



Original Research Article

Groundwater Quality Assessment using Integrated Geophysical and Physicochemical Approaches: A Case of Isheri-Oke Estate, Lagos, Southwestern Nigeria

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ABSTRACT

Geophysical and physicochemical investigations of groundwater in Isheri-Oke area of Lagos State were carried out to assess the quality of groundwater due to the presence of a suspected source of contamination of aquifer in the area. 2D electrical resistivity imaging (ERI) and vertical electrical sounding (VES) data were acquired. Five water samples were also collected for Groundwater quality index (GQI) analyses. The results of the 2D ERI revealed three (3) resistivity structures while geoelectric results revealed four to five layers indicating topsoil, clay, clay/peat, clayey sand and sand with resistivity and thickness varying from 2.0 – 1058.9 Ohm-m and 0.4 – 57.1 m respectively. Traverse 1 revealed an elevated case of contamination from the adjacent canal, perhaps due to its proximity. The 2D results from other traverses revealed mild cases of contamination near-surface. The clayey sand/sand at the second and third geoelectric layers showed contamination from the canal which runs perpendicular to traverses 2 and 4 and parallel to 1 and 3 with the impact being maximum along traverse 3. Physicochemical results revealed that all parameters tested are within permissible limits except Iron in BH1. Dissolved oxygen was also below the WHO limits except in BH1. GQI revealed that all water samples tested have values ranging from 50 – 100 signifying “good water quality”. Only the near surface is affected by contamination from the canal as confirmed from the geoelectric investigation and evident in shallow hand dug wells. Continuous geophysical monitoring is recommended for the onset of contamination of the deep-seated aquifers.

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1. INTRODUCTION

The water held in the subsurface within the zone of saturation under hydrostatic pressure below the water table is termed Groundwater (Ariyo and Banjo, 2008) while surface water is a term used to describe water on the earth's surface including rivers, creeks and wetlands. About two third of the total land space in the world is covered by water (Shiklomanov, 1993). The search for groundwater has been on the increase across

the globe and this is because it is considered all over the world to be the best source of potable and safe water for drinking, agricultural and industrial purposes (Hoque *et al.*, 2009). Several tools ranging from geophysical, remote sensing, geographic information system (GIS) among others, have been utilized for proper location of this precious resource within the subsurface. However, location of this resource is not enough without proper protection from harmful substances that can degrade its quality and render it unfit for human use. Groundwater reservoirs are easily affected by contamination through a process that is slow and consequently dreadful (Baghvand *et al.*, 2010). The availability and accessibility to potable and quality water resources is of major concern.

The quality of groundwater is a function of natural processes as well as anthropogenic activities (Badmus *et al.*, 2001). Quality of water is principally affected by contaminations from diverse sources (Sajil-Kumar *et al.*, 2013). Inorganic chemicals and micro-organisms are common in human environments. The majority of pathogenic micro-organisms (potentially disease-causing virus/bacteria or pathogens) that are found in water come from human and animal excrements. Thus, the presence of contaminants above World Health Organization (WHO) standard can cause different kinds of diseases such as typhoid fever, paratyphoid fever, dysenteries, gastroenteritis, infectious hepatitis, schistosomiasis, asiatic cholera, back pains, pneumonia, nasal congestion (Ojelabi *et al.*, 2001). Groundwater abstraction intensifies the migration of these contaminants to the subsurface, activates salt water encroachment into pumped aquifers from neighboring ones and sea water intrusion into coastal wells (Kalimas and Gregorauskas, 2002).

The electrical resistivity technique is one of the geophysical methods, which enables the determination of sub-surface resistivity by introducing artificially produced electric current into the ground through a set of two electrodes, and measuring the potential field generated by the current by the aid of another set of two electrodes. Electrical methods have been used to solve problems related to environmental studies, especially relating to contamination of subsurface soil, groundwater and aquifer vulnerability (Sorensen *et al.*, 2005). Drinking of water from polluted source by the local community without adequate treatment in advance could cause serious health hazards. Hence, the need to carry out comprehensive physicochemical analysis of water samples to determine the water treatment necessary before consumption (Amadi *et al.*, 2011; Sunmonu *et al.*, 2013; Odukoya *et al.*, 2013). Water quality index (WQI) is essential because it is one of the most effective tools for the assessment and management of surface and groundwater. It provides a single number that expresses the overall quality of water at certain location and time based on several water quality parameters (Adeogun *et al.*, 2019). The WQI is calculated from the point of view of suitability of the water for human consumption (Mufid, 2012).

Isheri-Oke community in Lagos southwestern Nigeria is a densely populated residential settlement straddling a big canal in the southern to southwestern and northwestern parts and whose residents depend solely on groundwater from boreholes and hand dug wells for their daily water need. In recent times, shallow hand-dug wells in the area have shown extreme cases of contamination in terms of quality. Few cases of groundwater pollution which resulted in the impairment of the health of some residents were also reported and these were suspected to arise from the impact of the canal leaking into the aquifer system in the study area which supplies the residents' utility and potable water. There is therefore the need for the assessment of the groundwater quality in the area with a view to determining the extent of impact for possible mitigation and monitoring. In this study, 2-D profiling using Wenner array, vertical electrical sounding (VES) using Schlumberger array, physicochemical analysis and water quality index were carried out to identify the groundwater zones and assess the quality of the groundwater to determine its potability in Isheri- Oke community, Lagos, southwestern Nigeria.

