Integrated Geophysical and Hydrochemical Investigation of Pollution Associated with the Ilara-Mokin Dumpsite, South-western Nigeria.

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Abstract

Geophysical and hydrochemical investigations have been used to map pollution in the area around a dumpsite in Ilara-Mokin, southwestern Nigeria. Three (3) Very Low Frequency Electromagnetic (VLF-EM) profiling, dipole-dipole 2-D electrical imaging and fourteen (14) Vertical Electrical Soundings (VES) were carried out in the study area. Four (4) water samples from hand dug wells and two (2) surface water samples were collected around the dumpsite for physical and chemical analyses. The inverted 2-D resistivity structures and the geoelectric sections delineated four subsurface geoelectric units. These are the topsoil, weathered layer, partly weathered/fractured basement and the fresh basement bedrock. Within the premises of the dumpsite, the topsoil, the weathered layer, and the partly weathered/fractured basement are characterized by relatively low layer resistivity values of 6 – 50 ohm-m suspected to be due to conductive leachate from the dumpsite. The conductive zones were also identified by the VLF-EM 2-D subsurface image. The physical and chemical characteristics of the sampled waters include: electrical conductivity of 850 – 1000 µmho/m; pH value of 6.2 – 7.3; total hardness values of 29 – 47 mg/l; sulphate concentration of 80 – 90 mg/l and nitrate concentration of non detectable – 10 mg/l. The relatively high electrical conductivity may be indicative of surface and groundwater pollution. The polluted zone has a depth extent of about 2.5 – > 15 m and lateral extent of about 140 m west and up to 50 m south of the dumpsite.

Keywords: Geophysical, Hydrochemical, Dumpsites, Surface, Groundwater Pollution.

1.0 Introduction

Due to industrial development and the explosion of the urban population, huge amount of various types of wastes are produced on daily basis and deposited in a chaotic manner at various dumpsites in Nigeria. The Ilara-Mokin dumpsite under investigation has been in existence for more than 50 years. The dumpsite hosts lots of in-homogenous materials which are largely non-biodegradable and have been compacted over the years. This has allowed long time interaction between the dumpsite materials, the soils and the subsurface geologic units.

Wastes disposed into landfill sites undergo oxidation, corrosion of metallic components, and decomposition of organic matter resulting in the generation and release of leachate which can impact the soil, surface and groundwater resources and thereby affecting the potability of underground water. The Ilara-Mokin dumpsite became inactive a year ago when part of the dumpsite was cleared to pave way for the construction of a road.

However, there are indications that the leachates generated at the dumpsite continue to impact the environment. Field observations showed that some hand-dug wells around the dumpsite had been abandoned for quite some time due to pollution arising from the dumpsite. Delineation of the geometry of the pollution plume and its migration path in the area around the dumpsite is necessary to facilitate the process of rehabilitation and remediation, where necessary.

Geophysics has two major advantages which makes it a suitable tool for environmental impact assessment. It is non-invasive or non-destructive and it can give continuous subsurface information along a profile.

Consequently, geophysics has an important role to play in contaminated land assessment. Several authors (Benson, et al. 1997, Adepelumi et al., 2005, , Ehinri, 2009, Obase et al., 2009, Alile et al., 2011, and Bayode et al., 2012) had engaged geophysical methods such as electromagnetic and electrical resistivity methods and hydrochemical measurements in mapping dumpsite pollution in both basement complex and sedimentary terrains of Nigeria and other parts of the world. This present study employed the Very Low Frequency Electromagnetic (VLF-EM), geoelectric, hydrogeology and hydrochemical measurements to investigate the environmental impact of the Ilara-Mokin dumpsite.

1.1 Description of the Study Area

Ilara-Mokin, the study area, is located in Ifedore Local Government Area of Ondo State (Fig. 1). It lies between the geographic co-ordinates of Northing's 811400 – 813200 mN and Easthing's 732200 – 733400 mE in the Universal Traverse Mercator (UTM) Minna Zone 31 (Fig. 1). The topographic elevation around the dumpsite ranges from 335.0 to 365.0 m above mean sea level and generally slopes gently from the north towards the southern part. The investigated dumpsite covers an areal extent of about 32,000 m^2. The area has a climate characterized by two seasons; the wet season and the dry season. The wet season starts from around mid march and ends in October with an average rainfall of 1500 mm to 2000 mm while the dry season starts around November and ends in March with an average maximum temperature of about 33 ˚C.

1.2 Geology and Hydrogeological setting

The study area is underlain by the Precambrian Basement Complex of southwestern Nigeria (Rahaman, 1976). Field observation showed that the study area is underlain by migmatite gneiss (Fig. 2). Groundwater is found in the weathered layer, faults, fractures and jointed basement column. The weathered layer in the study area is generally thin due to shallow depth of bedrock. Based on this, subsurface structural discontinuities (shear zones, fractures and joints) are targeted for productive boreholes in the study area.

2.0 Methodology

Three (3) traverses, which ranged in lengths from 100 m to about 250 m, were established across the study area. Traverses one and two were established perpendicular to each other over the dumpsite while traverse three was established at about 140 m from the dumpsite to serve as control (Fig. 3). Very Low Frequency Electromagnetic (VLF – EM), the electrical resistivity, hydrogeologic and hydrochemical methods were employed in this survey. The electrical resistivity method involved the Vertical Electrical Sounding (VES) and the dipole – dipole techniques. The resistivity measurements were made with the Omega resistivity meter. The VLF – EM and the dipole – dipole measurements were taken at 5 m interval along the traverse lines with the exception of the VLF – EM measurements along traverse one where a station separation of 10 m was adopted. The VLF – EM measurements were made using the ABEM WADI equipment. VLF– EM method was used for locating vertical/near vertical features (fractures, faults, joints and shear zones), geologic contacts as well as contaminated plume mapping (Greenhouse and Harris, 1983; and Benson et al. (1997). The real component data were filtered and modeled into 2-D subsurface image using the KHFILT software.

