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INVESTIGATION OF GROUNDWATER POLLUTION IN POMPOMARI AREA OF DAMATURU USING GEOPHYSICAL AND HYDROCHEMICAL METHODS

***Yakubu Mingyi Samuel and Agada Livinus Emeka**

Federal Polytechnic Damaturu, Yobe State.
Department of Physics, Yobe State University, P.M.B, 1144, Damaturu, Nigeria.

*Corresponding authors' email: tellmingyi68@gmail.com Phone: +234 08165875004

ABSTRACT

Pompomari is a district in Damaturu metropolis in Yobe State, northeast Nigeria, and it has been identified by some researchers to have groundwater pollution problem. In view of this problem, this study investigated the groundwater pollution in the area using geophysical and hydro-chemical methods. The findings of this study showed that the area is composed of five geo-electrical layers such as topsoil, clay, sandy clay, sand and clay. The fourth layer constitute the aquifer in the study area. The Electrical Resistivity Tomography (ERT) survey delineated the contaminant plumes in the study area as low resistivity materials in the subsurface. The contaminated zones were identified with resistivity values ranging from 2 - 20 Ωm. The results of the hydro-chemical analysis of the groundwater samples in the study area confirm that the groundwater is polluted and it validated the ERT survey results. Based on the findings of this study, we recommend that a high capacity drainage system should be constructed in Pompomari area of Damaturu to protect the area from flooding and groundwater pollution. Shallow boreholes in the study area should be closed and new borehole should be drilled to a depth of 100 m and above for quality groundwater abstraction from the fourth geologic layer which is a confined aquifer. The pollution index values for Cadmium, Lead, Iron, Arsenic, and Chromium showed that the groundwater in the study area is polluted.

Keywords: Aquifer, contaminants, electrical resistivity, flood, groundwater, pollution index, pompomari

INTRODUCTION

Groundwater has been identified as the major source of domestic and industrial water supply to people living in the semi-arid regions of Nigeria where there is scarcity of rivers, streams and oceans. The groundwater in semi-confined and unconfined aquifers in the semi-arid region of Nigeria are highly susceptible to pollution especially in lowland areas which are receptive to flood. The consumption of contaminated water has been identified as one of the major cause of morbidity and high mortality in developing countries (Agada and Habu, 2022). Groundwater, often get polluted when contaminants such as pesticides and fertilizers from farmlands, leachate from landfill and septic systems infiltrate into the aquifer. Deep aquifers under flooding condition often get contaminated through recharge from floodwater (Jasechko *et al*., 2017). Huebsch *et al*., (2014) observed that extreme rainfall and flood events accelerate groundwater pollution and increase the concentration of trace metals and nitrate in groundwater.

Many researchers have indicated that climate change in recent years has influenced the quality of groundwater through flooding in flood prone areas (Delpla *et al*., 2009; Ayolabi, 2013; Ezekwe and Edoghotu, 2015; Ojolowo and Wahab, 2017). Mosuro et al., (2016) investigated groundwater quality in Agbara industrial estate using electrical resistivity method and they observed that the groundwater in the area has been polluted. Leakages from rusted underground tanks often pollute the subsurface aquifer and contaminate groundwater as the petroleum products migrate deep into the subsurface. A study report by Adelusi *et al*., (2013) in Aule area of Akure in Ondo State, indicated that petroleum products leakages from a nearby Filing station has contaminated the groundwater in the area. The contaminant plumes were delineated at a depth of 10 metres. Water is an essential resources to human life. The consumption of quality water enhances good health. It has been observed that the consumption of contaminated water is responsible for high morbidity and mortality rates in some parts of Africa and Asian countries (WHO, 2017). In most parts of Africa, Nigeria inclusive, the provision of adequate quality drinking water is a serious challenge due to poor environmental sanitation, illiteracy and poverty. Infants and children have the highest mortality rate associated with the consumption of contaminated water (UNICEF, 2015). According to UNICEF report in 2015, about 85,700 children under the age of 15 years die from diarrhea linked to the consumption of contaminated water and poor sanitation. Pompomari is a district in Damaturu metropolis with a significant population. It is a lowland area which is prone to flooding annually. Erosion water from different parts of Damaturu converge in Pompomari with loads of contaminants which percolate into the subsurface to pollute the groundwater in the area. The runoff water comes with toxic contaminants such as human waste, animal waste, fertilizers, herbicides, pesticides, and other toxic contaminants from domestic, small and medium scale industries. It is obvious that the quality of groundwater in any given location is related to the environmental condition of the subsurface of the area. Organic fertilizer such as poultry manure, in most cases contain arsenic which is a byproduct of the drugs given to chickens and when infiltrated into the subsurface pollute the groundwater and cause health complications (Emeka and Weltime, 2008). Groundwater pollution may be exacerbated by climate change. The frequent occurrence of flash flood in recent times has increased the degree of groundwater pollution in many areas which are prone to flooding (Agada and Habu, 2022).

