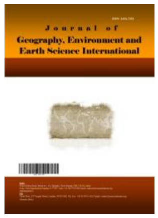

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Application of Electrical Resistivity and Hydrochemistry Methods for Mapping Groundwater Contamination around Okun Ilashe Island Area, Lagos State, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Authors TOA and SOI designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SOI, OEA, MAI and IA managed the analyses of the study. Authors KAA and BSA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

An application of Electrical Resistivity and hydrochemistry investigation involving Vertical Electrical Sounding (VES) and water quality analysis was conducted around Okun Ilashe Island area of Lagos state, southwestern Nigeria where there have been reported cases of groundwater contamination. The hydrochemical analysis was performed on five water samples in the area; two

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from boreholes and others from hand dug wells. Present study investigation showed that the groundwater had been contaminated by hydrocarbon arising from pipeline leakages in the studied area. The hydrocarbon contaminated plumes are specially characterized by relatively high resistivity values (> 800 Ω-m) and were delineated to a depth of about 12 m. Hydrochemical results showed that three of the sampled water have higher total dissolved solids (TDS) (>400 ppm) in compared to the remaining water samples. The major ions identified includes Na^+, K^+, Cl, $Mg2^+$, $Ca2^+$ and NO_3^-. Total Dissolved Solid (TDS) and Electrical Conductivity (EC) showed values not in agreement with WHO standards values. Ten (10) Vertical Electrical Sounding (VES) stations were occupied along four traverse lines trending E-W direction. The vertical electrical sounding results indicate maximum of four subsurface layers; Top soil, hydrocarbon contaminated sand, clay/clayey sand and sand/sandy clay. The contaminant plume has migrated to a significant depth of 12 m thus posing an inherent danger to the inhabitant of the area.

Keywords: Hydrocarbon; contaminant; geoelectric section; hydrochemistry.

1. 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 [1]. Contamination is the pollution involving constituents that are hazardous to health because of their nature or quality [2]. Potentially toxic elements (PTEs) in groundwater include geogenic metals and metalloids (As, Al, Cd, Hg, Ni, Pb, Se, U and Zn) which pose a major threat to human and environmental health across the world. PTEs frequently exceed World Health Organisation (WHO) drinking water guideline values in hotspots associated with Lower Paleozoic fractured bedrock environments. This has led to growing interest in the role of groundwater-surface water interfaces (hyporheic zones) for transforming and attenuating groundwater pollutants transported in base flow. This dynamic transition zone is often biogeochemically active where surface water brings dissolved organic matter (DOM) into stream bed sediments. The inhabitants of the study area depend majorly on groundwater as their source of water consumption. This situation has not been helped as a result of common occurrence of hydrocarbon pipeline leakages within this area which has really polluted the groundwater and this has led to the use of electrical resistivity and hydrochemical methods to map the hydrocarbon contamination plume

Plate 1. Destroyed palm tree

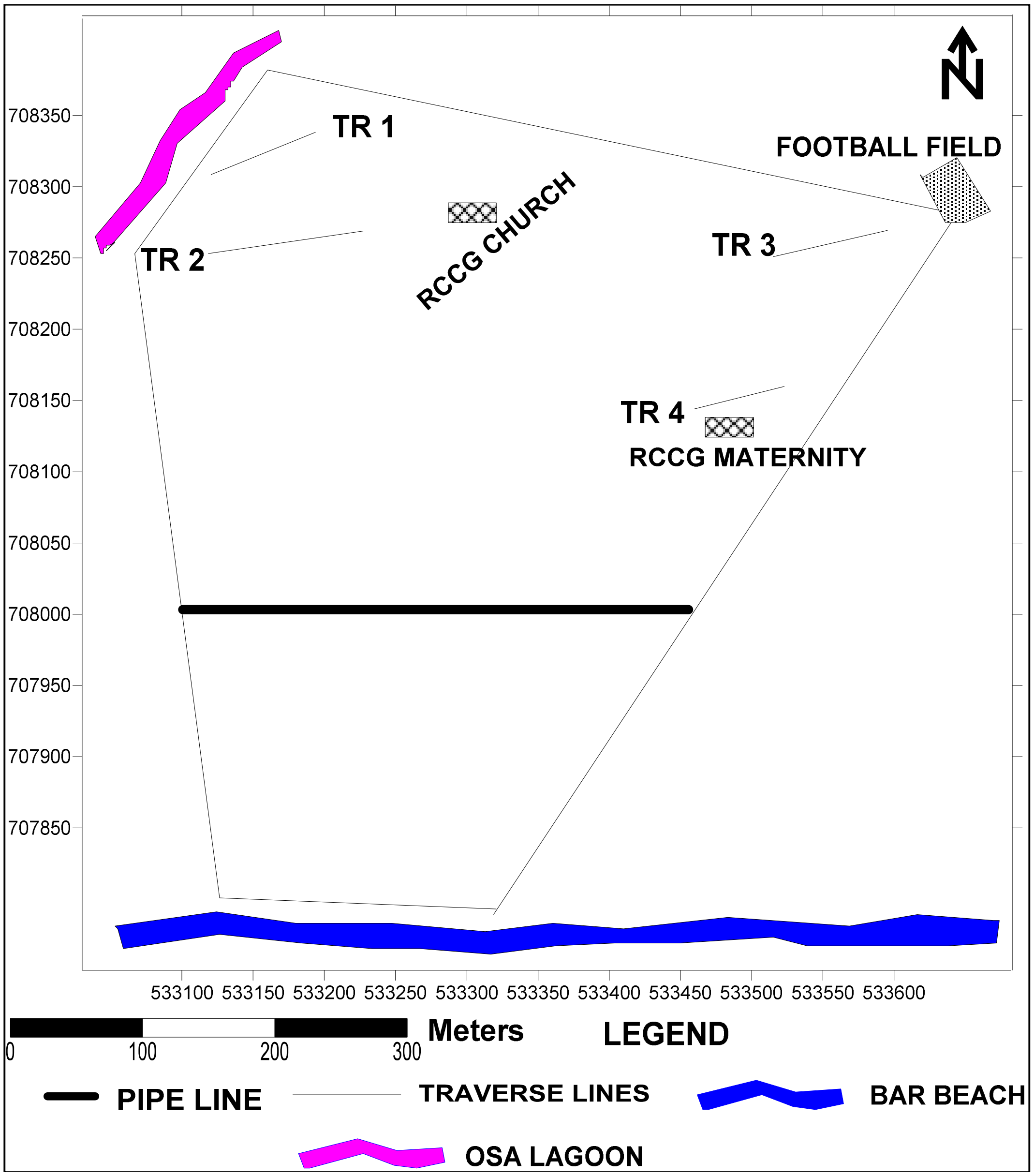

Fig. 1. Location map of the study area

within the subsurface, since geophysical methods has 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 [1,3, 4,5]. Apart from the effect on human beings, the hydrocarbon contamination also affected the ecology of the area. So many water animals and plants are destroyed as a result of this hydrocarbon leakage. Plate 1 shows the effect on palm trees.

