frequency (VLF) electromagnetic data are presented as plots of Raw real and Filtered real values against distance. The VLF sections were plotted as KarousHjelt filtered real components to delineate non-conductive zones which are indicative of the hydrocarbon contaminated points in the area. The hydro-chemical analysis involved the collection and analysis of water samples for chemical analysis (Table 1). Five water samples consisting of samples from two contaminated boreholes designated as BH1 and BH2 and three hand dug well designated as W1 - W3 were collected.

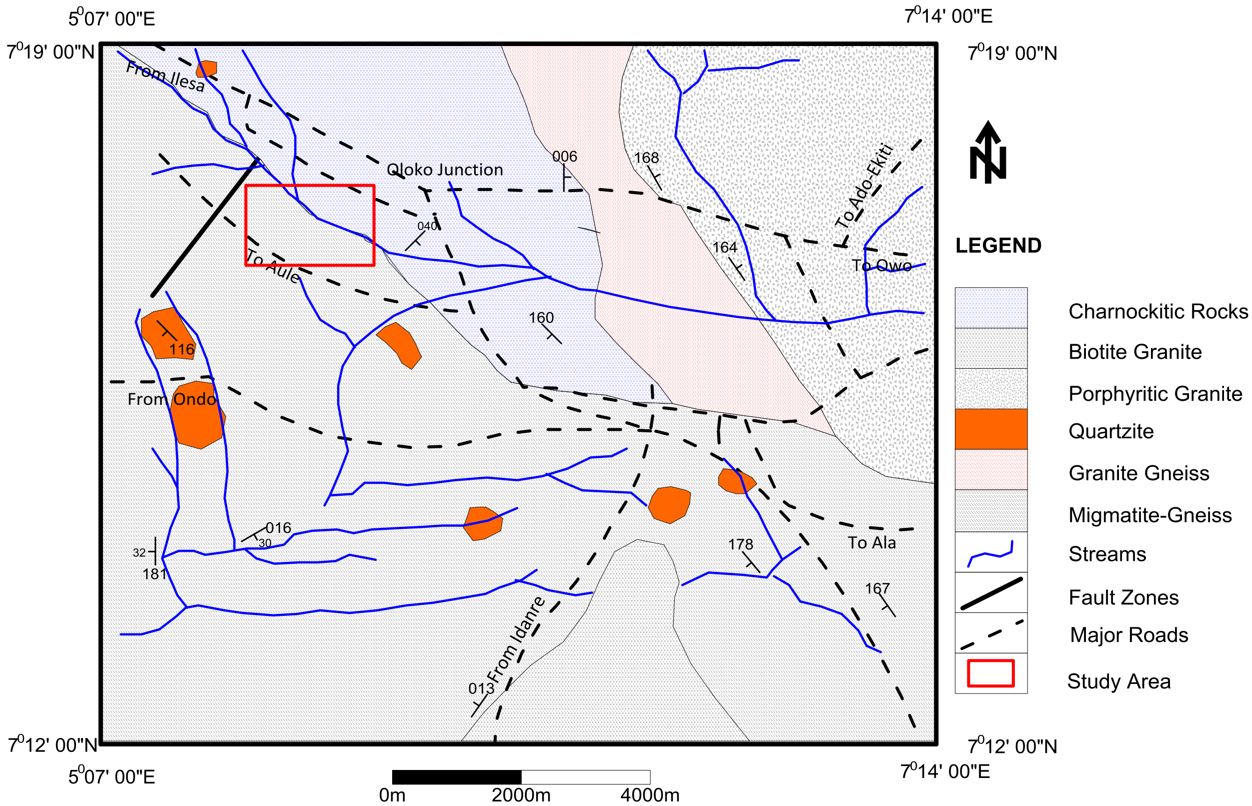

Figure 2. Geological map of Akure, showing the study location (modified after Owoyemi, 1996).

The five samples were analysed based on their proximity to the filling station. The other hand dug wells designated as W4 - W14.The groundwater flow direction in the area was determined based on the information obtained from the static water levels (swl) of the wells.