In view of the increasing rate of water related health complications in Yobe State, the need for this study cannot be over-emphasized. Groundwater in Pompomari area of Damaturu has been reported by some researchers to be contaminated (Emeka and Weltime, 2008; Kwaya et al., 2017) but the source of the contaminants has been not identified. This study seeks to unravel the source of the contaminants in the groundwater by using both geophysical and hydro-chemical methods.

MATERIAL AND METHODS

The study area

Pompomari is a district in Damaturu, northeastern Nigeria (Fig. 1), Damaturu is within the Chad Basin (Fig. 2). The Chad Basin extends to Niger Republic, Chad and Cameroon. The Basin belongs to the West Africa rift subsystem and it has three water bearing horizons which are; the upper, middle and the lower zones (Agada *et al*., 2020). Damaturu has a tropical continental climate characterized by short rainy season (June – September) and long dry season (October – May), with high temperatures of about 39^{o} C to 45^{o} C. The annual rainfall range from 500-1000 mm.

Figure 1: Map of Nigeria showing the study area Pompomari in Damaturu, Yobe State.

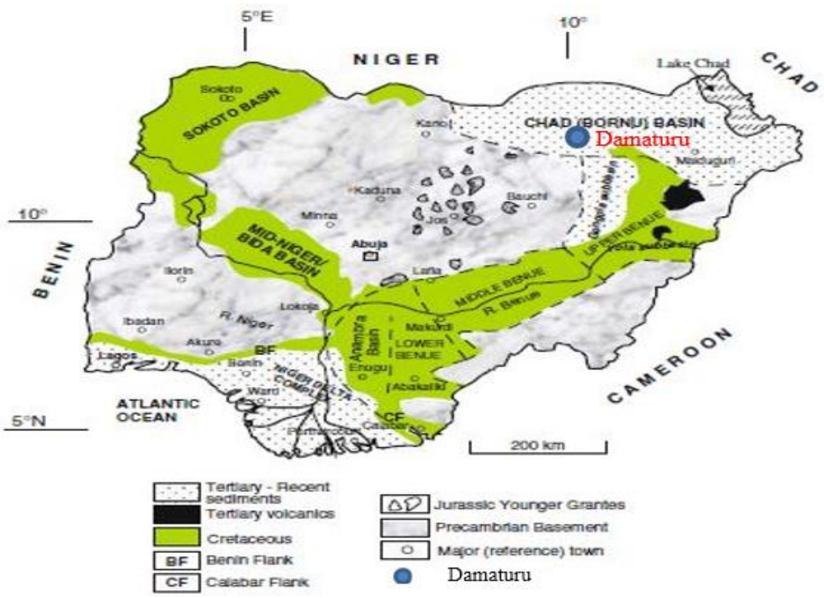


Figure 2: Geological Map of Nigeria showing the location of Damaturu in the Chad Basin (Obaje, 1999).

Methodology

Groundwater samples were collected during both dry and rainy seasons and they were analyzed hydro-chemically to determine their quality with reference to United States Environmental Protection Agency (USEPA) and the World Health Organization 2017 standards. Twenty (20) water samples were collected from Pompomari area of Damaturu, and were analyzed to determine the presence of lead, cadmium, chromium, iron, copper and arsenic and their concentrations in the water samples. An ABEM Terrameter

SAS1000 was used to carry out the geophysical survey. Electrical resistivity surveys involving both Vertical Electrical Survey (VES) and Electrical Resistivity Tomography (ERT) were carried out to determine the subsurface lithology of the study area and to map the contaminant plume in the subsurface. The VES data were used to delineate the overburden thickness and the depth to the groundwater. The ABEM Terrameter was set for four cycle stacking and the standard error of measurement was set at 5%. At each measurement, the resistivity meter displayed resistance value and the associated room mean square (RMS) error of the reading. During the VES data acquisition, the Terrameter measures the resistance, voltage and current which are indicated by R, V, I respectively. The apparent resistivity values were obtained by multiplying the resistance by the geometric factor (*K*), that is, (*R* x *K)*, where *K* is calculated by using,

$$K = \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right] X\ 3.142}{\left(\frac{MN}{2}\right) X\ 2} \quad (1)$$

Where AB is the current electrode spacing and MN is the potential electrode spacing. During sounding, apparent resistivity of the subsurface material was measured as a function of depth. The progressive increase in the distance between the current electrodes causes the current lines to penetrate to greater depths. The VES data were interpreted using IPI2WIN Software and the 2D imaging data were interpreted using RES2DINV Software.