1.1 Site Description and Geology of the Study Area

The Okun Ilashe area at snake Island of lagos falls entirely in the Dahomey Basin (Fig. 1). The geology of the area is underlain by sedimentary rocks with no basement outcrop. The Dahomey Basin was formed following the break-up of the African and South American Plates [6] and is partially separated from the Niger Delta and the Eastern Nigeria sedimentary basin by a Ridge of crystalline rocks. The earliest sediments in the

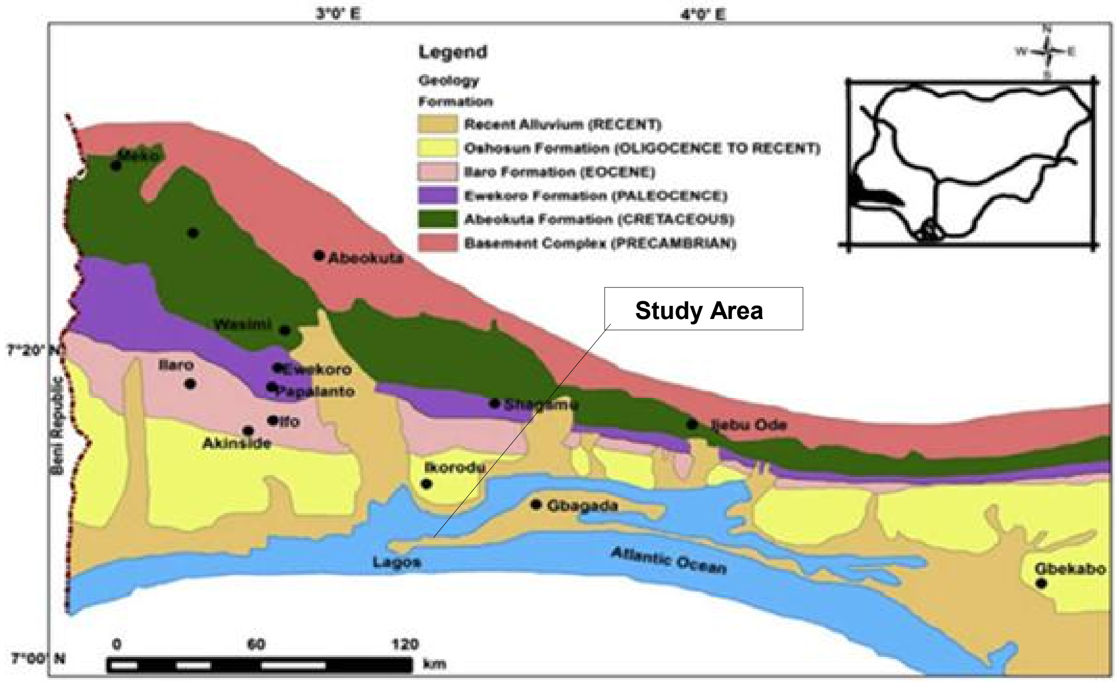

Fig. 2. Geological sequence of the Eastern Dahomey basin showing the study area

area were deposited as a result of the first major marine transgression in South Western Nigeria [7]. The upper sediments in the Dahomey Basin are recent (Fig. 2). This is underlain by Coastal Plain Sands of the Quaternary Age. Basically the geologic sequence in the Dahomey Basin extends from Precambrian to Recent. Three distinct sequences, which are closely related to the geology of the sediments, are identified from past studies of South-Western Nigeria [8,9].

2. MATERIALS AND METHODS

Electrical resistivity technique and hydro-chemical investigations were adopted for the study. The electrical resistivity method used vertical electrical sounding (VES) techniques. 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. Ten (10) vertical electrical sounding locations were obtained along four traverses (Fig. 3). The vertical electricity sounding data were obtained using DC resistivity meter R-50. In order to process the electrical resistivity data, the apparent resistivity values were plotted against the electrode spread (AB/2). This was subsequently interpreted quantitatively using the partial curve matching method and computer-assisted 1-D forward modeling with WinResist 1.0 version software [10]. The hydro-chemical analysis involved the collection and analysis of water samples for chemical analysis. Five water samples from borehole and hand dug well were collected within the investigated area. The five water samples were analysed by Department of Civil and Environmental Engineering, University of Lagos, Lagos State, Nigeria. Each waters samples analysed was based on World Health Organisation (WHO) procedure [11].

3. RESULTS AND DISCUSSION

The results of the study were presented as sounding curves, geo-electric sections, map and graphs.

3.1 Characteristic of the VES Curves

Curves types identified ranges from K, H and KH varying between three to four geo-electric layers. The K curve type was predominant. Typical curve types in the area are as shown in Fig. 4(a-c).