The 2-D subsurface imaging was carried out with the dipole – dipole technique. Measurements were made with electrode spacing of a = 5 m and expansion factor n = 1 – 5. The dipole – dipole data were inverted into 2-D resistivity structure using the DIPRO for windows (2004) software. Fourteen (14) Schlumberger Vertical Electrical Soundings (VES) were acquired in the study area (Fig. 3). Maximum electrode spacing (AB/2) m of 100 m was used. The VES data interpretation involved the partial curve matching and 1-D computer assisted forward modeling involving the Win RESIST 1.0 (Vender Velper, 2004) software. The interpreted layer parameters (resistivities and thicknesses) were used to generate the geoelectric sections. Six (6) water samples were collected from both hand dug wells and surface water (stream) for hydrochemical analysis. Water samples were collected from four (4) hand dug wells located around the dumpsite and two (2) stream samples from the upstream and the downstream segment of a stream that flows around the dumpsite. The data acquisition was carried out in the month of August, 2012. Physical Parameters such as temperature, conductivity, and pH were determined in the field due to their unstable nature. Other parameters analyzed for include anion concentrations of sulphate, nitrate, chloride, and cations concentrations of sodium, calcium, magnesium, iron and lead. Static water level measurements were also made in seven (7) hand dug wells around the dumpsite to enable the determination of the groundwater flow direction.

3.0 Results and Discussion

3.1 Geophysical Data

The VLF-EM measurements along Traverses 1, 2 and 3 are presented as profiles and 2-D subsurface images as shown in (Figs. 4a and b – 6a and b). The VLF-EM filtered real component amplitudes generally vary from a minimum value of -50% to a maximum value of 75% along Traverses 1, 2 and 3. The signature of -50% to 75% observed between distances 67 – 90 m along Traverse 1 is due to over head power line and a transformer located nearby or cultural noise along the traverse (Fig. 4a). Positive peak amplitudes (yellowish – reddish colour bands in the 2-D model) anomalies along the profiles are observed between distances 20 – 30 m, 55 – 65 m and 205 – 220 m; 20 – 35 m, 60 – 75 m, 95 – 115 m, and 140 – 160 m; 35 – 45 m, and 85 – 90 m along Traverses 1, 2 and 3 respectively (Figs. 4a and b – 6a and b). Anomalous zones suspected to be typical of poorly conductive targets (fractured/fault zones) characterized by relatively low amplitudes of (7 – 10)% were delineated between distances 55 – 65 m; 20 – 35 m, 95 – 115 m, and 140 – 160 m; and 35 – 45 m along Traverses 1, 2 and 3. The observed low amplitude positive peak filtered real amplitude anomalies of about 5% (yellowish – reddish colour band in the 2-D model) observed between distances 20 – 30 m, and 205 – 220 m; and 60 – 75 m along Traverses 1 and 2 respectively (Figs. 4a and b – 6a and b) gave some indication of the presence of clay or the suspected leachate plume within the near surface saturated soil layer along the traverses.

The 2-D resistivity image obtained from the inversion of the dipole-dipole data along the three traverses established around the dumpsite are presented in Figures 4c – 6c. The 2-D resistivity structures show that the topsoil has virtually merged with the weathered layer due to overlapping low resistivity values and relatively small thickness. The geoelectric parameters of the 2-D image obtained in the area around the investigated dumpsite are presented in Table 1. The 2-D resistivity structure delineated four subsurface geologic units which include the topsoil, weathered layer, weathered/fractured basement and the fresh basement bedrock.

The topsoil is the first layer, with low resistivity values of 6 – 38 Ωm, characterized by light to deep bluish colour band observed between distances 20 – 40 m and 130 – 230 m; 0 – 100 m and 125 – 200 m; and 25 – 60 m (Figs. 4c – 6c) along Traverses 1, 2, and 3 respectively. These relatively low resistivity values are suspected to be due to leachate saturation from the dumpsite and hence an indication of pollution. The second layer is the weathered layer. The light – deep bluish colour bands characterized by low resistivity values of 6 – 50 Ωm observed between distances 130 – 230 m; 5 – 95 m and 105.5 – 195 m (Figs. 4c and 5c) along Traverses 1, and 2 respectively are indicative of leachate saturation from the dumpsite and hence an indication of pollution. The third layer is the fractured basement. The light – deep bluish colour bands characterized by low resistivity values of 17 – 90 Ωm observed at a depth below 5 m between distances 5 – 85m and 152.5 – 195 m (Figs. 5c) along Traverses 2 are indicative of leachate saturation from the dumpsite and hence an indication of pollution. The light to deep bluish colour band within the resistivity range of 17 – 90 Ωm observed between distances 25 – 60 m along Traverse 3 could be associated with migrated leachate from the dumpsite. The last layer is the fresh basement bed rock. The depth to the top of the basement bedrock varies from 2.5 - > 30 m along the three traverses.

