Geophysical Investigation of Groundwater Contamination in a Solid Waste Disposal Site

***[1]Lawal, T.O., [1]Orosun, M.M., [1]Ige, S.O, [2]Sunday, J.A, [3]Shehu, A.T., [1]Bello, S.A. and [4]Nwankwo, L.I.**

[1]Department of Physics, University of Ilorin, Ilorin Nigeria
[2]Department of Science Laboratory Technology, Kwara State Polytechnic, Ilorin, Nigeria
[3]School of Preliminary Studies, Physics Unit, Federal University of Technology, Minna, Nigeria
[4]Department of Geophysics, University of Ilorin, Ilorin, Nigeria

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Abstract
A geophysical investigation of groundwater contamination within the solid waste disposal site was carried out at Tanke Tipper Garage, a typical non-controlled open dumpsite located in Ilorin, Nigeria. The aim of the investigation is to study the spatial distribution of contaminant plumes in the groundwater and ascertain if areas that can be free from contaminants are available in the study area. In view of this, four (4) vertical electrical soundings (VES) methods employing Half Schlumberger electrode array were conducted due to limited space in the area with maximum electrode spacing of 50 m. The field data were processed and Interpreted Resistivities Values were obtained by iterative computer modeling of the apparent resistivity data. The interpreted resistivity value showed that contaminant plumes at low zones with values ranging between 30.2 and 81.5 ohm-m extending from the surface down to the aquifer of shallow groundwater of less than 15 m. The hydraulic conductivity of the subsurface layers of interpreted VES points was also calculated and values ranging between 0.076 m/s and 0.418 m/s were obtained respectively. In order to complement the result of geophysical data, a physiochemical analysis of water samples from the existing hand dug well within the premises of the dumpsite was also conducted and high values of measured parameters were observed. This is an indication of groundwater contamination resulting from the solid waste leachate accretion found within the shallow aquifer zones.

Keywords: Dump site, Electrical resistivity, Half Schlumberger, Leachate plume

1.0 Introduction

Investigating the level of groundwater contamination has become increasingly important due to the fact that access to clean water is a human right and a basic requirement for economic development. However in an attempt to dispose solid waste, human beings have carelessly polluted the environment through dumping of refuse in non-controlled waste facilities. In some cases, these non-controlled waste sites are situated beside borehole which serves as a source of drinking water to the populace. Dump sites found within the borehole cause contamination of aquifer from landfills. This often results from leaking leachate and percolation of water through waste accumulated from various ions in solution and forms plumes, which moves from the surface to subsurface (underlying aquifers). This is mostly common in Africa [1]. The harms posed by non-controlled dumpsites are leachate production formed from decomposed wastes through percolated rainwater and related groundwater contamination. This contamination becomes evident as a result of hydraulic contact between the hazardous contents of the leachate plumes and groundwater [2]. Therefore, investigating level of groundwater contamination becomes necessary because of various degrees of water borne diseases such as diarrhea, typhoid, cholera, dysentery and skin cancer. These diseases occur world-wide causing over 4% of all deaths and 5% of health loss to disability [3].

***Corresponding Author: Tel: +234(0)8061313942, E-mail: taofeeqlawal4u@gmail.com**

Fundamentally, two distinct methods can be used to investigate the level of contaminants in groundwater analysis. Firstly, destructive method which involves taking samples using soil auger/core sampler in which case the geology of the area is continually disturbed. Secondly, non-destructive method which makes use of geophysical method and the geology of the area is not disturbed [4]. One of the well-known geophysical methods is electrical resistivity method which provides profitable and non-destructive means to identify, delineate and map the sub-surface defining leachate contaminant plumes from dump sites. This method is based on electrical conductivity of leachate which tends to be higher than that groundwater [5]. Studies have also shown that resistivity method is a tool for identifying, delineating and mapping of leachate contaminant plumes [2, 5–8]. Hence, the objective of this study is to apply electrical resistivity technique to detect and delineate leachate plume from a non-controlled solid waste dumpsite in Ilorin Northcentral Nigeria. The analysis of physio-chemical properties of water sample is to compliment the results of the geophysical data and measure the level of accumulation of the contaminants.