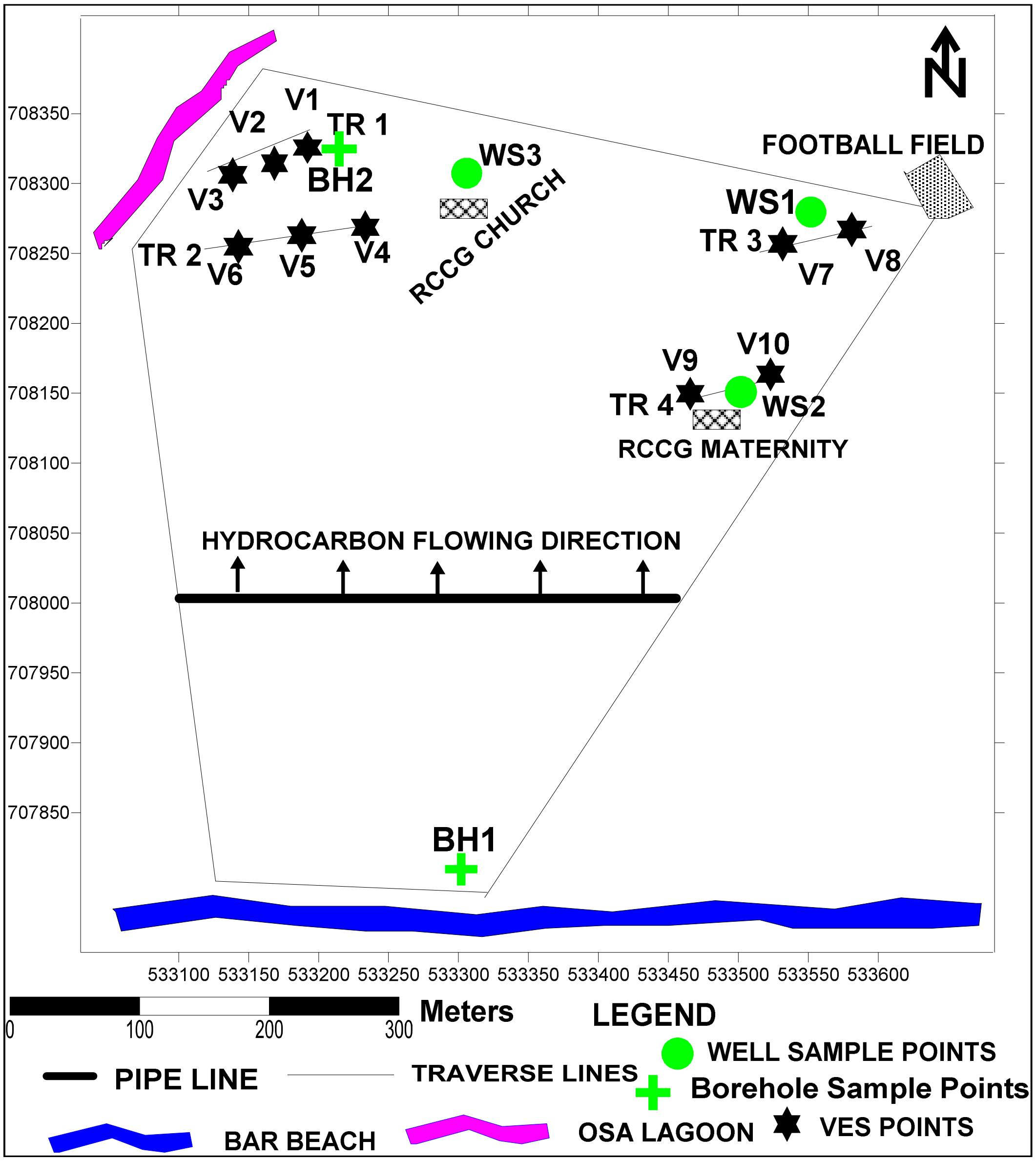

Fig. 3. Data acquisition map of the study area

3.2 Geoelectric and Lithological Characteristic along the Four Traverses

The geo- electric sections were represented by the 2-D view of the geo-electric parameters (depth and resistivity) derived from the inversion of the electrical resistivity sounding data The geoelectric section along Traverse 1 to traverse 4 (Fig. 5a to 5d) attempted to correlate the geoelectric sequence across the study area. The geoelectric sections identified three geoelectric/geologic subsurface layers vis-à-vis the topsoil, hydrocarbon contaminated sand, clay/clayey sand and sand/sandy clay. The topsoil comprising of clay, clayey sand and sandy clay with the resistivity values ranges from 17 to 399 Ω-m with its thickness varies from 0.1 to 1.9 m, the hydrocarbon contaminated sand has resistivity values range from 878 to 2294 Ω-m and thickness ranges from 3.6 to 10.8 m while the clay/clayey sand/sandy clay/sand layer resistivity varies from 25 to 401 Ω-m. The resistivity values of the hydrocarbon contaminated sand layer displays that it may not be of any major interest since the hydrocarbon has contaminated the groundwater to a depth of 12 m.

