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EFFECTS OF POOR SOLID WASTE MANAGEMENT ON GROUNDWATER: A CASE STUDY OF DAMATURU, NORTHEAST NIGERIA

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ABSTRACT

Groundwater quality monitoring is very important in cities and towns where there were poor solid waste management. In this study, the effects of solid waste on groundwater in Damaturu Metropolis along Potiskum road was investigated using both electrical resistivity survey and hydro-chemical methods. The results of the study showed that the solid waste at the dump sites generate leachate which percolate into the subsurface to pollute the groundwater. Two aquifers were delineated in the study area and the ERT survey results showed that the groundwater in the first aquifer was contaminated. The contaminants were characterized by very low resistivity which distinguished them from their host rocks. The contaminants are highly conductive which indicate that they were inorganic and possibly of metallic origin. The results of the analyzed water samples from the study area revealed that heavy metals such as Cadmium, Arsenic, Iron, Chromium, and Lead were in elevated concentration in the groundwater of the study area. The first aquifer in the study area is semi-confined and its proximity to the earth surface made it much vulnerably to pollution. The second aquifer is confined by a very thick sandy-clay formation which protects it from pollution by contaminant plumes. It is the most appropriate for groundwater abstraction in the study area. Considering the health hazards associated with the consumption of polluted groundwater, we therefore recommend that all the hand dug wells and shallow boreholes in the study area should be closed down for safety and the solid waste dump sites should be evacuated.

Keywords: Solid waste, groundwater, contaminant plumes, leachate, confined aquifer, heavy metals, health hazards

INTRODUCTION

Groundwater is one of the most essential natural resources which support human life on Earth. In both semi-arid and arid regions, it is the main source of water for human consumption and economic activities. Groundwater is the main source of water for domestic, industrial and sometimes, it also a source of water for agriculture (irrigation farming) in Damaturu, Yobe State, Nigeria. The quality of groundwater resources is under threat due to poor solid waste management. The major sources of groundwater pollution are anthropogenic activities (Singh and Mosley, 2005). The open space solid waste disposal system which is mostly practiced in Nigeria is a great threat to both surface and groundwater. The rapid growth in towns and cities due to increase in population density and industrialization has led to the generation of tremendous volume of solid waste. The improper management of these waste has led to an increase in both air and water pollution. The pollutants generated by the solid waste in the presence of moisture or precipitation affect the quality of soil, groundwater and the ambient air. Leachate from the decomposition of solid waste is a well-known groundwater pollutant. Its composition varies from one place to another based on the amount of precipitation, quantity and type of waste disposed. About 3.4 million people die yearly because of water related diseases (WHO, 2000). The decomposition of solid waste introduce significant amount of heavy metals and pathogenic microbes into surface and groundwater (Uffia *et al*., 2013).

Leachate from solid waste dumpsite mostly contains chemical substances which might be toxic to both soil and groundwater, such chemical elements are calcium, potassium, manganese, chromium, nickel, lead, arsenic, copper, iron, ammonia, benzene, methane, etc. (Freeze and Cherry, 1979). These chemical substances in elevated concentration in both soil and groundwater could cause kidney infections, lung damage, cancer, liver and bladder complications (ASTDR, 2000). The impacts of leachate derived from solid waste on groundwater have attracted the attention of so many researchers (Mor *et al.*, 2006; Talalaj and Dzienis, 2007; Suresh and Kottureshwara, 2009; Akudo *et al.*, 2010; Rajkumar *et al*., 2010; Uchegbulam and Ayolabi, 2014). Geophysical study of the impact of solid waste on groundwater has not been carried out in Damaturu, despite the prevailing groundwater quality challenges in the area. Agada *et al*. (2020) investigated the impacts of leachate from solid waste on groundwater in Gashua using electrical resistivity method. In their study, they observed that the leachates generated by the solid waste from the dumpsite have migrated into the aquifer and thereby contaminated the groundwater. A similar study was also conducted by Mosuro *et al*. (2016) in Agbara industrial estate, Ogun State southwestern Nigeria. They investigated groundwater vulnerability due to leachate infiltration, using electrical resistivity method and their results showed that the leachate plume had migrated to a depth of 10 m into the subsurface. The leachate plumes were identified as low resistivity materials. Enikanselu (2008) also used electrical resistivity method to investigate the effects of solid waste from dumpsite on the aquifer units around Giwa-Okearo area of Ogun State. The results that he obtained showed that the well water in the study area were contaminated.

All the people in Damaturu depend on groundwater from boreholes and hand dug wells for both their domestic and industrial consumption. In view of the importance of groundwater to human life and activities, the quality of groundwater needs to be monitored and secured. The implications of the consumption of contaminated water have attracted the interests of many researchers due to its huge effects on human health and economic activities. In Yobe State, there were reports of health hazards associated with water pollution, and the need to curtail it is highly imperative, in order to prevent future health risks. Effective pollution prevention and control requires proper strategies which involves the identification and mapping of pollution sources, establishment of effective monitoring and evaluation systems. There is a need for public awareness on the dangers associated with the consumption of contaminated water. The vulnerability of groundwater resources to pollution is a function of its geological and hydrological parameters as well as the contaminants sources. Solid wastes such as metals, batteries, tires, paints, fertilizers, electronic devices, gas tanks, engine oil containers, radioactive waste from hospitals, animal waste and plastics, upon decomposition in the dumpsites in the presence of moisture and precipitation constitute both organic and inorganic leachates which are potential groundwater pollutants.