The VES interpretation results were used to develop three geoelectric sections along the three traverses establish in the study area (Figs. 4d – 6d). The geoelectric parameters obtained in the area around the dumpsite are presented in Table 2. The geoelectric section also delineated four subsurface geologic layers. These are the topsoil, weathered layer, weathered/fractured basement and fresh basement (Figs. 4c – 6c). Table 2 shows that the area around the dumpsite is generally characterized by relatively low resistivity topsoil and weathered layer which ranges in value from 11 – 100 Ωm, and 19 – 40 Ωm respectively while the topsoil and the weathered layer along the control traverse far from the dumpsite has relatively higher resistivity values which range from 39 – 162 Ωm, and 56 – 110 Ωm respectively. It is suspected that the leachate generated at the dumpsite is suspected to have infiltrated the topsoil, weathered layer and the weathered/fractured basement. The correlation of the VLF – EM, 2-D resistivity structure and the geoelectric sections (Figs. 4 - 6) shows that the weathered and the weathered/fractured basement considered as the major aquifer units in the study area, contain zones that are characterized by VLF– EM peak filtered real values of > 5 – 10%, geoelectric section with resistivity values of 19 – 40 Ωm and 54 – 157 Ωm respectively and 2-D resistivity structure of 6 – 50 Ωm and 17 – 90 Ωm respectively are attributed to the conductive leachate from the refuse dumpsite. Hence, it is suspected that the groundwater beneath this dumpsite may have been polluted. The estimated depth of leachate migration from the VLF – EM 2-D image, 2-D resistivity structures and the geoelectric sections ranges from 2 m to > 15 m along Traverses 1 – 3 (Figs. 4 – 6).

The static water level measurements obtained from hand dug wells around the dumpsite generally varies from 1.4 – 5.5 m (Table 3). There is high static water level of 1.4 – 3.2 m in the area around the dumpsite while a lower static water level measurement of 5.5 m was obtained from well seven (7) located at far distance from the dumpsite (Fig. 3). Figure 7 shows the ground water flow map of the study area. The arrow on the map show that the groundwater flow around the dumpsite is generally towards the southwest direction thereby aiding the migration of leachate in this direction. Judging from the estimated depth of leachate migration of 2 – > 15 m from the VLF – EM 2-D model, 2-D resistivity structure and the geoelectric section, and the high static water level measurement of 1.4 – 3.2 m, the groundwater in the area around the dumpsite is suspected to have been polluted.

3.2.0 Hydrochemical Analysis

Hydrochemical analysis of water samples collected from four (4) hand dug wells and two (2) surface water samples from upstream and downstream sites located around the dumpsite were carried out and the results are presented in Table 4. The results show that the water samples collected around the waste dumpsite and the downstream sample have higher concentrations of the analyzed parameters compared to samples obtained at far distances from the dumpsite and the upstream samples.

3.2.1 pH: The pH value ranges from 6.2 – 7.3 with an average of 6.8. The pH value of 6.2 – 7.3 obtained around the dumpsite revealed that the surface and groundwater in the study area is acidic. The acidity is probably due to the presence of organic matter in the soil. However, free CO_2 generated from the dumpsite and the atmosphere, is suspected to enter the groundwater system as rain water percolates the subsurface soil and groundwater and reduces the pH value of the water in the area. Well 5 is located at 10 m away and being the closest well to the dumpsite, exhibit the lowest pH value of 6.2, well seven (7) has a value of 7.2. The downstream sample has a pH value of 6.4 while the upstream sample value is 7.3. The pH values of 6.2 – 6.7 are lower than the WHO (2004) recommended safe value 7.0 – 8.5. The low values of pH of 6.2 – 6.7 observed around the dumpsite are indicative of groundwater pollution.

3.2.2 Conductivity: Conductivity values range from 275 - 1000 µmho/m (Table 2) with an average value of 689 µmho/m. Conductivity usually indicates the concentration of dissolved ions in groundwater samples. The groundwater in the study area has moderate to high conductivity values which generally fall within the WHO (2004), FEPA, (1991) recommended safe values of less than 1000 µmho/m for drinking water. However the higher conductivity values of 1000 µmho/m in well 5 close to the dumpsite and 750 µmho/m observed in well seven (7) far from the dumpsite and also the upstream value of 275 µmho/m and downstream concentration value of 425 µmho/m give indication of both surface and groundwater pollution in the area around the dumpsite.

3.2.3 Total Hardness: The Total hardness of surface and groundwater samples in the study area which ranges from 16 – 47 mg/l is generally below the WHO (2004) recommended safe values for drinking water (Table 4). The concentration values for groundwater ranges from 17 – 47 mg/l while that of surface water for the upstream and downstream samples are 16 mg/l and 18 mg/l respectively. These values are generally less than the WHO (2004) recommended safe values of 100 mg/l for drinking water. Lower concentration value of 20 mg/l was obtained from well seven (7) at far distance from the dumpsite. Relatively higher concentration values of 29 – 47 mg/l obtained from wells around the dumpsite is an indication of pollution of the groundwater around the dumpsite.

3.2.4 Sulphate: The sulphate content of both surface and groundwater in the study area generally ranges from 55 – 160 mg/l (Table 4). The concentration values for groundwater ranges from 55 – 90 mg/l while that of surface water are 85 mg/l for the upstream and 160 mg/l for the downstream samples. These values are generally less than the WHO (2004) recommended safe values for drinking water (Table 4). Lower concentration value of 55 mg/l was obtained from well seven (7) at a far distance from the dumpsite. The relatively high concentration values of 80 – 90 mg/l obtained from wells around the dumpsite and the relatively high concentration value of 160 mg/l obtained for the downstream sample are indications of pollution of both surface and groundwater around the dumpsite.

3.2.5 Nitrate: The NO_3^- concentration values for groundwater ranges from undetectable – 10 mg/l while the concentration values for surface water ranges from 0.12 – 0.24 mg/l. The values generally fall within the WHO (2004) recommended save value of 10 mg/l for drinking water. The concentration value of 10 mg/l obtained at well 5 closest to the dumpsite and non detectable value obtained at well seven (7) far from the dumpsite (Fig. 3) is an indication of leachate saturation and hence confirm the leachate pollution around the dumpsite.