Each determination was based on standard methods of the American Public Health Association (APHA, 1992). Chemical methods of the British Drug House (BDH, 1978) and methods for physical and chemical analysis of fresh waters.

RESULTS AND DISCUSSION

Qualitative and quantitative interpretation of the VLF-EM AND 2D-Wenner profiles and sections with their corresponding geo-electric sections.

The qualitative interpretation of the VLF-EM profiles reveals the low conductive zones which is indicative of hydrocarbon contamination. Quantitatively, the VLF-EM data assist in the generation of KH sections produced with the help of Karous Hjelt (KH) filtering software. The sections delineate resistive zones which reveal the zones of hydrocarbon contamination.

RES 2D inversion software was used to generate 2D–Wennerpseudo-section which also shows the image of the subsurface. Interpretation of geo-electric parameters obtained from the vertical electrical sounding (VES) datahelped in the production of geo-electric sections and subsurface characterization along the traverses.

Figure 3 (a to d) reveals low conductive responses corresponding to highly resistive zones occurring at distances 0 to 30 m and 50 to 80 m along Traverse 1. These zones are indicative of hydrocarbon contamination at shallow and deeper depth. The KH section delineates low conductive zones at distance between 0 to 30 m and 48 to 65 m expanding depth-wise to 70 m from the initial starting position. This shows that hydrocarbon contamination vary in concentration as it migrates down the surface. The 2D-Wenner pseudo section along Traverse 1 shows resistivity values > 200 Ω-m at distances 10 to 35 m at a depth of 6.3 m, 40 m at a depth of 9.26 m and 80 m at a shallow depth of about 3.75 m, 90 to 110 m at a depth of 8.5 m and 130 m at a depth of 6.38 m and 135 m at 9.26 m depth. The geo-electric section along traverse 1 is occupied by VES 1 to VES 6. The geo-electric section reveals four geo-electric layers which consist of top soil, hydrocarbon contaminated clay, clay/sandy clay and fractured/fresh basement. The interpretation of the different sections and profiles produced from the processing of results obtained from the VLF-EM profiles and section coupled with the 2D-wenner pseudo - section and geo-electric section along traverse 1 reveals that the geophysical methods employed