This study is aimed at assessing the impact of solid waste leachate on ground water resources in Damaturu. The results of this study will be helpful to police makers in both groundwater resources and environmental protection managements. The image of a typical dumpsite in Damaturu is shown in figure 1 below. This study was carried out around two dumpsites along Potiskum road in Damaturu and a chemical analyses of some water samples within the vicinity of the dumpsites were carried out.

Figure 1: Solid Waste Dumpsite along Potiskum Road, Damaturu.

MATERIALS AND METHODS

Materials

In this study, the geophysical study was carried out using the following instruments: ABEM SAS1000 Digital Terrameter, Reels of electrical cables, Cable Jumpers, Steel electrodes, Personal Computer, Global Positioning System (GPS), Hammers, Measuring Tapes and 12V Battery which was used to power the ABEM SAS1000 Terrameter. Software such as OriginPro 2017, RES2DINVX64 Ver.4.9.1., and WINRESIT version 1.0 were used to process the geophysical data. Water samples, Nitric acid (HNO_3), Atomic Absorption Spectrometer (AAS), and Filter paper were used for the hydro-chemical analysis.

The Study Area

Damaturu is located on latitude 11^o 39’N and longitude 11^o 54’E. It is situated within the Chad Basin and has a semi-arid climate characterized by short rainy season and prolong dry season. The people in Damaturu depend mostly on groundwater for their domestic and industrial consumption due to the scarcity of streams and rivers in the area. The groundwater in Damaturu is derived from the Chad Formation (Hess *et al*., 1996).

