

APPLICATION OF 2D DIPOLE IMAGING IN GROUNDWATER CONTAMINATION STUDIES OF SABON-LAYI AND ITS ENVIRONS, KEFFI, CENTRAL NIGERIA

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Abstract

The long-time practice of careless disposal of commercial, electronic and domestic wastes especially along stream channels in Sabon-Layi and its environs, in the ancient city of Keffi, Central Nigeria could lead to groundwater contamination from leachates of some dangerous heavy metals emanating from the open wastes, thereby rendering it unsafe for use since majority of the inhabitants of the area depend on groundwater from shallow hand dug wells. The area comprises of low lying schist and weathered gneissic rocks exposed on the surface, with presence of mainly joint, faults and exfoliations. A groundwater contamination study was conducted with a total of nine water samples - five from hand dug wells and four from boreholes, collected within the area for chemical analysis of some harmful heavy metals. Results obtained revealed the presence of As, Ba, Cd, Cu, Fe, Mn, Pb and Zn with range values of 0.21-0.80, 0.51-0.80, 0.05-0.33, 0.70-4.90, 0.95-1.00, 0.05-1.37, 0.10-0.74 and 2.10-3.90 respectively in five hand dug wells samples, implying that except for Cu and Zn, other metals analyzed are present in amounts above the WHO and NSDWQ quality standards making the water unsafe for consumption. However, heavy metal contents in the four borehole water samples all fall below the WHO and NSDWQ standard with range values of 0.001 – 0.008, 0.02– 0.40, 0.002-0.005, 0.008-0.017, 0.44-1.05, 0.16- 0.52, 0.001-0.014, and 0.038-0.138 for As, Ba, Cd, Cu, Fe, Mn, Pb and Zn respectively which means they are safe for consumption. Results of calculation of contamination status indicate slight heavy metal contamination for waters in shallow wells in the area under investigation. 2D electrical resistivity tomography using dipole configuration was conducted on two profile lines spread across the area to depict plume locations and extent. Results show the presence of plumes in Sabon-layi and Kofar Kokona indicated as areas of appreciably low resistivity values ranging from 1.0 ohm/m to 20 ohm/m at shallow depths of 3 m to 7 m. These areas should be avoided during water well constructions and groundwater should be obtained from wells with depth of 25 m and above in the area.

Keywords: Waste disposal, Groundwater contamination, Tomography and Consumption

INTRODUCTION

Wastes, according to Wikipedia are unwanted or unusable materials arising from human activities that are discarded either after primary use, or because it is worthless, defective and of no use. Waste disposal has become an integral aspect of man's daily activities and a possible source of environmental contamination. Dumping of refuse in Sabon Layi and its nearby areas

has been a long-time practice and water required for drinking and other domestic uses by most of the residents is obtained from shallow hand-dug wells which in most cases are carelessly sited very close to the open waste dumpsites, pit latrines, sewage systems rendering the water highly prone to chemical as well as biological contamination. Waste disposal sites contain some poisonous substances, most

of which are metallic bio- accumulators whose negative effects on living things (humans) may not be felt immediately. These substances may dissolve in rain water, percolate to join the groundwater and consequently contaminate it depending on some factors such as the geology of the area, the structures present, and the amount of poisonous substances available. Some immediate consequences of this unfortunate situation on the water supply systems are the prevalence of water-borne diseases like guinea worm, cholera and typhoid fever. This calls for concern therefore creating the need to investigate the water quality and possible underground contaminant plumes over Sabon Layi and its surrounding areas through chemical as well as geophysical means.



Plate 1(a & b). Sections of Open waste dumps in Sabon Layi (N8°50'12.6" E7°52'18.9")

The electrical resistivity imaging technique is an appreciable tool for delineating the degree and extent of contamination owing to the resistivity contrast between the contamination zone and the immediate subsurface vicinity (Enikanselu, 2008). The technique is fast to use, and economical in delineating ground water contamination zones, as well as other environmental issues. Though the technique is not used to directly detect contaminants, it is used in the delineation of the geological environment through which the contaminants move, and in the determination of the distribution of contaminant in space and time through monitoring, hence the need for direct geochemical investigation. Using electrical resistivity methods, the presence of underground contaminants plume over an area can be depicted as areas with a very low resistivity values which can be differentiated with that of pure water and other rocks (Pomposiello, Dapeña, Favetto and Boujon, 2012).

The study area is Sabon Layi, a nucleated settlement located in the ancient town of Keffi, North Central region of Nigeria, seated on the Basement Complex rocks comprising mainly of schists, migmatite-gniesses intruded by biotite granites with pegmatite veins in places. It is geographically sited within latitude N8°50'10" to N8°51'15" and longitude E7°51'40" to E7°52'20 " part of Keffi Sheet 208NE, published by the Office of the Surveyor General of the Federal Republic of Nigeria (2008). Two contrasting climatic