The pollution index (PI) of the contaminants were determined using the standard approach. Pollution index is the ratio of the concentration of the individual contaminant to the baseline standard and gives information on the relative pollution that is contributed by individual contaminant. A magnitude of 1.0 is considered as a critical value, while values higher than 1.0 are considered as significant level of pollution and the values less than 1.0 are not significant and does not constitute pollution in the groundwater.

Water sample analysis

The water samples were digested and analyzed for the presence of lead, cadmium, arsenic, iron, copper and chromium using Atomic Absorption Spectrometer (AAS). The analysis was carried out based on the US EPA and WHO standards. Basic statistics such as minimum, maximum, mean and standard deviation were used to evaluate the concentration of the heavy metals in the groundwater.

RESULTS AND DISCUSSION

The results of the Vertical Electrical Sounding (VES) showed good correlation when constrained with an existing borehole log records from the nearby boreholes. Figures 2a to 2d showed, the typical VES curves obtained from the study area. The first layer is the topsoil and it has resistivity values ranging from 59.0 to 452.0 Ωm and it has an average resistivity value of 232 Ωm (Table 1). The thickness of the first layer ranged from 0.75 to 1.2 m and an average thickness of 0.93 m. The first layer is a mixture of sand, silt and little amount of clay. The second layer is a clay formation that is intercalated in some areas with sand. Its resistivity values ranged from 15.7 to 232.0 Ωm and it has an average resistivity value of 99.0 Ωm. Its thickness ranged from 1.25 to 48.5 m and the average thickness is 12m. It serves as a source of water in some areas where the aquifer is unconfined, especially during rainy season when the water table is high. The unconfined aquifer is easily infiltrate by contaminants such as leachate from septic systems, landfills, solid waste dumpsites and flood water. The magnitude of the resistivity of the third layer ranged from 30.1 to 570.0 Ωm, and has an average resistivity of 159 Ωm. The third layer is clayey in some areas and sandy-clay in other areas within the study area. It has an average resistivity value of 35.0 Ωm. The thickness of this layer ranges from 8.9 to 67.3 m. It has an average thickness of 35 m. The fourth layer has resistivity values which ranged from 125 to 1646 m. It has an average resistivity of 355.0 Ωm (Table 1).

The thickness of the fourth layer ranged from 65.7 to 202 with an average thickness of 97.3 m. It is a sandy formation and it is considered to be a good aquifer for groundwater exploitation in the study area. The fourth layer is underlain by a clay formation whose resistivity range from 24.5 to 93.7 Ωm (Table 1). Some of the boreholes in the study area have shallow depth and therefore, they are prone to contamination due to their proximity to the surface. Boreholes drilled to semi-confined or unconfined aquifers are highly susceptible to the infiltration of leachate and other toxic substances. Secured boreholes in the study area should be drilled to a depth of 100 m and above in order to exploit safe drinking water.

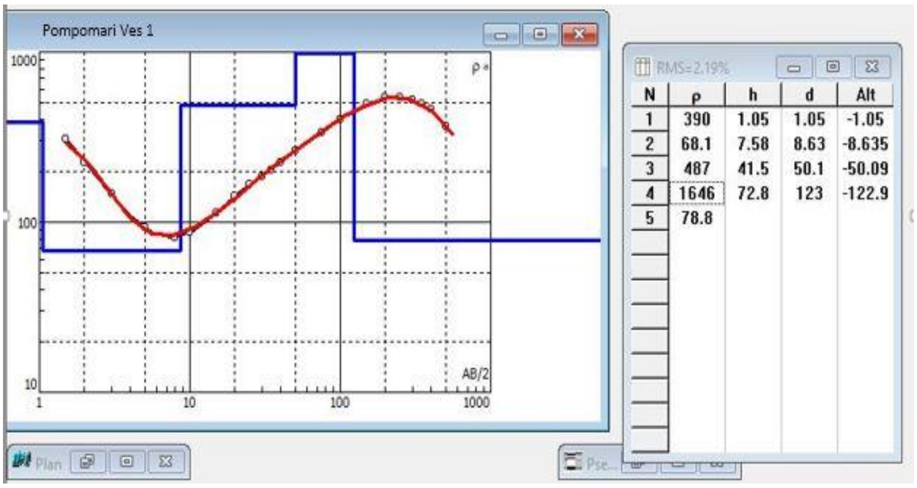


Figure 2a.