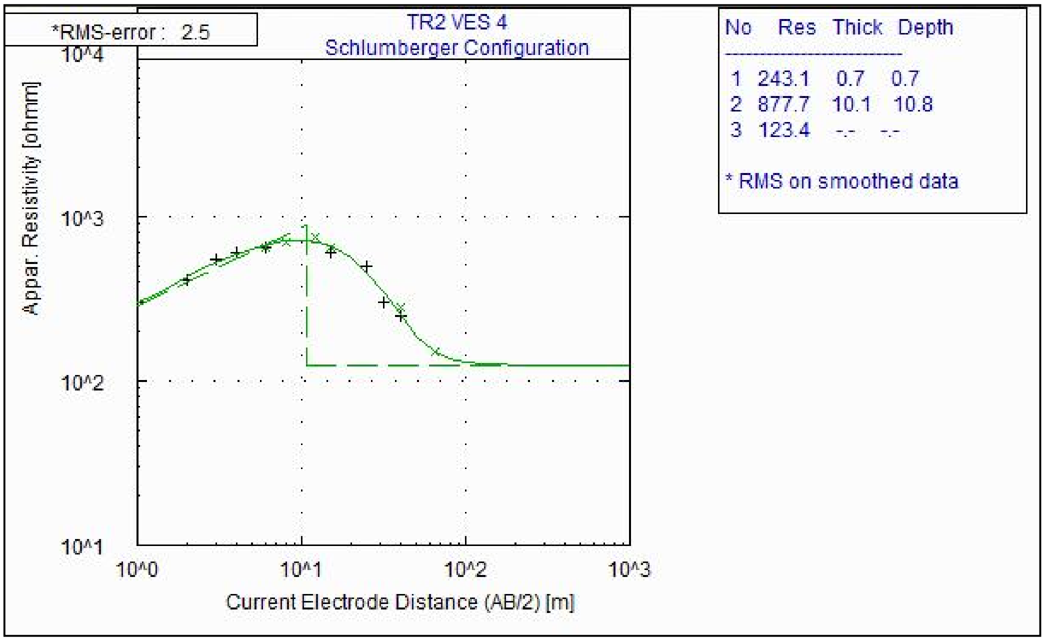

Fig. 4a. Typical 'K' sounding curve

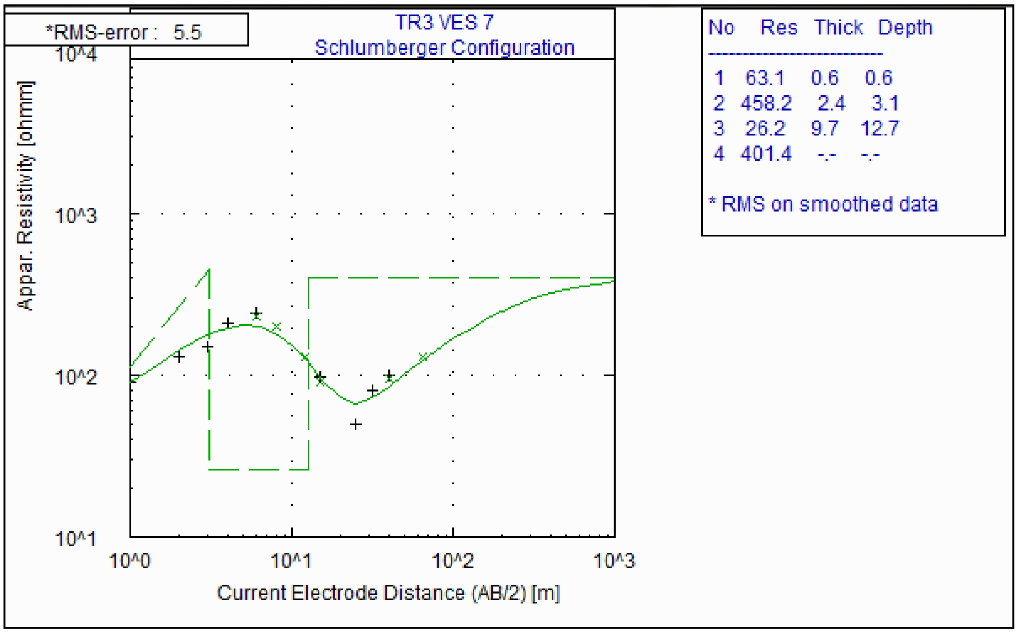

Fig. 4b. Typical 'KH' sounding curve

3.3 Geoelectric Map of the Investigated Area

Fig. 6 illustrates hydrocarbon contamination plume. 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 pipe line explosion/linkage and suspected to have affected zones characterized by relatively high resistivity (>800 Ω-m). There has been a vertical and lateral movement of the hydrocarbon contaminant plume down to depths of about 12 m.

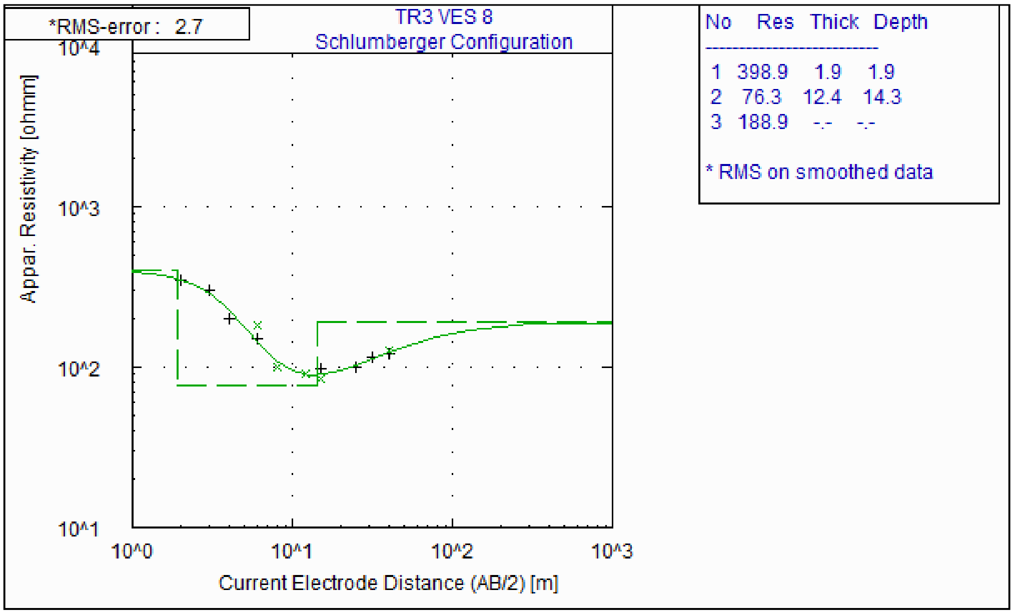

Fig. 4c. Typical 'H' sounding curve

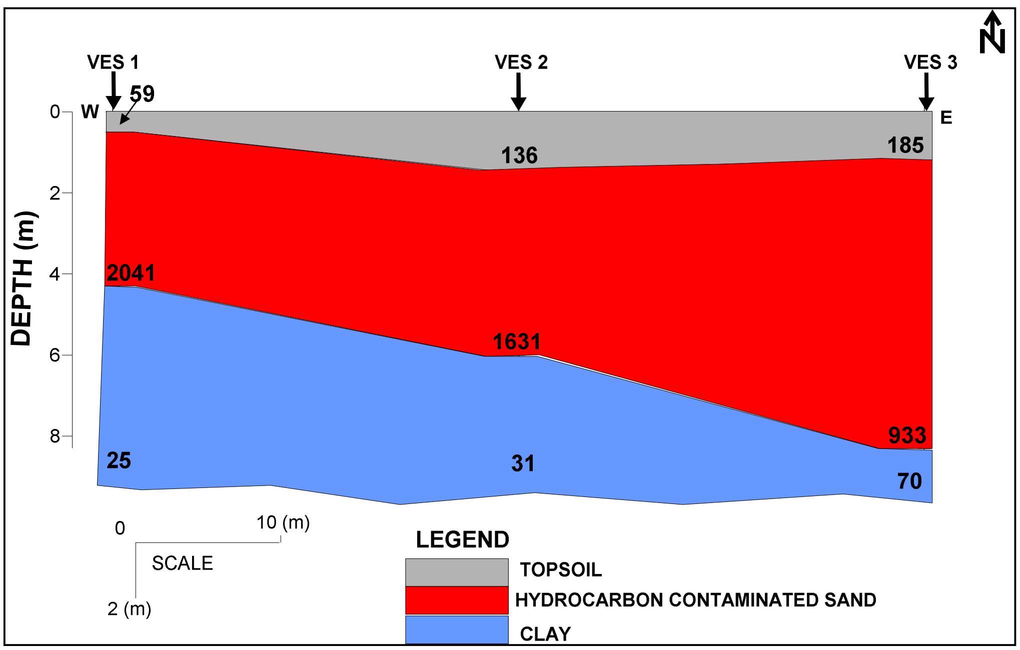

Fig. 5a. Geoelectric section along traverse one

3.4 Hydrochemical Analysis

Results of hydro-chemical analysis are presented in Tables 1, 2 and 3. The results show that BH2, WS2 and WS3 have high concentrations of conductivity and total dissolved solid (TDS) which correspond to the high resistivity obtained from the electrical resistivity method as show in Fig. 6. The relatively low conductivity and TDS observed at BH1 and WS1 is due primarily to the presence of non–biodegraded hydrocarbon over the water table. BH1, WS2 and WS3 have a relatively high TDS compare to BH1 and WS1 (Table 1), which is indicative that the hydrocarbon plume contaminant is yet to reach their location (Fig. 6).