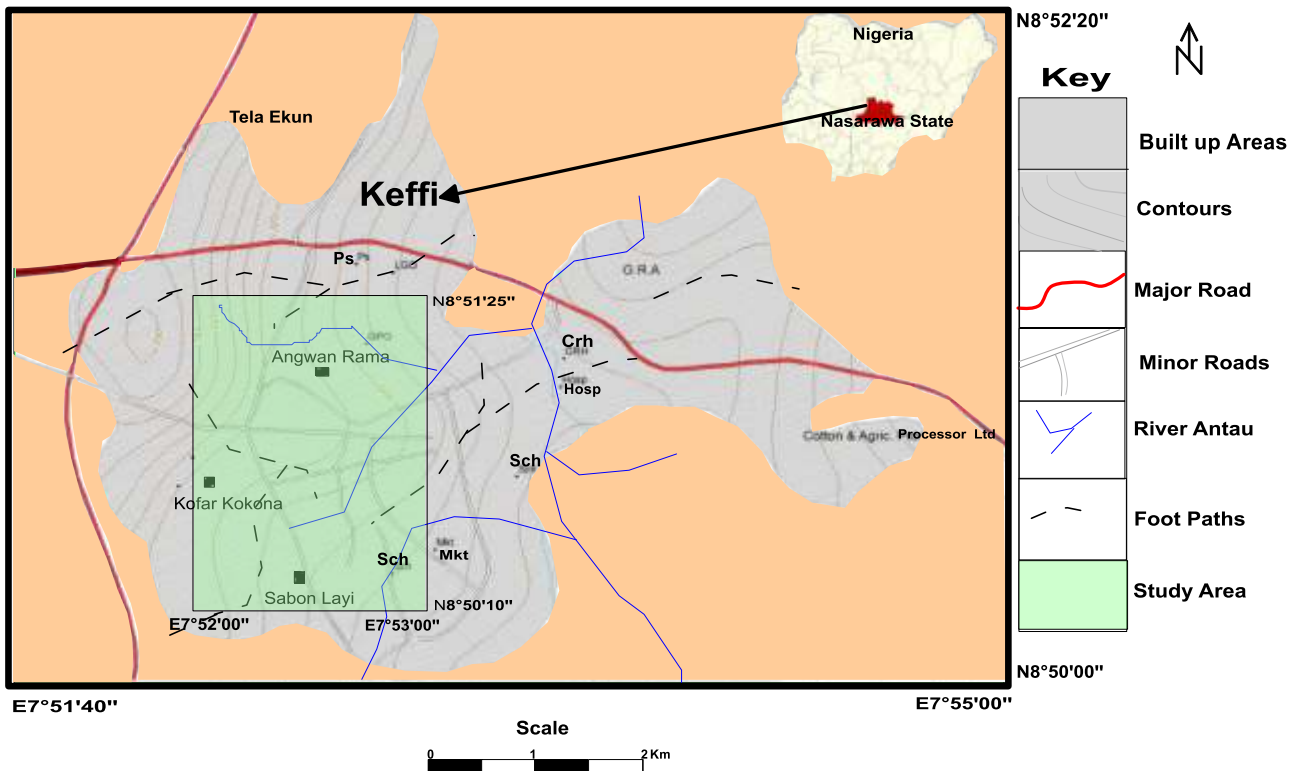


Figure 1: Location Map of Keffi Town (Inset: The Study Area)

conditions characterizes the area, namely; the rainy and dry season. The Harmattan (dry and dusty wind) experienced from November to January also characterizes the dry season. The area is covered mainly by lowlands, with the highest elevation rising to a height of about 350 m on the popular Maloney Hill, an igneous intrusion outcropping around the area. Prominent drainage features comprise of several running water bodies (streams) along channels which drain in a dendritic manner into the SW trending River Antau. Vegetation of the area falls under the Guinea Savanah with a mixture of trees, shrubs and grasses (NASEEDS, 2005). Indigenous tribes in the area include Hausa, Fulani, Eggon, and Mada.

Geology of the Study Area

Rocks in the area include biotite granite, pegmatites, granite gneiss, banded gneiss, and schists. The medium grained

granite gneiss outcrops are characterized by the presence of mainly feldspars, biotites and quartz with alternating light (quartz - feldspathic) and dark (ferro magnesian) mineral bands (Plate 2). They are exposed in places such as Angwan-Rama, GRA, under Antau Bridge (dipping 38°W); some of them also display porphyroblastic texture. The southern part of Keffi, particularly areas around Sabon Layi and Keffi south secondary school compose of low lying schists striking NE –SW and dipping 42°W along a stream channel in Angwan Kutare area (Plate 3). They are mainly composed of prominent flakes of muscovite minerals. The most prominent outcropping granite is the Maloney Hill which intrudes into the pre-existing gneissic rocks around karoffi area of Keffi town. It mainly consists of biotites with other minerals such as quartz, feldspars and Muscovites (Plate 4).



Plate 2: Banded Gneiss N8°51'47.2" E7°52'04.6"

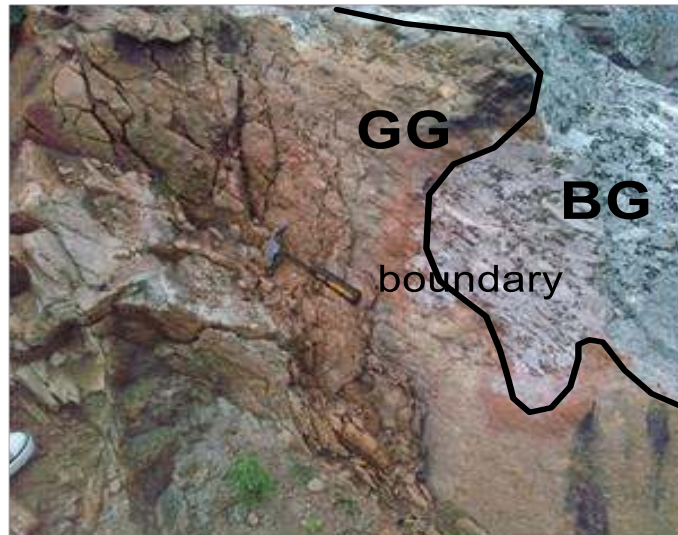


Plate 3: Schist N8°50'07.7" E7°52'50.4" (Angwan Kutare)



Plate 4 : Biotite Granite (N8°51'47.2" E7°52'04.6")

A Sharp contact exists between the biotite granite and the granite gneiss at the foot of the Maloney Hill (Plate 5). Pegmatitic veins, which host minerals such as tourmaline cuts through many of the outcrop in the area (Plate 6). Plate 7 shows joint sets observed on schist, outcropping around Keffi South Secondary School trending in the NNE –SSW direction. Laterally displaced faults were recorded on the outcropping gneiss, schist and granite (Plate 8). Exposures of gneiss and schist appear to be dipping and presence of structures indicates tectonism that most probably accompanied the regional magmatic intrusion and this serves as a good condition for secondary porosity in rocks of the area which could store viable amounts of groundwater that could be exploited for use in the area (Indicating that the area has potential for groundwater availability).