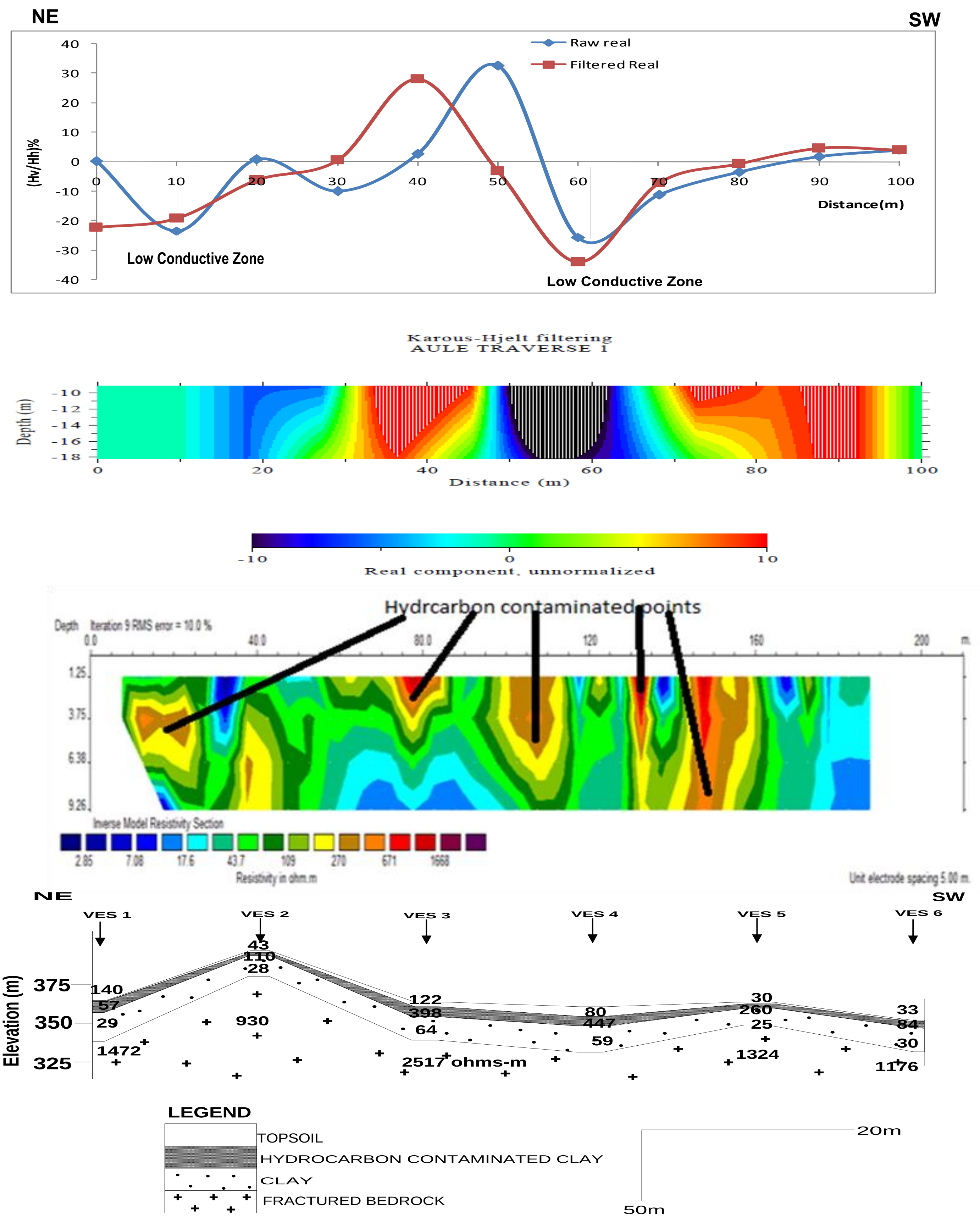

Figure 3(a-d). Profiles and Pseudo sections along traverse 1 in NE-SW direction of the study area.

Table 1. Summary of methodology and analytical techniques used in physiochemical water analysis.

Item	Method and analytical technique	Accuracy (ppm)
EC	(Field) EC meter, Combo pH and EC	-
pH	(Field) EC meter, Combo pH and EC	-
TDS	(Field) EC meter, Combo pH and EC	-
Na^{+}	(Lab.) Flame photometer	0.1
K^{+}	(Lab.) Flame photometer	0.1
Ca^{2+}	(Lab.) Volumetric method using EDTA	0.1
Mg^{2+}	(Lab.) Volumetric method using EDTA	0.1
Cl^{-}	(Lab.) Titration against $AgNO_3$	0.5
HCO_3^{-}	(Lab.) Titration with sulphuric acid	0.5
SO_4^{2-}	(Lab.) Turbidimetric method using Barium Chloride	0.5

are complimentary as they tend to delineate non-conductive zones indicative of hydrocarbon contamination at distance 0 to 30 m and at distance 40 and 80 m. The Wenner pseudo section also assists in identify zones not delineated by the VLF-EM technique.

Figure 4 (a to d) shows low conductive responses occurring at distances between 43 to 85 m indicating that the subsurface has been contaminated by hydrocarbon in the stated distance range along Traverse 2. The VLF-EM section shows low conductivity at distance of about 70 m and at distance 90 to 115 m which is also indicative of hydrocarbon contamination at those points. The 2D-wenner pseudo-section reveals high resistivity values at distance of about 80 m at depth 9.26 m, distance 115 m at a depth of about 5.5 m, distance 150 m at depth 2.8 m and distance 170 m at depth of 9.26 m. The geo-electric section identified 4 subsurface geologic layers which are the top soil, hydrocarbon contaminated clay, clay/clayey sand and fractured/fresh basement. The curve type is KH and AKH along the VES points on the traverse (Table 2). The hydrocarbon contaminated clay occurs at depth ranging between 4.4 and 5.7 m. The results obtained from the geophysical methods suggest that the methods are complimentary (Table 1).