2.0 Materials and Methods

2.1 Location and Geology of the Study Area

The study area (Fig. 1) is located behind Tanke Tipper Garage along University of Ilorin Road with coordinates 08^0 56'' – 08^0 57'' N and 04^0 60'' – 04^0 61'' E, in Ilorin South Local Government Area of Kwara State, North Central Nigeria. Geologically, the study area lies within the crystalline basement rocks of Northern part of north central Nigeria. The rock types are mainly banded gneiss, sheared gneiss and augen gneiss intruded by grano diorites and granites at the southeast. The structural fabric is mainly a North-South trending fracture system dominated by a southerly plunging (6^0-10^0) anticlinorium with a gentle westerly dipping limb [9–11]. Also, basement rocks are undifferential which are made up of granites, gneisses, migmatite, quartzite, calc silicates, biotite hornblende schist and amphibolies rocks. There are also older granites and unmetamorphosed dolerite dykes, which comprises of pegmatite, quartz veins and dolerite dykes. The study area has a distinct climate condition of wet and dry seasons: a dry season which usually last from October to February and a rainy season which last from March to September. Temperature variation is between 25^0C around November/December and 35^0C in February/March. Information about the groundwater occurrence reveals that major aquifers in the area are lithologic layers with the topmost layer majorly laterite, weathered and fractured basement. Investigation about the evaluation of groundwater potential also reveals that the aquifers in the area are located mostly within the fractured basement found at a depth between 16.8 to 88.6 m [12–13]. In some locations, these aquifers are interconnected and form a hydrogeological unit of water table.

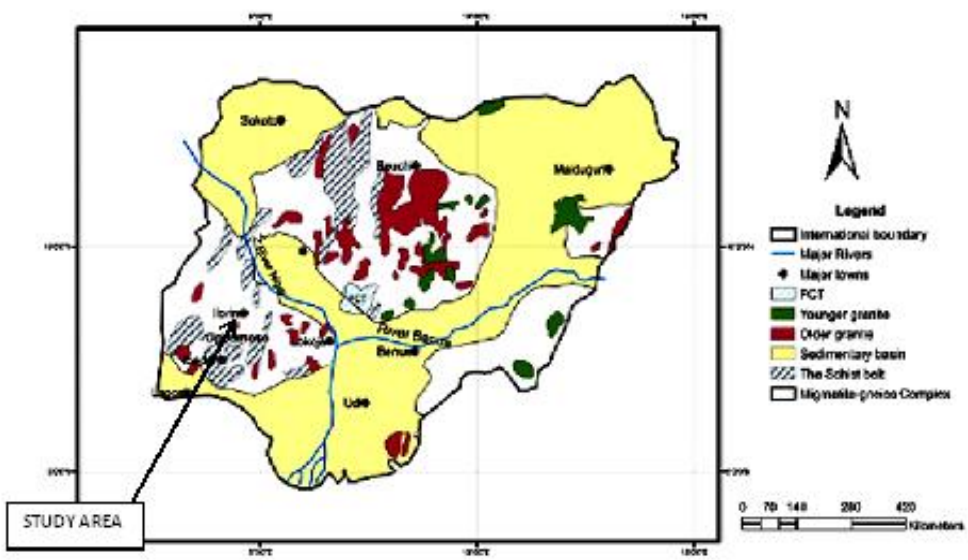

Fig. 1: Geologic Map of Nigeria showing the study area

2.2 Electrical Resistivity Survey and Data Processing

If a current source electrode is planted on the surface of a homogenous medium of uniform resistivity, ρ with the return current electrode at a great distance from the source, there is a radial flow of currents away from the source electrode. This ensures that current distribution is uniform over hemispherical surface centered on the electrode (Fig. 2).

