ELECTRICAL RESISTIVITY AND HYDROGEOCHEMICAL EVALUATION OF SEPTIC-TANKS EFFLUENT MIGRATION TO GROUNDWATER

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ABSTRACT

Water quality degradation through different kinds of pollutants is a major concern globally. Hence, this study becomes imperative in order to determine the effects of groundwater pollution due to septic tank effluent. Integrated electrical resistivity imaging, physicochemical and microbiological analyses of water samples from ten hand-dug wells (HdW) and three boreholes (BH) were carried out around residential areas surrounded by septic tank systems using standard field and laboratory procedures. Results of the 2-D resistivity imaging of the subsurface along nine traverses around the study area using Wenner configuration with constant electrode separation ranging from 2 to 12 m showed anomalously low resistivity zones, less than 20 Ω m suspected to be septic plume accumulation. The accumulation was more pronounced in the northern and southern part of the study area to a depth of about 10 m. The direction of groundwater flow suggests that the water in the wells is flowing towards the direction of the septic plume. Physicochemical analyses showed the groundwater samples to be within the specified limits of WHO/NSDWQ for drinking purpose. However, higher values of concentrations of most analyzed parameters were noticed in HdW 6 and HdW 7 due to their nearness to septic tank system. The microbiological analysis indicates excessive amount of microbes in the samples, an indication of groundwater contamination by effluent from the septic tanks. The study recommends treatment and regular monitoring of groundwater sources, adequate distance from water sources to septic systems and adoption of clean technology to prevent contamination of groundwater flow.

KEYWORDS

Resistivity, Microbiological, Septic-tank effluent, Groundwater, Hydrogeochemical, Contamination.

1. INTRODUCTION

Groundwater constitutes a viable option for potable water provisions all year round in the study area [1]. Groundwater pollution is one of the major problems threatening human and environmental health globally. Groundwater pollution occurs when unsuitable substances released by human activities and natural processes find their means into groundwater bodies or insoluble liquid droplets that become suspended in it deteriorate/degrade the natural quality of the water. Septic systems also referred to as "on-site wastewater treatment systems" are designed for the purpose of treating human waste. A septic system consists of two main parts, a septic tank and field lines installed into a drain field or soil absorption field (Fig. 1). The septic tank is a watertight box, usually made of concrete or fiberglass, with an inlet and outlet pipe (Fig. 2). Wastewater flows from the home to the septic tank through the sewer pipe. The septic tank treats the wastewater naturally by holding it in the tank. If the tank is properly constructed, only wastewater will flow through the field lines. Field lines generally are installed in trenches dug into soils having a minimum thickness of 3 feet, where the bottom of the trench is underlain by at least 2 feet of soil above the water table [2].

Much of the population increase is occurring in rural areas that are typically not served by municipal waste facilities, resulting in the expanded use of on-site waste water disposal systems. The most common type of residential on-site waste water disposal system is the conventional gravity flow septic tank system that consists of a septic tank, which promotes removal of solids by settling or liquefaction (Fig. 2), and the subsurface soil absorption system, or drain field, that treats waste water by soil filtration, chemical and biological processes (Fig. 3) [3]. Unlike a sewer system, which discharges treated wastewater into a body of water, the septic system depends on the soil around the home to treat and

dispose of sewage effluent (Fig. 3). For this reason, a septic system can be used only on soils that will adequately absorb and purify the effluent. If a septic system is installed in soil that cannot do so, the effluent will seep out onto the soil surface overlying the drainfield. In addition to causing an unpleasant smell, this untreated effluent can pose health problems. In some cases where the soils do not adequately absorb the wastewater, the toilets and sinks might not drain freely. If the soil can absorb the effluent but cannot treat it, the sewage may contaminate the groundwater.

When operating properly, septic systems remove many pollutants and provide some measure of protection for human and environmental health. Subsurface sewage disposal systems are the largest sources of wastewater to the ground, and are the most frequently reported causes of groundwater contamination [4]. The likelihood of groundwater contamination by these systems is greatest where septic systems are closely spaced as in subdivided tracts in sub-urban areas and in areas where the bedrock is covered by little or no soil [2].

Figure 1: A typical septic system [5]

Figure 2: A septic tank [6]

The disposal of domestic wastewater in the study area is not performed by sewer systems, except by using septic tanks and seepage fields. The waste is hereby processed in septic tanks and the resulting effluent leaches into the subsoil from more drains. Leakage of effluents and solid wastes from septic tanks may find its way into groundwater and contaminate it with phosphorus, nitrates, chloride, sulphate, household chemicals, oil, detergents, bacteria, viruses and other pollutants resulting to health environmental problems. Elevated concentrations of chloride, ammonia and sulfate have been interpreted to be the result of septic tank effluent [7]. Septic plume develops and moves with groundwater flow.

Approximate times for septic effluent to pass through the unsaturated zone to groundwater range from a few hours to fifty days, depending on the volume of effluent and the distance to groundwater [8]. In urban areas, the infiltration of wastewater from septic tanks into groundwater increases the pollution problems. A septic plume in groundwater moves at a rate similar to the groundwater velocity. Contaminant removal efficiencies by septic tank systems are dependent on design and maintenance, properties of waste water, and site hydrologic, soil and climatic characteristics [3].