3.2.6 Cations: Generally, the cations determined in this study area include K^+, Na^+, Mg^{2+} and Ca^{2+}. The concentration levels of K^+, Na^+, Mg^{2+} and Ca^{2+} in the groundwater are in the range of 0.20 – 0.49 mg/l, 0.08 – 0.34 mg/l, 0.30 – 0.73 mg/l and 0.06 – 0.3 mg/l respectively. The concentration level for K^+, Na^+, Mg^{2+} and Ca^{2+} in the upstream surface water samples are 0.08 mg/l, 0.10 mg/l; 0.21 mg/l, 0.10 mg/l; while the downstream sample values are 0.21 mg/l, 0.18 mg/l,; and 0.36 mg/l, 0.56 mg/l. These concentration values are generally below the WHO (2004) recommended save values for drinking water.

3.2.7 Anions: The anions determined in this study include Cl^- and PO_4^{3-}. The concentration values of Cl^- and PO_4^{3-} for wells and surface water samples in the study area generally range from 0.44 – 7.3 mg/l and 30.0 – 60.0 mg/l respectively. These values are also much lower than the WHO (2004) recommended safe values for drinking water (Table 4).

4.0 Conclusions

Geophysical, hydrochemical and hydrogeologic investigation of a dumpsite located in Ilara-Mokin, southwestern Nigeria has been carried out to assess the pollution in the area around the dumpsite. The results of the Fraser filtering and the 2-D model of the real components of the VLF-EM profiles obtained along Traverses 1, 2 and 3 identified VLF-EM filtered real positive peak amplitudes of < 5 – 10 % (characterized by yellowish – reddish colour bands in the 2-D model) which are indicative of both poorly conductive bodies and leachate saturated near surface soil. The geoelectric sections and the 2-D resistivity structures delineated four subsurface layers. These include the top soil, weathered layer, weathered/fractured basement and the fresh basement bed rock. The weathered layer and the weathered/fractured basement rock are considered as the main aquifer units. Both the geoelectric section and the 2-D resistivity image show that the top soil, weathered layer and the weathered/fractured basement in the area around the dumpsite are characterized by relatively low resistivity values of 6 – 100 ohm-m, 6 – 50 ohm-m and 17 – 157 ohm-m respectively, suggesting that the area around the dumpsite has been impacted. The 2-D images show that the leachate depth of migration varies from about 2.5 – 7.5 m along Traverse 1, and 2.5 – > 15.0 m along traverses 2 and 3.

The results of hydrochemical parameters from hand dug wells and surface water samples generally indicate values that fall within the WHO (2004) recommended safe values for all the parameters analyzed. Some of the physical and chemical characteristics of the sampled waters are: electrical conductivity of 850 – 1000 μmho/m; pH values of 6.2 – 7.3; total hardness values of 29 – 47 mg/l; sulphate concentration of 80 – 90 mg/l, phosphate of 30 – 60 mg/l and nitrate concentration of non detectable – 10 mg/l. The relatively high electrical conductivity may be indicative of surface and groundwater pollution. Judging from the relatively high water table of 1.5 – 3.5 m around the dumpsites and the estimated leachate migration depth of 2.5 – > 15.0 m from the 2-D resistivity structures, the groundwater in the area beneath the dumpsites is suspected to have been polluted. The pollution migration has a predominantly southwest flow in line with the direction of groundwater flow in the area around the dumpsite. The polluted zone has a lateral extent of about 140 m west of the established control traverse 3 and up to 50 m south of the dumpsite.

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Table 1: Geoelectric Characterization of the Investigated Dumpsites along the Traverses from 2-D Resistivity Structure Interpretation Results.

Layering	Colour bands	Resistivity Range (ohm-m)	Resistivity within Dumpsite Area (ohm-m)	Thickness (m)	Lithologic Description
Topsoil	Deep blue to green	6 – 90	6 – 38	1.0 – 2.5	Made ground, fill materials, clay and sandy clay.
Weathered Layer	Deep blue to green	6 – 200	6 – 50	2.5 – 10.0	Clay and Sandy Clay.
Weathered/ Fractured basement	Light to deep blue and greenish.	17 – 726	17 – 90	5 – > 20	Partly weathered and Fractured basement rock.
Basement Bedrock	Yellowish – Red.	290 – 6199	457 - 10000		Fresh basement.

*Depth to Bedrock varies from 2.5 to > 30 m

Table 2: Geoelectric Characterization of the Investigated Dumpsites from VES Interpretation Results.

Layering	Resistivity Range (ohm-m)	Resistivity within Dumpsite Area (ohm-m)	Thickness (m)	Lithologic Description
Topsoil	24 – 158	11 – 100	0.9 – 2.0	Made ground, fill materials, clay and sandy clay.
Weathered Layer	11 – 131	19 – 40	1.0 – 20.0	Clay and Sandy Clay.
Weathered/ Fractured basement	54 – 157	54 – 157	10.1 – 35	Partly weathered and Fractured basement rock.
Basement Bedrock	457 – 10219	457 - 10000		Fresh basement.

