ASSESSMENT OF LEACHATE CONTAMINATION OF GROUNDWATER USING GEO-ELECTRICAL AND PHYSICOCHEMICAL METHODS AT ALBISHIRI, MINNA, NORTHCENTRAL NIGERIA

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ABSTRACTS

Assessment of leachate contamination of groundwater was carried out at Albishiri landfill, one of the old and major waste disposal sites in Minna. The geo-electrical method namely Vertical Electrical Sounding (VES) and Induced Polarisation (IP); and physicochemical analysis of sampled water were applied to assessing the leachate contamination of the subsurface resource. Two parallel profiles at the margins of the landfill consisting of 18 VES and IP stations were investigated. Interpretation of the data was done using the 1-D iterative program IPI2win. The results obtained show that the area is generally underlain by three geologic formations (lateritic top soil, weathered/fractured basement and fresh basement) corresponding to the geo-electric models. However, where the basement has experienced more weathering leading to fracturing of the basement rocks, four layer models were obtained. Leachate plume seepage and contamination is at varying moisture content and depth. Prominent areas with significant IP effect, permeability and overburden thickness of 15 m and above were located at the eastern region of the landfill. The rate of leachate contamination at the study area was found to be 0.7 m per year. Physicochemical analysis of the water sampled indicated elevations in chromium and iron with values of 0.06 mg/L and 0.31 mg/L. These were clearly above the recommended guideline for quality drinking water thus, may be detrimental to human health.

INTRODUCTION

Albishiri is a neighbourhood in Minna the capital city of Niger State and it lies within 9.5869° and 9.5865° N; 6.5069° and 6.5074° E. The landfill at Albishiri resulted from the deposition of domestic or municipal waste on an excavated land. This is the case in most parts of the city and its environs where municipal wastes are disposed indiscriminately. Leachate generates in a landfill from the flow of percolating water through the waste materials which then seeps through the soil under the site (Olowofela and Akinyemi, 2001). Contamination of the groundwater takes place when the leachate reaches the water table (Osazuwa and Abdullahi, 2008a).

Groundwater has been a major source of water supply in Minna metropolis, just as most arid regions hence, the mode of disposal of municipal waste that could have direct consequence on the quality of water for the consumption of the populace is of greater concern. Groundwater is usually located in the weathered layer, joints, fractures and faults of host rock in basement complex (Rafiu and Mallam, 2014).Hence, there is the need to delineate and monitor leachate migration path through the weathered and fractured basement that forms the aquifer unit of the study area.

METHODOLOGY

Geophysical Survey

Two parallel profile lines were sectioned at the margins of the disposed waste at landfill. Resistivity data were collected using a terrameter or resistivity meter (ABEM SAS4000). Vertical Electrical Sounding (VES) mode was deployed using the Schlumberger array to enable investigation of the depth penetration of contaminant plume. The VES readings were measured at 7.5 m inter VES spacing with a maximum current separation of 160 m and potential electrode separation of 30 m. The maximum current separation of 160 m was due to residential inhibition. VES points were used to pick the induced polarization (IP) readings. A total of 18 VES and 18 IP station data were recorded on the waste and its control site (6 sounding stations on each margin of the waste disposal site and 6 stations on the control site respectively). The control site was 10 m westward away from the exposed site (Figure 1).

The initial resistance field values in ohms was recorded and used to calculate the apparent resistivity values afterwards, using the appropriate geometric factor. An iterative 1-D software program IPI2win was used for data analysis. Pseudo-sections, resistivity cross sections, digitized resistivity and chargeability layer curves or log graphs and resistivity-depth tables were generated.

Physicochemical Survey

A shallow well was dug at the down gradient on the waste site in order to carry out physical and chemical analysis of sampled water. The second well had been in the neighbourhood. The wells named Abishiri well$_1$ and Albishiri well$_2$-(control) located at 20 m in the south direction and 30 m in the north direction away from the landfill site respectively were examined. The physical and chemical analysis of the sampled groundwater was done at the Federal Ministry of Water Resources Regional Water Quality Laboratory, Minna according to APHA (1995). Two samples were collected, acidified with dilute nitric acid and stored in a refrigerator prior to the chemical analysis. Determination of physical parameters (turbidity, pH, total dissolved solid, conductivity, temperature, dissolved oxygen, total hardness and alkalinity) involved the use of test equipment and models such as multi-purpose meter/multi 3420, turbidity meter/wag – NT 3020 and titration apparatus. The equipment Hach Colorimeter/DR890 and titration apparatus was used to determine the chemical parameters of the water sampled. Some trace elements like manganese, zinc, copper, fluoride were also examined and determined using standard methods of analysis.