Reliance on groundwater for drinking, agriculture and industrial activities in some areas has made the rate of abstraction surpass recharge from rainfall and snow. Septic tanks are not highly efficient at nutrient removal; estimates of removal are on the order of 5% to 8% for nitrogen and 20% to 30% for phosphorus [9]. While not very effective in waste water nutrient removal, anaerobic processes within septic tanks result in the conversion of organic forms of phosphorus and nitrogen to inorganic forms. Soluble orthophosphates and ammonium comprise approximately 75% to 80% of the total phosphorus and nitrogen within septic tank effluent [10; 11]. There is need for surface and groundwater sustainability and integrity, as groundwater resources have been under increasing stress in some parts of the world due to pollution. Therefore, the availability of quality and quantity groundwater resources is important to improve the state of well-being of the people and socioeconomic development of an area. The design life of many septic tank systems is in the order of 10-15 years. Due to the rapid rate of placement of septic tank systems in the 1960's, the usable life of many of the systems is being exceeded, and groundwater contamination is beginning to occur [12]. The use of electrical resistivity method for groundwater resource mapping and water quality evaluations has increased over the years because it is versatile, fast, cost effective and a non-destructive geophysical technique. Electrical resistivity imaging has no adverse impacts to the environment and serves as a good method for delineating the relatively rapid variations in the subsurface during environmental remediation [13].

Water quality is determined by assessing three classes of attributes which are biological, chemical, and physical and there are standards of water quality set for each of these three classes of attributes. The biological and chemical characteristics of wastewater from individual households can have a profound impact on the performance of freshwater system [12]. This study is conducted by integrating electrical resistivity method and hydro-physicochemical analysis with the aim of assessing the impact of septic systems density and nearness to water sources on groundwater quality. Also, determine the suitability of the water in the study area for human consumption from WHO and NSDWQ established standards, clarifying the risks associated with health implication on existing hand-dug wells and boreholes around the septic systems and suggest options for mitigation.

Figure 3: Schematic cross-section through a conventional septic tank soil disposal system for on-site disposal and treatment of domestic liquid waste [14]

2. DESCRIPTION OF THE STUDY AREA (GEOLOGY AND HYDROGEOLOGY)

Pioneer Girls' Hostel of Adekunle Ajasin University, Akungba Akoko is located within the North Senatorial district of Ondo State, Nigeria (Fig. 4). It lies between latitudes 7° 26' to 7° 29' North of the equator and longitudes 5° 43' to 5° 45' East of the Greenwich meridian. The study area falls within the humid and sub-humid tropical climate of southwestern Nigeria, characterized by alternating wet and dry seasons with a mean annual rainfall of over 1500 mm. The area is also characterized with a fairly uniform temperature and high relative humidity of about 75% - 95% [15]. The inhabitants of this town are mainly indigenous, students and government workers. This restricts their occupation mainly to farming, schooling and civil service. The area is drained by river Odowara and river Ose with many tributaries. The rivers dominate the drainage system of the study area and they are mainly dendritic. The area is moderately to highly undulating with an average surface elevation of about 359 m.

The study area falls within the Precambrian basement complex terrain of southwestern Nigeria. The basement complex rocks consist of crystalline igneous and metamorphic rocks, which form part of the African Crystalline shield with the rocks belonging to the youngest of the three major provinces of the West African Craton [16]. These rocks occur either exposed or covered by shallow mantle of superficial deposits. They are loosely categorized into three main subdivisions namely the migmatite-gneiss complex; the schist belt and Pan-African (Ca 600 Ma) Older granite series [17].

Based on field observation of the study area, the identified lithological units comprise of predominantly migmatite gneiss, charnockitic rocks and fine to medium grained biotite granite. Granite gneiss is the dominant rock type in the study area (Fig. 5) and they occur as ridges and hills which contain quartz veins, dykes, quartz-feldspar intrusions and pegmatitic veins usually very extensive. The structural elements in the study area include faults, joints, xenoliths, minor folds and foliations. The older granite of the study area is grey with a speckled appearance caused by the darker crystals. Granite gneiss in the study area is of two types; the biotite rich gneiss and the banded gneiss. The biotite rich gneiss is fine to medium grained that show strong foliation trending westwards and is usually dark in colour. The banded gneiss show parallel alignment and alteration.

The aquifer system around the study area is typical of the basement complex terrain with the aquifer types consisting of weathered layer aquifer and weathered/fractured (unconfined) aquifer. Various rock types of both igneous and metamorphic generally occur and they are impermeable except in areas where they are cleaved, sheared, jointed and fissured [18]. The hydrogeological setting of the area is such that the fractured basement of granite gneiss, grey gneiss and charnockite acts as aquifers for the boreholes and the wells in the area draw their water from the clay overburden. The unconfined nature and the near-surface occurrence of the aquifer system makes it vulnerable to surface/near surface pollutants from septic tank effluent in the area.

Figure 4: Geological map of Ondo State showing the study area [19]

Figure 5: Geological map of the study area and adjoining areas

3. MATERIALS AND METHODS

3.1 Two-Dimensional (2-D) Electrical Resistivity Survey

The study area was selected due to the closely spaced septic-tank systems in the area and determine if the occurrence or existence of the septic tank systems have influence on groundwater system. Two-dimensional (2-D) resistivity survey was carried out within the study area using a digital read-out Abem Terrameter SAS 1000C. Eight traverses were mapped out

within the hostel and a control traverse at about 500 m away from the location of septic tank systems using Wenner array configuration. A maximum of eight levels were attained for each of the traverses with an electrode spacing ranged from 2 – 16 m and a station interval of 2 m. The traverse length ranged from 25 to 80 m. The orientation of four of the traverses were in N-S direction, while, the remaining four were in W-E direction (Figure 6). The orientation of control traverse was in N-S direction.