2. METHODOLOGY

2.1. Location and Geology of Study Area

Geologically, Lagos State falls within Eastern Dahomey Basin. The stratigraphy of Cretaceous to Tertiary sedimentary sequence of the Eastern Dahomey Basin is divided into: Abeokuta Group, Imo Group, Ilaro Formation, Benin Formation, Coastal plain sands and recent alluvium (Omatsola and Adegoke, 1981). The study area is underlain by the Coastal Plain Sands of Lagos (Figure 1). The study area lies within latitude N 06° 38' 20" to N 06° 39' 0" and longitude E 003° 23' 0" to E 003° 23' 40" in the South Western part of Nigeria, with elevation ranging from 4.7 to 42 m above mean sea level (Figure. 2). The two prevailing climatic seasons are the dry (November to March) and wet (April to October) seasons and it is found in the rain forest environment with mean annual rainfall ranging between 1500 mm and 2500 mm.

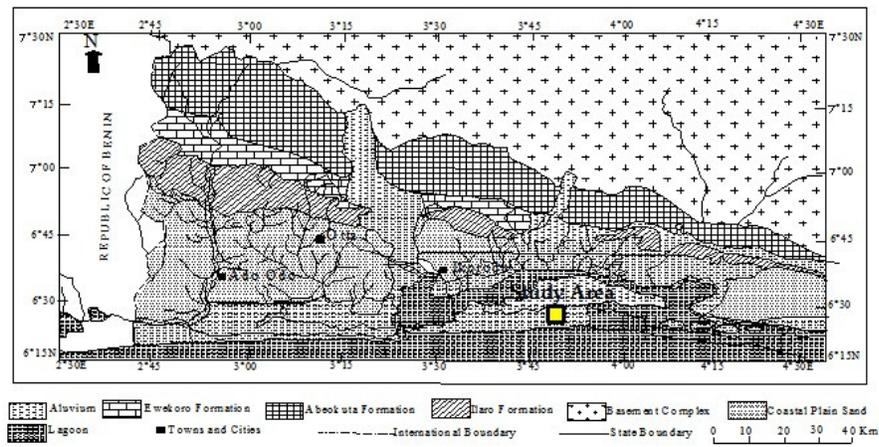


Figure 1: Regional map of the study area (Kogbe, 1976)

2.2. Geophysical Investigation

The electrical resistivity survey was carried out along four (4) traverses using VES and 2D electrical resistivity imaging/profiling methods. The sets of data were acquired using the PASI earth resistivity meter, twenty-one metallic electrodes, measuring tape, four reels of cables, Garmin global positioning system (GPS), crocodile clips and four pieces of hammer.

2.2.1. Two-dimensional (2D) resistivity imaging (IR)

The Wenner array electrode configuration was used for the 2D resistivity imaging/profiling. This is because it is well suited for the constant spacing data acquisition as many data points can be recorded at the same time for each current injection (Milson, 2003). Four (4) profiles were run with the spacing between the profiles dependent on the accessible points on the field. The cables were connected to the electrodes by means of crocodile clips and the electrodes were driven into the soil with the aid of the hammers along the measuring tape in a straight line. Measurements were made at sequences of electrodes at 10, 20, 30, 40, 50 and 60 m interval using four (4) electrodes for all the four traverses covering a maximum distance of 200 m. The coordinates of each traverse line were taken using the GPS. The 2D data were processed with the

DIPROWIN software for the inversion of the 2D apparent resistivity data to produce the 2D resistivity section along each traverse.

2.2.2. Vertical electrical sounding (VES)

The Schlumberger electrode configuration was used to acquire twenty (20) vertical electrical sounding stations at different points along the four profiles. The Schlumberger current electrode spacing (AB) was varied from a minimum of 2.0 m to a maximum of 500.0 m at the VES locations. On each 2D electrical imaging (EI) profile, four VES points were carried out in order to integrate the VES and the 2D. The geodetic system of coordinates was obtained using the GPS. The acquired apparent resistivity data were processed both quantitatively and qualitatively. The VES data were partially curve matched (Bhattacharya and Patra, 1968) to generate the first order geoelectric parameters which were inverted with WinResist Software to generate the thickness, depth and resistivity values for each geoelectric layer. These were combined across each traverse to generate the geoelectric sections using AUTOCAD software.

2.3. Physicochemical Investigation

The location coordinates of the three hand-dug wells and two boreholes, were taken with a global positioning system. Location W1 has latitude $06^{\circ} 38' 38.6''$ N and longitude $03^{\circ} 23' 13.9''$ E, Location W2 has latitude $06^{\circ} 38' 37.3''$ N and longitude $03^{\circ} 23' 18.1''$ E and Location W3 latitude $06^{\circ} 38' 34.4''$ N and longitude $03^{\circ} 23' 22.4''$ E while Location BH1 has latitude $06^{\circ} 38' 34.8''$ N and longitude $03^{\circ} 23' 18.7''$ E and Location BH2 has latitude $06^{\circ} 38' 35.0''$ N and longitude $03^{\circ} 23' 23.0''$ E. The water samples were collected from hand dug wells at 30 m depth in south to southwestern part of the area (Figure 2).