*Depth to Bedrock varies from 5 to 20m

Table 3: Static Water Level Measurement from Hand Dug Wells around the Dumpsite

Well No.	3	2	1	4	5	6	7
Static Water Level (m)	4.7	2.6	3.2	2.4	1.4	2.5	5.5

Table 4: Summary of Chemical Parameters of Surface and Groundwater from the Study Area

PARAMETER	**WELL 5 (10 m from dumpsite)**	**WELL 1 (25 m from dumpsite)**	**WELL 6 (35 m from dumpsite)**	**WELL 7 (150 m from dumpsite)**	**STREAM 1 Upstream**	**STREAM 2 Downstream**	**WHO (2004) STANDARD MPL (mg/l)**
EC (μmho/m)	**1000.0**	**850.0**	**750.0**	**350.0**	**275.0**	**425.0**	**1000**
Temp. (°C)	**27.0**	**25.0**	**24.0**	**20.5**	**20.2**	**22.5**	**-**
pH	**6.2**	**6.7**	**7.1**	**7.2**	**7.3**	**6.4**	**8.5**
TOTAL HARDNESS (Mg/l)	**47.0**	**29.0**	**20.00**	**17.00**	**16.0**	**18.0**	**100**
ALKALINITY(Mg/l)	**122.0**	**122.0**	**73.20**	**48.0**	**91.0**	**164.70**	**-**
SO_4^{2-} (Mg/l)	**90.0**	**80.0**	**60.0**	**55.0**	**85**	**160.0**	**200**
PO_4^{3-} (Mg/l)	**60.0**	**55.0**	**45.0**	**30.0**	**30.0**	**50.0**	**10**
NO_3^- (Mg/l)	**10.0**	**0.40**	**4.0**	**ND**	**0.12**	**0.24**	**10**
CL^- (Mg/l)	**7.2**	**0.44**	**0.51**	**0.44**	**0.43**	**7.30**	**250**
K^+ (Mg/l)	**0.49**	**0.47**	**0.45**	**0.20**	**0.08**	**0.21**	**-**
Na^+ (Mg/l)	**0.34**	**0.33**	**0.30**	**0.08**	**0.10**	**0.18**	**200**
Mg^{2+} (Mg/l)	**0.73**	**0.42**	**0.40**	**0.30**	**0.21**	**0.36**	**30**
Ca^{2+} (Mg/l)	**0.30**	**0.27**	**0.10**	**0.06**	**0.10**	**0.56**	**75**
Pb^{2+} (Mg/l)	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**0.01**

MPL = Maximum Permissible Level, ND = Non Detectable

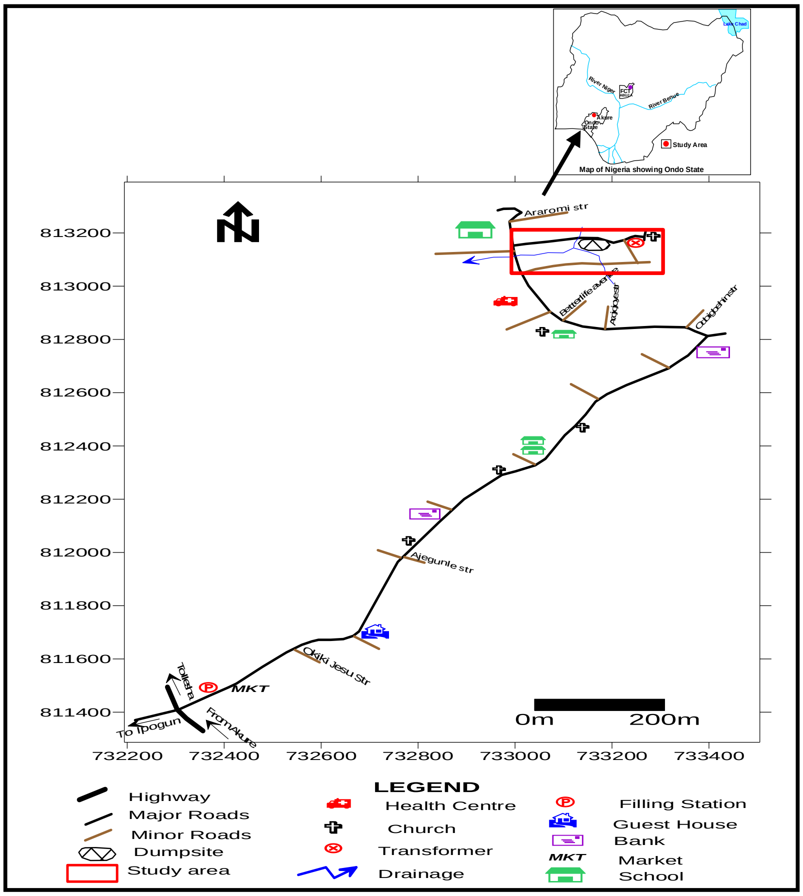

Fig. 1: Map of Parts of Ilara-Mokin Showing the Location of the Investigated Dumpsite