Measurements were made at sequences of increasing offset distances at electrode spacing of 2 m along each traverse oriented in the North-South and East-West directions. Electrical resistivity imaging involves measuring a series of constant separation traverses along the same line but with the electrode spacing being increased with each successive traverse. In Wenner array, a fixed electrode spacing is chosen. The Wenner electrode array consists of four electrodes (C_1 , P_1 , P_2 and C_2), one current electrode (C_1) followed by two potential electrodes, (P_1 , P_2) and ends with second current electrode (C_2). These electrodes are equally spaced and the whole arrangement is moved progressively along the traverse after each measurement is taken. The geometric factor K , for the Wenner spread is $K_W = 2\pi a$. Measurements commenced at one end of the traverse line with electrode spacing $a = 2$ m at electrode positions 0, 2, 4 and 6. Next, each electrode (C_1 , P_1 , P_2 and C_2) was shifted a distance of 2 m, the active electrode positions being 2, 4, 6 and 8. The procedure was continued to the end of the traverse line. At each measurement, the resistivity meter displayed field resistance value and the corresponding root mean square (rms) error of the reading. The apparent resistivity of the subsurface can be computed using the formula $\rho_a = 2\pi aR$, where " a " is the electrode spacing distance and R is the field resistance value.

To be able to give a two-dimensional picture of the resistivity distribution within the subsurface as well as show a qualitative picture of the resistivity data obtained, the resistivity measurements obtained are used to construct a pseudosection and then contoured. The 2-D inverse resistivity models of the subsurface were obtained from the input resistivity data using [20] software. This 2-D inversion program automatically determines the 2-D resistivity models of the subsurface from the input resistivity data using iterative smoothness constrained least squares method [21]. It is a 2-D inversion program that needs no previous knowledge of the subsurface as the initial guess model is constructed directly from field measurements. The resistivity measurement is based on the difference in resistivity values of the model blocks directing towards minimizing the difference between the calculated and the measured apparent resistivity values from the field. The accuracy of fit is expressed in terms of the RMS error [22].

Figure 6: Data acquisition map for electrical resistivity survey

3.2 Sampling and Sample Preparation

Quality of water is mainly characterized by physicochemical indicators, such as pH, electrical conductivity (EC) and heavy metals, especially cadmium and lead concentrations in the water environment. Sampling sites were chosen with the aim of collecting water samples that truly represents the entire locations. A global positioning system (GPS) was used at each sample station to measure coordinates of the station and heights above sea level. Duplicate water samples were collected using pre-cleaned bottles to which a rope was attached in the case of hand-dug wells. At the point of collection, the bottles were rinsed for about three times with the water samples. Each bottle was labeled according to the sampling location.

Thirteen representative water samples (ten from different hand-dug wells, HdW 1 – HdW 10, and three from boreholes, BH 1, BH2 and BH 3) were collected randomly from thirteen different locations. The depth of the wells and static water level of the wells were noted. The groundwater flow direction in the area was determined based on the information obtained from the static water levels of the wells. Samples for anion

analyses were unfiltered and unacidified. However, samples for the analysis of dissolved trace elements were filtered through 0.45 μ m cellulose acetate membrane filter (Whatman, Schleicher and Schull FP 30) and acidified with 30 μ l of HNO_3 (conc. Suprapure) [23]. Samples were transported in ice-box to the laboratory and later stored in the refrigerator at a temperature of about 4 $^{\circ}C$ prior to the analysis (American Public Health Association, [24]. Parameters like pH, electrical conductivity (EC), turbidity and temperature were determined in the field using calibrated Hannah pH meter, EC meter, turbidity meter and mercury-bulb thermometer respectively.

3.3 Chemical Analysis

The physicochemical parameters observed in this study were determined using the standard methods [24]. The chloride and sulphate were determined using Mohr's and turbidimetric methods respectively. For the nitrate and phosphate, the cadmium reduction method and ascorbic acid methods were employed respectively. Others like total dissolved solids (TDS), total hardness (TH) and all the mineral elements were determined using titration methods. The concentrations of trace metals in water samples were determined after digestion with acid mixture (HCl/HNO_3) with flame atomic absorption spectrophotometer (Alpha 4AAS). The calibration standards were prepared using the metal stock solutions. The bacteriological quality analysis included the determination of total heterotrophic bacteria (THB), total heterotrophic fungi (THF), total coliform bacteria (TCB) and faecal coliform (FC). The total bacterial count was determined by pour plate technique and most probable number (MPN) index techniques following standard method. The analysed data can be used for the classification of water for various purposes and their percentage compliance with WHO and Nigerian Standard for Drinking Water Quality permissible limits [25; 26]. All the data obtained were subjected to statistical analysis; the mean, range, standard deviation were calculated.

4. RESULTS AND DISCUSSION

4.1 Interpretation of 2D resistivity sections

The inverted sections of the subsurface and resistivity distribution derived from measured 2-D resistivity data taken along the nine traverses are presented in Figures 7 - 15. The results indicate the lateral variation of the subsurface lithology with depth. Figure 7 shows inverse model section of traverse 1, where low resistivity anomalies below 10 Ω m, an indication of septic plume migration occur at horizontal distances 51 – 58 m along the traverse. The septic plume has accumulated up to 5 m, have reached the water table due to weathered basement before the dome shaped septic plume. The weathered zone with resistivity values ranging from 27 – 102 Ω m shows that the layers are prone to groundwater contamination as the septic system ages. There is an indication that the deeper layers are prone to groundwater contamination towards the northern side and vertical migration up to 5 m depth below the surface and up to 2 m depth along horizontal distances 20 – 48 m and 52 to 76 m. Along the horizontal distances 18 – 48 m and 64 – 74 m, high resistivity layer indicating fresh basement is seen to an extent that the basement outcrop the surface towards the southern part of the traverse. As shown in Figure 8, the 2D section showed a low resistivity oval shaped anomaly which is an indication of septic plume accumulation with resistivity values between 14 and 20 Ω m towards the southern end of the traverse 2 up to the depth of 10 m below the surface. The rest of the traverse towards the northern and southern end of the traverse at horizontal distance of 4 – 13 m and 25 – 36 m showed resistive anomaly between 45 – 100 Ω m suggesting presence of clay materials while an isolated high resistive region of resistivity values between 224 and 500 Ω m, an indication of sandy material was observed mainly at position 12 – 24 m along the traverse.