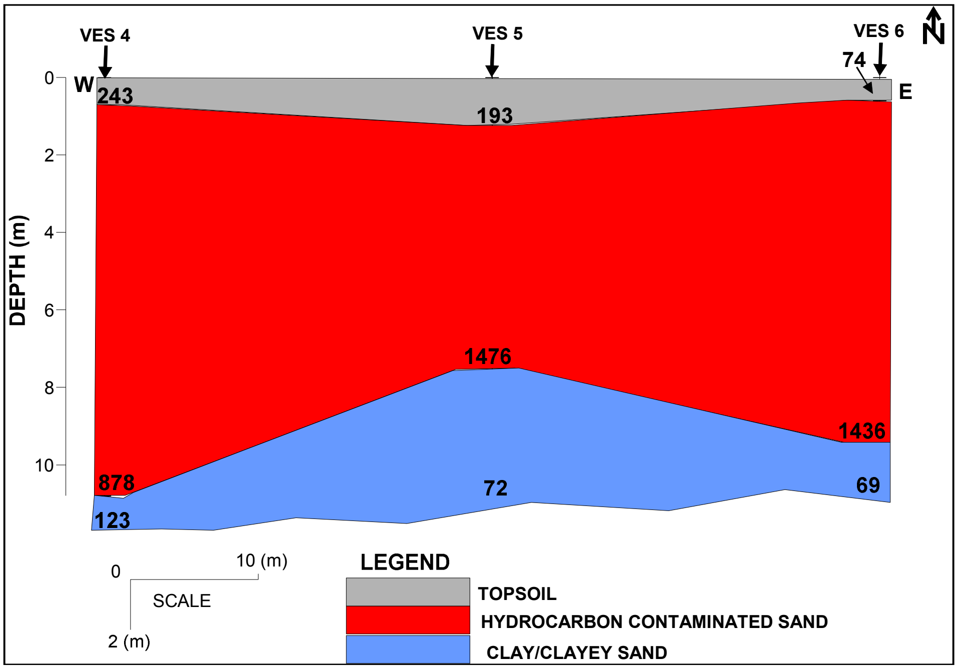

Fig. 5b. Geoelectric section along traverse two

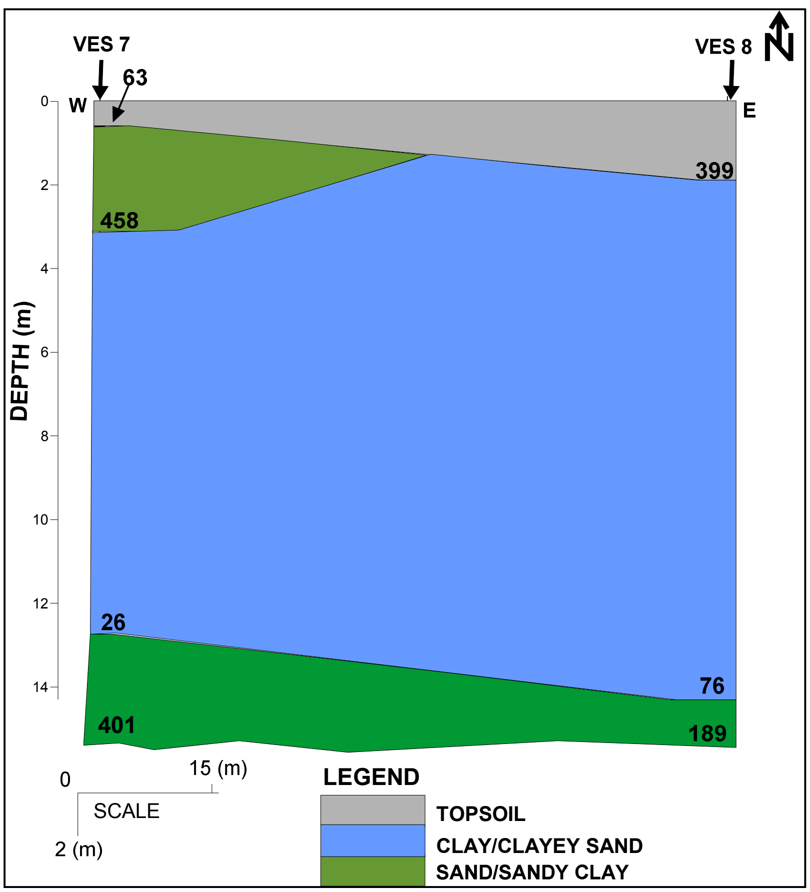

Fig. 5c. Geoelectric section along traverse three

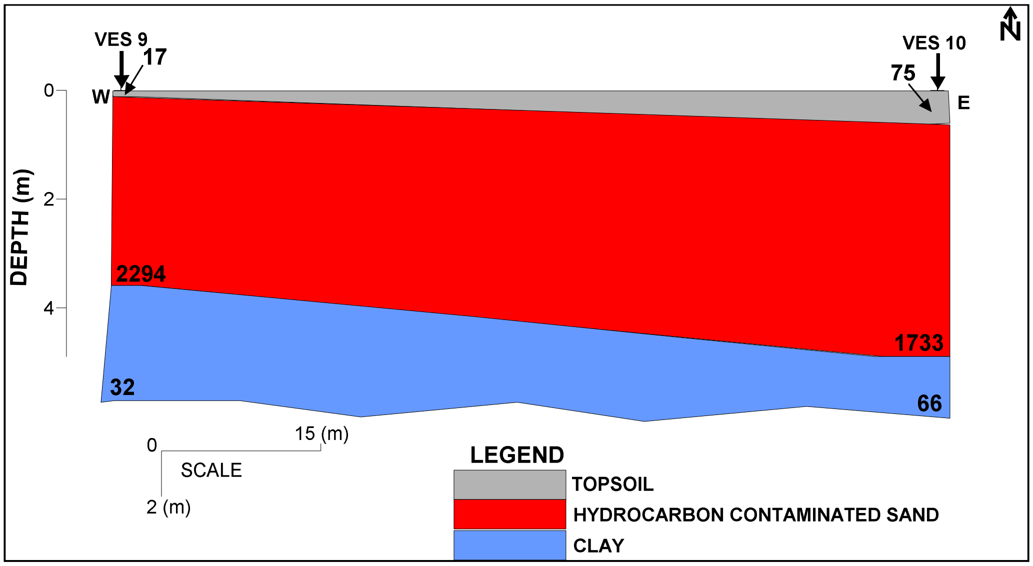

Fig. 5d. Geoelectric section along traverse four

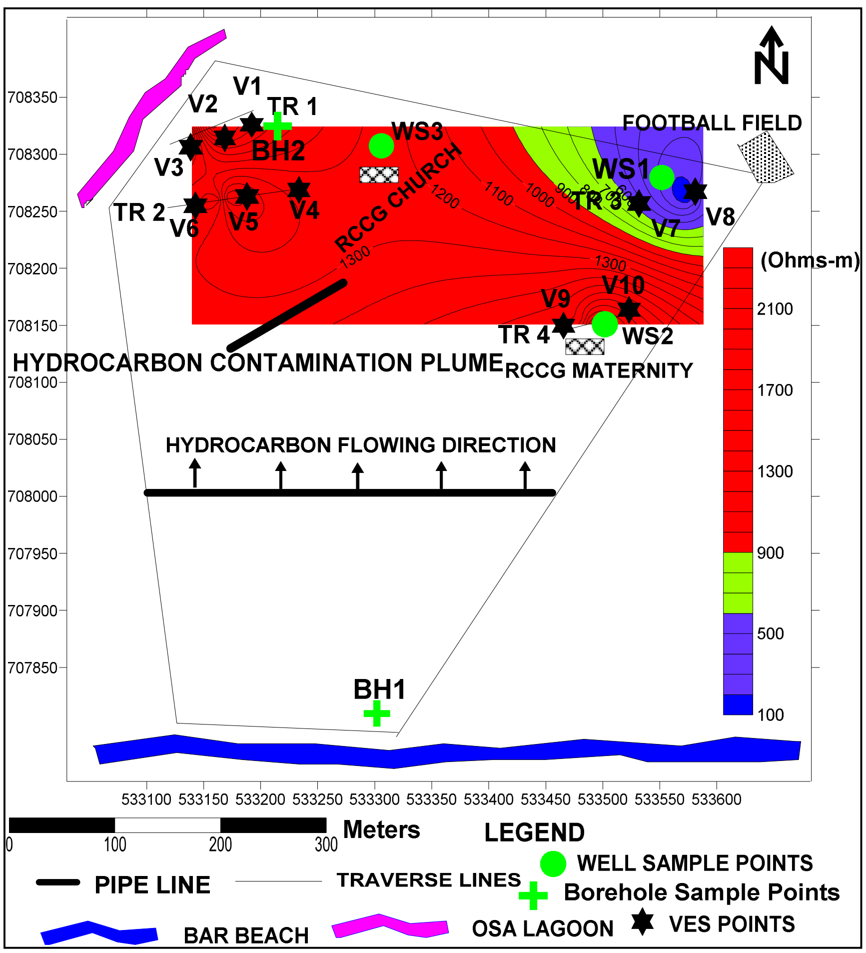

Fig. 6. Map showing the hydrocarbon contamination plume in the study area

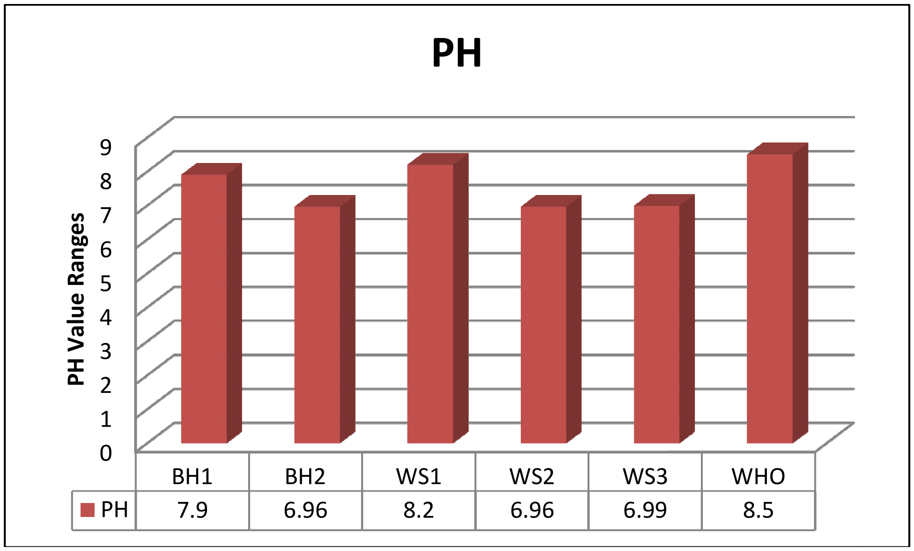

Fig. 7. Histogram showing the soil PH of the study area

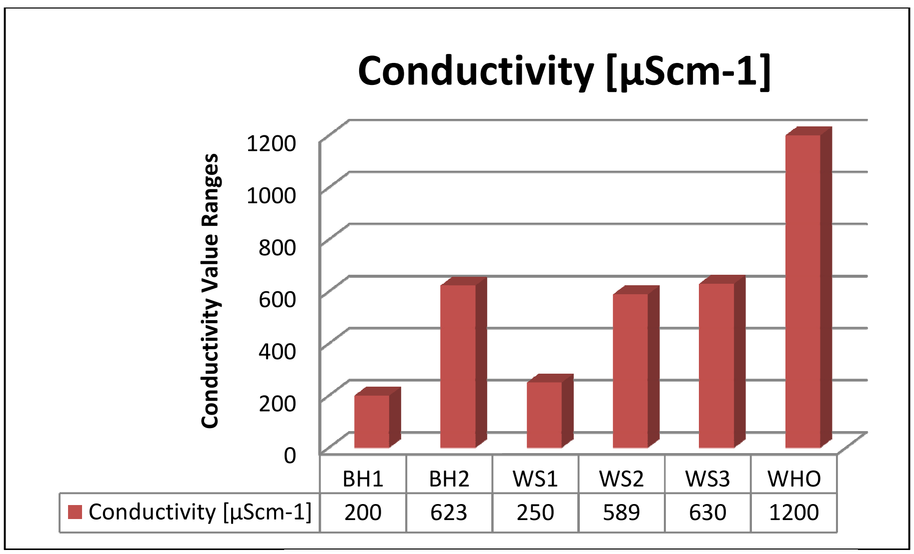

Fig. 8. Histogram showing the conductivity of the study area

pH: The pH value ranges from 6.96 – 8.2 with an average of 7.40 (Table 1). pH value of 6.96 – 6.99 obtained from BH2, WS2 and WS3 revealed that the groundwater in the study area is acidic. The acidity is probably due to the presence of organic matter in the soil. However, free CO_2 generated from the hydrocarbon explosion and the atmosphere, is suspected to enter the groundwater system as rain water percolates the subsurface soil and groundwater and reduces the pH value of the water in the area. The pH values of 6.96 – 6.99 are lower than the WHO (2004) recommended safe value 7.0 – 8.5 which is an indicative of groundwater pollution (Fig. 7).