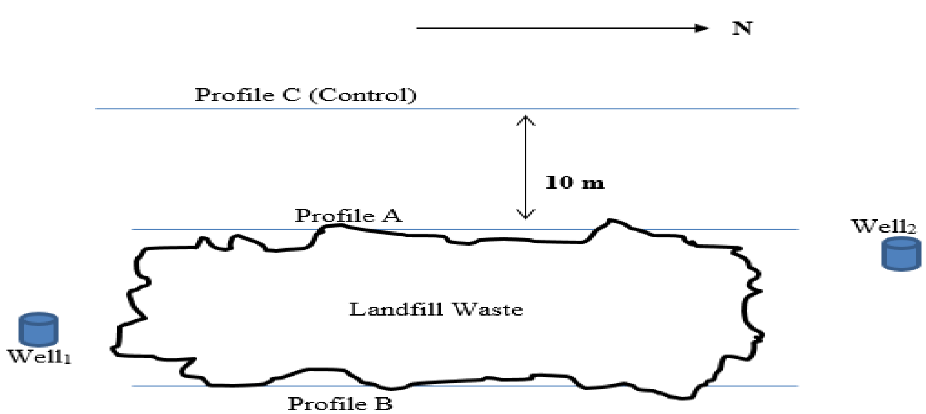

Figure 1: Profile Layout of Albishiri Waste Disposal and Control Site

Results and Discussions

There are six VES points on each profile. The first profile referred to as Albishiri landfill A as presented in Figure 2 had three and four distinct layers observed on the profile showing H, HA, KH and KQ curve types (Table 1). Maximum first layer thickness is 1.09 m at VES A_1 and a minimum of 0.87 m at VES A_3, as resistivity ranges between 135 Ωm and 2663 Ωm. Second layer resistivity ranges between 13.0 Ωm and 297 Ωm with a maximum layer thickness of 6.69 m at VES A_2 and the minimum thickness of 0.04 m at VES A_5. The last layer resistivity also ranges between 581 Ωm and 33,182 Ωm.

The three geo-electric sections have a topsoil first layer and at VES A_1 it had isolated resistivity of near surface basement material. The second layer is the weathered/fractured basement which has very low resistivity values for most VES points (A_2 – 50.6 Ωm, A_3 – 34.8 Ωm, A_4 – Ωm, A_5 – 23.6 Ωm, A_6 – 26.0 Ωm) compared to the resistivity values of the VES points on the control profile C (C_1 - 132 Ωm, C_2 – 99.7 Ωm, C_3 – 521 Ωm, C_4 - 633 Ωm, C_5 - 171 Ωm, C_6 - 145 Ωm) which were mostly higher as presented in Figures 1 and 2. Leachate diminishes the electrical resistivity of the formation containing them hence, the presence of leachate on the waste site (Martinho and Almeida, 2006). Horizontal trending of leachate migration southward is evident across the VES points on the profile at varying thickness and moisture content. Leachates migrate from a waste deposit in the direction of water flow (Jegede *et al.,* 2011). Hence, leachate permeability through these layers peaked at 10.04 m as was the case on VES A_4. The third layer is the fresh basement.