**Plate 5: Contact between Gneiss and Granite
N8°51'47.2" E7°52'04.6"**



Plate 6: Pegmatitic veins N8°51'15" E7°51'10.4"

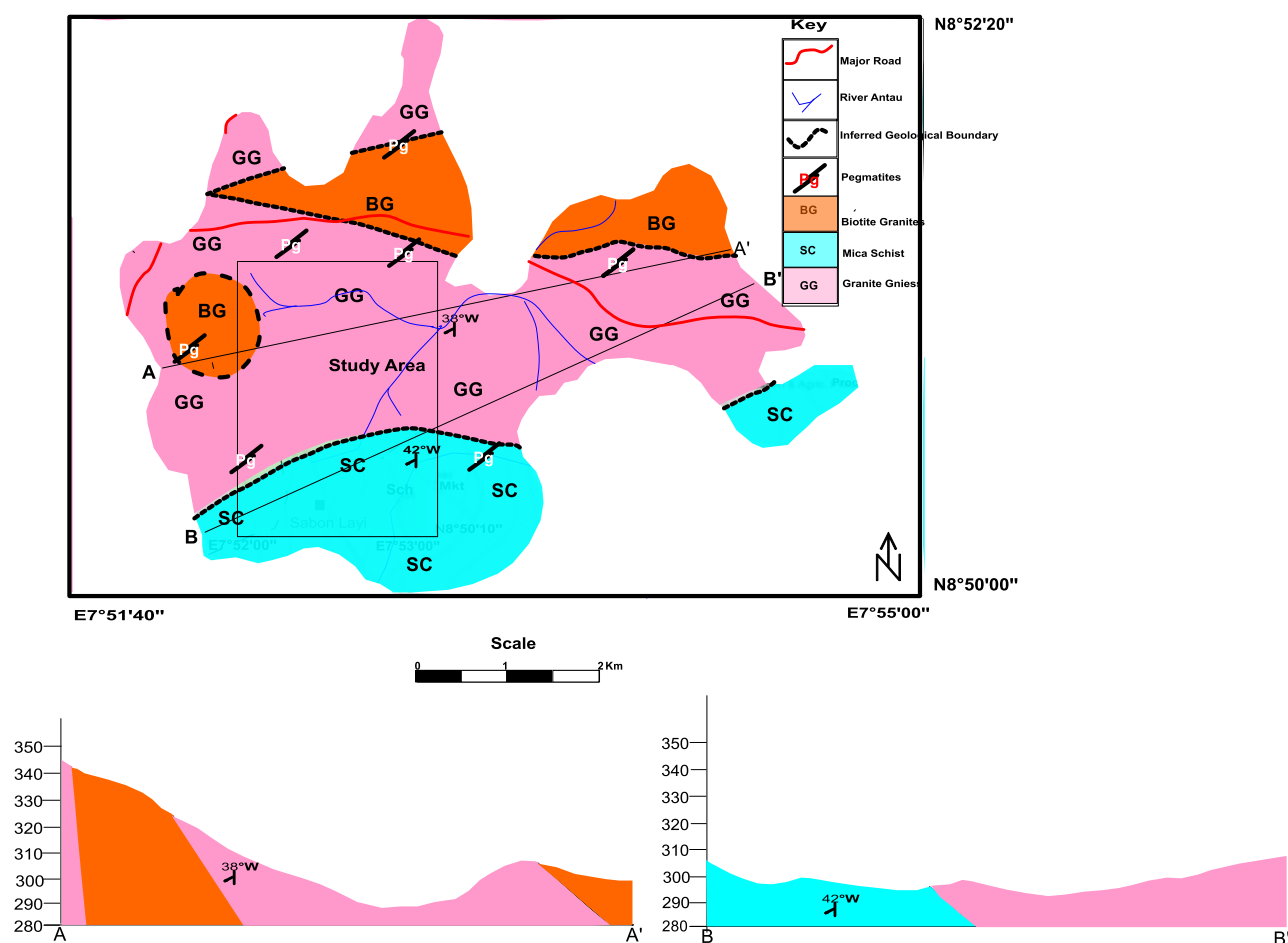


Plate 7: Joints. N8°51'49.1" E7°53'05.7"



Plate 8: Faults. N8°51'49.1" E7°53'05.7"

Figure 2 illustrates the geological map of the Study area in Keffi town generated from field mapping exercise.



METHODOLOGY

Methods adopted for this study include; geological mapping, physico-chemical water sampling and geo-electrical resistivity survey. Surface geological mapping was conducted to delineate the major rock units and structures which influence contaminants transport under the earth surface. A total of nine (9) water samples were collected (five from hand dug wells and four from boreholes) for physical tests attained in-situ using a digital physical parameter testing kit while geochemical analysis carried out at Acme Analytical Laboratory, Vancouver, BC, Canada using the ICP-MS method to analyze for heavy metals in the water samples. Results obtained were processed using the contamination indices to determine the level of heavy metals contamination of groundwater in the area. Data was further compared with the Nigerian Standard for Drinking Water Quality (NSDWQ, 2005) the World Health Organization (WHO, 2011) quality standards.