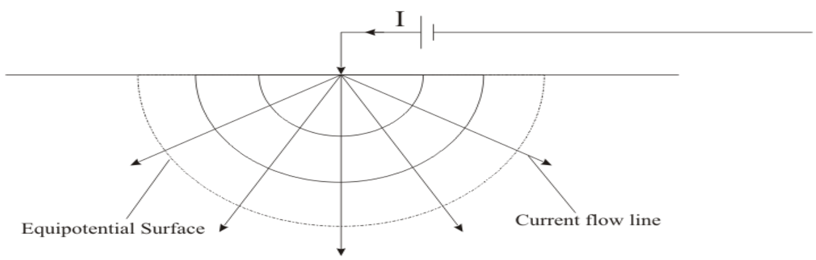

Fig. 2: Current flow from a single surface electrode

At a distance $'r'$ from the source electrode, the hemispherical shell has a surface area, $A = 2\pi r^2$ (volume $= \frac{2}{3}\pi r^3$) so that the current density 'j' which is a ratio of current 'I' to the surface area A, is given by [14–16]

$$j = \frac{I}{A} = \frac{I}{2\pi r^2} \quad (1)$$

Ohm's law in the case of a linear isotropic medium states that, field strength E,

$$E = \rho j \quad (2)$$

Substituting equ (2.1) in to equ (2.2) so that the field strength E, becomes

$$E = \frac{\rho I}{2\pi r^2} \quad (3)$$

The field strength is associated with current density by

$$E = \frac{dv}{dr} \quad (4)$$

Since j is the negative partial derivative of field potential E, V divided by resistivity 'ρ', the potential gradient, $\frac{\partial V}{\partial r}$ associated with current density, j is given as

$$\frac{\partial V}{\partial r} = -\rho j = -\frac{\rho I}{2\pi r^2} \quad (5)$$

Integrating $\frac{\partial V}{\partial r}$ with respect to r gives the potential V_r at distance r from the current source and these becomes

$$\int \frac{\partial V}{\partial r} = -\int \rho j = -\int \frac{\rho I}{2\pi r^2} \quad (6)$$

$$V_r = \int \partial V = -\int \frac{\rho I}{2\pi r^2} \partial r \quad (7)$$

The electric potential V_r at any point P, distance r from a point electrode emitting an electric current I, in an infinite homogenous and isotropic medium of resistivity, ρ is given by:

$$V_r = \frac{\rho I}{2\pi r} \quad (8)$$

$$\rho = \frac{V}{I} 2\pi r \quad (9)$$

For a semi-finite medium, this is the simplest earth model with both current and potential point-electrodes placed at the earth's surface.

$$\rho = \frac{\Delta V}{I} . G = R.G \quad (10)$$

where R is the measured resistance and G is the Geometric Constant which is a function of the electrode configuration employed during the survey.

2.3 Data Acquisition

A total of four VES measurements were conducted with a maximum electrode spacing (AB/2) 100 m. The VES points (1–4) were located at 10 m away from the dump site (Fig. 3) and the interval between each point is 5 m. The location of each sounding station was recorded in Universal Traverse Mercator (UTM) coordinates with the aid of a GERMIN 12 channel personal navigator Global Positioning System (GPS) unit. The survey was carried out during the rainy season to allow good contact resistance of the electrodes in the ground for high conductivity of the subsurface.