Figure 5 (a-d) shows low conductive zone at distance 40 m. The KH section shows high conductive responses at distance 20 to 30 m which is due to overhead cable wire. Low conductivity responses were observed at distance between 40 to 48 m at shallow depth. High resistivity values greater than 200 Ω-m was observed at distances 20 m at a depth of 6.38 m, 58 m at a depth of 9.26 m and distance 75 m at depth 2.0 m. This indicates that the hydrocarbon contaminated plumes varies in concentration in the subsurface and decreases as it migrates via traverse 2 to traverse 3. The geo-electric section identified subsurface geologic layers which are the top soil, hydrocarbon contaminated clay, clay and the fractured basement. Traverse 3 was occupied by VES 7, 8 and 9 and the depth to hydrocarbon contaminated clay ranges between 3.3 m and 6.5 m which are relatively similar to depth to the resistive zones delineated by the 2D-Wenner pseudo-section which occurs at depth ranging from 2.0 to 9.26 m.

Static water level (SWL)

The static water level obtained from the wells in the area ranges from 3.3 m to 12.5 m as seen on the static water level contour map (Figure 6). The static water level assists in determining the groundwater flow direction in the area which is flowing in the NW to SE direction. The direction of groundwater flow suggests that the water in the wells around the study area is flowing towards the direction of the contaminant plume showing why the wells have been contaminated.

Hydrochemical analysis

Results of hydro-chemical analysis are presented in Tables 3, 4 and 5. The results show that W1 and BH1 that are closer to the filling station have higher concentrations of conductivity and total dissolved solid (TDS) which correspond to the high resistivity obtained from the electrical resistivity method as seen in traverse 1 and traverse 3. The relatively high conductivity and TDS observed at W1, BH1 and BH2 is due primarily to the presence of non–biodegraded hydrocarbon over the water table. W2 and W3 have a relatively low TDS compare to W1 (Table 4), which is indicative that the hydrocarbon plume contaminant is yet to reach their location due to their distance from the filling station (Figure 7).

As a result of non-biodegradation of the hydrocarbon, there is no significant effect on anions and cations that are present in the groundwater.

Conclusion

Based on field observations, 2-D resistivity structures obtained from the 2DWenner profiling technique and the