The Metal Pollution Index (MPI) approach was used in this study to assess the overall effect of individual parameters on the general water quality (Tamasi and Cini, 2004). MPI connotes the sum of the ratio between the analyzed parameters and their equivalent standard values. It can be calculated using the equation below after Sarala and Uma (2013);

$$MPI = \text{Log} \sum_{n=1}^{10} \left(\frac{x}{\text{Ref}} \right) \quad \dots 1$$

Where x is the concentration value of obtained for a given heavy metal and Ref is the Recommended Permissible limits.

2D geo-electrical survey which provides horizontal and vertical pictures of the sounding mediums was conducted using the dipole array with an Omega Ohms Terameter along three profiles spread within the study area. C_1 , C_2 and P_1 , P_2 electrode pairs are maintained apart at a regular distance (a) from each other and are progressively moved along the profile line on the earth surface (Loke, 1999). At every step, a measurement is taken and at the first inter-electrode spacing, the set of all measurements gives a profile of resistivity values. The inter-electrode spacing is further increased by a factor $n = 2$, taking a second set of resistivity measurements. Factor n was increased repeatedly until the maximum desired spacing between electrodes was reached; the larger the n -value, the greater the depth of investigation (for this study, an imaging depth of 25 m was considered). Sets of data obtained were processed using the RES 2D inversion software (Loke, 1997).

RESULTS AND DISCUSSION

Geochemistry

Results of chemical water analysis are presented in Table 1 and 2.

Table 1 Result of Chemical analysis for Heavy metals in Borehole water samples

Sample No.	As	Ba	Cd	Cu	Fe	Mn	Pb	Zn
BH1	0.001	0.02	0.004	0.017	1.05	0.38	0.014	0.138
BH2	0.001	0.04	0.002	0.009	0.59	0.25	0.009	0.047
BH3	0.008	0.09	0.002	0.008	0.44	0.16	0.008	0.038
BH4	0.002	0.40	0.005	0.015	0.92	0.52	0.001	0.108
Range	0.001	0.02	0.002	0.008	0.44	0.16	0.001	0.038
	–	–	–	–	–	–	–	–
	0.008	0.40	0.005	0.017	1.05	0.52	0.014	0.138
WHO (2011)	0.01	0.7	0.003	2	-	0.4	0.01	3
NSDWQ (2005)	0.01	0.7	0.003	1	0.3	0.2	0.01	3

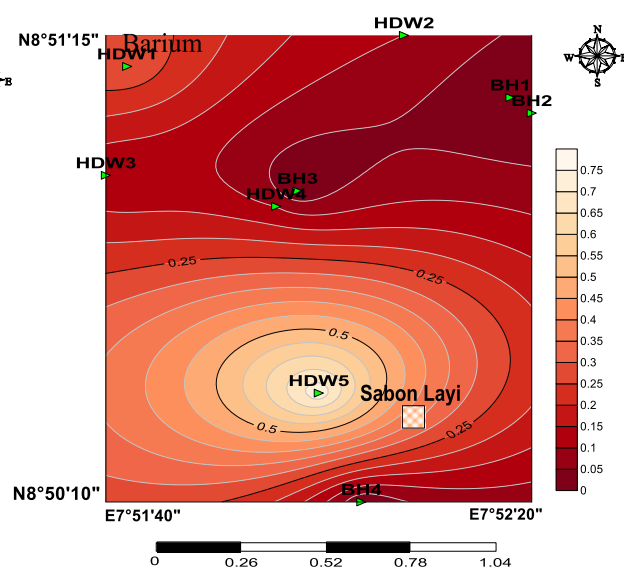
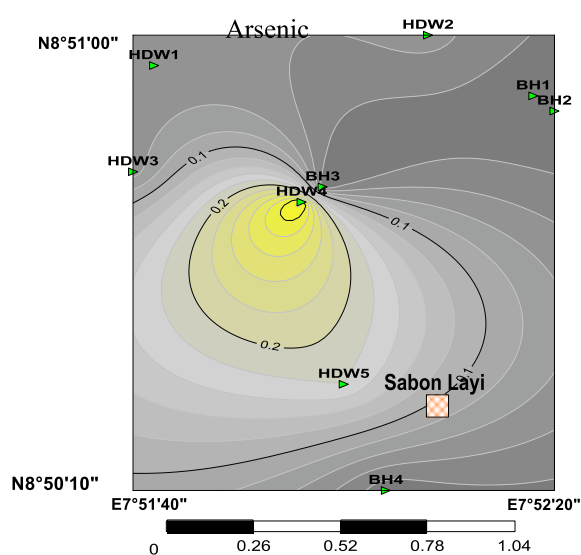
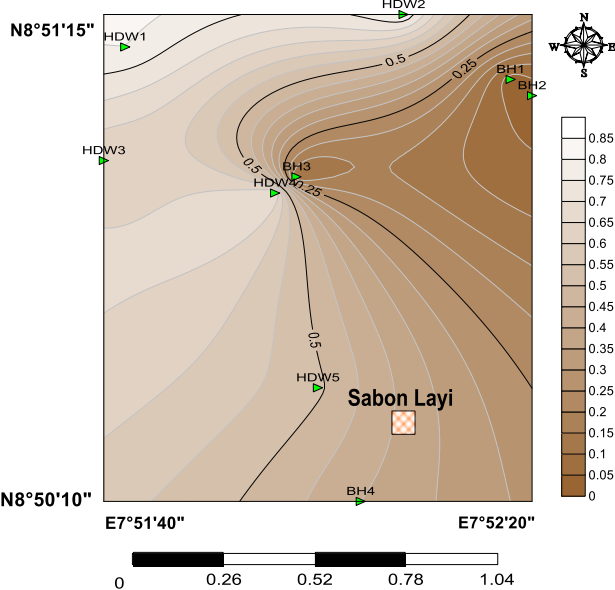
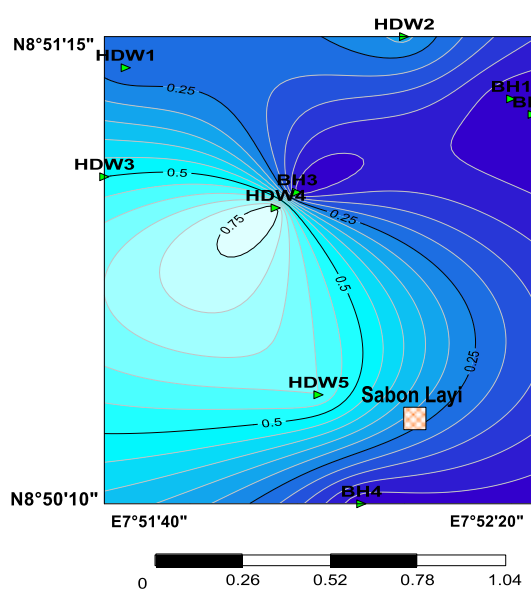
Table 2 Result of Chemical analysis for Heavy metals in Hand-dug wells water samples