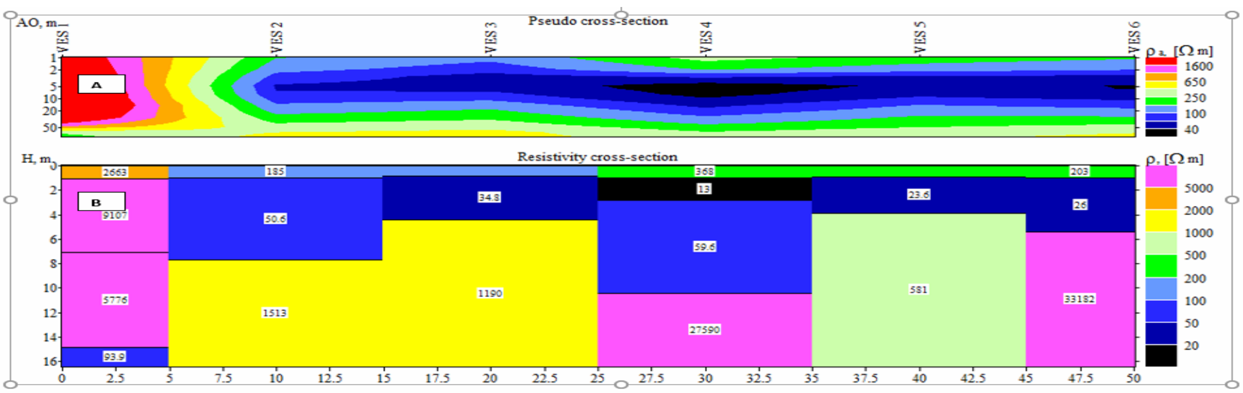

Figure 2: (a) Pseudo cross-section (b) Resistivity cross-section along profile AL A

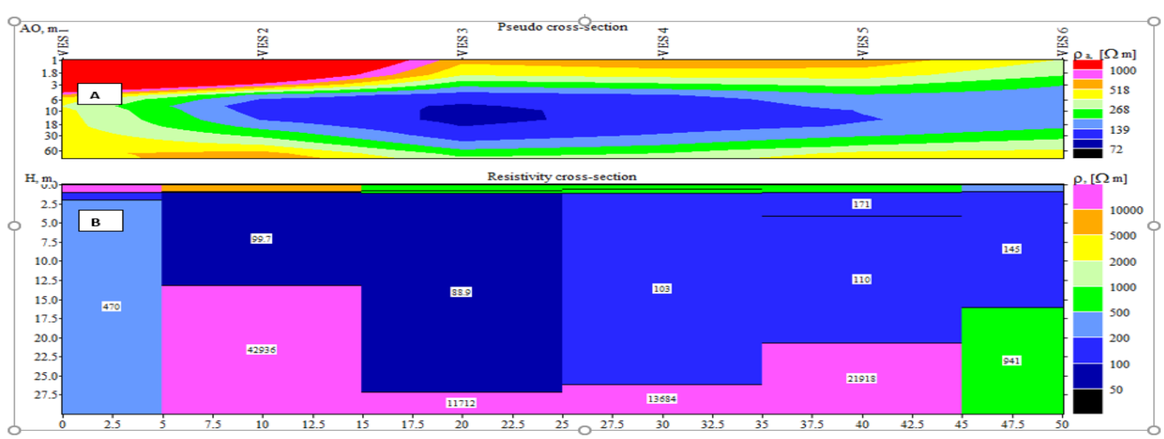

Figure 3: (a) Pseudo section (b) Resistivity section along profile AL Control

Effect of IP on profile A indicated increased chargeability values moving downwards from the first layer to the second as presented on Table 1. Considering VES A_3, the resistivity value lowered from 135 Ωm to 34.8 Ωm as chargeability value increased from 1.95 msec to 2.29 msec. This characteristic is same for VES A_4 and A_6. However, chargeability variations on VES A_2 and A_5 at the second layer with corresponding low resistivity may be due to the porous nature of the saturated weathered layer with contaminant leachate plume resulting from the increase in salinity of groundwater and disseminated organic waste (Barker, 1990). VES A_2 and A_5 with chargeability values > 16 msec can be interpreted as IP-effect resulting from mineralization in the contact metamorphism zone between the weathered and the fresh basement rock (Dahlin *et al.*, 2002).