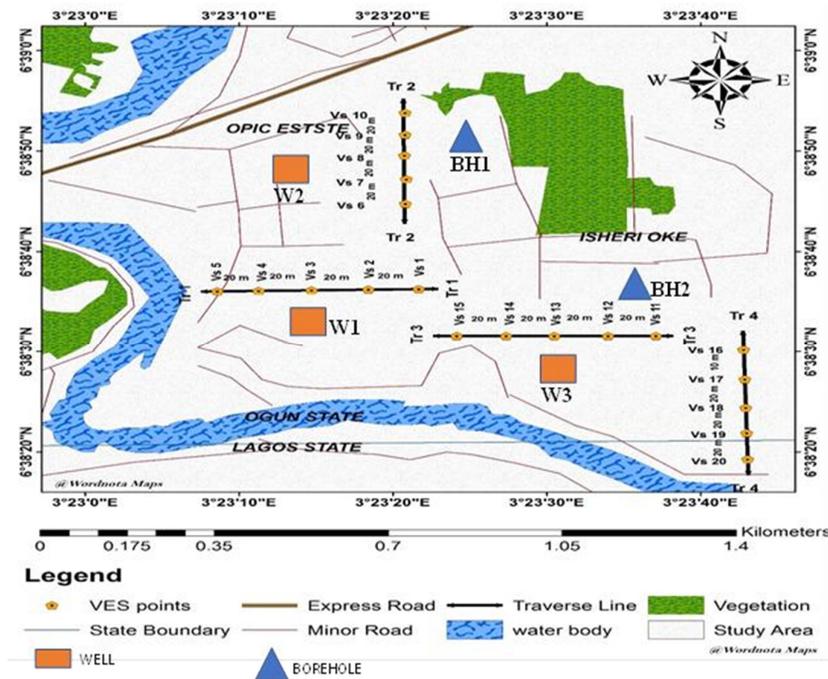


Figure 2: Base map of the study area

Water samples were collected from boreholes at 40 m depth in the southern part of the study area. The five samples were collected each in one litre plastic bottle and sealed. The physical parameter observed in the field was the colour of the water. The collected samples were sent directly to the laboratory for analysis. The water samples were filtered to remove suspended particulates from the samples before analysis.

2.3.1. Chemical analysis of water samples

World Health Organization (WHO) guidelines of 2017 were followed in the chemical analysis of the water samples in the laboratory. Turbidity of the water samples was determined using the nephelometer. The nephelometer measured the intensity of light scattered at 90 degrees as the beam of light passed through each water sample and recorded the values in nephelometric turbidity unit (NTU). The pH was determined by the use of a pH meter (WHO, 2017). Conductivity was measured with a probe and a meter (WHO, 2017). Alkalinity of each water sample was determined by measuring the amount of acid needed to bring the sample to a pH of 4.2. At this pH all the alkaline compounds in the water sample was "used up." The result was reported as milligrams per liter (WHO, 2017). Acidity of each water sample was determined by pipetting a known volume of each sample into Erlenmeyer flask and titrated against a known volume hydroxide solution. The end point was noted when colour change from orange red to yellow (WHO, 2017). The total suspended solids (TSS) was determined by filtering a known volume of the sample, dried, and weighed (WHO, 2017). The total dissolved solids (TDS) was determined using a TDS meter (WHO, 2017). The total solids (TS) in each water sample was determined by weighing the amount of solids present in a known volume of each sample. This was done by weighing a beaker, filling it with a known volume, evaporating the water in an oven and completely drying the residue, and then weighing the beaker with the residue (WHO, 2017). Oil and grease in each water sample were determined by the partition gravimetric method using an extracting solvent (WHO, 2017). The concentration of dissolved oxygen (DO) in the water samples was determined by the Winkler test while the biological oxygen demand (BOD) was determined by a bioassay procedure that measured the oxygen consumed by bacteria from the decomposition of organic matter (WHO, 2017). The anions (nitrate, chloride and phosphate) were determined by using the colorimeter method while the cations (iron, lead and copper) were analyzed using Atomic Absorption Spectrophotometer (WHO, 2017).

The concentrations in water samples were compared with the WHO standards (WHO, 2017). The measured parameters were used to calculate the water quality index for predicting water quality using Equations (1-4) as demonstrated by Mufid (2012). The relative weight (RW) of the measured parameters was determined using Equation (1). Quality rating (Q_i) scale was determined using Equation (2). The WQI was determined using Equation (4). The WQI was calculated based on the suitability of groundwater for human consumption. The correlation analysis was carried out based on the measured closeness between water quality parameters and WQI (Adeogun *et al.*, 2019).

$$RW = \frac{SW}{\sum SW} \quad (1)$$

Where: RW = Relative weight; SW = Specific weight of measured parameters; $\sum SW$ = Total Weight of measured parameters

$$Q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

Where: C_i = Detected Concentration (mg/L), S_i = Safe Standard Concentration (mg/L), Q_i = Quality rating

$$SI_i = RW \times Q_i \quad (3)$$

$$\text{Water quality index (WQI)} = \sum SI_i \quad (4)$$

3. RESULTS AND DISCUSSION

3.1. 2-D Electrical Resistivity Imaging

3.1.1. 2-D Resistivity section along traverse one

2D resistivity structure along traverse 1 is presented in Figure 3. Lateral distance of 200 m was covered and a depth of 50 m was imaged. Resistivity varied from 2 – 53 Ohm-m along this traverse in the study area. Three (3) resistivity structures are imaged which are indications of clay/peat, sandy clay/clayey sand and sand (Figure 3). The resistivity of the clay/peat ranged from 2 – 3.2 Ohm-m, sandy clay/clayey sand from 5.1 – 13 Ohm-m and the sand from 21 – 53 Ohm-m. It is suspected that the sandy clay/clayey sand and the sand have been impacted within the depth imaged because of the relative proximity of the traverse to the canal (Figure 2).