Sample No.	As	Ba	Cd	Cu	Fe	Mn	Pb	Zn
HDW1	0.21	0.80	0.05	0.70	1.0	0.23	0.30	3.90
HDW2	0.32	0.80	0.05	1.20	1.0	0.80	0.10	2.10
HDW3	0.50	0.60	0.05	2.10	1.0	0.05	0.10	3.30
HDW4	0.80	0.70	0.33	4.90	1.0	0.51	0.10	2.30
HDW5	0.60	0.51	0.18	1.09	0.95	1.37	0.74	3.57
Range	0.21	0.51	0.05	0.70	0.95	0.05	0.10	2.10
	–	–	–	–	–	–	–	–
	0.80	0.80	0.33	4.90	1.00	1.37	0.74	3.90
WHO (2011)	0.01	0.7	0.003	2	-	0.4	0.01	3
NSDWQ (2005)	0.01	0.7	0.003	1	0.3	0.2	0.01	3

From Table 1, heavy metals content in all boreholes water samples (BH1 to BH4) fall below the WHO and NSDWQ permissible limits, meaning that residents of Sabon-Layi and its surrounding areas can rely on groundwater from boreholes with depth of 25 m and above for drinking and other domestic purposes. However, Iron (Fe) appears to be above the permissible limits. Deely and Fergusson,

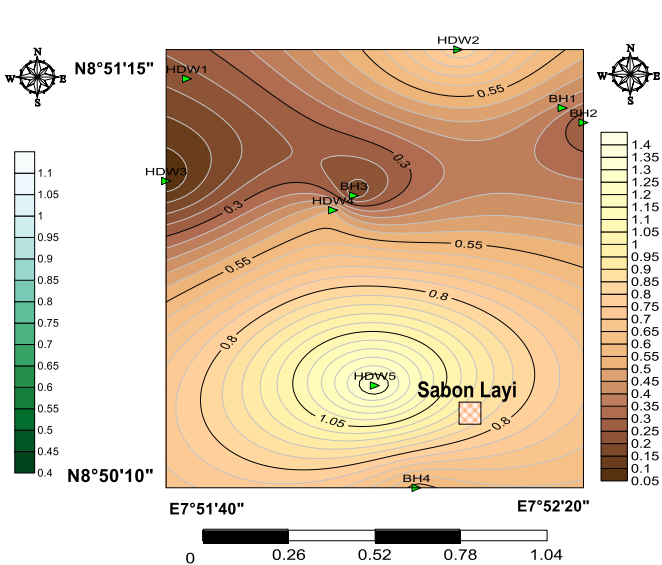
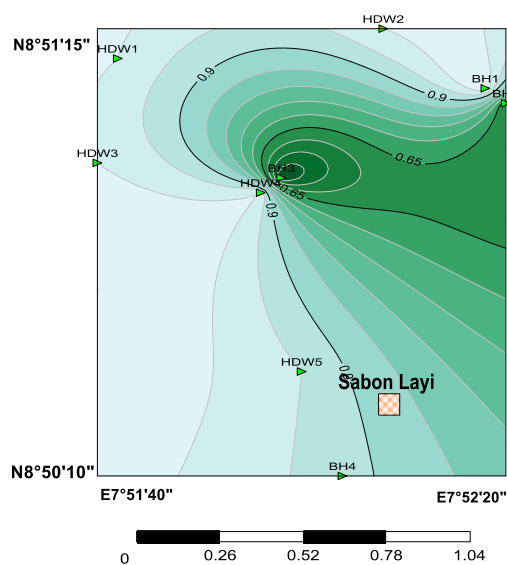
(1994) considered that the distribution of iron may not necessarily be related to other heavy metals concentration, it has a relatively high natural concentration from geogenic sources and may not be toxic.

Figure 3 to 10 below depicts the distribution of analyzed heavy metals in the study area. Heavy metals concentrations are higher at shallow depths (HDW).