Table 1: VES and IP Interpretation along Profile A

VES PT	No of Layers	Type of layer curve	Resistivity (Ωm)	Chargeability (η_a)	Layer thickness (m)	Depth from the surface (m)
A_1	1	HQ	2663	1.40	1.09	0.00
	2		9107	3.87	6.01	1.09
	3		5776	3.48	7.77	7.10
	4		93.9	1.98	∞	14.9
A_2	1	H	185	3.27	0.98	0.00
	2		50.6	0.83	6.69	0.98
	3		1513	23.6	∞	7.67
A_3	1	H	135	1.95	0.87	0.00
	2		34.8	2.29	3.52	0.87
	3		1190	9.37	∞	4.39
A_4	1	HA	368	2.13	0.98	0.00
	2		13	2.89	1.86	0.98
	3		59.6	7.60	7.56	2.84
	4		27590	2.18	∞	10.4
A_5	1	KH	262	2.23	0.88	0.00
	2		297	2.93	0.04	0.88
	3		23.6	0.50	2.94	0.92
	4		581	16.2	∞	3.86
A_6	1	H	203	2.53	0.96	0.00
	2		26	2.62	4.47	0.96
	3		33182	2.54	∞	5.43

Similarly, profile Albishiri landfill B consist of six VES stations as presented in Figure 4 which has three and four layers that are prominent on the profile having a characteristic H, AA and QH curve types (Table 2). The first layer has resistivity ranging between 9.93 Ωm and 342 Ω m and thickness ranging between 0.50 m and 1.02 m. Second layer resistivity ranges between 10.9 Ω m and 195 Ω m with maximum thickness of 4.60 m situated at VES B_2 and the minimum thickness of 0.06 m stated at VES B_5. Third layer resistivity ranges between 11.6 Ωm and 82.8 Ωm. The last layer resistivity also ranges between 1303 Ω m and 16,510 Ωm.

The geo-electric section has first layer topsoil, second layer weathered/fractured basement and the fresh basement. Very low resistivity at the second and third layer ranging between 10.9 Ω m and 195 Ω m, is an indication of the presence of leachate contamination likely due to disseminated organic matter as posited by Rafiu and Mallam (2014) derivable from the downward seepage around the region of VES B_1as presented in Figure 4. First layer low resistivity at VES B_1 with 9.93 Ωm indicated the presence of leachate contamination and a soil rich in disseminated organic matter (Meju, 2006) which seeped down the subsurface. However, high first layer resistivity between VES B_2 and B_6 is indicative of lateritic/sandy topsoil. In fact, VES B_1 and B_5 situate the highest level of leachate contaminant plume (deep blue colour scale on Figure 4) on the profile. In comparison with the control profile, the second and third layer resistivity are in contrast. The control profile had very high resistivity which was an indication of the absence of contamination.

Increased chargeability noticed on VES B_2 from 1.72 msec to 4.45 msec correlates with the lowered resistivity values from 155 Ωm to 28.2 Ωm. This characteristic is same for VES B_4 and B_5 at the second and third layer. However, chargeability value variations on VES B_1, B_3 and B_6 at the second layer without corresponding low resistivity may be due to structural variation (primarily clay control) and salinity of water (Osazuwa and Abdullahi, 2008b). This is further confirmed by the significant IP effect exhibited between the first and second layer and the varying degree of thickness, weathering and moisture content of the leachate seeping down and transiting the entire profile represented by the blue colour variation in Figure 4. This is in consonance with the work of Jegede *et al* (2011). The very high chargeability of 20.5 msec seen in Table 2 on VES B_4 may be resulting from mineralization in the contact metamorphism zone between the weathered and the fresh basement rock (Dahlin *et al*.2002).

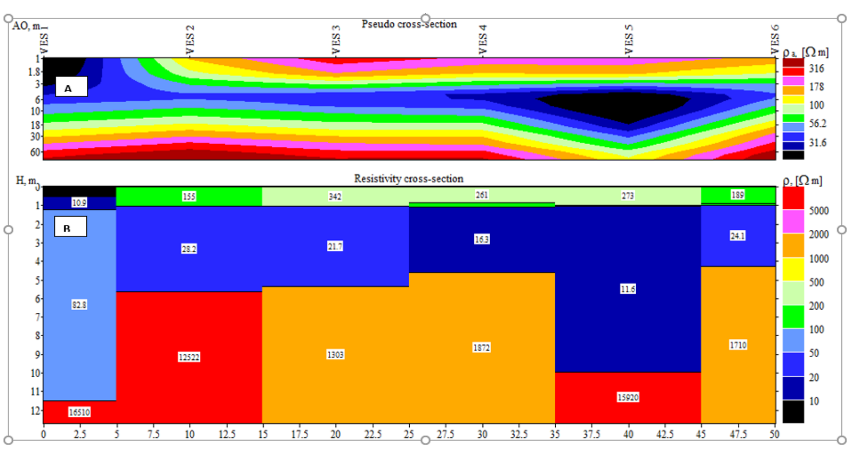

Figure 4: (a) Pseudo cross-section (b) Resistivity cross-section along profile AL B