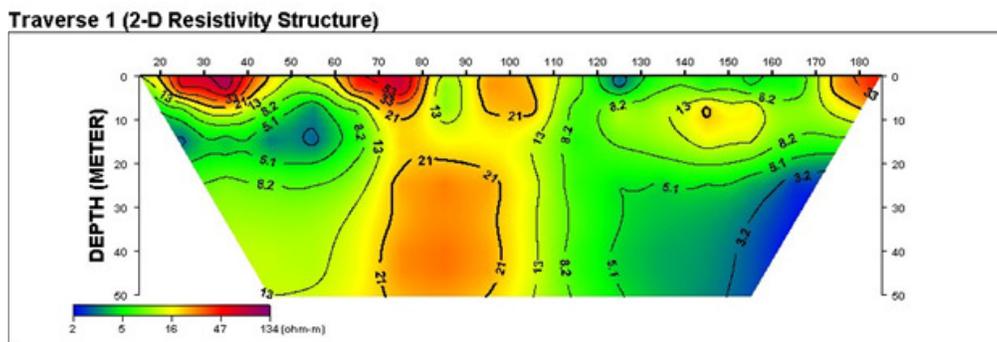


Figure 3: 2D Resistivity section along traverse 1

3.1.2. 2-D resistivity section along traverse two

2D resistivity structure along traverse 2 is presented in Figure 4. Lateral distance of 200 m was covered and a depth of 50 m was imaged. Resistivity varied from 9 – 389 Ohm-m along this traverse. Three (3) resistivity structures are imaged which denote clay (with resistivity ranging from 9 – 14 Ohm-m), sandy clay/clayey sand (with resistivity values of 21 - 73 Ohm-m) and sand (having resistivity ranging from 111 – 389 Ohm-m). Along this traverse, there seems to be less indication that the subsurface has been impacted by the contents of the canal within the ambit of the depth imaged. This is perhaps because the traverse is far away from the canal unlike traverse one that is closer to the canal and established sub-parallel to it, thus increasing its vulnerability to pollution from the canal. The resistivity structure of the clay seems to be localized along the traverse while that of the sand is both surficial and at relatively deep depth (Figure 4).

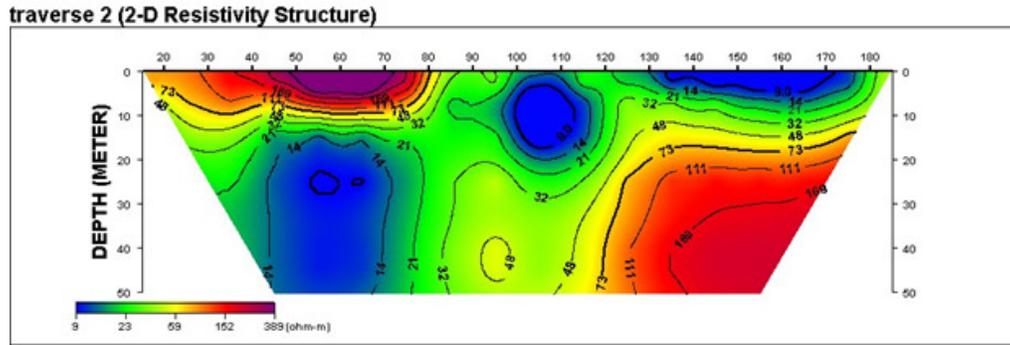


Figure 4: 2D Resistivity section along traverse 2

3.1.3. 2-D resistivity section along traverse three

Figure 5 represents the 2D resistivity structure along traverse 3. Lateral distance of 200 m was covered and a depth of 50 m was imaged. Resistivity varied from 1.3 – 207 Ohm-m along this traverse in the study area. Three (3) resistivity structures are imaged which connote clay/peat with resistivity of 1.3 – 3.9 Ohm-m, sandy clay/clayey sand with resistivity of 6.9 – 67 Ohm-m and sand with resistivity of 118 – 207 Ohm-m (Figure 5). The clay/peat is localized at lateral distance 80 – 100 m along the traverse at a depth range of 5 – 45 m. There is an indication of a subsurface impact along this traverse mainly in the sandy clay/clayey sand subsurface horizon.

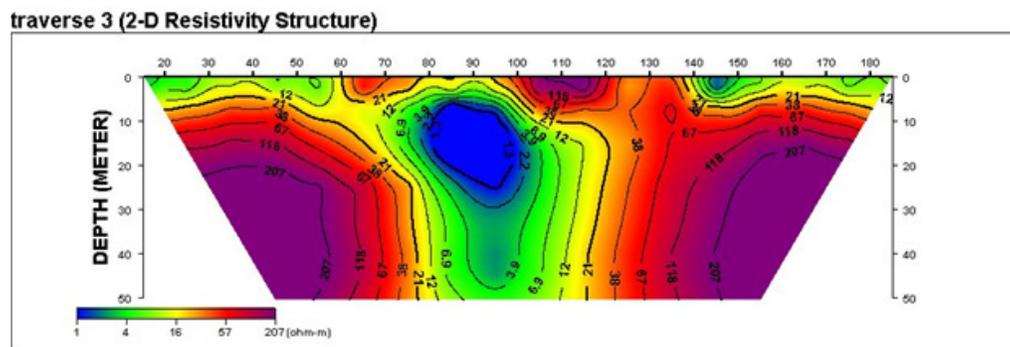


Figure 5: 2D Resistivity section along traverse 3

3.1.4. 2-D resistivity section along traverse four

2D resistivity structure along traverse 4 is presented in Figure 6. Lateral distance of 200 m was covered and a depth of 50 m was imaged. Resistivity varied from 1.2 – 128 Ohm-m on the traverse. Three (3) resistivity structures are imaged revealing clay/peat with resistivity values ranging from 1.2 – 2.9 Ohm-m, sandy clay/clayey sand having resistivity values ranging from 4.7- 50 Ohm-m and sand with resistivity values ranging from 80 – 128 Ohm-m. On this traverse, there is a likelihood of the subsurface being polluted by the contents of the canal within the range of the depth imaged. The traverse 4 and traverse 3 are oriented parallel and close to the canal axis. This therefore predisposes the subsurface beneath these two traverses to quick

impact from the canal. The inferred resistivity structure at depth is laterally extensive and seems to be mildly impacted (Figure 6).