Cadmium

Copper



Iron

Manganese

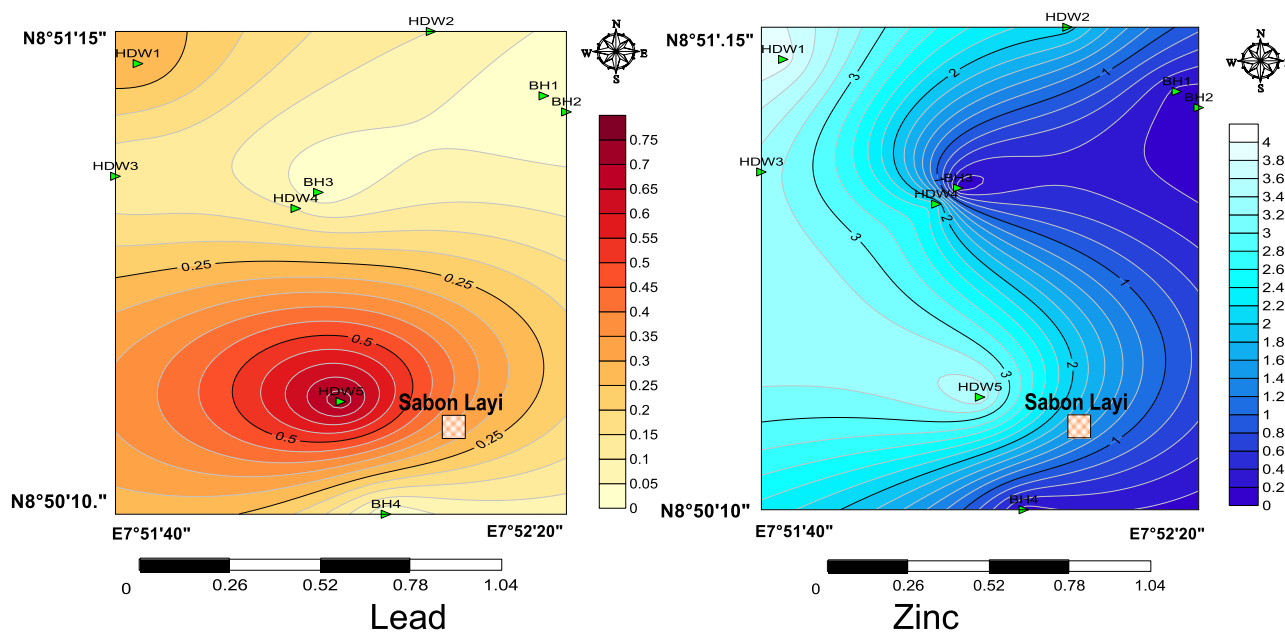


Figure 3:Concentration of Heavy Metals t in groundwater within Sabon-Layi

Figure 4 shows the mean concentrations of heavy metals in Sabon Layi and its surroundings. The continual drinking of water from the hand-dug wells whose heavy metal concentrations exceed the standard permissible limits of WHO and NSDWQ could lead to heavy metal poisoning which

causes cancer, heart disease, thickening of skin or numbness. The permissible boundary of barium in potable water is 0.7 mg/l (WHO, 2011) but the concentration of barium in HDW 1 and 2 (both 0.80 mg/l) falls slightly above the permissible limit and is considered not very safe for drinking.

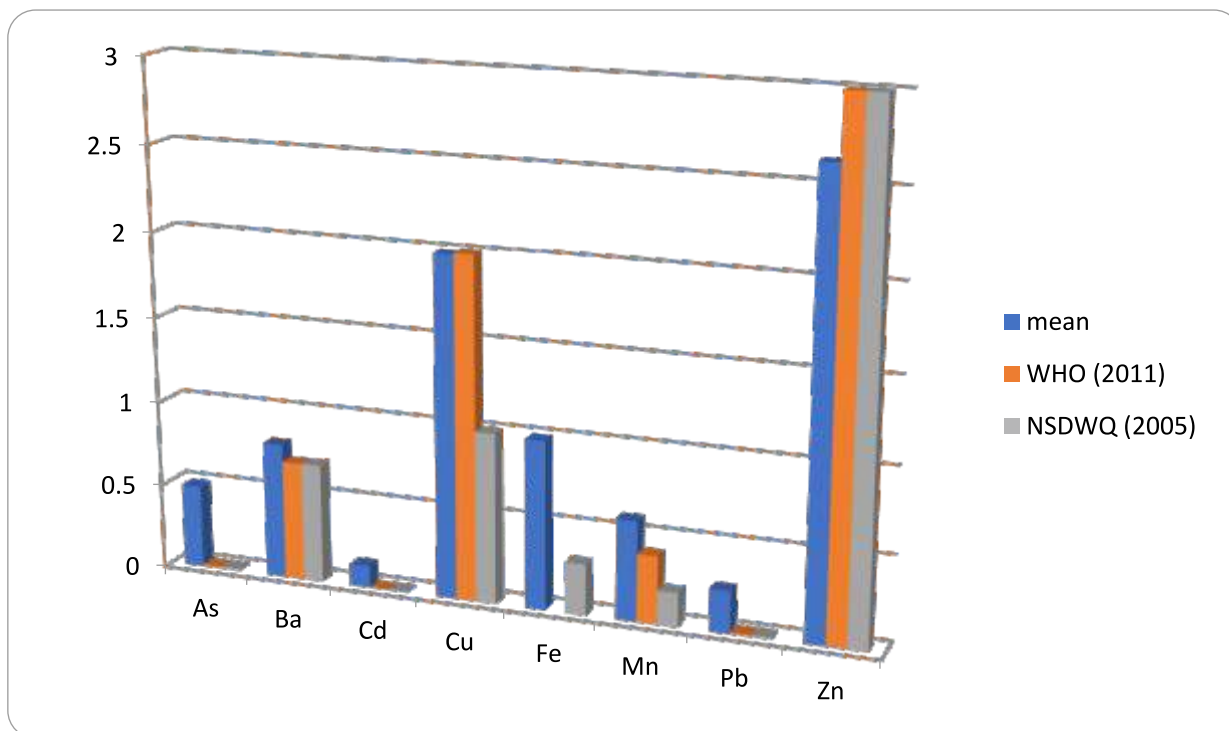


Figure 11: Graph of mean Concentration of Heavy metals in the Study Area versus their Max. Permissible limits