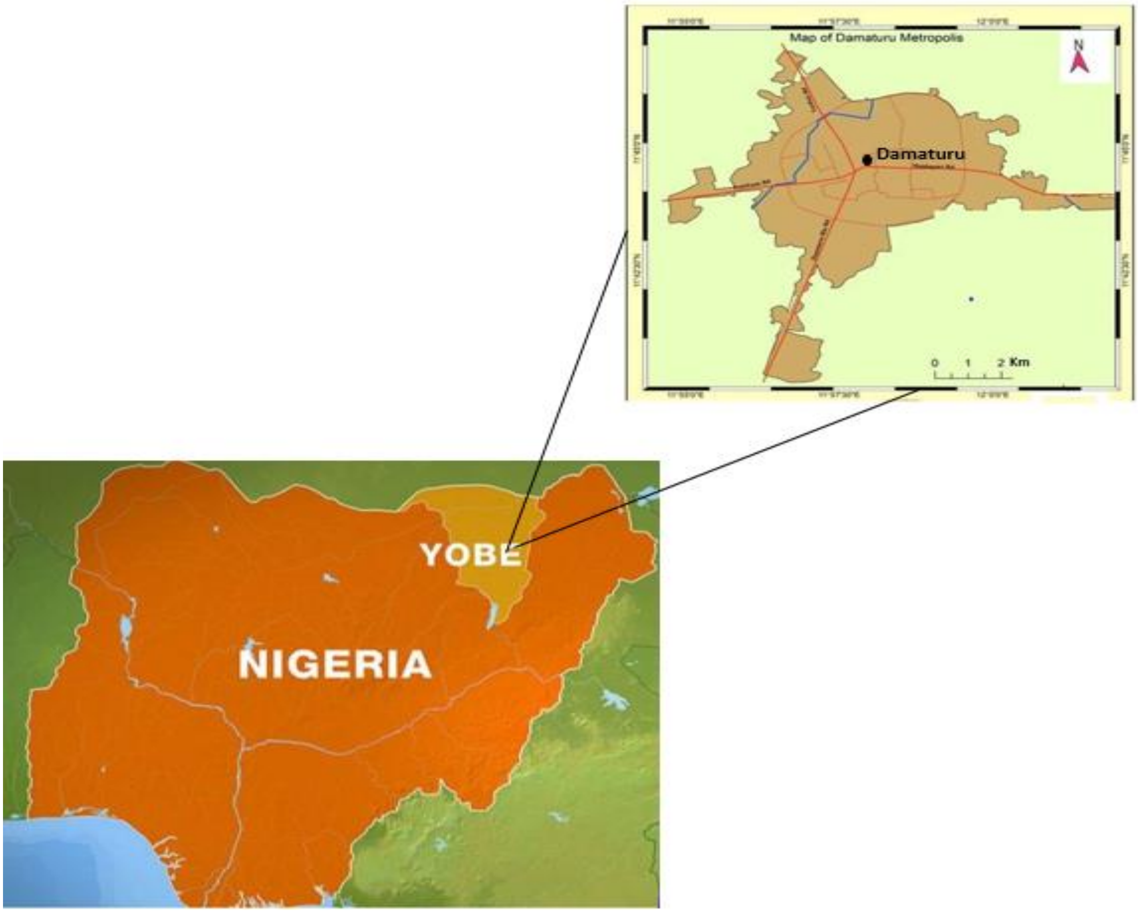

Figure 2: Map of Nigeria showing Damaturu in Yobe State

Field Measurements

An Electrical Resistivity Tomography (ERT) survey was carried out in the study area to elucidate the nature of the subsurface lithology. A Wenner-Schlumberger configuration using 42 electrodes separated by 2 m was used to obtain a 2-D image of the subsurface. The 2-D ERT data was acquired with an ABEM SAS 1000 Terrameter provided by the National Centre for Geodesy and Geodynamics Toro. The acquired 2-D data were processed to generate 2-D resistivity models using RESIST2DINV Software. The software discretized the surface model into a finite element model (Loke, 1999). The finite element model was automatically modified by an iterative process to enable it converge to the measured data.

Ten (10) vertical electrical resistivity soundings were also carried out in the study area with the aim to determine the various subsurface layers resistivities and thicknesses in the study area. A Schlumberger array was adopted to obtain a 1-D resistivity data of the study area. An ABEM SAS 1000 was used to acquire the data. The acquired data was interpreted by plotting the apparent resistivity values against the current electrode separation ($\frac{AB}{2}$) m. The apparent resistivity curves were partially curve matched with theoretical curves to obtain the input data for an iteration process. The data were further processed using WINRESIT Software version 1.0. The results from the graphs drawn by the processing Software shows the thickness, depth, and the true resistivity values of the various subsurface layers. The results obtained were correlated with an existing bore logs. The subsurface layers were characterized using Palacky 1988 true resistivity value charts (Figure 3).

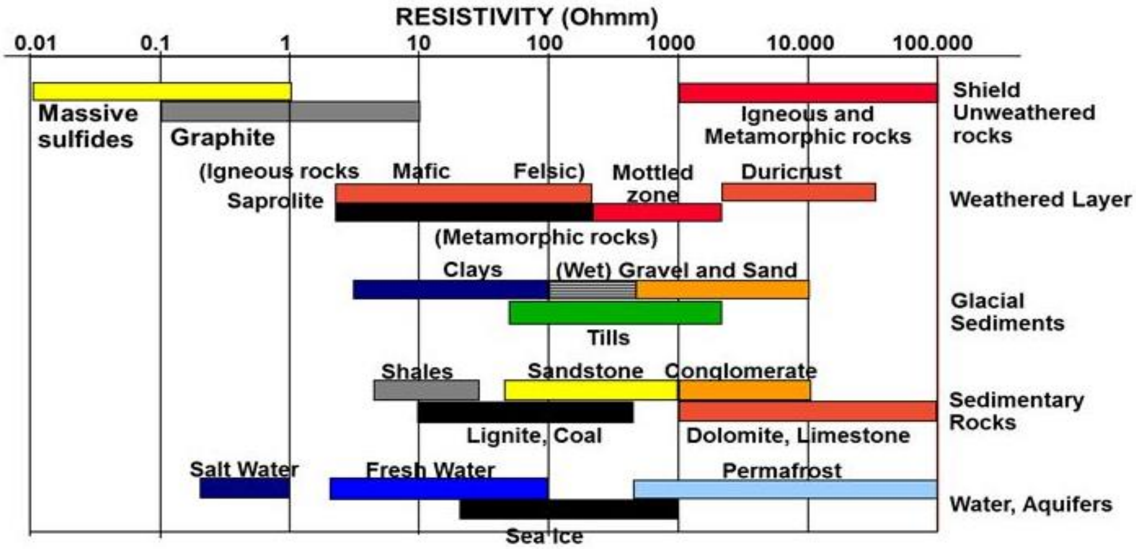

Figure 3: Rock true resistivity values (After Palacky, 1988).

Water Sampling

A total of fifteen (15) water samples were collected from nearby boreholes in the vicinity of the solid waste dumpsites which were used as case study. The water samples were analyzed and the results were used to complement the electrical resistivity survey results. The water samples were digested and analyzed for the presence of heavy metals such as lead, cadmium, arsenic, iron, copper and chromium. The analysis of the water samples were carried out according to the NAFDAC and WHO standards. The water samples were digested using concentrated Nitric acid ($HN0_3$). The digested water samples were analyzed for the presence of heavy metals using Atomic Absorption Spectrometer (AAS).

Pollution Index

The Pollution Index (P.I.) of the contaminants were determined using the single index factor method (Table 1). The pollution index was determined by comparing the results obtained from the water sample analysis with the international and national standards. The single factor index were determined using the expression:

$$P.I = \frac{C_i}{S_i} \quad (1)$$

Where C_i is the measured value of pollutant content (mg/L) and S_i is the standard value of environmental quality (mg/L).