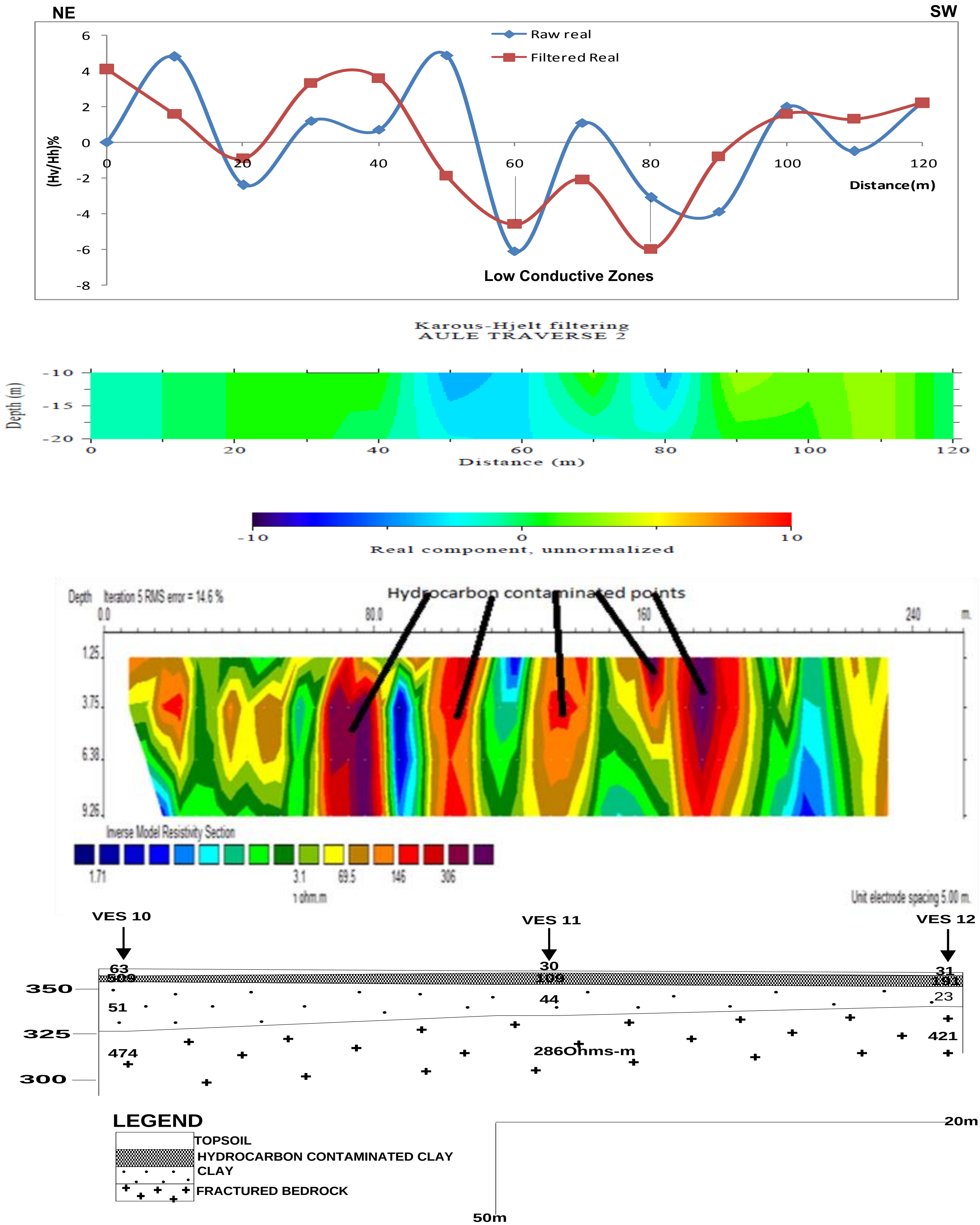

Figure 4(a-d). Profiles and Pseudo sections along traverse 2 in NW-SE direction of the study area.