The same applies for Cadmium (Cd), Iron (Fe), Lead (Pb), and Manganese (Mn) which are capable of accumulating in human's body system for a long time,

causing metal poisoning. However, Copper (Cu) and Zinc (Zn) falls within the permissible limits of WHO and NSDWQ in the hand dug wells water samples.

Heavy Metal Pollution Index

Table 3: Results of computed Metal Pollution Index for samples in shallow Hand dug wells

Metals	Mean concentration x	Reference value Ref	x/ref
As	0.49	0.01	49
Ba	0.85	0.7	1.21
Cd	0.13	0.003	43.3
Cu	1.99	1	1.99
Fe	0.99	0.3	3.3
Mn	0.59	0.2	2.95
Pb	0.25	0.01	25
Zn	2.63	3	0.88
		Σ	127.6
		MPI = log Σ	2.1

The computed MPI given in Table 3 MPI is 2.1. This is greater than 1, indicating that the study area is anthropogenically contaminated with heavy metals, although of a slight degree.

Geophysics

Results of 2D geo-electrical profiling conducted in the study area are depicted as 2D Resistivity Structures (Figure 4 & 5) and interpreted in accordance with Omolayo & Tope, (2014). Profile Line 1 is located in Sabon-Layi and stretches up to 75m, trending in the NE-SW direction. Three zones were delineated in this profile as follows (Figure 4):

Zone A consist of regions with low resistivity values ranging between 13 to 50 ohms/m. These regions are interpreted as areas containing the leachate plumes (the

blue coloured portions in Figure 4) generated from the open waste dump. This zone could be said to be impacted by heavy metals leachates. These leachate plumes are seen to occur sparsely at shallow depths between 0 m to 3m on the eastern and western ends of profile line 1 respectively, which spreads gently into the more competent Zone B, with resistivity values ranging between 55 ohms/m to 238 ohms/m (greenish to yellowish portion of Figure 4). This zone could be regarded as slightly disturbed to negligibly disturbed zone. The presence of weathered and/or fractured basement in these regions renders them susceptible to contamination. The plumes spread from east and west of the profile line at depths of about 5 m into the middle areas of the profile, reaching a depth of about 25 m

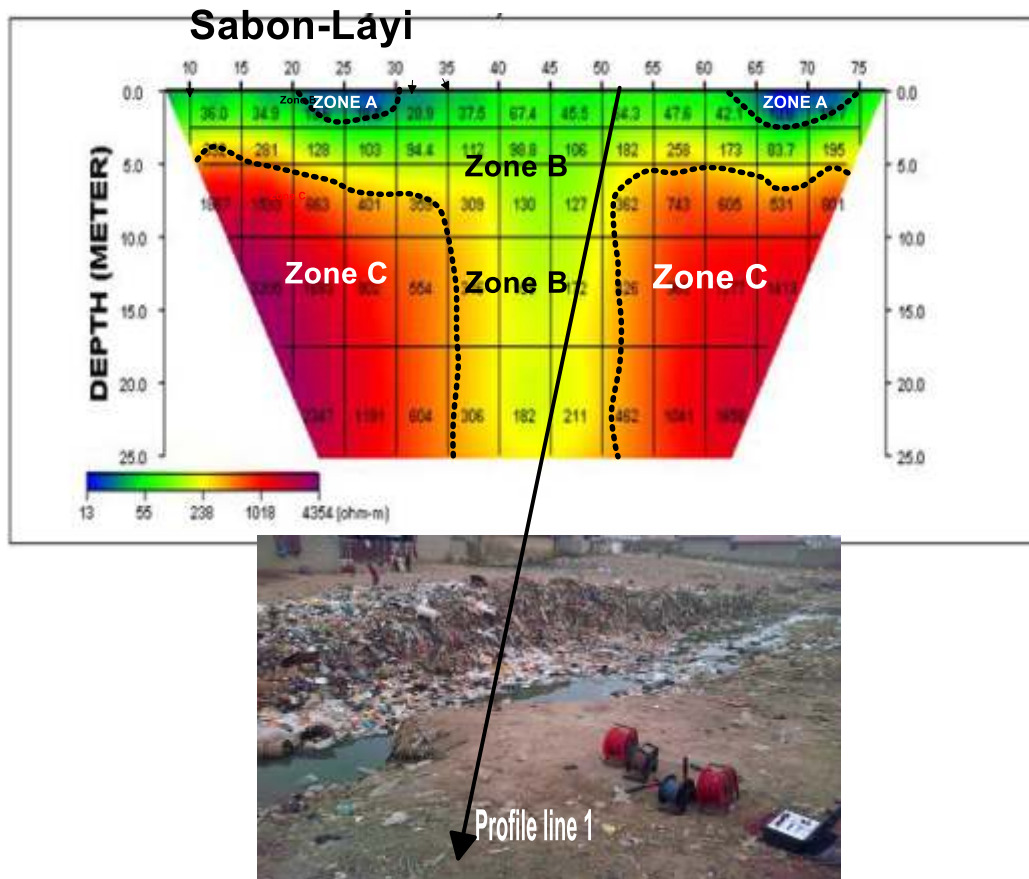


Figure 4: 2D Resistivity Structure of Profile line 1, Sabon Layi (N8°50'12.6" E7°52'44.9")

which shows that these layers are porous and permeable. Predominant schists in the area could be responsible for impeding heavy metals contaminants in the open dump from travelling into deeper layers as they are observed just close to the surface. Zone C (red-pink coloured areas), consist of the undisturbed zone which is not affected by the leachate plume. High resistivity values between 1018 ohms/m to 4354 ohms/m suggest that these regions consist of fresh rocks. This goes in line with the geochemical analysis results which revealed contamination only for water samples at shallow depths.