In Figure 9, the resistivity section for traverse 3 shows low resistivity anomaly zone at position 12 – 16 m with resistivity values between 10 and 20 Ω m occurring at approximately 4 – 10 m depth below the surface. This is an indication of septic plume accumulation. Weathered basement rock with resistivity values between 20 – 77 Ω m were noticed at depth. High resistive region which tends to separate the weathered basement along the traverse were seen protruding to the surface which is an indication of bedrock at position 19 m – 27 m at the central part of traverse at depth up to 10 m with resistivity values between 305 and 1000 Ω m.

Figure 10 shows 2-D inverted section of traverse 4 in which at position 10 – 24 m towards the northern part of the traverse, there is presence of low resistivity anomaly with resistivity values below 10 Ω m, an indication of septic plume accumulation that formed a dome shape at the base of the traverse at approximate depth of 4 – 10 m. there is an indication that the top soil within the position 6 – 28 m compose high resistive materials with resistivity values ranging between 405 and 1500

Ωm at approximate depth of 0 – 6 m. Following the resistive top soil is an underlying layer of low resistivity values ranging between 30 and 110 Ωm indicating weathered materials protruding to the surface towards the southern end of the traverse at depth. This weathered layer is prone to groundwater contamination as the plume has reached the depth of 10 m along the traverse.

The 2-D inverted section of traverse 5 is shown in Figure 11. Generally for the traverse, the resistivity distributions are mostly greater than 50 Ωm . High resistivity anomaly with resistivity values between 370 and 1000 Ωm was noticed at horizontal position 8 – 14 m and 18 – 20 m indicating clayey sand and laterite protruding to the surface along the traverse. Low resistive region of resistivity values between 20 – 160 Ωm and 160 – 370 Ωm characterized the whole traverse which suggests weathered basement rock. This is an indication of no evidence of septic accumulation on the traverse as the near surface resistivity values were higher than 20 Ωm .

The 2-D inverted section of traverse 6 shows an upper layer of high resistive material with resistivity values between 510 and 1600 Ωm to the depth of about 2 m below the surface towards the western part and continues to the eastern part up to the depth of 10 m. Weathered basement rock with resistivity values between 59 and 173 Ωm were noticed at approximate depth 2 – 10 m at horizontal position 4 – 12 m towards the western side of the traverse. There is no evidence of septic plume across the traverse (Figure 12).

Generally for traverse 7, the resistivity distributions are greater than 50 Ωm , an indication of no septic plume across the traverse (Figure 13). The resistivity section shows an upper layer of high resistive material with resistivity values between 376 and 1000 Ωm to the depth of about 2 m below the surface towards the western part and continues to the eastern part up to the depth of 10 m. Weathered basement rock with resistivity range values 51 – 141 Ωm and 141 – 376 Ωm were noticed at approximate depth 2 – 10 m at horizontal position 4 – 12 m towards the western side of the traverse.

Figure 14 shows 2-D inverted section of traverse 8 in which the upper part of the section at position 4 – 28 m, 32 – 44 m, 48 – 54 m and 58 – 64 m across the traverse, there is presence of high resistive anomaly from western to eastern side. The resistivity distribution section shows the top 2 m of the high resistive region having resistivity values between 224 and 2500 Ωm , an indication that the top soil within this position range is clayey sand, laterite and even basement outcropping/protruding the surface. Following the resistive zone is an underlying layer of low resistivity values ranging between 39 and 67 Ωm indicating closures of clay materials across the traverse. The eastern end at horizontal position 64 – 76 m showed low resistive anomaly at depth from the surface to 10 m with resistivity values ranging from 20 – 67 Ωm and 67 – 224 Ωm , suggesting presence of clayey materials (clay and sandy clay/clayey sand). This is an indication of no evidence of septic plume on the traverse as near surface resistivity values were higher than 20 Ωm . The lower part of the section shows undulating bedrock at position 6 m in the western part of the traverse to 48 m towards the eastern part of the traverse with resistivity values between 628 and 2500 Ωm .

The 2-D inverted section of control traverse is shown in Figure 15. High resistivity anomaly with resistivity values between 255 and 1300 Ωm majorly characterized the entire traverse from the surface to the depth of 10 m. It was noticed at northern part of the traverse at horizontal position 14 – 24 m that an isolated low resistive region of resistivity values between 50 and 113 Ωm was observed, an indication of clay material. This is an evidence of no septic plume accumulation on the control traverse as near surface resistivity values were higher than 20 Ωm . Weathered basement rock with resistivity values between 113 and 255 Ωm was also observed at approximate depth of 3 m to 10 m at the same position 14 – 24 towards the northern part of the traverse. It forms closures of resistive anomaly with resistivity value of 255 Ωm towards the southern part of the traverse. The measurement encounters the bedrock at horizontal position 62 – 96 m at depth greater than 5 m with resistivity values between 576 and 1300 Ωm .