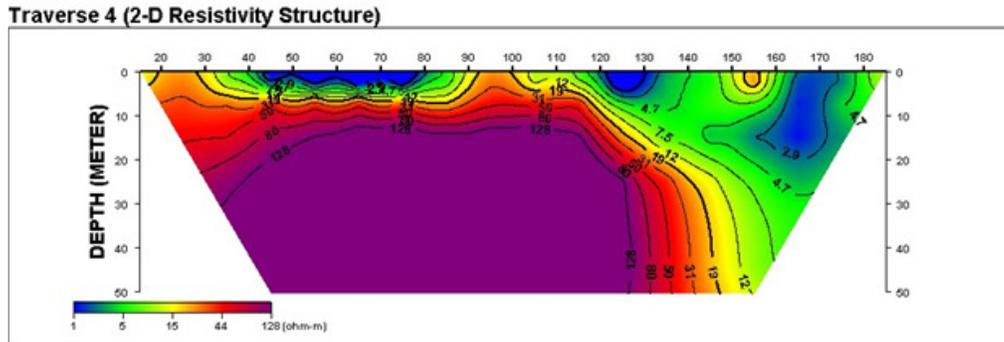


Figure 6: 2D Resistivity section along traverse 4

3.2. VES

Samples of the resistivity curves generated are shown in Figure 7. The geoelectric sections generated from the results of VES curves are presented in Figures 8 to 11.

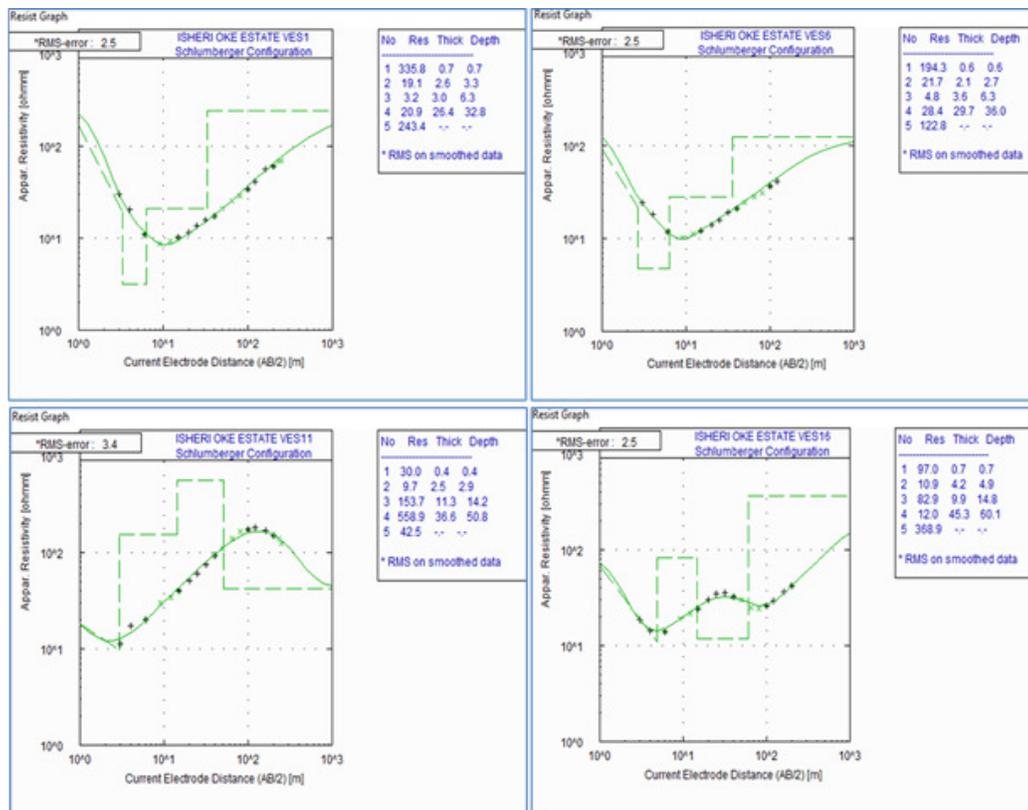


Figure 7: Representative VES curve along each traverse

3.2.1. Geoelectric sections along traverses AA' BB' CC, and DD'

The geoelectric results reveal four to five layers indicating topsoil, clay, clay/peat, clayey sand and sand across the four traverses. The topsoil is characterized by resistivity and thickness values ranging from 16 – 449 Ohm-m and 0.4 – 0.9 m respectively. The second geoelectric layer which is clay/peat has resistivity and thickness values of 5.2 - 19.1 Ohm-m and 1.6 - 6.5 m. The third geoelectric layer is symptomatic of clay/peat/clayey sand / sand with resistivity and thickness values ranging from 3.0 -792.1 Ohm-m and 1.4 – 39.7 m. The fourth geoelectric layer is indicative of clay/clayey sand/sand with resistivity and thickness values ranging from 12 - 792 Ohm-m and 4.9 – 57.1 m respectively. The fifth geoelectric layer reveals clay/peat/sand having resistivity values ranging from 6.0 – 1058.9 Ohm-m but their thicknesses could not be determined because the probing current terminated within this zone. It is important to note that the near surface clayey sand/sand at the second and third geoelectric layers having resistivity values ranging from 67.7 – 82.9 Ohm-m show an indication of pollution from the content of the canal that runs perpendicular to traverse 2 and 4 and parallel to traverse 1 and 3 with the impact being maximum along traverse 3.