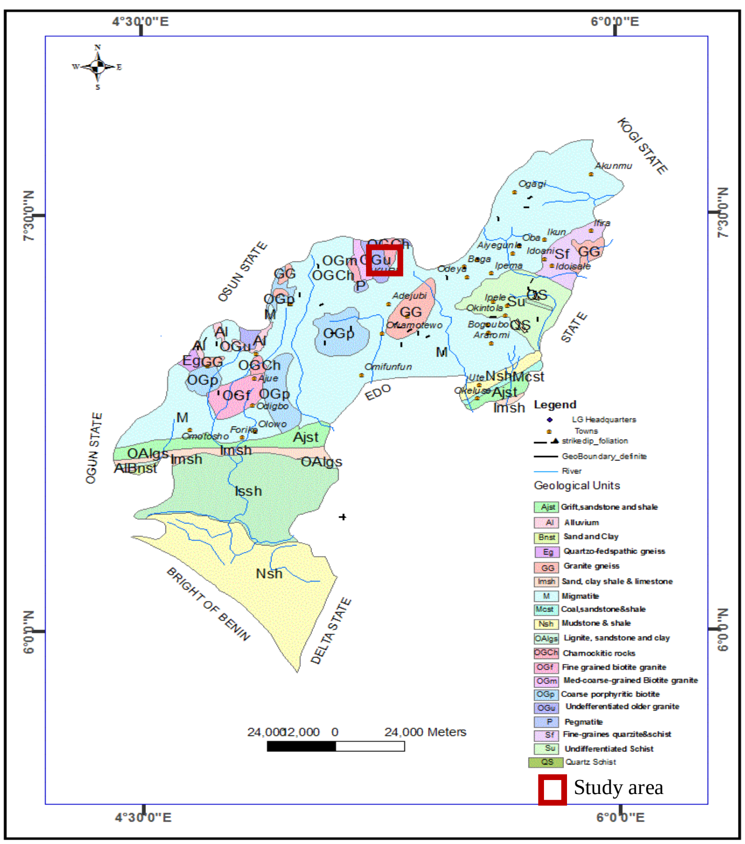

Fig. 2: Geological Map of Ondo State (Adapted from the Geological Survey of Nigeria, 2006).