Generally, the results obtained from the geophysical method suggest that the septic plume occurs in traverses oriented in N-S direction at depth ranging between 1 – 5 m in traverse 1 and 3 – 10 m in traverses 2, 3 and 4.

Figure 7: 2-D subsurface resistivity images along traverse 1

Figure 8: 2-D subsurface resistivity images along traverse 2

Figure 9: 2-D subsurface resistivity images along traverse 3

Figure 10: 2-D subsurface resistivity images along traverse 4

Figure 11: 2-D subsurface resistivity images along traverse 5

Figure 12: 2-D subsurface resistivity images along traverse 6

Pioneer Hostel TR 7 (2-D Resistivity Structure)

Figure 13: 2-D subsurface resistivity images along traverse 7

Pioneer TR 8 (2-D Resistivity Structure)

Figure 14: 2-D subsurface resistivity images along traverse 8

Pioneer Hostel Contor (2-D Resistivity Structure)

Figure 15: 2-D subsurface resistivity images along traverse 9

4.2 Static water level (SWL)

The static water level is the distance from ground level down to the water in a well, also known as the resting level ground of water when the well is not being pumped. The static water level obtained from the wells (HdWs) in the area varies between 2.23 – 5.4 m as seen on the static water level contour map (Figure 16). From the analysis of hydrogeological data, the total depth of wells varies from 5.33 m to 8.92 m and the static water level elevation across the study area ranges from 345 m to 359 m (Table 1). The static water level helps in determining the groundwater flow direction in the area which is flowing in the N – S and NE – SW directions. The direction of groundwater flow suggests that the water in the wells around the study area is flowing towards the direction of the septic plume as the results obtained from the geophysical method suggest that septic plume occurs in traverses oriented in N – S directions.

Table 1: Sampling well characteristics

Well	Elevation (m)	Depth to water table (m)	Depth to bottom (m)
HdW 1	345	3.4	5.3
HdW 2	351	4.6	7.1
HdW 3	354	4.8	7.3
HdW 4	353	5.6	7.7
HdW 5	352	5.5	7.9
HdW 6	350	2.4	6.0
HdW 7	352	4.4	8.7
HdW 8	353	3.6	5.9
HdW 9	359	3.8	6.1
HdW 10	352	4.5	8.9

Figure 16: Static water level contour map showing groundwater flow direction

4.3 Groundwater Physicochemical parameters

The results of the groundwater physicochemical parameters are presented in Table 2. However, the distribution pattern across the various sampling locations compared with WHO standard is presented in form of line graph and bar chart as shown in Figures 17a and 17b respectively. 77 % of the water sampled are colourless and odourless with a temperature ranged between 26.2 °C and 27.3 °C. The presence of colour is an indication of pollution and confirmed septic effluent infiltration into the well bodies of HdW 6, HdW 7 and BH 2. The temperatures were found outside the range of the WHO standard of 5 °C for domestic water, hence suggesting the presence of foreign bodies.

Contamination from the closely spaced septic tanks and well bodies may also be responsible for the high values recorded for temperature in the water samples analyzed. The pH of the HdWs vary from 4.7 to 8.0 with the mean values of 6.89 ± 0.9 , while for the BHs, it ranged between 4.5 and 6.8 with the mean values of 6.0 ± 1.3 indicating that the groundwater is generally neutral-alkaline with the exception of the pH parameter values in the HdW 6 and BH 2. The pH values of HdW 6 and BH 2 are 4.7 and 4.5 respectively, which is slightly acidic as against the WHO standards of 6.5 to 8.5 pH value (Table 2).

The acidic nature of HdW 6 and BH 2 suspected that septic tank effluent or disinfectants have found their ways to the well water levels through seepage. The electrical conductivity (EC) is an indicator of the amount of material dissolved in water. The EC of the HdWs ranged between 147 and 956 $\mu\text{S}/\text{cm}$ with the mean values of $367.4 \pm 239 \mu\text{S}/\text{cm}$, while for the BHs, it ranged between 462 and 603 $\mu\text{S}/\text{cm}$ with the mean value of $522.3 \pm 73 \mu\text{S}/\text{cm}$. Chloride is potentially a good indicator of a septic plume. The range in chloride concentration was very wide (4.1 – 31.1 mg/l) for the HdWs. However, for the BHs, there were significant differences ($\text{SD} > 1.0$) in chloride limits. The low concentrations of electrical conductivity and chlorides indicate that there is absence of salt water intrusion in the study area.

From the result of the analysis, low levels of turbidity ranging from 1.6 to 4.3 NTU were obtained. The WHO recommends a limit of 5 NTU. The groundwater obtained from the study area is therefore suitable for drinking. Total hardness is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} in mg/l. Total hardness of water sampled ranged between 52.1 and 246.7 mg/l. Values above 200 mg/l for total hardness (TH) do not have any associated health implications on humans but it's an indication of deposits of Ca and /or Mg ions. Their presence will disallow water from forming lather with soap thereby preventing economic management of water resources. The bicarbonates concentration of groundwater samples from the study area is however low (23.5 – 94.3 mg/l) with a mean value of $52.0 \pm 24.4 \text{ mg/l}$ while for the BHs, it ranged between 24.8 and 29.1 mg/l with the mean value of $26.7 \pm 2.2 \text{ mg/l}$ compared to WHO limit of 600 mg/l. Carbondioxide is the main source from the atmosphere.