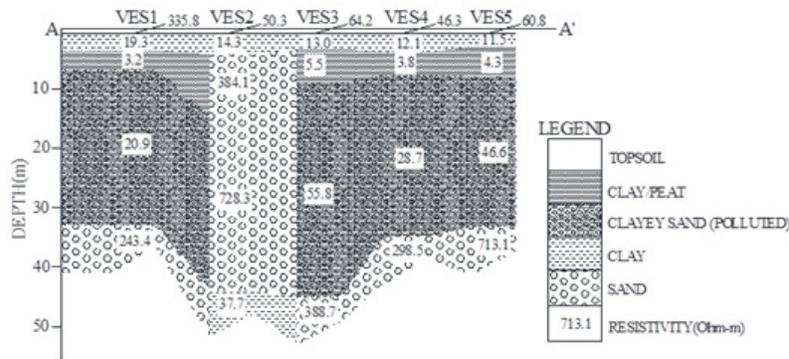


Figure 8: Geoelectric section for VES 1, 2, 3, 4 and 5

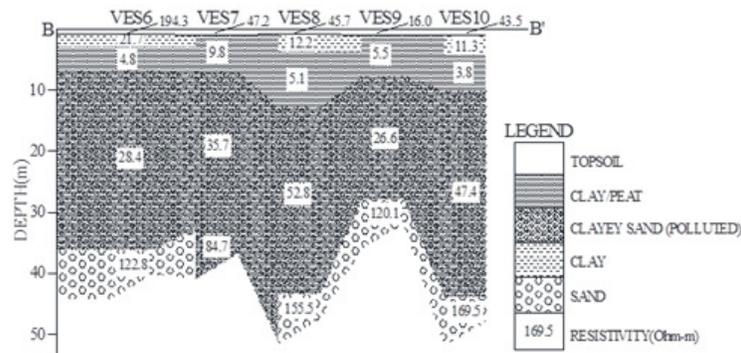


Figure 9: Geoelectric Section for VES 6, 7, 8, 9 and 10

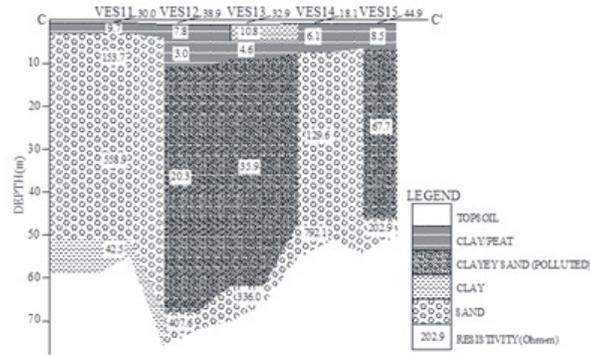


Figure 10: Geoelectric Section for VES 11, 12, 13, 14 and 15

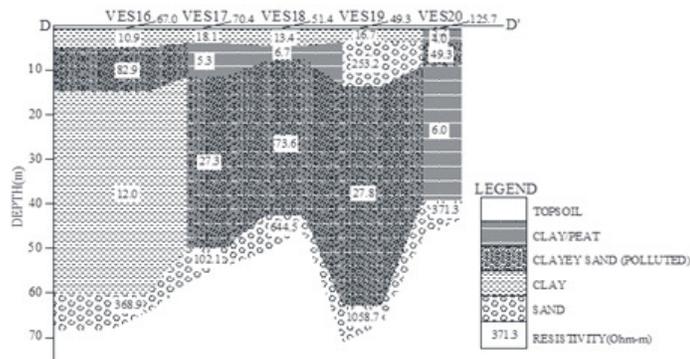


Figure 11: Geoelectric Section for VES 16, 17, 18, 19 and 20

3.3. Physicochemical Analysis

A summary of the physicochemical parameters of the water samples analyzed is presented in Table 1. Table 2 presents the WQI of the collected water sample. Table 3 gives the water quality classification based on WHO value. Table 4 presents the degree of a linear association between any two of the water quality parameters as measured by the simple correlation coefficient (r). The correlation coefficient (r) values nearer to +1 or -1 shows perfect linear relationship between any chosen two variables (Mufid, 2012). This indicates the relationship between each pair of the water quality parameters (Table 4).

Turbidity is the measure of relative clarity of a liquid. The more total suspended solids (TSS) in water, the murkier it seems and the higher the turbidity. Turbidity is a key parameter in water supply engineering, because turbidity will both cause water to be aesthetically unpleasant and cause problems in water treatment processes, such as filtration and disinfection. Turbidity is also often used as indicative evidence of the possibility of bacteria being present (Huey and Meyer, 2010). The turbidity of the water samples across study area is only significant in BH 2, having a value of 5 NTU while in other samples (BH 1, Well 1 – 3), the turbidity value is zero NTU (Table 1). The turbidity value of 5 NTU in BH 2 indicates a water source that is turbid but still within the permissible limit of WHO for human consumption because the WHO maximum water turbidity value for human consumption is 5 NTU (Table 1). Other tested water samples have turbidity of zero NTU which denote non-murky and non-turbid water.

Table 1: Summary of the physicochemical analysis

Parameter	BH 1	BH 2	Well 1	Well 2	Well 3	WHO permissible limit (2017)
Turbidity (NTU)	0	5	0	0	0	5
pH	6.36	6.70	6.82	6.92	7.19	6.5-8.5
Conductivity ($\mu\text{S}/\text{cm}$)	446	348	543	387	484	1000
Alkalinity (mg/L)	8.60	17.3	26.2	13.5	29.0	200
Acidity (mg/L)	50.9	23.2	35.0	28.8	18.7	56
Chloride (mg/L)	88.6	58.7	105	70.5	94.2	250
Total suspended solids (mg/L)	ND	70	ND	20	10	
Total dissolved solids (mg/L)	230	180	280	200	250	500
Total solids (mg/L)	230	250	280	220	260	2000
Oil & grease (mg/L)	ND	ND	ND	ND	ND	
Dissolved oxygen (mg/L)	3.4	7.6	6.2	6.7	5.8	>7.5
Biological oxygen demand (mg/L)	3.20	8.80	18.4	14.7	7.80	40
Sulphate (mg/L)	6.71	13.1	4.97	10.6	13.5	250
Nitrate (mg/L)	0.460	2.31	6.27	9.62	8.44	10
Nickel (mg/L)	ND	ND	ND	ND	ND	0.02
Copper (mg/L)	0.017	0.020	0.026	0.025	0.023	0.07
Chromium (mg/L)	ND	ND	ND	ND	ND	0.05
Iron (mg/L)	0.387	0.041	0.095	0.272	0.156	0.3

ND: Not detected

The pH of a water sample is a measure of the acid–base equilibrium in the water. In most natural waters, the pH is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. An increased carbon dioxide concentration will therefore lower pH, whereas a decrease will cause it to rise (McClanahan and Mancy, 1974). The pH of the water samples obtained in the area varied from 6.36 in BH 1 to 7.19 in Well 3 (Table 1). This indicates that the pH of all tested samples is within the WHO allowable limit for consumption except the pH for BH 1 with value 6.36 (Table 1). This implies that the water from BH 1 is mildly acidic and may not be suitable for human consumption (WHO, 2017).