Table 1: Water quality level indicator

Water Quality Level	Pollution Index (P.I)	Pollution Level
I	< 1	No Pollution
II	2	Slightly polluted
III	3	Lightly polluted
IV	4	Moderately polluted
V	5 or > 5	Seriously polluted

RESULTS AND DISCUSSION

The interpretation of the Vertical Electrical Sounding data showed that the study area is composed topsoil, clay, sand, sandy clay and sand formations (Figures 4 and 5). The topsoil is made up of a mixture sand, clay and plant remains, it has resistivity values which ranged from 64.5 – 189 Ωm with an average of 127.4 Ωm. The second layer has resistivity values which ranged from 9.7 – 78.2 Ωm with an average value of 38.5 Ωm (Table 2). The resistivity of the second layer showed it is a clay formation. The thickness of the first and the second layers ranged from 0.5 – 1.5 m and 2.8 - 9.2 m respectively. Their averages are 0.9 and 5.7 m respectively. The thickness of the third layer ranged from 48.7 – 94.2 m and it has an average thickness 61.2 m (Table 2). The third layer has resistivity values which range from 192.3 – 305.6 Ωm and an average resistivity value of 232.3 Ωm (Table 2). The resistivity range of the third clearly indicated that it is a sand formation (Figure 3). It is the first aquifer in the study area and it is the source of water to all the hand dug wells and shallow boreholes the study area. It is semi-confined and highly susceptible to contamination by percolating leachate from solid waste dumpsite.

Table 2: Results of the interpreted Vertical Electrical Sounding (VES) Data

			Resistivity (Ωm)					Thickness (m)				Depth (m)			
VES Point	**Longitude (ºN)**	**Latitude (ºN)**	$\rho1$	$\rho2$	$\rho3$	$\rho4$	$\rho5$	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4
1	11.94634	11.73830	114.2	9.7	269.3	86.6	580.2	1.5	2.8	48.7	66.7	1.5	4.4	53.0	119.7
2	11.94275	11.73783	120.0	15.1	192.3	112.5	369.0	1.3	4.2	94.2	41.5	1.3	5.5	99.7	141.3
3	11.94270	11.73722	64.5	27.2	263.5	142	314.8	0.5	6.3	68	73.1	0.5	6.8	74.8	147.9
4	11.94118	11.73833	127.5	69.0	214.7	130	292.6	0.8	5.2	62	56.4	0.8	6.0	68	124.4
5	11.93987	11.73757	180.0	52.5	194.2	119	250.1	0.9	6.9	71	59.6	0.9	7.8	78.8	138.4
6	11.93912	11.73866	119.5	78.2	205.5	110	220.0	0.7	7.2	55	65.8	0.7	7.9	78.9	144.7
7	11.93468	11.73720	189.2	29.6	244.0	105	294.3	0.6	5.9	49	70.4	0.6	6.5	55.5	125.9
8	11.93438	11.73602	140.0	47.4	305.6	121	356.4	0.8	6.0	60	81.2	0.8	6.8	67.6	148.8
9	11.93278	11.73530	98.7	35.7	233.0	136	210.8	1.0	5.5	49	76.9	1.0	6.5	56.5	133.4
10	11.93029	11.73524	120.6	20.5	201.4	125	300.2	1.1	7.0	55	81.2	1.1	8.1	63.1	144.3
	Maximum		189.2	78.2	305.6	142.0	580.2	1.5	7.2	94.2	81.2	1.5	8.1	99.7	148.8
	Average		127.4	38.5	232.3	118.7	318.8	0.9	5.7	61.2	67.3	0.9	6.6	69.6	136.9
	Minimum		64.5	9.7	192.3	86.6	210.8	0.5	2.8	48.7	41.5	0.5	4.4	53.0	119.7

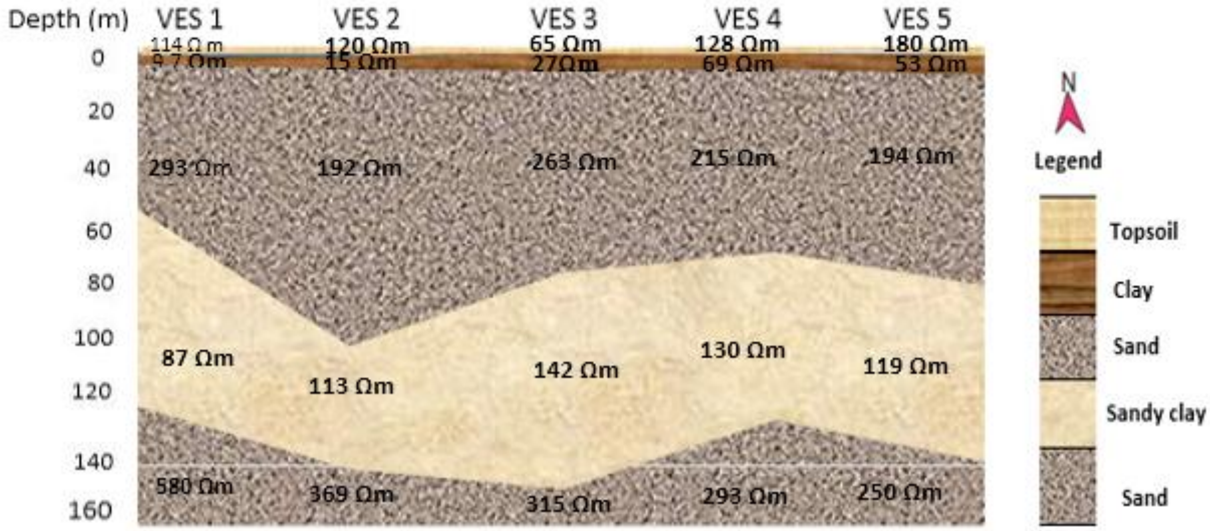

Figure 4: Geoelectric section of VES 1- 5 showing the lithology of the study area.
The third layer is the first aquifer in the study area and it is semi-confined by the thin clay layer.