The total dissolved solids (TDS) of the HdWs ranged between 83.5 and 647.3 mg/l with the mean value of $398.9 \pm 189.9 \text{ mg/l}$ while for the BHs, it ranged between 286.4 and 311.2 mg/l with the mean value of $296.9 \pm 12.8 \text{ mg/l}$. Based on WHO limit (1000 mg/l), the water is fresh. The range falls within the stipulated 1000 mg/l recommended by WHO and NSDWQ. Though, the concentration of TDS in the groundwater samples is low and found within the specified WHO and NSDWQ standards for drinking water quality (Table 2), it still indicates pollution as a result of suspension that were shown during analysis.

Concentrations of sulphate, phosphate and nitrate in groundwater samples were low and found within the specified WHO and NSDWQ standards for drinking water quality (Table 2). Sulphate ion concentration from the analysis ranged from 3.1 to 26.3 mg/l and 6.8 to 19.4 mg/l for HdWs and BHs respectively. The observed values of sulphate ions were low and within the permissible limit of 250 mg/l specified by [25; 26]. Based on the results, the water is not likely to pose health risk to those consuming it. Thus, the groundwater obtained from the study area is suitable for drinking. High concentrations of sulphate in water could cause bitter taste and lead to dehydration and diarrhea in children because children are more sensitive to it than adults. Phosphate levels are in the range 0.07 to 0.19 mg/l in all locations with average value of 0.13 ± 0.04 mg/l for HdWs and 0.08 ± 0.01 mg/l for BHs, far below the WHO stipulated tolerance level of 5.0 mg/l for potable water. Traces of PO_4^{2-} as small as 0.1 mg/L in water has harmful effect on water quality by promoting growth of algal and the development of an unpleasant thick liquid substance known as slimes [27].

The concentration of nitrate in the groundwater samples ranged from 1.8 to 12.7 mg/l (Table 2). Studies by US Geological Survey (USGS) defined concentrations of nitrate in water above 2 mg/l as the level indicating human impact on water quality [2]. All obtained values are below the WHO permissible limit of 10 mg/l for potable water except HdW 6 recording the highest level in the analysis, but the level of nitrate in HdW 6 is far below the NSDWQ maximum permissible level of 50 mg/l. The natural levels of nitrate in groundwater may be increased by the leaching of waste waters from waste disposal sites, cesspools or cesspits, agricultural chemicals and sanitary landfills. The concentration of nitrate in water samples depends on the nitrification activities of micro-organisms. The higher concentration of chloride over sulphate, nitrate and phosphate may be as a result of rocky nature of the study area suspected to contain some chloride mineral salts.

Total suspension solid (TSS) concentration ranged from 0.1 to 1.4 mg/l. The values are below the WHO standard of 30 mg/l. This is an indication of absence of suspended particles in the groundwater. The effect of presence of total suspended solids is the turbidity due to silt and organic matter. The dissolved oxygen is an important factor used for water control quality as a result of the capacity of water to hold oxygen. The dissolved oxygen concentration in groundwater samples ranged from 3.9 to 4.8 mg/l with a mean concentration of 4.1 ± 0.8 mg/l and 4.4 ± 0.4 mg/l for HdWs and BHs respectively. These values indicate a fairly high level of dissolved oxygen in groundwater samples. The value of 2.1 mg/l in the HdW 6 sample is an indication of oxygen depletion which infers the presence of pollutants that use up the oxygen in water. Total/heavy usage of the dissolved oxygen by the pollutants were observed and indicated that the well is unsuitable for drinking consumption.

All the mineral elements (Ca, Mg, Na and K) were obtained at levels below WHO tolerable limits. The metals averaged of the HdWs and BHs are between 55.1 ± 26.6 mg/l and 57.1 ± 21.7 mg/l for calcium, 24.9 ± 8.6 mg/l and 28.1 ± 3.9 mg/l for magnesium, 9.7 ± 3.4 mg/l and 12.1 ± 2.2 mg/l for sodium and 17.9 ± 6.7 mg/l and 17.9 ± 8.9 mg/l for potassium (Table 2 and Figures 18a and 18b). They are all below the WHO and NSDWQ standard limits (Figures 18a and 18b). Presence of calcium ion in groundwater is as a result of dissolution from silicate and feldspar minerals percolating the water. The primary source of sodium in the groundwater is from the release of soluble products during the weathering of plagioclase feldspars [28].

Table 2: Statistical Description of Chemical Characteristics of water samples in the study area and their comparisons with the WHO and NSDWQ standards

Parameters		Min.	Max.	Mean $\pm$ SD ^a	WHO(2011)	NSDWQ(2007)
pH	HdW	4.7	8.0	6.9 ± 0.9	6.5 – 8.5	6.5 – 8.5
	BH	4.5	6.8	6.0 ± 1.3		
EC ($\mu\text{S}/\text{cm}$)	HdW	147	956	367 ± 239	1000	
	BH	462	603	522 ± 73		
Cl^- (mg/l)	HdW	4.1	31.1	11.6 ± 8.2	250	250
	BH	5.4	8.0	6.8 ± 1.3		
Turbidity (NTU)	HdW	1.6	4.3	2.7 ± 0.9	5	
	BH	2.2	4.1	3.3 ± 1.0		
TH (mg/l)	HdW	52.1	246.7	144.5 ± 55.4	500	200
	BH	60.6	225.3	142.5 ± 82.4		
CO_3^{2-} (mg/l)	HdW	23.5	94.3	52.0 ± 24.4	600	
	BH	24.8	29.1	26.7 ± 2.2		
TDS (mg/l)	HdW	83.5	647.3	398.9 ± 189.9	1000	500
	BH	286.4	311.2	296.9 ± 12.8		
SO_4^{2-} (mg/l)	HdW	3.1	26.3	17.1 ± 7.1	250	250
	BH	6.8	19.4	12.5 ± 6.4		
PO_4^{3-} (mg/l)	HdW	0.09	0.19	0.13 ± 0.04	5.0	
	BH	0.07	0.09	0.08 ± 0.01		
NO_3^- (mg/l)	HdW	2.5	12.7	6.1 ± 2.9	10	50
	BH	2.2	6.9	3.9 ± 2.6		
TSS (mg/l)	HdW	0.1	1.4	0.87 ± 0.4	30	
	BH	0.1	0.6	0.33 ± 0.3		
DO (mg/l)	HdW	2.1	4.8	4.1 ± 0.8	NS	NS
	BH	3.9	4.7	4.4 ± 0.4		
Ca (mg/l)	HdW	9.3	55.2	33.1 ± 12.7	200	200
	BH	23.5	44.5	34.0 ± 14.8		
Mg (mg/l)	HdW	12.4	46.5	27.6 ± 9.1	150	
	BH	34.5	34.5	34.5 ± 0		
Na (mg/l)	dW	15.3	87.5	51.9 ± 23.7	200	200
	BH	18.5	73.4	45.9 ± 38.9		
K (mg/l)	HdW	1.2	26.7	6.0 ± 7.2	50	50
	BH	1.2	4.6	2.9 ± 2.4		