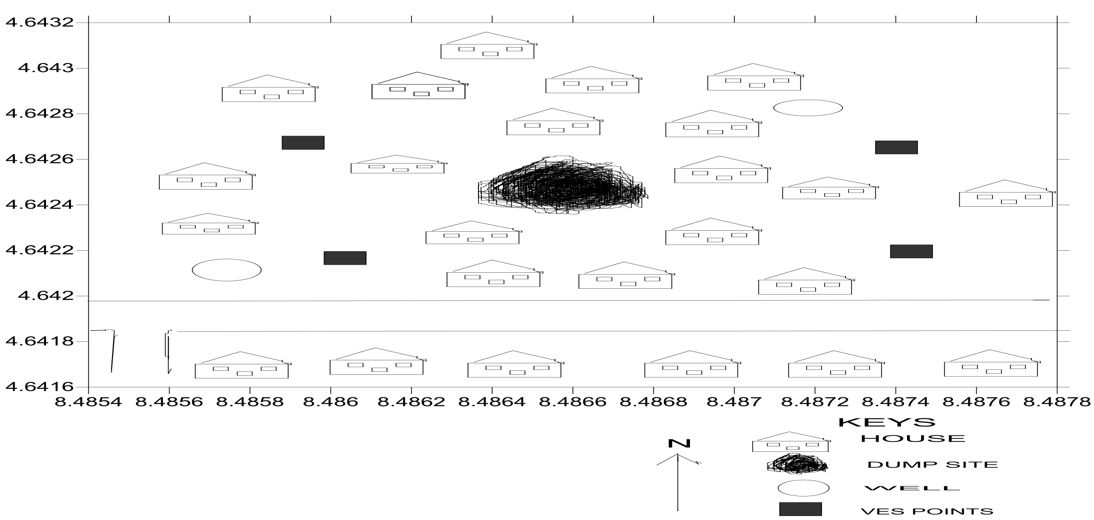

Fig. 3: Map of the study area showing the dumpsite and the houses within

The electrode arrangement used in the study area was half Schlumberger array, due to limited space and presence of buildings within the area (Fig. 3). The half Schlumberger array involves the movement of current electrode (A) while the other electrode (B) is fixed orthogonally at a large distance away which is relative to the potential electrode (M–N) at the centre (Fig. 4).

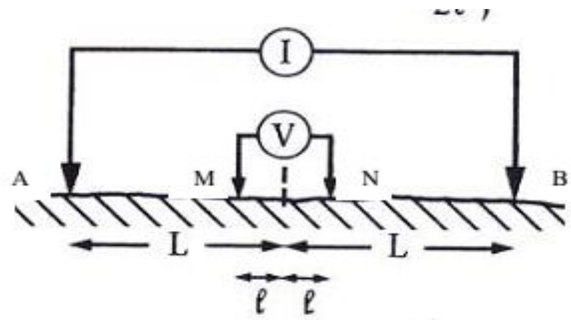

Fig. 4: Schematic electrode configuration for Half Schlumberger array

For this type of arrangement, resistivity measurements are usually taken by moving electrode A from the midpoint of the array towards 50 meters distance while electrode B will be located at 3 x (AB/2) away from the midpoint before the survey is carried out. During this development, the change in apparent resistivity reflects the distributions of resistivity with depth and causes deeper layers to affect the value of resistivity. Barounis and Karadim [17] observed that whenever the distance AB/2 increases, the current intensity bulb penetrates deeper than the previous one. For half schlumberger configuration, the apparent resistivity P_a is calculated with the formulae:

$$\rho_a = 2G\frac{\Delta V}{I} \quad (11)$$

Where ρ_a is the apparent resistivity, G is geometric factor. Also the geometric factor G for half schlumberger configuration is given by the equation

$$G = \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{2MN} \times \pi \quad (12)$$

Where AB is the distance between the two current electrodes, MN is the distance between the two potential electrodes as shown in Fig. 4.

The field data which consist of apparent resistivity, ρ_a and the electrode spacing (AB/2) were partially curve matched and plotted against each other on a bi-logarithmic scale (log-log scale) with the apparent resistivity (ρ_a) on the ordinate and the electrode spacing (AB/2) on the abscissa using a computer software known as IPIWIN developed by the Geophysics Group, Moscow State University.