Table 2: VES and IP Interpretation along Profile B

VES PT	No of Layers	Type of layer curve	Resistivity (Ωm)	Chargeability (η_a)	Layer thickness (m)	Depth from the surface (m)
B_1	1	AA	9.93	0.58	0.50	0.00
	2		10.9	1.86	0.70	0.50
	3		82.8	4.44	10.3	1.20
	4		16510	1.25	∞	11.5
B_2	1	H	155	1.72	1.02	0.00
	2		28.2	4.45	4.60	1.02
	3		12522	2.19	∞	5.61
B_3	1	H	342	2.68	1.02	0.00
	2		21.7	2.15	4.35	1.02
	3		1303	5.71	∞	5.37
B_4	1	QH	260	2.49	0.87	0.00
	2		195	2.84	0.20	0.87
	3		16.3	2.74	3.52	1.06
	4		1872	20.5	∞	4.59
B_5	1	QH	273	2.76	0.98	0.00
	2		163	2.75	0.06	0.98
	3		11.6	3.24	8.92	1.03
	4		15920	2.76	∞	9.95
B_6	1	QH	189	4.26	0.89	0.00
	2		130	6.62	0.09	0.89
	3		24.1	2.39	3.31	0.99
	4		1701	3.62	∞	4.29

Geologic Sections of Albishiri Waste and Control Sites

The geologic sections of the Albishiri waste and control sites are presented in Figures 5a and 5b. Albishiri waste has three geologic sections which is the first layer topsoil, second layer weathered/fractured basement and the fresh basement which is similar to the work Mohammed *et al*. (2007). Similarly, the control site also has three geologic sections corresponding to the geo-electric sections.

The resistivity of the first layer ranges between 145 Ωm and 355 Ωm, and the corresponding thickness is between 0.69 m and 4.15 m. Second layer resistivity ranges between 12.3 Ωm and 71.2 Ωm and the corresponding thickness is between 4.08 m – 10.95 m. The third layer has resistivity ranging between 526 Ωm – 38,059 Ωm. The second layer in this case forms the region of the leachate contaminations up to the depth of 11 m as presented in Figure 5a and it is in agreement with the resistivity cross section. However, comparing these features with the control that is an aquifer bearing uncontaminated region as presented in Figure 5b; the extent of leachate permeability through the profiles on the waste site is within depth of the aquifer zone. This agrees with the work of Ehirim and Ofor (2011).