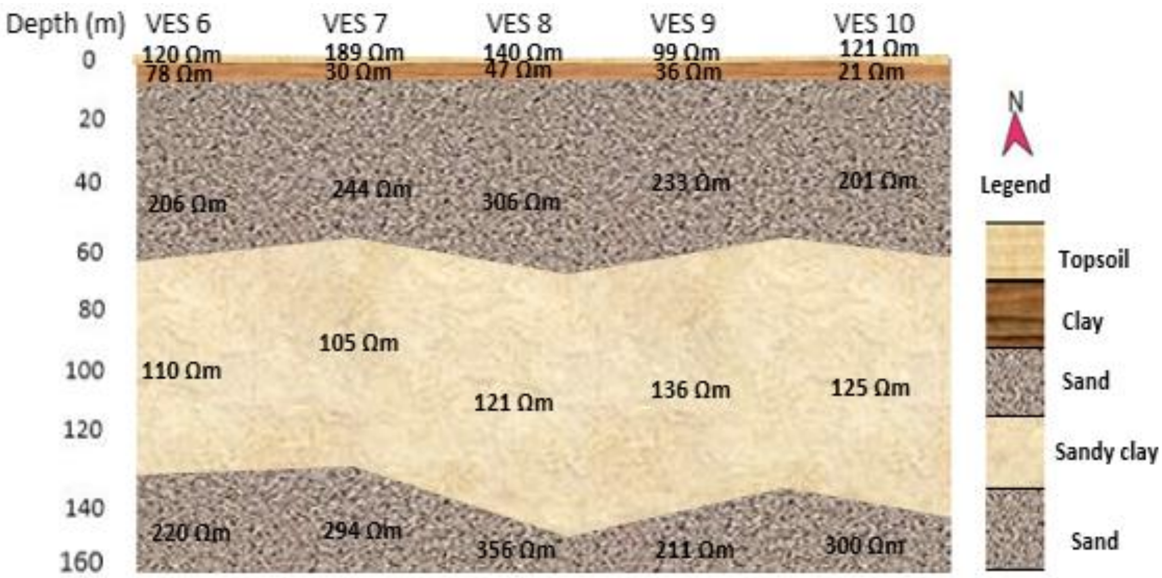

Figure 5: Geoelectric section of VES 6 - 10 showing the lithology of the study area.
The fifth layer is the second aquifer in the study area and it is confined by a thick sandy-clay formation, which helps to restrain contaminants from reaching the second aquifer.

The resistivity of the forth layer ranged from 86.6 and 142 Ωm, and it has an average resistivity of 120 Ωm. The resistivity ranged of the forth layer indicates that it is a sandy-clay formation. The thickness of the forth layer ranged from 41.5 – 81.2 m and it has an average value of 67.3 m. The forth layer helps to protect the second aquifer from pollution (Figure 5). The fifth layer has resistivity values which ranged from 210.8 – 580.2 Ωm and an average resistivity of 318.8 Ωm. The resistivity value range clearly indicated that the layer is sand formation (Table 2). Its thickness was not determined in this study. It is the second aquifer in the study area. It is a confined aquifer with an average depth of 137 m (Table 2). The typical curves obtained from the study area are shown in figure 6 below.

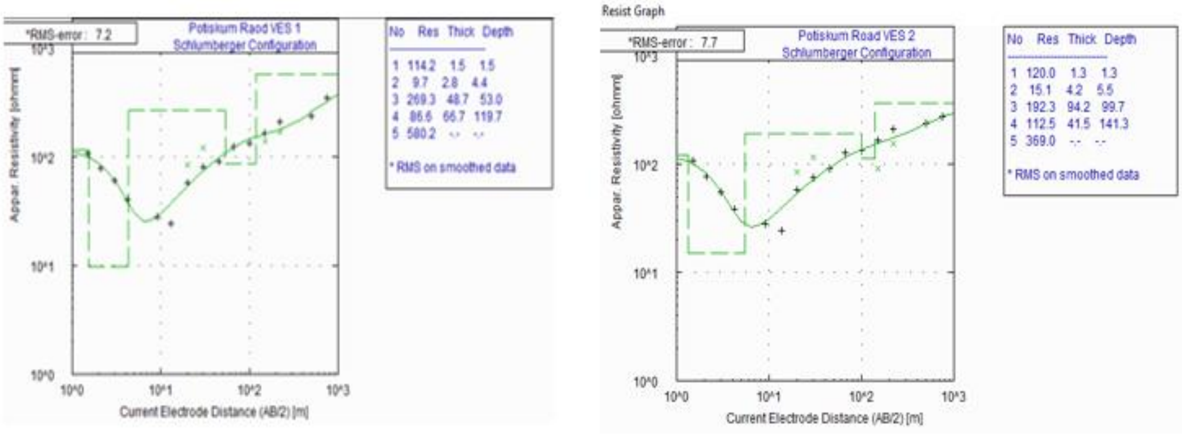

Figure 6: Typical VES Curves obtained from the study area.