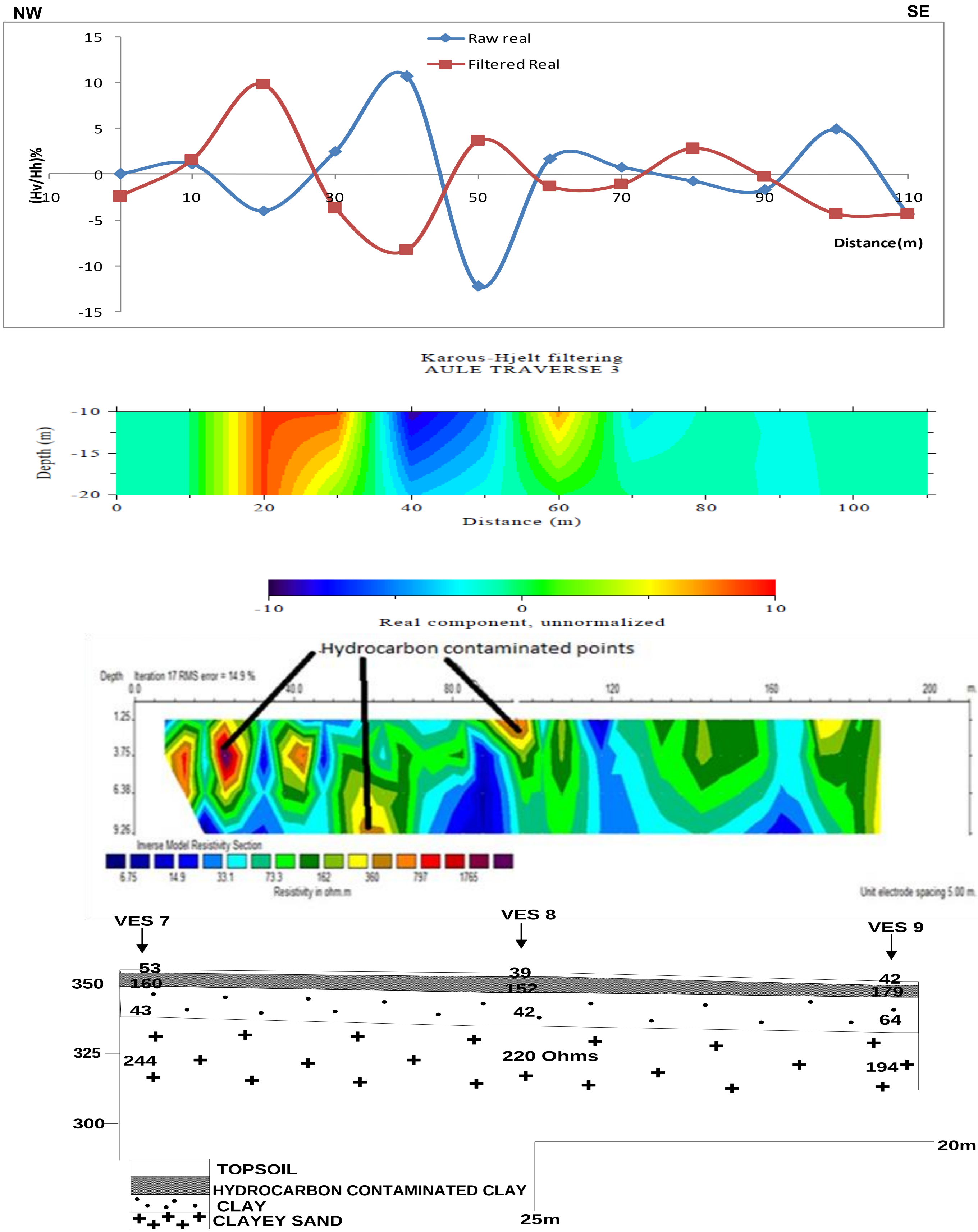

Figure 5(a-d). Profiles and Pseudo sections along traverse 3in NW-SE direction of the study area.

Table 2. VES Interpretation results.

VES stations	Traverse lines	Thickness (m) $h_1/h_2/h_3$---/h_n	Resistivity (Ω-m) $\rho_1/\rho_2/\rho_3$/--- ρ_n	Type curves
1	1	0.4/7.5/19.2	140/57/29/1472	QH
2	1	1.3/1.9/13.8	43/110/28/930	KH
3	1	3.0/6.7/15.4	122/398/64/2517	KH
4	1	1.4/6.4/17.2	80/54/447/59	HK
5	1	1.0/3.1/11.1	30/260/25/1324	KH
6	1	0.6/4.7/15.5	33/84/30/1176	KH
7	3	1.1/4.6/11.1	53/160/43/244	KH
8	3	1.4/5.7/12	39/152/42/220	KH
9	3	1.4/4.4/12.5	42/179/64/194	KH
10	2	1.1/2.7/3.3/27	63/69/509/51/474	AKH
11	2	1.1/6.5/17.0	30/109/44/286	KH
12	2	1.6/6.0/11.1	31/191/23/421	KH