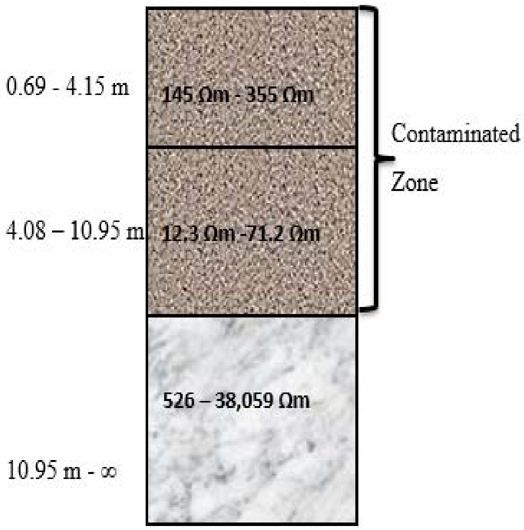

Figure 5: (a) Geologic Section of Albishir Waste Disposal Site

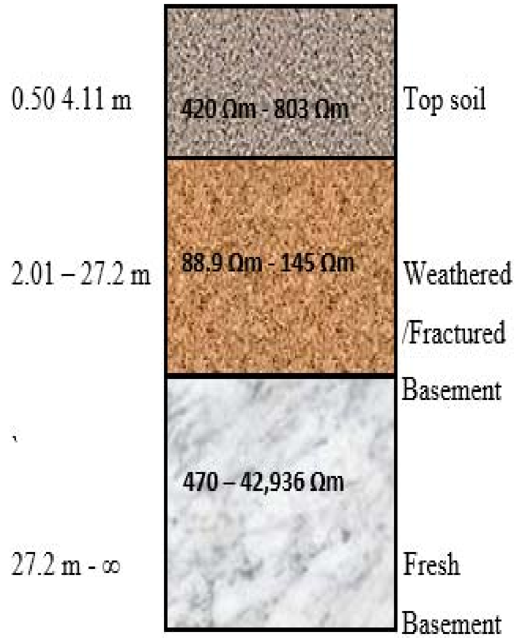

Figure 5: (b) Geologic Section of Albishir Control Site

Physicochemical Analysis of Water

There were elevations in some physical and chemical parameters based on the World Health Organization (WHO, 1993) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) that indicated contaminations that are summarised in Table 3.

Physical parameters investigated on Albishiri $well_1$ and Albishiri $well_2$-(control) included total dissolved solid (TDS) with the values 549 mg/L and 209 mg/L respectively; conductivity (703 µS/cm and 308 µS/cm); turbidity (25.4 NTU and 3.68 NTU); pH (7.56 and 8.63) and temperature on field (33.0°C and 33.4°C). The TDS (549 mg/L) and turbidity (25.4 NTU) of Albishiri $well_1$ all exceeded the recommended limits of 500 mg/L and 5 NTU. More so, the conductivity of Albishiri $well_1$ with 703 µS/cm and Albishiri $well_2$-(control) with 308 µS/cm, are both high and conductive when compared with WHO guideline (1993). Some parameters examined for chemical properties included total hardness, total alkalinity, nitrate – nitrogen and nitrate. Others included iron, chromium, zinc, copper, lead, arsenic, nickel and fluoride. Those having significant elevations in $well_1$ and control $well_2$ are: fluoride (1.23 mg/L and 0.49 mg/L); zinc (2.20 mg/L and 0.56 mg/L); iron (0.31 mg/L and 0.12 mg/L); chromium (0.06 mg/L and 0.02 mg/L); nitrate (51.5 mg/L and 23.5 mg/L); nitrate – nitrogen (11.0 mg/L and 5.3 mg/L) and total hardness (149 mg/L and 72 mg/L). The elevation in nickel with the value of 0.01 mg/L and arsenic with 0.01 mg/L occurred only in $well_1$.

Furthermore, the elevations of chromium in Albishiri $well_1$of 0.06 mg/L and iron of 0.31 mg/L both exceeded the recommended limits of 0.05 mg/L and 0.3 mg/L. Total hardness in Albishiri $well_1$with the value of 149 mg/L and fluoride with 1.23 mg/L are a little less than the recommended limits of 150 mg/L and 1.50 mg/L by the NSDWQ. Those of nitrate (51.5 mg/L) and nitrate – nitrogen (11.0 mg/L) in Albishiri $well_1$ exceeded the recommended limits by 1.5 mg/L and 1.0 mg/L.