The reuslts of the Electrical Resistivity Tomography (ERT) showed that the decomposition of the solid wastes in the presence of moisture generates leachate which migrates from the dumpsites and percolate into the subsurface to pollute the groundwater (Figures 7 and 8). The migrating leachates are characterized with very low resistivity values which distingushed it from the surroundings rocks. The conductivity of the leachate clearly indicate that it contains mobile ions which are inorganic in nature and mostly likely metals. The contaminants have resistivity values which ranged from 2 - 7Ωm (Figure 7).

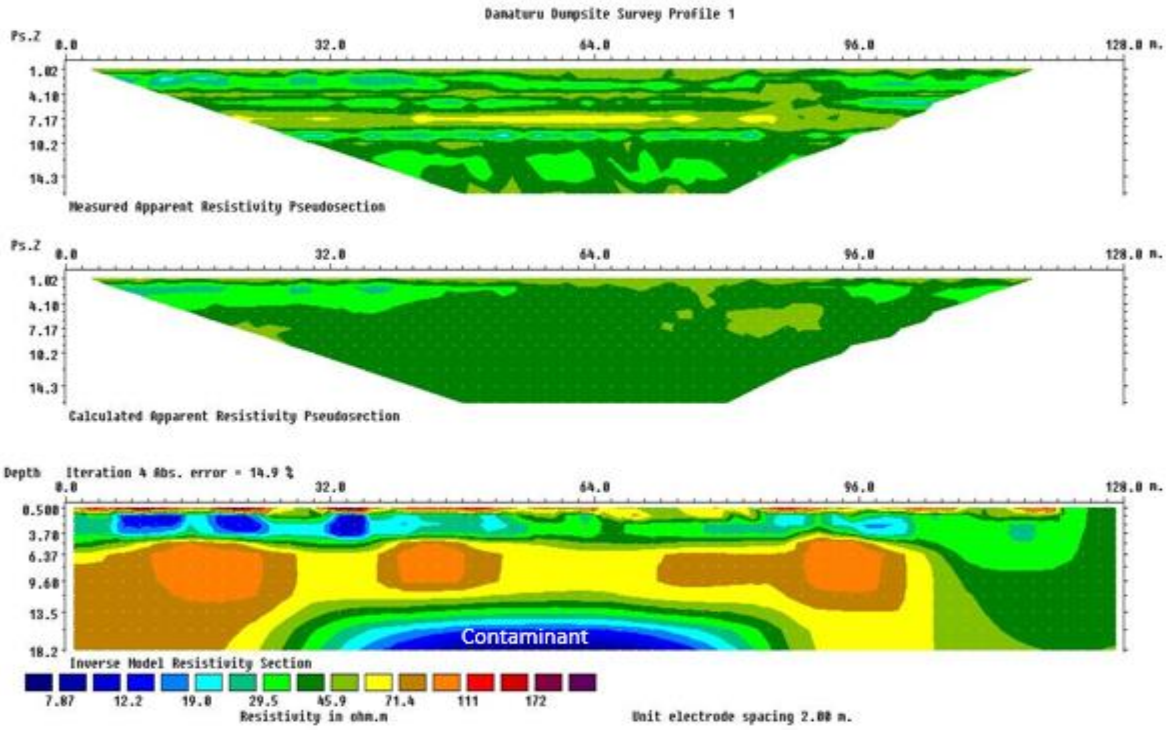

Figure 7: Inverse resistivity model showing the contaminants migrating into the first aquifer. The contaminants are associated with very low resistivity values due to their conductivities. The contaminants are identified in deep blue colour.

The leachate plumes migrate into the subsurface through the vadose zone to the aquifer (saturated zone). The contaminants often dissolve into the groundwater and thereby making it toxic and dangerous to human health. Some of the metals associated with the leachates are mostly heavy metals derived from the decomposition of metallic objects of various types. The contaminants from the dumpsite are transported from the earth surface into the aquiferous area of the subsurface through the process of diffusion, advection and adsorption. The movement of the contaminants might be slow, but in a porous area such as the study area the transportation of the contaminant might be enhanced by the porosity of the soil (Figure 8).