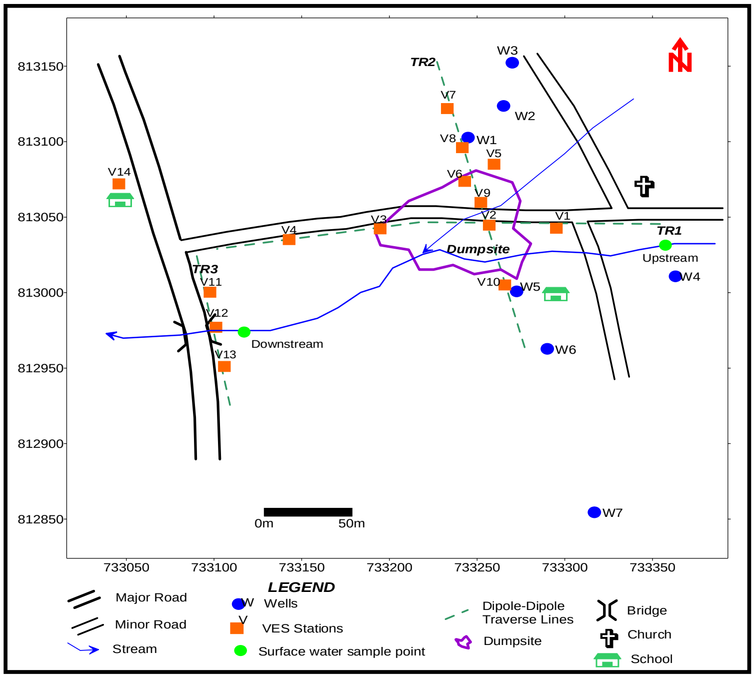

Fig. 3: Data Acquisition Map of the Study Area

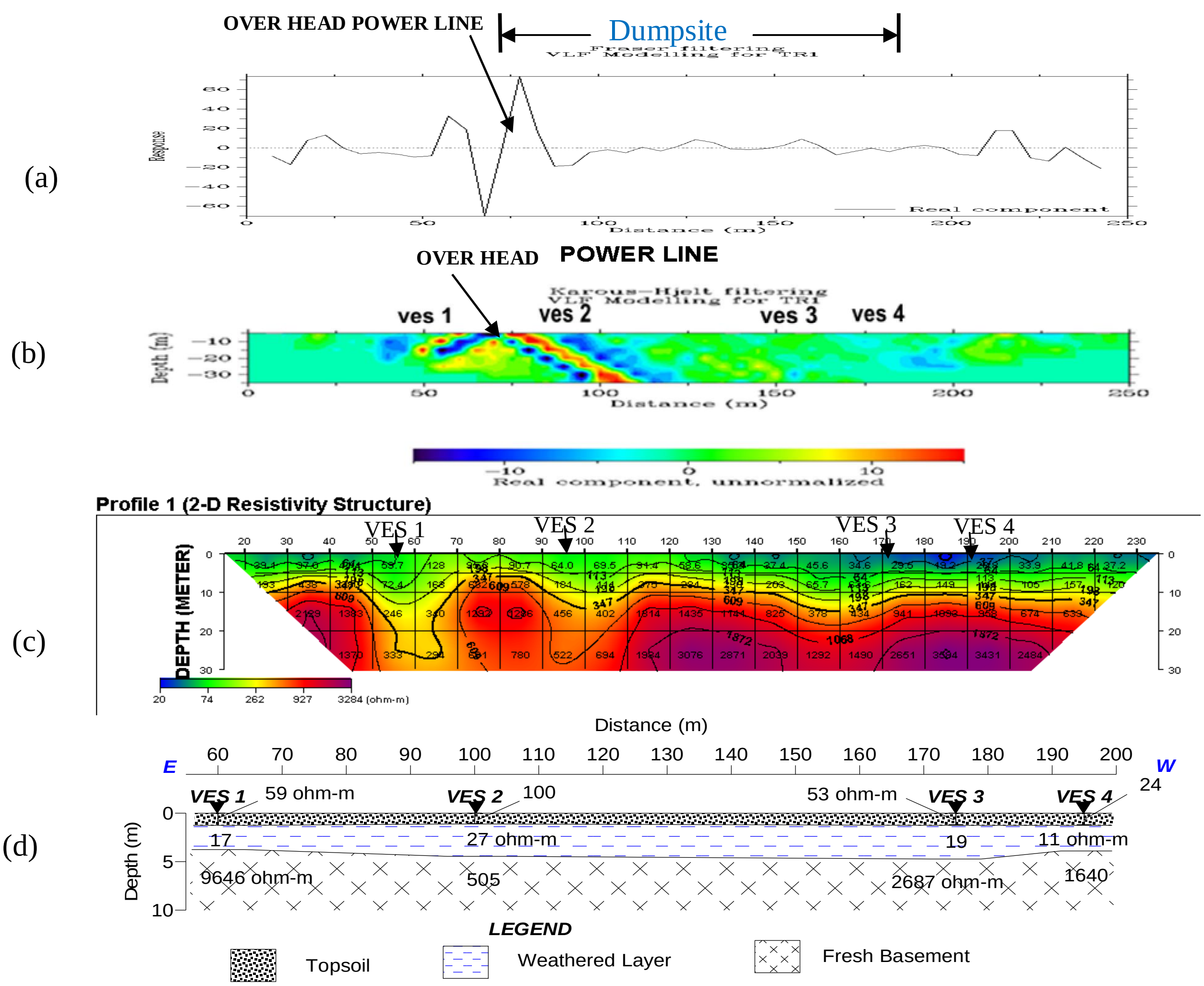

Fig. 4.: Correlation of (a) VLF-EM Profile, (b) VLF-EM 2-D Model (c) 2-D Resistivity Structure and (d) Geoelectric section Along Traverse 1

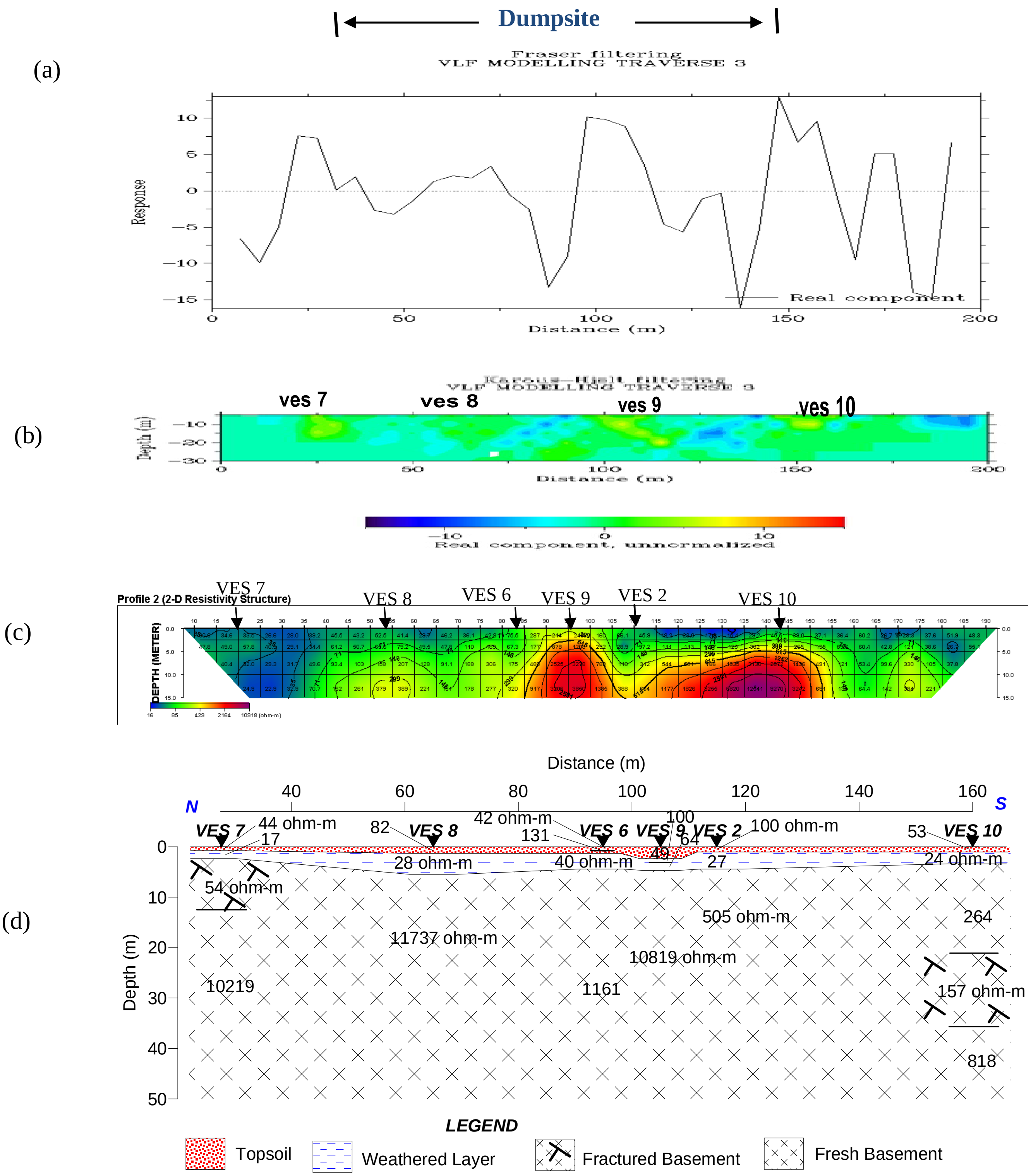

Fig. 5: Correlation of (a) VLF-EM Profile, (b) VLF-EM 2-D Model (c) 2-D Resistivity Structure and (d) Geoelectric section Along Traverse 2