2.4 Physicochemical Survey

In order to investigate the level of groundwater contamination by the solid waste leachate, groundwater quality analysis were conducted on water samples from the hand dug well located 10 m away from the dumpsites. Groundwater samples were analyzed for physical and chemical parameters. Physical parameters include Temperature, pH, Conductivity, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Dissolved Solids (TDS) while chemical analysis was conducted for five (5) trace elements. Water samples collected for both physical and chemical analyses were adequately stored in a clean polythene bottle rinsed with water and acidified with dilute nitric acid and stored in a refrigerator prior the analysis. These analyses were done using various standard methods for water analysis [2]. The refrigerated and preserved water samples were analyzed using Modern Atomic Absorption Spectrometer (MAAS). The technique employed absorption spectrometry to assess the concentration of an atomized sample using an electro thermal atomizer.

3.0 Results

The result obtained from the partial curve matching revealed the layers of the VES points, the apparent resistivity, ρ_a of each layer, the thickness (h) of each layer (Table 1). These parameters were again iterated with IPIWIN computer software with a minimized root mean square error to get the sounding curves, the true resistivity ρ_a of the layers, their real saturated aquifer thickness (h). The interpretation of the VES curves (Fig. 5) reveals four major Lithologic layers with the topmost layer majorly laterite varying with a depth of 0.50 m and 1.11 m, the second layer being clay or sand, while the third being weathered basement and the forth layer being fractured basement which is the main aquifer unit with the depth to the over burden varying between 0.61 m and 3.73 m. The VES data were subsequently plotted as a pseudo and resistivity cross sections in order to see the spatial distribution of leachate plumes and the plots for the VES points are shown in Fig. 6. Also the results of the physical and chemical analyses are presented in Tables 2 and 3.

Table 1: Geoelectrical Parameters, Lithologic Delineation and Protective Capacity of the Study Area

VES	Layer	Resistivity (Ωm)	Thickness (m)	Longitudinal Conductance (S)	Remarks
VES 1	1 2 3 4	48.9 94.1 20.3 11544	0.679 1.43 2.81	0.17	Weak
VES 2	1 2 3 4	61.5 629 10.2 27703	0.5 1.18 3	0.31	Moderate
VES 3	1 2 3 4	117 10.4 120 33557	0.5 0.108 10.5	0.102	Weak
VES 4	1 2 3 4	83.2 37.3 25455 4255	1.11 2.62 31.3	0.085	Poor