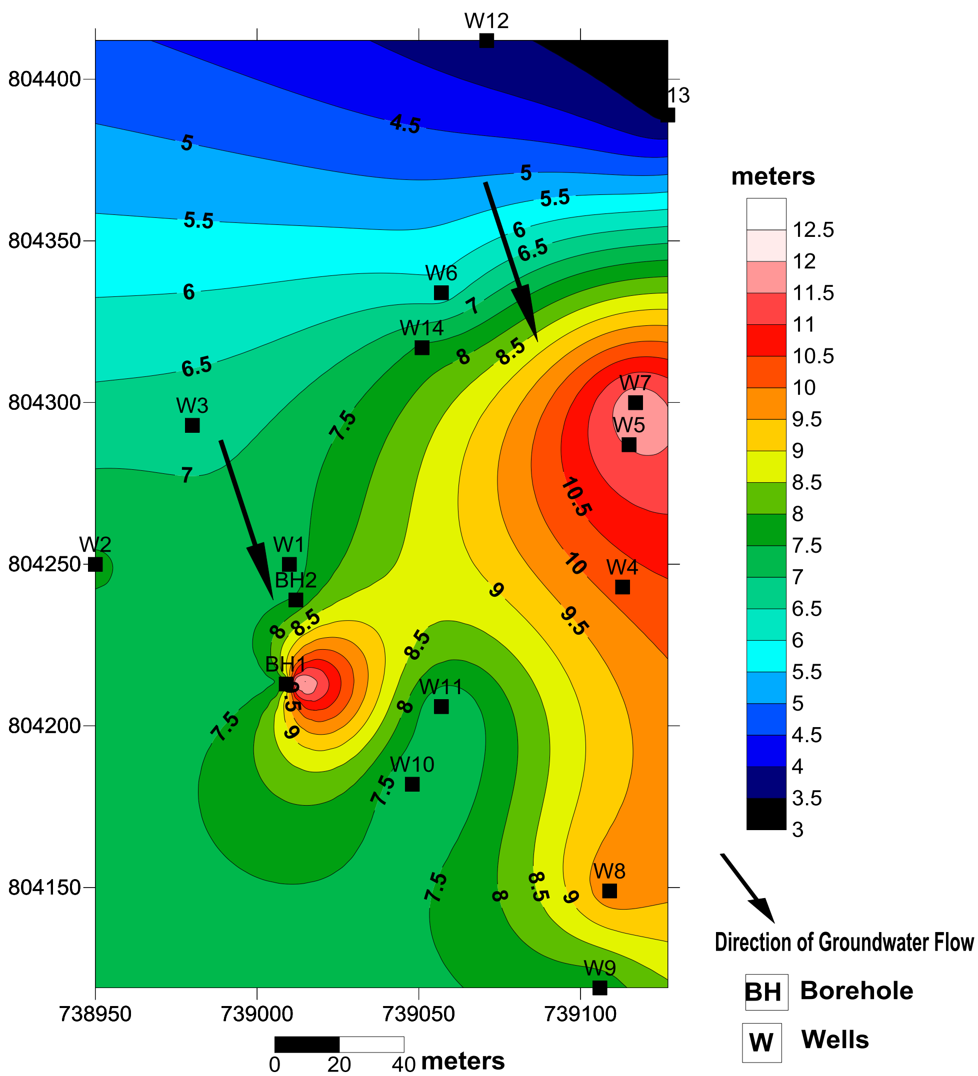

Figure 6. Static water level contour map showing well locations and flow direction.

Table 3. Physico-chemical properties of water samples.

Physico-chemical properties	Water samples		
	BH1	BH2	W3
pH	6.73	7.03	6.85
Chloride (mg/L)	22.40	19.51	23.63
Sulphate(mg/L)	10.45	15.63	18.50
Nitrate(mg/L)	3.21	4.50	6.32
Total Dissolved Solid (TDS) (mg/L)	15.47	21.33	19.67
Bicarbonate(HCO_3^{2-})(mg/L)	85.42	91.38	102.08
Calcium(mg/L)	6.18	9.12	10.25
Magnesium(mg/L)	11.25	10.08	11.33
Copper(mg/L)	ND	ND	ND
Iron(mg/L)	0.02	0.01	0.11
Lead(mg/L)	ND	ND	ND
Potassium (mg/L)	15.32	17.68	22.30
Sodium(mg/L)	18.02	35.20	16.58
Manganese(mg/L)	0.01	0.02	0.02
Zinc(mg/L)	8.32	11.27	9.63
Nickel(mg/L)	ND	ND	ND
Phosphate(mg/L)	13.45	12.36	11.58

Table 4. Specific measured parameters of water samples using combo meter.