Conductivity: Conductivity values range from 200 - 630 µScm^{-1} (Table 1) with an average value of 458.4 µScm^{-1}. Conductivity usually indicates the concentration of dissolved ions in groundwater samples. However the higher conductivity values within BH2, WS2 and WS3 give indication groundwater pollution within the island (Fig. 8).

Total Hardness: The Total hardness of groundwater samples in the study area which ranges from 199 – 350 ppm $CaCo_3$ with an average value of 281.4 ppm $CaCo_3$ (Table 2). These values are generally more than the WHO recommended safe values of 200 ppm $CaCo_3$ for drinking water. Relatively higher total hardness values of 322 – 350 ppm $CaCo_3$ obtained from BH2, WS2 and WS3 is an indication of pollution of the groundwater around Okun Ilashe Island (Fig. 9).

Sulphate: The sulphate content of groundwater in the study area generally ranges from 95 – 201 ppm (Table 2). These values are generally less than the WHO recommended safe values for drinking water around BH2, WS2 and WS3 (Table 2). The values within BH1 and WS1 fall within the WHO recommended safe values for drinking water. The relatively low sulphates concentration around are indications of pollution for groundwater around the investigated area (Fig. 10).

Nitrate: The NO3- concentration values for groundwater ranges from 8.9 – 31 ppm with average values of 17.78 ppm (Table 2). The values within BH2, WS2 and WS3 generally fall