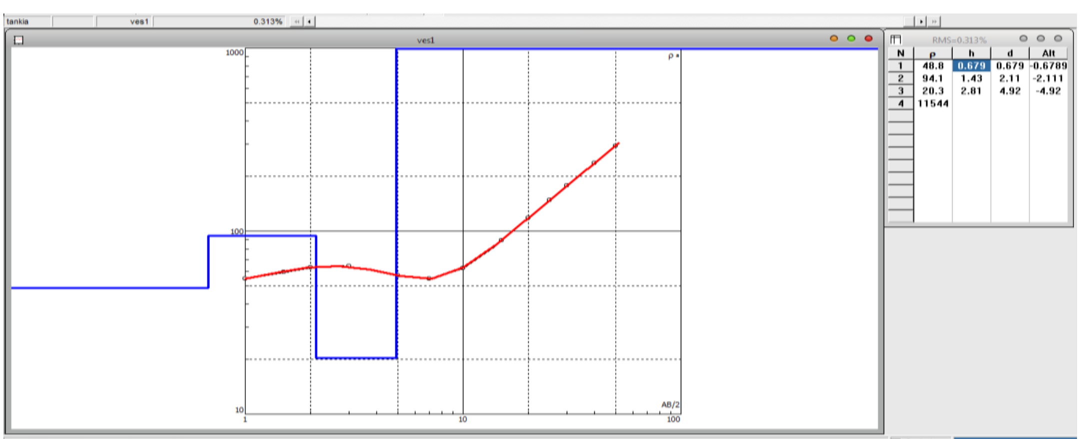

Fig. 5: DC Curve Interpretation for VES 1

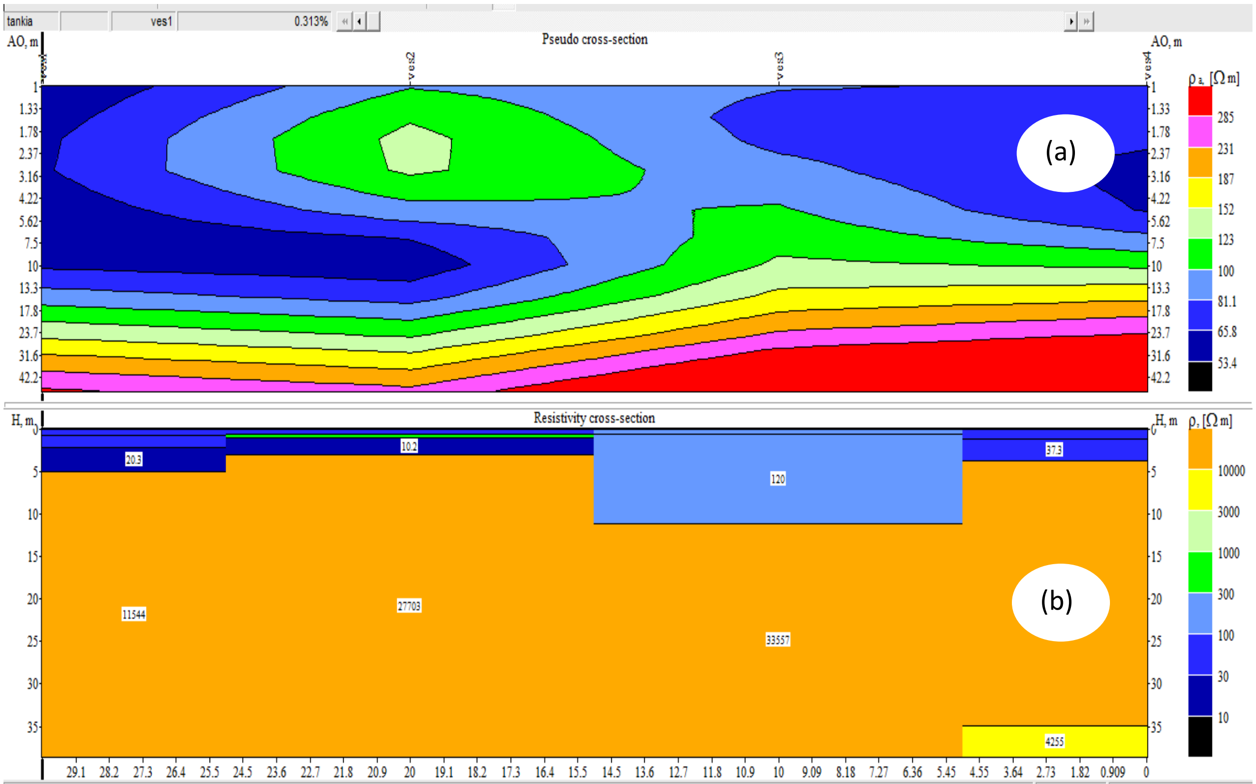

Fig. 6: (a) Pseudo-section and (b) Resistivity cross-section of VES Stations

Table 2: Values of Physical Analysis of Hand Dug Well

Parameters	Unit	Well water	*NIS	*WHO
Conductivity	μs	326	100	1000
pH		6.78	6.5 – 8.5	6.5 – 8.5
Total Dissolved Solids (TDS)	mg/l	860	500	600
Total Suspended Solids (TSS)	mg/l	135	100	150
Chemical Oxygen Demand (COD)	mg/l	1880	800	900
Biological Oxygen Demand (BOD)	mg/l	286	40	50

NIS: Nigerian Industrial Standards; WHO: World Health Organization

Table 3: Values of Chemical Analysis of Hand Dug Well

Parameters	Unit	Well water	*NIS	*WHO
Lead (Pb)	mg/l	1.30	0.0100	0.0100
Iron (Fe)	mg/l	0.52	0.300	0.100
Cadmium (Cd)	mg/l	0.03	0.0030	0.002
Chlorides (Cl^{-1})	mg/l	106	50	60
Chromium (Cr)	mg/l	0.10	0.050	0.050