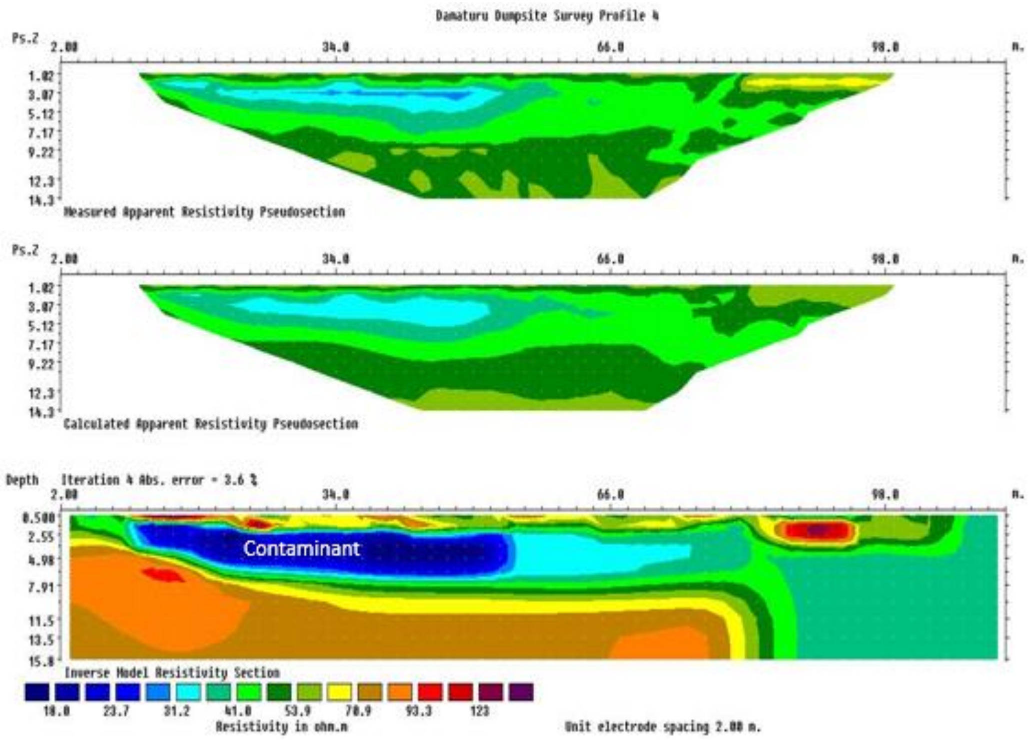

Figure 8: Inverse resistivity model showing the migration of the contaminant plume into the subsurface.

The results of the analyzed water samples showed that the concentration of Lead (Pb) in the groundwater ranged from 0.011- 0.034 mg/L with an average value of 0.019 mg/L (Table 3). A comparison of the lead concentration in the groundwater with both national and international standards showed a pollution index of 1.9 (Table 4). The pollution index of lead in the groundwater showed that the water contain elevated concentration of Lead and it is therefore polluted. Lead is a known highly toxic metal with extensive health complications. An elevated concentration of lead in groundwater affects human, animals and plant. A high concentration of lead in drinking water could lead to cardiovascular disorder, rise in blood pressure and the incidence of hypertension. It also contributes to kidney malfunctioning and low cognitive development in Children.

Cadmium is one of the most dangerous heavy metal which is released into the environment through the disposal of batteries, paints, coated metallic materials and plastic stabilizers. The concentration of Cadmium in the groundwater ranged from 0.01 – 0.063 mg/L with an average value of 0.035 mg/L (Table 3). The pollution index of Cadmium in the groundwater is 3.5 (Table 4). The groundwater has an elevated concentration of Cadmium which make it contaminated. Human activities such as the consumption of fossil fuels and burning of wastes could increase the Cadmium content in the environment. Studies have shown that high concentration of lead in human body could lead to cancer and skeletal system disorder. The concentration of Arsenic in the groundwater ranged from 0.00 - 0.05 mg/L with an average value of 0.029 mg/L (Table 3).

The pollution index of Arsenic in the study area is 2.9 (Table 4), which indicated that the groundwater is polluted. Arsenic contamination of groundwater could occur as results of both geologic and anthropogenic activities. Arsenic minerals precipitate into groundwater to cause water pollution. Agricultural activities such as fertilizer application, pesticides and the use of animal feeds introduce Arsenic into the environment. Arsenite and Arsenate are inorganic forms of Arsenic which are known to be very dangerous to human health. They are carcinogenic and could cause cancer of bladder, lungs, liver and skin (Hoque *et al*., 2011).

Table 3: Results of the analyzed water samples

Sample	Lead (mg/L)	Cadmium (mg/L)	Arsenic (mg/L)	Iron (mg/L)	Copper (mg/L)	Chromium (mg/L)
1	0.025	0.059	0.034	0.87	0.78	0.062
2	0.020	0.063	0.023	0.90	0.45	0.070
3	0.014	0.032	0.050	0.72	0.65	0.090
4	0.022	0.050	0.000	0.58	0.28	0.053
5	0. 024	0.023	0.046	1.20	0.48	0.06
6	0.019	0.034	0.013	1.90	0.56	0.01
7	0.034	0.026	0.032	1.40	0.33	0.047
8	0.021	0.024	0.018	0.80	0.91	0.067
9	0.015	0.060	0.047	1.20	1.25	0.07
10	0.012	0.043	0.035	2.00	0.37	0.034
11	0.011	0.021	0.041	0.40	0.45	0.023
12	0.018	0.012	0.024	0.56	0.22	0.056

13	0.015	0.01	0.045	0.70	0.63	0.078
14	0.020	0.042	0.018	0.60	0.72	0.055
15	0.012	0.032	0.012	0.89	0.95	0.067
Maximum	0.034	0.063	0.050	2.00	1.25	0.09
Average	0.019	0.035	0.029	0.98	0.60	0.05
Minimum	0.011	0.010	0.000	0.400	0.22	0.01

Table 4: Comparison of the average heavy metal concentration of the water samples with NAFDAC and WHO standards.