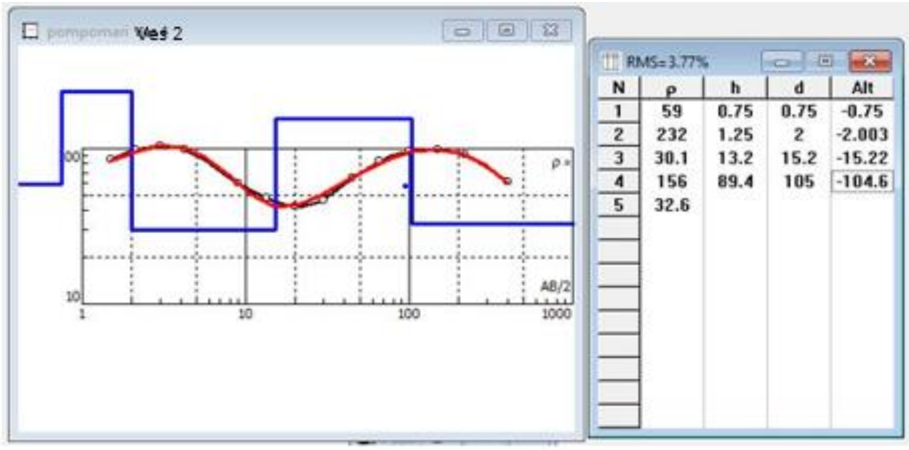


Figure 2b.

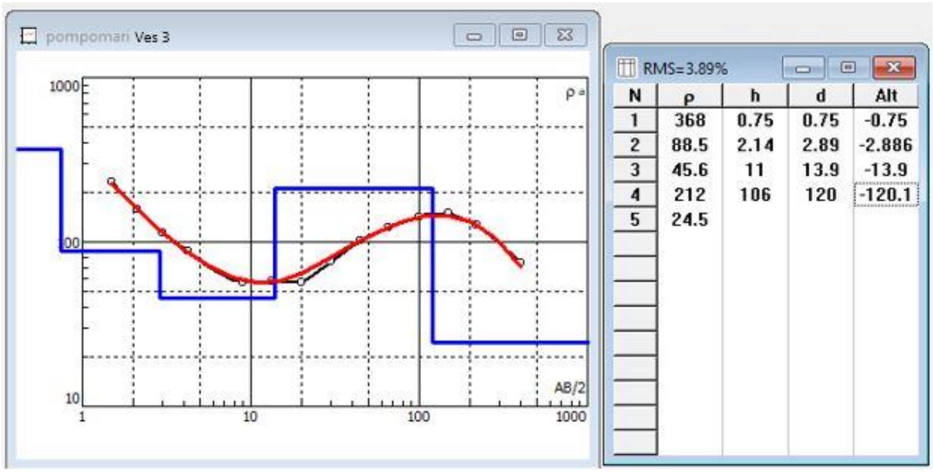


Figure 2c.

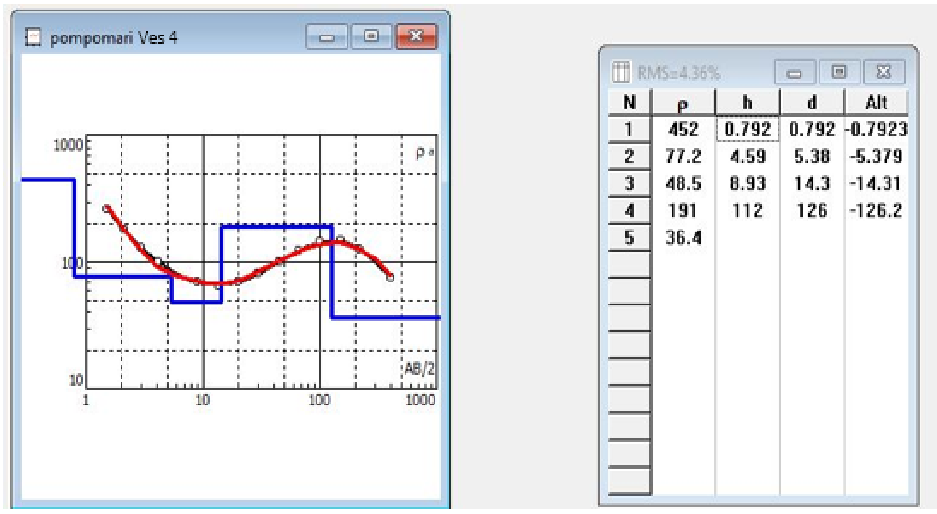


Figure 2d.