Conductivity is a measure of water's capability to pass electrical flow. This ability is directly related to the concentration of ions in the water (Light *et al.*, 2005). The conductivity of the tested water samples ranged from 348 – 543 $\mu\text{S}/\text{cm}$, (Table 1) which denotes that this conductivity values are below the WHO permissible limit of 1000 $\mu\text{S}/\text{cm}$ for potability and thus non-conductive and safe for consumption (WHO, 2017).

The alkalinity of water sample varied from 8.6 – 29.0 mg/L (Table 1). These values are lower than the maximum WHO allowable limit of 200 mg/L alkalinity for potable water, indicating that these water sources are fit for human consumption in terms of alkalinity (WHO, 2017). Acidity of water is a measure of the capacity of the water to neutralize bases. Acidity is the sum of all titrable acid present in the water sample (WHO, 2017). The acidity of the tested water sample across the study area ranged from 18.7 mg/L in Well 3 to 50.9 mg/L in BH 1 (Table 1). It should be noted that BH 1 had an elevated acidity of 50.9 mg/L, although slightly lower than the WHO allowable limit value for acidity, however it may not be unconnected with a high pH value in BH 1 (Table 1) which renders the water source unfit for potability. These values are

nevertheless below maximum WHO permissible limit of 56 mg/L acidity for potable water (WHO, 2017). The water samples are non-acidic and thus potable.

The total suspended Solids (TSS) in water is a measure of all particles suspended in the water which will not pass through a filter. TSS were not detected in BH 1 and Well 1 samples while in BH 2, Well 2 and Well 3, the TSS were 70, 20 and 10 mg/L respectively (Table 1). This indicates that in BH 1 and Well 1, there are no suspended solids in the water while in other tested samples, there are suspended solids in the water. WHO does not prescribe a particular allowable limit value for TSS in water (WHO, 2017). Total dissolved solids (TDS) refer to any minerals, salts, metals, cations or anions dissolved in water. TDS comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water (Mohammad *et al.*, 2016). TDS values from the water samples ranged from 180 to 280 mg/L (Table 1). The values are below WHO recommended standard of 500 mg/L for TDS in water and therefore the water sources are potable (WHO, 2017). The total solids (TS) values from the water samples ranged from 220 to 280 mg/L (Table 1) which are below the WHO permissible limit of 2000 mg/L in water for potability. Oil and grease were not detected in all the water samples, indicating that the water sources are free from oil and grease contaminants (Table 1).

Dissolved oxygen (DO) concentrations ranged between 3.4 – 7.6 mg/L (Table 1) and the WHO standard must be above 7.5 mg/L. The concentration of dissolved oxygen in groundwater and the oxidation reduction potentials control the chemical and microbial reactions that can occur in the groundwater. Only BH 2 had a concentration of 7.6 mg/L and therefore falls within the WHO allowable limit of >7.5 mg/L for water potability while others (BH1, Wells 1-3) fall below the allowable limit (WHO, 2017). Biological oxygen demand (BOD) is a generalized parameter in the environmental monitoring of water and wastewater. It is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. BOD provides information about the readily biodegradable fraction of the organic load in water (Jouanneau *et al.*, 2014; Rezvani pour *et al.*, 2014). The BOD ranged from 3.2 – 18.4 mg/L (Table 1). These values are below the WHO allowable BOD limit of 40 mg/L for water potability, signifying that the water is safe for consumption because a higher BOD in water implies that Oxygen is used-up from organic impurities and therefore the water will be unsafe for consumption (WHO, 2017).

The WHO limit for chloride ion concentration is 250 mg/L (Table 1). The chloride values ranged between 58.7 to 105 mg/L. All the values are below the WHO standards and therefore fit for drinking. The sulphate ion concentrations ranged from 4.97 – 13.5 mg/L in the water samples (Table 1). These values are far below the WHO sulphate ion concentration permissible limit of 250 mg/L for potable water (WHO, 2017). The water is therefore safe for consumption. The nitrate ion concentration values obtained from the water samples were between 0.460 to 9.62 mg/L (Table 1). These values are lower than the WHO nitrate ion concentration permissible limit of 10 mg/L for potable water (WHO, 2017). The water is therefore potable.

Nickel and Chromium ions were not detected in the tested water samples (Table 1). The copper ion concentrations of the water samples taken from the study area all lie within the WHO copper ion concentrations permissible limit of 0.07 mg/L (Table 1). This implies that the water is potable. The iron ion concentrations in the water samples from the area of investigation were less than 0.3 mg/L WHO permissible limit except for BH 1 which was 0.387 mg/L (Table 1). The result shows that the iron ion content of BH 1

which is slightly higher than WHO allowable limit of 0.3 mg/L for potability has rendered water from BH 1 unfit for consumption, hence iron treatment must be set-up for BH 1 to make it suitable for human consumption.