Table 3: Physicochemical Analysis of hand dug wells at Albishiri

Parameter	Method	Albishir Well$_1$	Albishir Well$_2$ (Control)	Nsdwq[1] 2007	Who 1993
Longitude (E)	GPS	6°30'49.4"	6°30'43.5"	N/A	N/A
Latitude (N)	GPS	9°35'15.7"	9°35'08.9"	N/A	N/A
Elevation (m)	GPS	235	234	N/A	N/A
TDS (mg/L)	APHA 2510B	549	209	500	500 – 550
Conductivity (µS/cm)	APHA 2510B	703	308	1000	100
Dissolved Oxygen (mg/L)	DO_2 Meter	5.40	6.64	N/A	N/A
Temperature (°C)	APHA 2550 B	33.0	33.4	AMBIENT	35 – 40
pH	APHA 4500H^+B	7.56	8.63	6.5 – 8.5	6.5 - 9.2
Turbidity (NTU)	Turbidity Meter	25.4	3.68	5	N/A
Total Hardness (mg/L)	APHA 2340C	149	72	150	500
Total Alkalinity (mg/L)	APHA 2320B	8	5	N/A	200
Nitrate – Nitrogen (mg/L)	APHA 4500NO_3^- B	11.0	5.3	10	N/A
Nitrate (mg/L)	APHA 4500NO_3^- B	51.5	23.5	50	N/A
Acidity (mg/L)	TITRIMETRIC	5	0	N/A	N/A
Manganese (mg/L)	COLORIMETRIC	0.13	0.04	0.2	0.5
Iron (mg/L)	APHA 3500-Fe D	0.31	0.12	0.3	0.3
Chromium (mg/L)	APHA 3500 – Cr^{+6} D	0.06	0.02	0.05	0.05
Zinc (mg/L)	APHA	2.20	0.56	3	3
Copper (mg/L)	APHA 3500 Cu-D	0.23	0.05	1	2
Lead (mg/L)	APHA	0	0	0.01	0.01
Arsenic (mg/L)	APHA	0.01	0	0.01	N/A
Nickel (mg/L)	APHA	0.01	0	0.02	0.02
Fluoride (mg/L)	APHA	1.23	0.49	1.50	N/A

[1] Nigerian Standard for Drinking Water Quality

Discussion

The study has shown that several VES points on the site are hydraulically active. The geologic sections indicated leachate contamination of the layers reaching 11 m on the landfill. Therefore, the rate of leachate contaminants migration is 0.7 m per year which is similar to the work of Andrews *et al.* (2011). Waste had been deposited for at least 15 years at Albishiri landfill.

Results of the physicochemical analysis of sampled water from the wells indicated elevations in most parameters, some of which were above the recommended guideline for drinking water. The contamination of sampled wells only confirms the presence of leachate contaminants that migrated through pore spaces of the subsurface materials which are interconnected. This is in agreement with Osazuwa *et al*. (2010). Rafiu, and Abu (2014) that also carried out similar studies in parts of Minna and environ showed reasonable presence and elevation of some heavy metals and trace elements.

Conclusion

Leachate contamination of the subsurface was observed on most part of the waste site, as varying degree of weathering and moisture content pervaded both the waste and control sites seen in the resistivity cross sections and geologic sections presented. Those prominent with significant IP effect, permeability and overburden thickness (i.e. 15 m and beyond) at the Albishiri site were located at VES C_3, C_4 and C_5 which are water bearing. Elevations in TDS and conductivity of water from Albishiri $well_1$ exceeded standard limits by 49 mg/L and 603 μS/cm. Turbidity that is a measure of clarity or degree, to which the water loses its transparency due to the presence of suspended particulates, far exceeded the allowable limit of 5 NTU. Albishiri $well_1$ is turbid compared to the control well and established standards. The temperatures of sampled water at Albishiri (33.0 ^oC – 33.4 ^oC) were all below the WHO limits. pH of both Albishiri $well_1$ and Albishiri $well_2$-(control) was found to be basic (7.56 and 8.63).

There are elevations in the concentration of some trace elements like manganese, zinc, copper, fluoride and other parameters like total hardness and alkalinity of Albishiri $well_1$ as compared to the Albishiri $well_2$-(control). This is a measure of the leachate concentrate and seepage though within permissible limits. However, Iron and chromium with 0.01 mg/L above the standard are hazardous. Elevations of Nitrate – Nitrogen and Nitrate in Albishiri $well_1$were 1.0 mg/L and 1.5 mg/L above recommended limits respectively. The rate of leachate contaminant migration at Albishiri waste site had been evaluated to be 0.7 m per year hence; it can graduate to about 20 m for a currently contaminated depth of 12 m in another ten years all things been equal which will set the health risk for drinking water at such neighbourhood at a peak if left unchecked.

Recommendation

The associated health risk from the findings of this study makes the following recommend-dation handy.

Sanitary land filling practice should be adopted. Materials (liners) that are naturally suited to protect the underground water or daily covers with soil cap to minimize water infiltration, mitigate odours and limit vector breeding should be used.

Future consideration for site selection of a disposal site should be based on geological and hydrogeological rather than geographical factors.

Drinking water in this area should be purified to forestall the risk of chromium and iron contaminants.

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