NIS: Nigerian Industrial Standards; WHO: World Health Organization

4.0 Discussion

The pseudo cross–section shows a low resistivity zone (20–90 **Ω**-m) for AB/2 of 1–13.3 m. This zone varies laterally from VES 1 to VES 3 and VES 4. This can be attributed to contamination of the top-most soil as a result of accumulation of leachate plume. These zones are also indication of solid wastes dumped in the area. VES 2 which has a resistivity value above 100 **Ω**-m (high resistivity value) and lies between AB/2 of 1 and 3.16 can be attributed regions that are not contaminated but it will be observed that below this zone are regions of low resistivity which cut across VES 1, 3 and 4. Areas on the pseudo section plot which are made up green, gray, yellow, pink and red colour observed at AB/2 spacing of 17.8 to 42.2 m with resistivity values ranging between 123–285 **Ω**-m are attributed to be the water bearing zones of the area and contaminant plumes are yet to reach these zones. Though the resistivity values of these layers depends solely on the sand to clay ratio and saturation, the resistivity cross–section (Figure 6b) revealed a sequence of three geoelectric section of K VES 1, 2 and 4 while VES 3 geoelectric section is H. The low resistivity values observed in all the VES stations of the first layer is an indication of downward migration of leachate plumes. All the VES points have resistivity values that exceed 1000 **Ω-**m but fractured at VES 3. This fracture zone is the aquifer region of the basement complex.

The hydraulic conductivity of the subsurface layers of interpreted VES points was also calculated using the established non–linear relationship between hydraulic conductivity (K) and apparent resistivity (**ρ**) [18] and values range between 0.076 m/s and 0.418 m/s. These values are moderately low and correspond to the movement of leachate plume through the pore spaces of the sub surface materials that are interconnected. Interpretation was also carried out using the Dar–zarrouk parameters, particularly the total longitudinal conductance (S). High S values usually indicate relatively thick succession and should be accorded the highest priority in terms of groundwater potential and vice versa [13]. The result of longitudinal conductance (Table 1) shows that VES 2 is classified as a moderate zone for groundwater exploration supposing the place is not used for dumpsite any longer.

In respect of the NIS and WHO standards, it could be inferred from the result of the physical and chemical analyses that the values of the different parameters showed pollution of the groundwater at certain depth. High conductivity can be attributed to contaminant fluids rich in total dissolved solids. The high value of COD concentration is as a result of oxidizable organic and inorganic pollutants while the high value of BOD concentration is an indication of high concentration of biodegradable organic substance at the dumpsite. The high concentrations of traceable elements (Iron, chloride, zinc, cadmium, lead and chromium) observed at the dumpsite could possibly due to the effect of the leachate migrating from the body of the waste resulting from the conductivity of the geoelectric layers. These concentrations are an indication of hazardous substance in form of solid in the leachate which can cause water borne diseases such as diarrhea, typhoid, cholera, dysentery, skin cancer [2]. These diseases occur world-wide and cause over 4% of all deaths and 5% of health loss to disability. This is most commonly caused by gastrointestinal infections which kill close to 2.2 million people globally each year, mostly children in developing countries [3]. This area is therefore calling for an urgent attention so that the life of people living within will not be at risk.

5.0 Conclusion and Recommendation

Based on the findings from this study, it can be concluded that contamination of groundwater in the study area is within the shallow aquifer zone. Therefore, evacuation of the solid waste on the site needs to be carried out as soon as possible to prevent further movement of leachate plumes to the deeper aquifer zones. When this is done, further investigation of groundwater quality should be carried out in the same area after about three to five years. It is therefore recommended that borehole in this area should be sited at depth of 50 m and above. This will give the area an uncontaminated groundwater for domestic purposes.

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