SD = Standard deviation, Min. = minimum, Max. = maximum, NSDWQ = Nigerian Standard for Drinking Water Quality; where a = n1 or n2: n1 = Number of samples for HdW = 10 and n2 = Number of samples for BH = 3, NS = not specified

Figure 17a: Plots of distribution pattern of some physicochemical parameters across sampling locations compared with [25] standard.

Figure 17b: Distribution pattern of some physicochemical parameters across sampling locations compared with [25] standard.

Figure 18b: Distribution pattern of the mineral elements across sampling locations compared with [25; 26] standards.

4.4 Heavy Metals Distribution

The total metal concentrations in groundwater from the study area are summarized statistically in Table 3 while Figures 19a and 19b display the distribution of each heavy metal (Fe, Mn, Pb, Zn and Cr) across the various sampling locations. Apart from Fe, Mn, Pb, Zn and Cr, other metals like Cd, Cu and Ni were below the instrument detection limits. Across all the locations, the concentrations (in mg/l) of Fe, Mn, Pb, Zn and Cr in HdWs and BHs were found to be below the recommended WHO limit and NSDWQ maximum concentration for drinking water [25; 26]. The exception of HdWs 6 and 7 are indications of water contact with the

septic tanks. Consequently, adverse effects such as blue baby syndrome, goiter in adults, objectionable tastes and precipitation problems, neurological problems and corrosion of intestinal tracts due to of Fe, Mn, Pb, Zn and Cr respectively may occur [25; 29]. The usually high level of these chemical parameters in HdW 6 and HdW 7 may be attributed to the closeness to the septic tank system and contamination of groundwater by septic tank effluent. This suggests that wells must be properly lined and should not be sited very close to septic tank in order to avoid heavy contaminations.

Table 3: Statistical Description of Heavy metals in the water samples

Parameters (mg/l)		Min.	Max.	Mean $\pm$ SD ^a	WHO (2011)	NSDWQ (2007)
Fe	HdW	0.06	2.1	0.43 $\pm$ 0.73	0.3	0.3
	BH	0.07	0.2	0.12 $\pm$ 0.07		
Mn	HdW	0.03	1.1	0.27 $\pm$ 0.37	0.3	0.2
	BH	0.07	0.1	0.09 $\pm$ 0.02		
Pb	HdW	0.001	0.8	0.14 $\pm$ 0.30	0.01	0.01
	BH	0.003	0.008	0.01 $\pm$ 0.003		
Zn	HdW	1.8	3.6	2.36 $\pm$ 0.59	3 - 5	3.0
	BH	1.6	2.2	1.83 $\pm$ 0.32		
Cr	HdW	0.01	1.1	0.21 $\pm$ 0.40	0.05	0.05
	BH	0.01	0.03	0.02 $\pm$ 0.01		
Cd	HdW	nd	nd	nd	0.003	0.003
	BH	nd	nd	nd		
Cu	HdW	nd	nd	nd	2.0	1.0
	BH	nd	nd	nd		
Ni	HdW	nd	nd	nd	0.07	0 (< 0.01)
	BH	nd	nd	nd		

SD = Standard deviation, Min. = minimum, Max. = maximum, WHO = World Health Organization, NSDWQ = Nigerian Standard for Drinking Water Quality, nd = Not detectable, where a = n₁ or n₂: n₁ = Number of samples for HdW = 10 and n₂ = Number of samples for BH = 3

Figure 19a: Plots of heavy metal distribution across sampling locations compared with [25].

Figure 19b: Heavy metal distribution across sampling locations compared with [25].

4.5 Microbiological Characteristics

Table 4 summarizes the microbiological studies of the water from the study area. Water samples analyzed from the HdWs showed average concentrations of total heterotrophic bacteria (THB) count and total heterotrophic fungi (THF) count of $2.3 \times 10^2 \pm 0.7 \times 10^2$ cfu/100 ml and $2.1 \times 10^2 \pm 1.0 \times 10^2$ cfu/100 ml while that of the BHs showed average concentrations of $1.8 \times 10^2 \pm 0.4 \times 10^2$ cfu/100 ml and $2.3 \times 10^2 \pm 1.0 \times 10^2$ cfu/100 ml. The temperature of any water body affects the rate of proliferation of micro-organisms [30]. The temperature range of 26.2 °C and 27.3 °C could be responsible for the growth of heterotrophic bacteria species present in the samples. The total heterotrophic bacteria count of the water samples do not conform to the limit of 100 cfu/ml allowed for potable water [26]. The bacteriological constituents of the water samples indicate bacterial contamination and sources may be due to water contact with the septic tanks.