Water sample	Parameters measured			
	Ph	TDS (ppm)	COND. (µs/cm)	Temperature (°C)
BH 1	6.85	209	104	25.4
BH 2	7.01	240	120	25.6
W 1	6.32	394	197	27.2
W 2	6.21	73	148	27.2
W 3	5.95	80	159	26.3

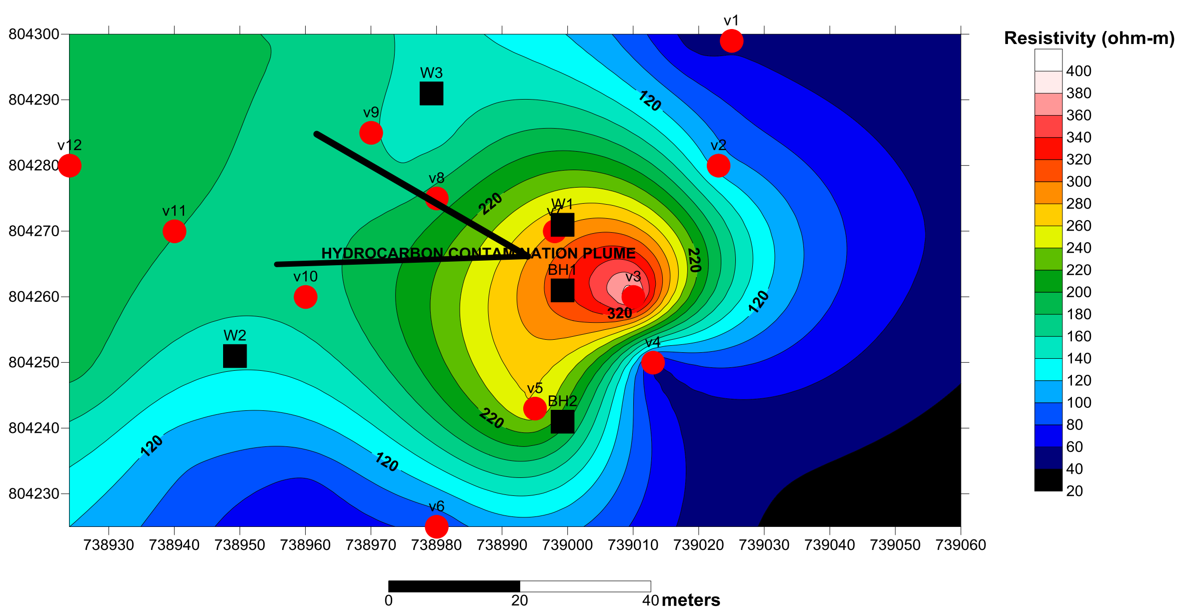

Figure 7. Map showing the contamination plume in the study area.

Table 5. Maximum permissible concentration of constituents in water (WHO, 2004).

Constituents	Maximum allowable concentration
Chloride	200 ppm
Nitrate	50 ppm
Hydrogen-ion concentration (pH)	7 - 8.5
Sulphate	200 ppm
Total dissolved solids	1000 ppm
Calcium	75 ppm
Magnesium	50 ppm
Electrical conductivity	1000 μScm^{-1}
Potassium	100 ppm
Sodium	200 ppm
Bicarbonate	100 ppm

filtered very low frequency electromagnetic method (VLF-EM) data, it can be inferred that the sources of groundwater in the area are hand dug wells and boreholes and not all these sources are of good quality. The groundwater in the study area is suspected to have been contaminated by hydrocarbon from the filling station nearby and suspected impacted zones are characterized by relatively high resistivity (>200 Ω-m) and low conductivity responses. There has been a vertical and lateral movement of the hydrocarbon contaminant plume down to depths of about 9.26 m. The static water level map reveals that direction of flow of groundwater in the area is typically towards the wells in the NW-SE direction. Good correlations exist between the geophysical results and hydrochemical analysis for hydrocarbon contamination in some strategically located wells notably BH1, BH2 and W1. Areas beyond wells W2 and W3 are yet to be contaminated and can be relatively said to be of good water quality based on their locations and anions concentrations falling within the maximum permissible limit for water constituents by the World Health Organization (Table 5). The geo-electric sections identified a maximum of 4 subsurface layers namely, the topsoil, the hydrocarbon contaminated clay, clay/clayey sand/sandy clay unit and the fractured/fresh basement layer basement. Three curve types which include KH, QH and AKH were obtained from the layer resistivities in the study area. The KH curve type occupies about 75% in the area. The KH curve type is typical of a basement complex terrain (Ariyo, 2009).

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