Table 2: WQI of the collected water sample

Parameter	BH 1 (SI_i)	BH 2 (SI_i)	Well 1 (SI_i)	Well 2 (SI_i)	Well 3 (SI_i)
pH	6.96	7.33	7.46	7.57	7.87
Alkalinity (mg/L)	0.20	0.41	0.62	0.32	0.68
Acidity (mg/L)	10.54	4.78	7.25	5.96	3.87
Chloride (mg/L)	2.48	1.65	2.94	1.97	2.64
Total dissolved solids (mg/L)	32.20	25.20	39.20	28.00	35.00
Total solids (mg/L)	0.54	0.59	0.66	0.52	0.61
Dissolved oxygen (mg/L)	3.13	7.00	5.71	6.17	5.34
Biological oxygen demand (mg/L)	0.74	2.04	4.28	3.42	18.14
Sulphate (mg/L)	0.13	0.25	0.09	0.20	0.25
Nitrate (mg/L)	0.32	1.62	4.39	6.73	5.91
Nickel (mg/L)	0	0	0	0	0
Copper (mg/L)	1.70	2.00	2.60	2.50	2.30
Chromium (mg/L)	0	0	0	0	0
Iron (mg/L)	12.00	1.27	2.95	8.44	4.84
Water quality index (WQI) $WQI = \sum SI_i$	70.94	54.14	78.15	71.80	87.45

3.4. Water Quality Index (WQI)

The computed WQI values for the two boreholes (BH1 and BH2) and three hand dug wells (Well1 – Well 3) ranges between 54.14 and 87.45 (Table 3). From these WQI values it could be suggested that the ground water is of good quality (WHO, 2012). Specifically, the water sources; BH1, BH2, Well 1, Well 2 and Well 3 reflect good water (Table 3).

Table 3: Water quality classification based on WQI Value (WHO, 2012)

WQI Value	Class	Water quality	Percentage of studied water sample
<50	I	Excellent	---
50-100	II	Good Water	100% (BH1, BH2, Well 1, Well 2 and Well 3)
100-200	III	Poor Water	---
200-300	IV	Very Poor Water	---
>300	V	Unsuitable Water	---

3.5. Correlation Coefficient Matrix of Water Quality

Table 5 presents the degree of a linear association between any two of the water quality parameters as measured by the simple correlation coefficient (r). The correlation analysis measures the closeness of the relationship between chosen variables. If the correlation coefficient is nearer to +1 or -1, it shows the perfect linear relationship between the two variables. This way analysis attempts to establish the nature of the relationship between the water quality parameters and WQI (Mufid, 2012). It is observed that the TDS variations are mainly controlled by alkalinity ($r = 0.99$), acidity ($r = 0.99$), Cl ($r = 0.99$), TS ($r = 0.99$), BOD ($r = 0.92$), SO_4 ($r = 0.99$), NO_3 ($r = 0.80$), Ni ($r = 0.99$) and Cr ($r = 0.99$) concentrations (Table 4).

Table 4: Correlation coefficient matrix of water quality parameters

	pH	Alkalinity	Acidity	Cl	TDS	TS	DO	BOD	SO ₄ ²⁻	NO ₃ ⁻	Ni	Cu	Cr	Fe
pH	1													
Alkalinity	0.336062	1												
Acidity	0.420707	0.991186	1											
Cl	0.341996	0.999979	0.991883	1										
TDS	0.388816	0.998276	0.996169	0.998635	1									
TS	0.334889	0.999998	0.990917	0.999966	0.998177	1								
DO	0.855626	0.526506	0.626803	0.531762	0.573136	0.524848	1							
BOD	0.357798	0.915578	0.949632	0.916396	0.922778	0.914913	0.666531	1						
SO ₄ ²⁻	0.335114	0.999999	0.990976	0.999969	0.998198	1	0.525216	0.915064	1					
NO ₃ ⁻	0.467305	0.780623	0.844783	0.782915	0.80049	0.779355	0.831114	0.925004	0.779661	1				
Ni	0.334637	0.999997	0.990889	0.999964	0.998161	1	0.524643	0.914888	1	0.779281	1			
Cu	0.454077	-0.6651	-0.57565	-0.66023	-0.62024	-0.66633	0.258451	-0.50659	-0.66607	-0.24581	-0.66653	1		
Cr	0.334637	0.999997	0.990889	0.999964	0.998161	1	0.524643	0.914888	0.779281	-0.66653	1			
Fe	0.095124	-0.51592	-0.40881	-0.51296	-0.48657	-0.51759	0.267022	-0.14233	-0.51721	0.102914	-0.51769	0.694708	-0.51769	1

4. CONCLUSION

Due to the presence of a suspected source of pollution of groundwater in Isheri Oke area of Lagos State, geophysical and physicochemical investigations of the groundwater were carried out to assess the quality of the groundwater. Four traverses were occupied for the 2D ERI and VES data. Five water samples were collected for GQI analyses. The results of the 2D ERI revealed three (3) resistivity structures while geoelectric results revealed four to five layers indicating topsoil, clay, clay/peat, clayey sand and sand with resistivity and thickness varying from 2.0 – 1058.9 Ohm-m and 0.4 – 57.1 m respectively. Traverse 1 revealed an elevated case of contamination from the adjacent canal, perhaps due to its proximity. The 2D results from other traverses revealed mild cases of contamination near-surface. The clayey sand/sand at the second and third geoelectric layers showed contamination from the canal which runs perpendicular to traverses 2 and 4 and parallel to 1 and 3 with the impact being maximum along traverse 3. Physicochemical results revealed that all parameters tested are within permissible limits except Iron in BH1. Dissolved oxygen was also below the WHO limits except in BH1. GQI revealed that all water samples tested have values ranging from 50 – 100 signifying “good water quality”. This may not be unconnected with the fact that the sources of the tested water samples are suspected to tap groundwater from the deep-seated aquifer at >70 m depth in the study area. At this depth, the aquifer is less vulnerable to impact from the canal and this explains the “good quality” obtained from the WQI. Only the near surface is affected by contamination from the canal as confirmed from the geoelectric investigation and evident in shallow hand dug wells. Continuous geophysical monitoring is recommended for the onset of contamination of the deep-seated aquifers.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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