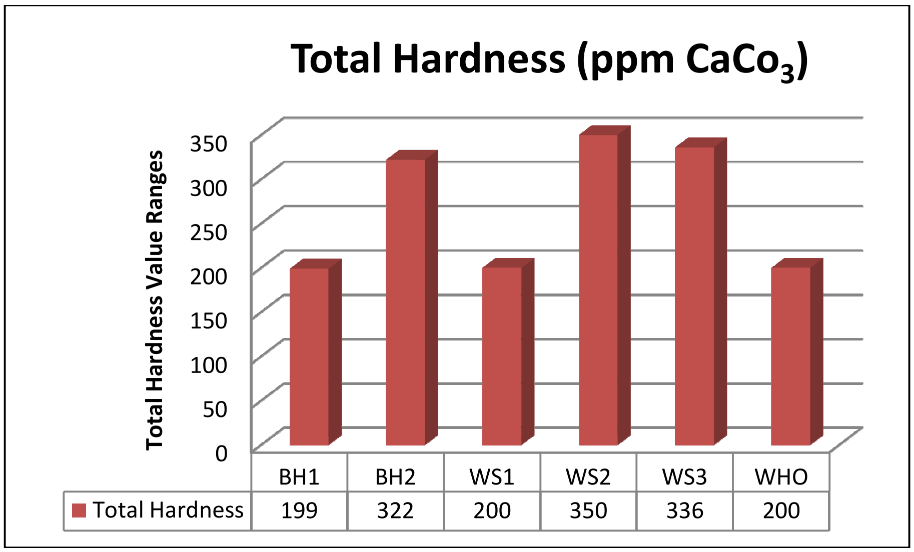

Fig. 9. Histogram showing the total hardness of the study area

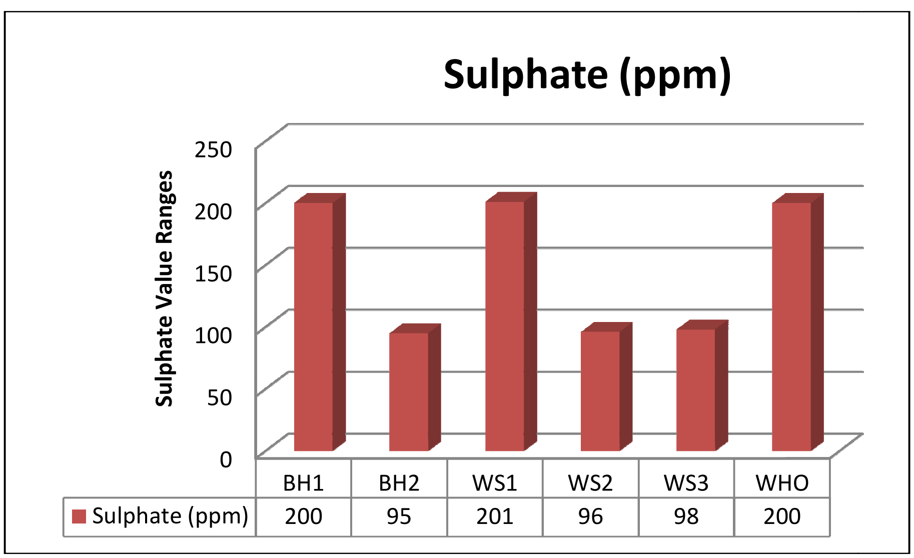

Fig. 10. Histogram showing the sulphate concentration of the study area

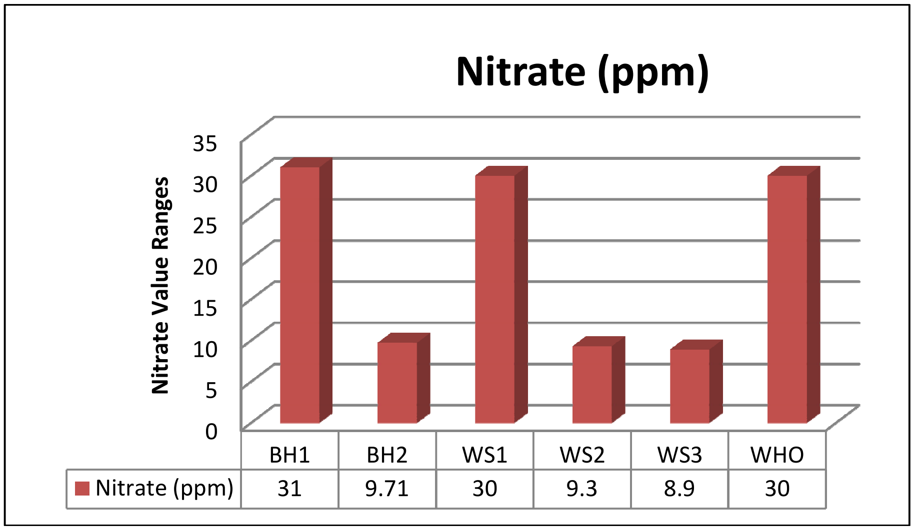

Fig. 11. Histogram showing the nitrate of the study area

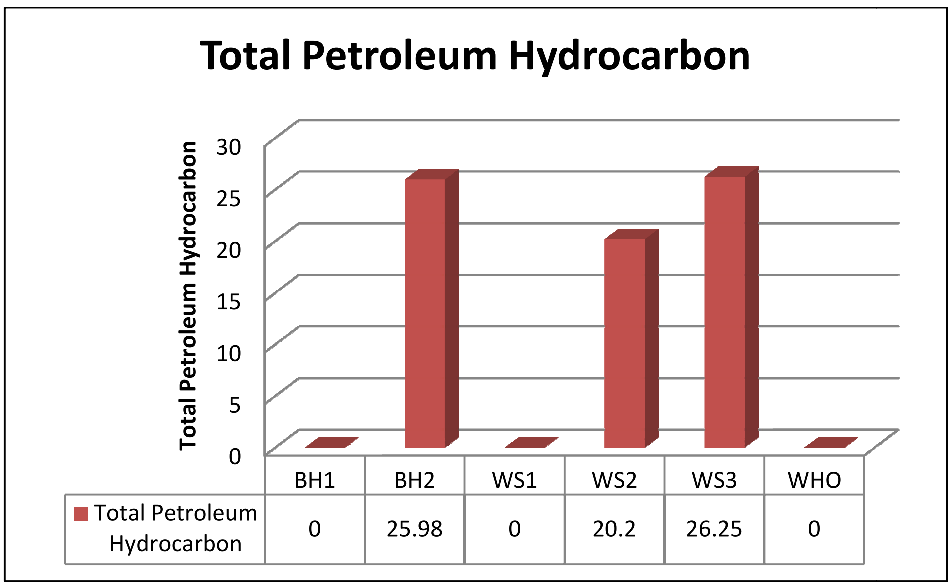

Fig. 12. Histogram showing the total petroleum hydrocarbon of the study area

below the WHO recommended save value for drinking water. The lower concentrations of nitrate are an indication of leachate saturation and hence confirm the leachate pollution around the Island (Fig. 11).

Total Petroleum Hydrocarbon (TPH): The TPH content of groundwater in the study area generally ranges from 0.00 to 26.15 ppm (Table 2). BH1 and WS1 have no concentration of TPH which fall within the WHO recommended safe values for drinking water. The relatively high concentration of TPH in BH2, WS2 and WS3 is in indication of pollution of the groundwater which has really affected a wide range of land around Okun Ilashe Island (Fig. 12).

Total Bacterial Count (cfu/Mi): The total bacteria count values for groundwater ranges from 3.6 x 10^1 – 1.1 x 10^2 cfu/Mi (Table 3). The values within BH2, WS2 and WS3 generally fall below the WHO recommended save value for drinking water.

Table 1. Physical properties parameters of water samples

	Water sample BH1	Water sample BH2	Water sample WS1	Water sample WS2	Water sample WS3	WHO limit
Apperance	Clear	Not Clear	Clear	Not Clear	Not Clear	Clear
Colour	Colourless	Brownish	Colourless	Brownish	Brownish	Colourless
Odour	Odourless	Objectionable	Odourless	Objectionable	Objection-able	Odourless
PH@27^{0}C [No Unit]	7.9	6.96	8.2	6.96	6.99	7.0 - 8.50
Turbidity [FTU]	5.0	1.78	5.1	1.76	1.79	5.0
Conductivity [μScm^{-1}]	200	623.0	250	589.0	630.0	1,200
Total Dissolve Solids [ppm]	500	424.0	501	420	412	500
Total Solids [ppm]	1497	424.9	1480	550.0	492.2	1,500
Salinity [ppm]	990.0	300.0	998.0	400.2	350.1	1,000

Table 2. Chemical properties parameters of water samples

	Water sample BH1	Water sample BH2	Water sample WS1	Water sample WS2	Water sample WS3	WHO limit
Alkanity – M (ppm $CaCo_3$)	498	258.0	501	300	263	500
Total Hardness (ppm $CaCo_3$)	199	322	200	350	336	200
Calcium Hardness (ppm $CaCo_3$)	76	240	82	280	256	75
Cholride CL^- (ppm)	249	260	247	280	276	250
Sulphate SO_4^{2-} (ppm)	200	95	201	96	98	200
Nitrate, NO_3^- (ppm)	31	9.71	30	9.3	8.9	30
Phosphate, PO_4^{2-} (ppm)	0.01	1.24	0.02	2.0	1.98	0.03
Iron, Fe^{2+} (ppm)	0.3	0.186	0.32	0.121	0.110	0.3
Copper, Cu (ppm)	1.45	0.072	1.48	0.064	0.057	1.5
Manganese, Mn (ppm)	0.45	0.02	0.49	0.01	0.08	0.5
Dissolved Oxygen (DO)	-	4.0	-	4.3	4.15	-
TPH (ppm)	0.00	25.98	0.00	20.20	26.15	0.00

TPH = Total Petroleum Hydrocarbon

Table 3. Microbiological examination of water samples

Organism	Water sample BH1	Water sample BH2	Water sample WS1	Water sample WS2	Water sample WS3	WHO limit
Total Coliform (cfu/Mi)	0.00	0.00	0.00	0.00	0.00	0.00
Total Bacterial Count (cfu/Mi)	1.1×10^2	4.0×10^1	1.0×10^2	4.5×10^1	3.6×10^1	1.0×10^2

4. CONCLUSION

Electrical resistivity and hydrochemical investigation around Okun Ilashe Islnad of Lagos State, Southwestern Nigeria has been carried out to assess the case of groundwater contamination. The geo-electric sections identified a maximum of 4 subsurface layers namely, the topsoil, the hydrocarbon contaminated sand, clay/clayey sand and sand/sandy clay unit. Three curve types which include K, H and KH were obtained from the layer resistivities in the study area. The K curve type occupies about 90% in the area. The second layer which is hydrocarbon contaminant sand is an indication that the groundwater in the area has been affected by hydrocarbon contamination from the pipe line explosion It can be inferred from the hydrochemistry analysis 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 hydrocarbon pipeline explosion nearby and suspected impacted zones are characterized by relatively high resistivity (>800 Ω-m) and low conductivity responses. There has been a vertical and lateral movement of the hydrocarbon contaminant plume down to depths of about 12 m. Good correlations exist between the electrical resistivity results and hydrochemical analysis for hydrocarbon contamination in some strategically located wells notably BH2, WS2 and SW3. Areas around BH1 and SW1 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. Since the quality of the groundwater does not conform to the WHO standard. Necessary treatment should be applied to make it suitable or alternative source of water may be sought.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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