	Heavy Metal Concentration (mg/L)					
	Lead	**Cadmium**	**Arsenic**	**Iron**	**Copper**	**Chromium**
NAFDAC	0.010	0.100	0.010	0.20	2.00	0.05
WHO	0.010	0.100	0.010	0.30	2.00	0.05
Damaturu	0.019	0.035	0.029	0.98	0.60	0.05
Pollution Index	1.900	3.500	2.900	3.30	0.30	1.00

The concentration of Chromium in the groundwater of the study area ranged from 0.01- 0.09 mg/L with an average value of 0.05 mg/L (Table 4). The pollution index of Chromium in the groundwater of the study area is 1.0 (Table 5), this value indicated that the groundwater is slightly polluted by Chromium. Chromium exist in both trivalent and hexavalent forms. Trivalent Chromium Cr (III) is mostly harmless, but the hexavalent Chromium Cr (VI) is very dangerous to human health as it has been classified as a group 1 human carcinogen by the International Agency for the Research on Cancer (Zhang *et al*., 2011). The concentration of Copper in the groundwater of the study area ranged from 0.22 – 1.25 mg/L with an average value of 0.6 mg/L. The pollution index of Copper in the study area is 0.03 (Table 4), this value clearly indicated that the groundwater in the study area is not polluted by Copper. The concentration of Iron in the groundwater of the study area ranged from 0.4 – 2.0 mg/L with an average value of 0.98 mg/L (Table 3). The pollution index of Iron in the study area is 3.3 (Table 4), this magnitude showed that the groundwater in the study area is polluted by Iron. The effects of an elevated concentration of Iron in drinking water are dangerous to human health as they could cause diabetes, stomach problems, nausea, and damage to liver, pancreas, and heart.

The correlation of the magnitude of the heavy metals identified in the groundwater indicated that most of the metals do not have a common origin. The results showed that the metals originated from different sources (Table 5). Although there were slight correlations between Arsenic and Chromium, Iron and Cadmium. The correlation coefficient of Copper and Chromium showed that they both have a common source (Table 5). These heavy metal contaminants are the products of the decomposition of solid wastes of high metallic contents.

Table 5: Correlation coefficient of the heavy metal content in the water samples

	Lead	**Cadmium**	**Arsenic**	**Iron**	**Copper**	**Chromium**
Lead	1	0.085	-0.170	0.118	-0.255	-0.014
Cadmium		1	-0.173	0.227	0.133	0.009
Arsenic			1	0.050	0.166	0.294
Iron				1	-0.029	-0.456
Copper					1	0.400
Chromium						1

Generally, the results of the study showed that the solid wastes generate leachates which percolate through the vadose zone to pollute the groundwater. The results of the hydro-chemical analysis complemented the results of the Electrical Resistivity Tomography (ERT) which showed that the groundwater is polluted by leachate plumes from the solid wastes dumpsites. The contamination is more severe in areas near the dumpsites and in shallow aquifers. The presence of some heavy metals such as Lead, Cadmium, Arsenic, Chromium and Iron in elevated concentrations in the groundwater of the study area constitute serious health complications. It is therefore imperative that the dumpsites should be evacuated and the shallow boreholes and hand dug wells in the area should be shut down. The findings of this study were in agreement with the reports of Waziri *et al*., (2009); Emeka and Weltime, 2008; Kwaya *et al*., 2017; Yakubu and Agada, 2022.

CONCLUSION

This study investigated the effects of poor solid waste management on groundwater resources in Damaturu. The results of the study showed that the solid waste in the dumpsite decomposes to generate leachate which percolate into the subsurface to pollute the groundwater in the study area. The Vertical Electrical Sounding results showed that the first aquifer in the study area is shallow and it has high susceptibility to contamination due to its proximity to the earth surface. The ERT survey results showed that the groundwater is contaminated by migrating leachates from the dumpsites. The contaminants were delineated as high conductive plumes of metallic origin. The hydro-chemical analysis results showed that the groundwater in the study area contains Cadmium, Arsenic, Iron, Chromium and Lead in elevated concentrations which are much beyond the permissible limits of both the National and International set standards. These results confirm that the groundwater in the study area is polluted by leachate from the Dumpsite. Considering the susceptibility of the first aquifer to pollution, the second aquifer is confined by a thick sandy clay formation is recommended for quality groundwater abstraction. Considering the effects of poor solid waste management on groundwater resources, efficient waste management system should be encouraged in Damaturu Metropolis to avoid the pollution of groundwater by leachate emanating from solid wastes.

CONFLICT OF INTEREST

The authors declared that there were no competing interests.

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