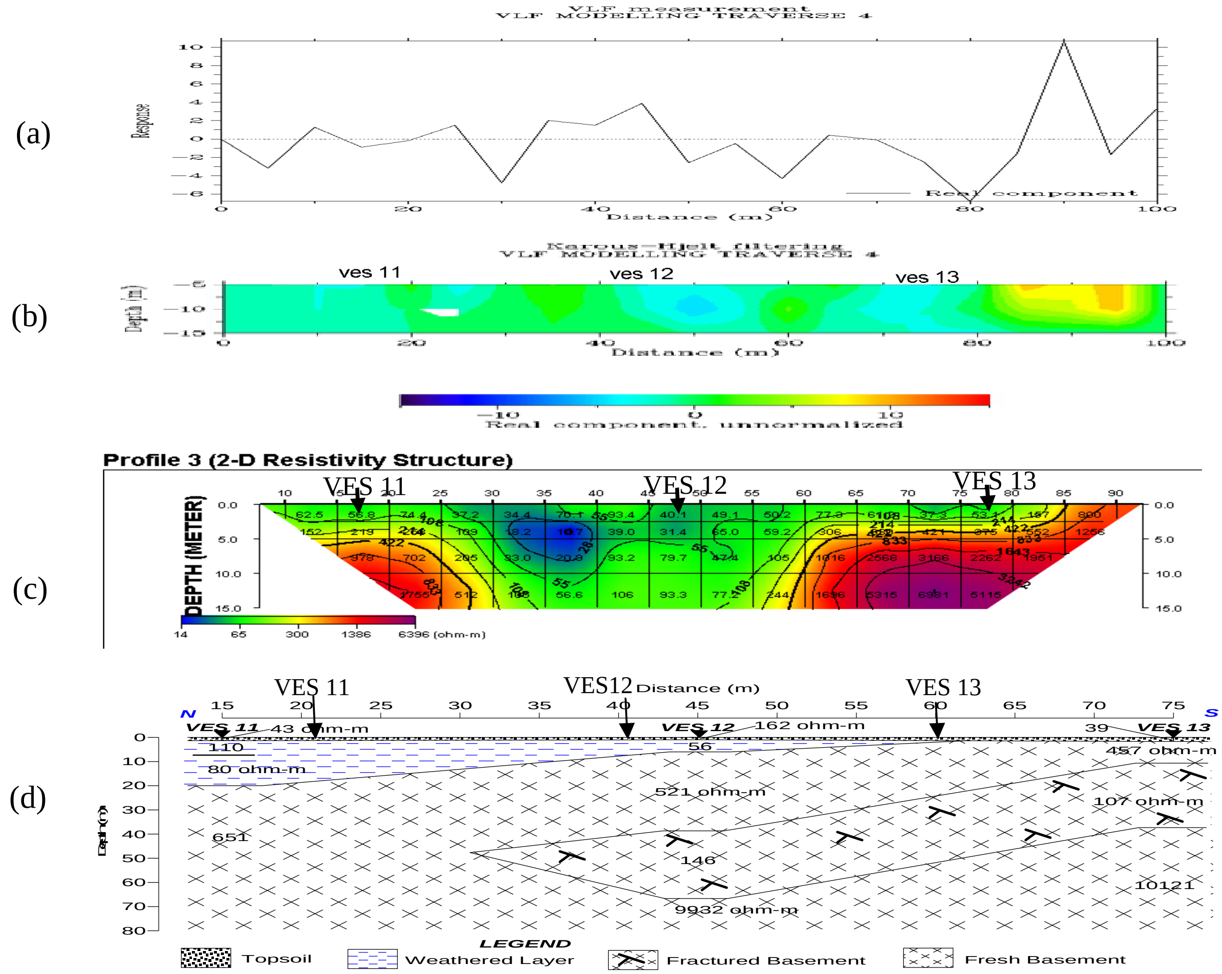

Fig. 6: Correlation of (a) VLF-EM Profile, (b) VLF-EM 2-D Model (c) 2-D Resistivity Structure and (d) Geoelectric section Along Traverse 3

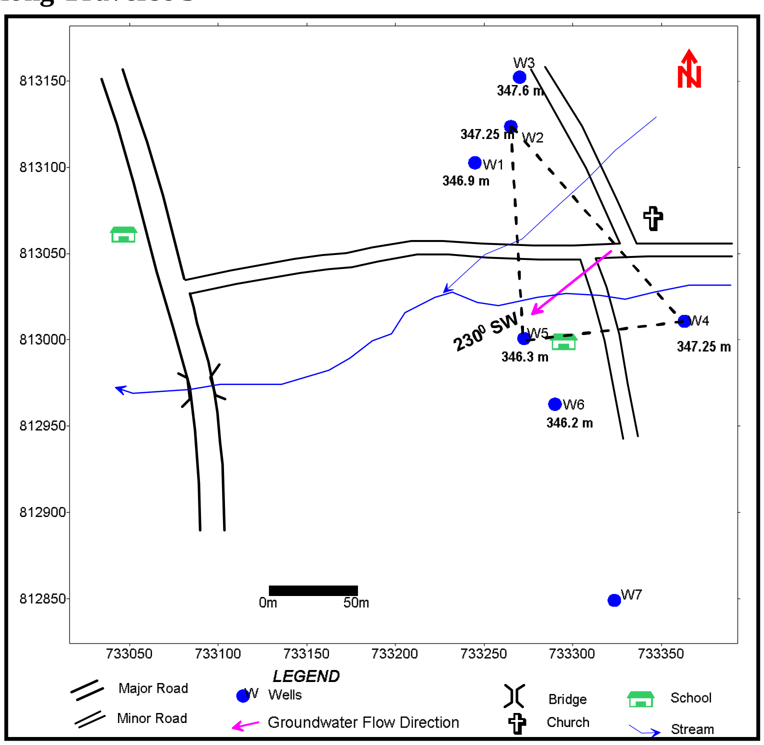

Fig. 7: Map of the Study Area Showing the Groundwater Flow Direction around the Dumpsite