Profile line 2 is also located along a stream channel in Kofar Kokona. Due to inaccessibility as a result of urbanization

and rugged topography of the area, a profile length of 45 m was covered from west to east. Four zones were delineated for profile line 2 (Figure 5) as follows:

Zone A (the bluish coloured areas) consists of regions with resistivity values ranging between 5 ohms/m to 15 ohms/m described in this study as highly impacted zones, containing the leachate plumes. This zone can be observed slightly occurring very close to the surface at the beginning of profile line 2 which tends to attenuate as it spread into the surrounding zones. The leachate plumes tend to have higher impact on the surrounding rocks beneath profile line 2 probably due to the presence of more structures compared to profile 1. The highly-impacted zone is seen

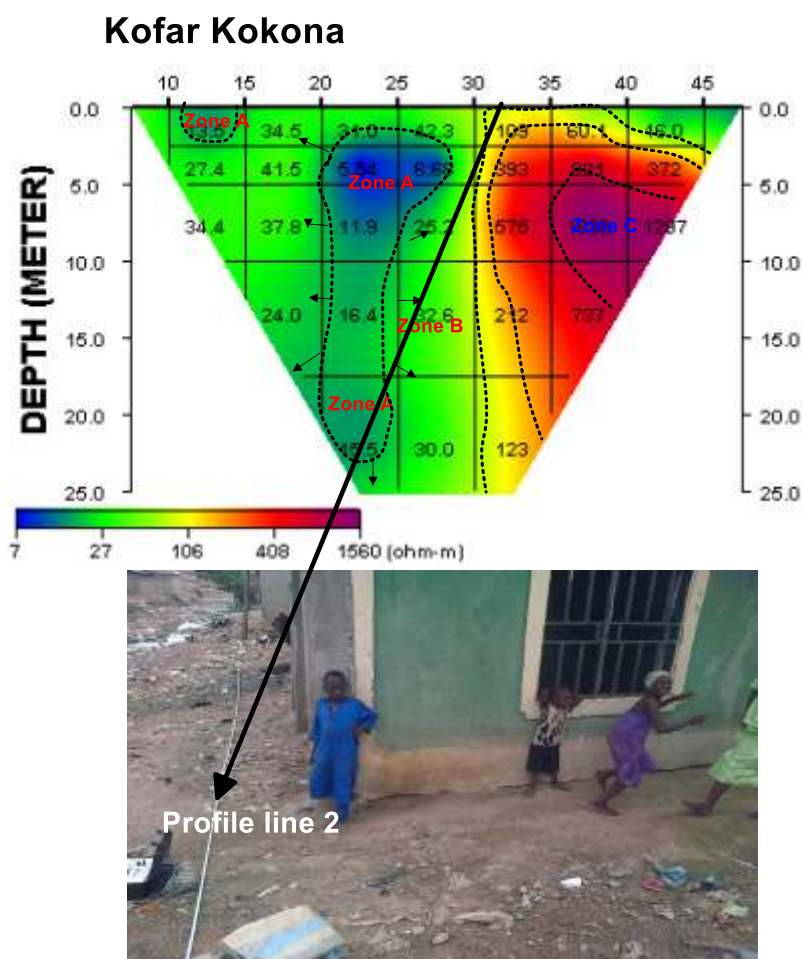


Figure 5: 2D Resistivity Structure of Profile line 2, Kofar Kokona (N8°50'26.3" E7°52'56.5")

to be confined around west to the middle of profile 2, reaching a depth of up to 20 m. It may be that the plume was trapped in a less permeable rock, which transmits it gradually into the surrounding Zone B with resistivity value ranging between 27 ohms/m to 100 ohms/m described here as the impacted zone (the greenish coloured areas). Zones C and D indicate the slightly/negligibly disturbed zones and undisturbed zones respectively. It can be stated that rock competence increases from west to east for the area cover in profile 2.

CONCLUSION

From geological, geochemical and geo-electrical investigations conducted in Sabon-Layi and its environs, rocks play a major role in the mode of contaminants travel. Schists, predominant in the area tend to prevent heavy metals contaminants from leaching into deep seated aquifers as geochemical water analysis revealed contamination for waters in shallow wells (less than 10 m deep) and non-contamination for waters in more deeply seated aquifers (20 to 30 m deep). Confirming the geochemical analysis results, the generated 2D resistivity images showed areas of appreciably low resistivity

values obtained in upper layers (0 to 7 m), with proportionally high resistivity values at deeper layers. The application of 2D dipole survey method to the geochemical results lead to the conclusion that in profile 1, the upper layers retain contaminants from the open wastes dump sites, preventing them from further leaching into the more competent rocks as against profile 2, with more weathered/fractured zones. For Sabon-Layi and its surrounding areas, it is safe to obtain drinking water from boreholes with depths of 25 m and above.

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