The average concentrations of total coliform bacteria and faecal coliform bacteria of the water samples from the HdWs are $3.0 \times 10^2 \pm 1.5 \times 10^2$ ml and $2.1 \times 10^2 \pm 0.4 \times 10^2$ ml while that of the BHs are $2.9 \times 10^2 \pm 2.1 \times 10^2$ ml and

$1.7 \times 10^2 \pm 0.6 \times 10^2$ ml in 100 ml of the original water sample respectively (Table 3). The total coliform bacteria exceeded the acceptable level of no bacteria. According to [25], potable drinking water should be devoid of total coliform and faecal coliform in any given sample. All the HdWs and BHs are contaminated with faecal coliform. The presence of faecal coliform in water indicates faecal contamination and may indicate possible presence of diseases causing pathogens such as bacteria, viruses and parasites.

The total heterotrophic bacteria, total heterotrophic fungi, coliform bacteria and faecal coliform are high and greater than one in all the samples analyzed, which is an indication of faecal pollution of human wastes. The results of this study show that the samples do not conform to the WHO and NSDWQ requirements for microbiological characteristics for human consumption. The presence of these microbes in the samples of the study area is also an indication of possible groundwater contamination by effluent from the septic tanks. The concentration of the contaminants corresponds to the density of the septic systems in the area. It is clear that the water need to be treated for domestic consumption.

Table 4: Statistical description of microbial analysis of the water samples

Parameters (cfu/100 ml)		Min.	Max.	Mean±SD ^a	WHO (2011)	NSDWQ (2007)
THB count	HdW	1.8×10^2	3.8×10^2	$2.3 \times 10^2 \pm 0.7 \times 10^2$	100cfu/ml	100cfu/ml
	BH	1.4×10^2	3.2×10^2	$2.1 \times 10^2 \pm 1.0 \times 10^2$		
THF count	HdW	1.1×10^2	2.3×10^2	$1.8 \times 10^2 \pm 0.4 \times 10^2$		
	BH	1.1×10^2	3.0×10^2	$2.3 \times 10^2 \pm 1.0 \times 10^2$		
Total Coliform	HdW	1.1×10^2	4.9×10^2	$3.0 \times 10^2 \pm 1.5 \times 10^2$	0/100 ml	0/100 ml
	BH	1.1×10^2	5.2×10^2	$2.9 \times 10^2 \pm 2.1 \times 10^2$		
Faecal Coliform	HdW	1.7×10^2	3.0×10^2	$2.1 \times 10^2 \pm 0.4 \times 10^2$	0/100 ml	0/100 ml
	BH	1.1×10^2	2.2×10^2	$1.7 \times 10^2 \pm 0.6 \times 10^2$		

SD = Standard deviation, Min. = minimum, Max. = maximum, WHO = World Health Organization, NSDWQ = Nigerian Standard for Drinking Water Quality; where a = n₁ or n₂: n₁ = Number of samples for HdW = 10 and n₂ = Number of samples for BH = 3

5. CONCLUSION

Integrated electrical resistivity imaging and hydrogeochemical investigation were employed to assess groundwater contamination around a girls' hostel with closely spaced septic-tanks. These have led to a detailed understanding of the area than could have been achieved with the use of a single investigative method. The interpretation of 2-D resistivity structures obtained from the electrical resistivity imaging show low resistive zones with resistivity values less than 20 Ωm as indicative of septic plume which has migrated to depths 10 m below the aquifer in the study area. Traverses oriented in North-South direction show strong evidence of septic plume at varying depth.

The static water level map reveals that direction of flow of groundwater in the area is towards the wells in the N-S and NE - SW directions. This suggests that the water in the wells is flowing towards the direction of the septic plume. This is buttressed by elevated concentrations of heavy metals parameters observed from HdW 6 and HdW 7 above the maximum permissible limit for quality water by the WHO. The level of metals observed in this study has shown that some of the water used for drinking and domestic purposes are polluted. This has posed a major threat to human and environmental health. The result of other physicochemical parameters of analyzed groundwater samples lie within WHO and NSDWQ specification limits for drinking purpose.

Evidence of groundwater contamination is also showed by the low pH values in HdW 6 and BH 2 and excessive amount of micro-organisms (Bacteria, fungi and coliform) in all the analyzed groundwater samples. The low pH value is an indication that the groundwater is slightly acidic. The presence of these microbes in the water samples of the study area is an indication of effluent/contaminated run-off from leaky septic tanks into the water sources.

This study has shown that contaminations of the shallow wells in the study area can be linked up to large number of people residing in the area. This is a major threat to human population consuming the water for drinking purpose. Hence, groundwater contamination from septic systems can only be minimized by limiting the density of septic systems within a given area.

It is therefore recommended that hand-dug wells and boreholes are drilled far away from septic tanks. Septic tank must be properly designed, sited and monitored to prevent leaking of effluent to nearby water sources because leaks in concrete septic tanks can occur most readily around the inlet and outlet holes. Distance from water sources to septic systems in a particular location must be widely spaced. Regular investigation using integrated electrical resistivity method and chemical analyses of groundwater samples from nearby hand-dug wells and boreholes around septic tank should be carried out to determine position of septic plume and quality for drinking and consumption purposes as the septic tank ages. Finally, ideal technologies for wastewater management must be operative to protect the environment and prevent contamination of drinking water sources.

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