Figure 2(a-d): Typical VES curves obtained from the study area.

Table 1. Vertical Electrical Resistivity Sounding Results

VES	Layer Resistivity (Ωm)					Layer Thickness (m)				Depth (m)			
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4
1	390.0	68.1	487.0	1646.0	78.8	1.05	7.58	41.5	72.8	1.05	8.6	50.1	123.0
2	59.0	232.0	30.1	156.0	32.6	0.75	1.25	13.2	89.4	0.75	2.0	15.2	105.0
3	368.0	88.5	45.6	212.0	24.5	0.75	2.14	11.0	106.0	0.75	2.9	13.9	120.0
4	452.0	77.2	48.5	191.0	36.4	0.79	48.5	8.9	112.0	0.79	5.4	14.3	126.0

5	232.0	39.9	570.0	125.0	54.3	0.82	6.30	14.5	202.0	0.82	7.1	21.6	223.6
6	190.0	31.5	198.6	342.0	93.7	0.85	7.45	53.2	96.5	0.85	8.3	61.5	158.0
7	124.3	15.7	41.6	184.3	67.2	1.10	10.56	44.8	74.9	1.10	11.7	56.5	131.4
8	175.7	102.0	51.5	258.9	49.8	1.05	12.62	67.3	80.6	1.05	13.7	81.0	161.6
9	117.5	208.4	67.2	247.3	51.4	0.93	11.52	48.5	65.7	0.93	12.5	60.9	126.6
10	208.3	126.3	50.3	189.7	67.4	1.20	9.46	50.7	72.8	1.20	10.7	61.4	134.2
AVE.	232	99	159	355	56	0.93	12	35.0	97.0	0.93	8.3	44.0	141.0

AVE = Average, VES = Vertical Electrical Sounding.

The 2D Electrical Resistivity Tomography (ERT) results showed that some contaminants have infiltrate into the subsurface and they were mapped as low resistivity plume. The contaminant plume were indicated in deep blue color in the inverse resistivity model (Fig.3a to 3c). The contaminants had seeped into the aquifer to pollute the groundwater. The contaminated region of the subsurface was marked with very low resistivity values which range from 2.0 to 25.0 Ωm.

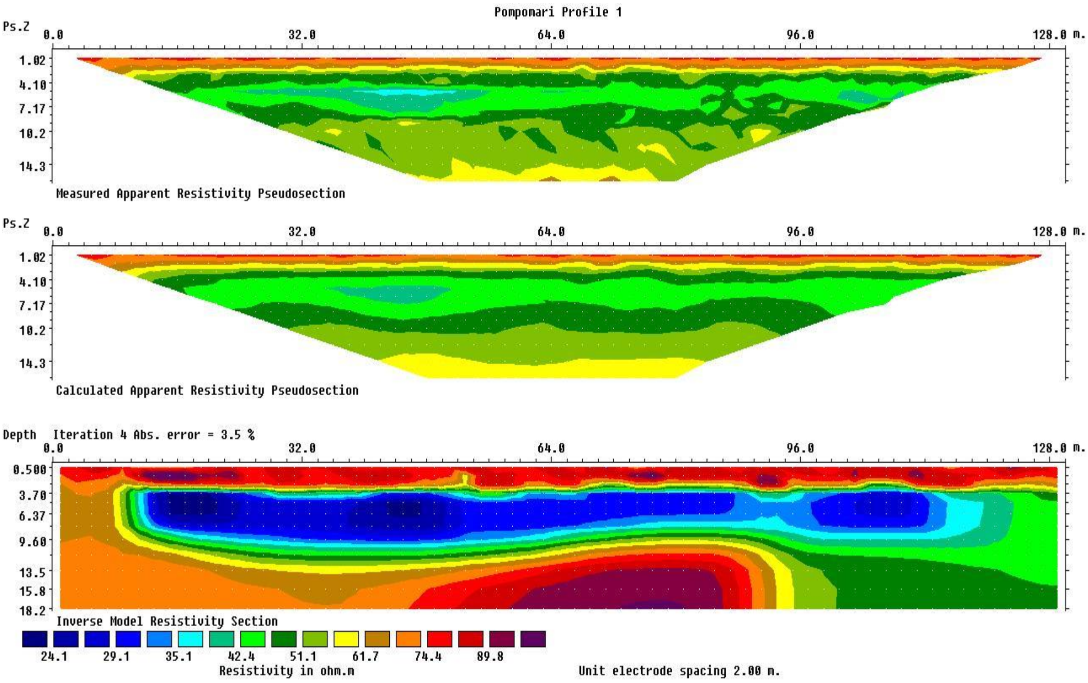
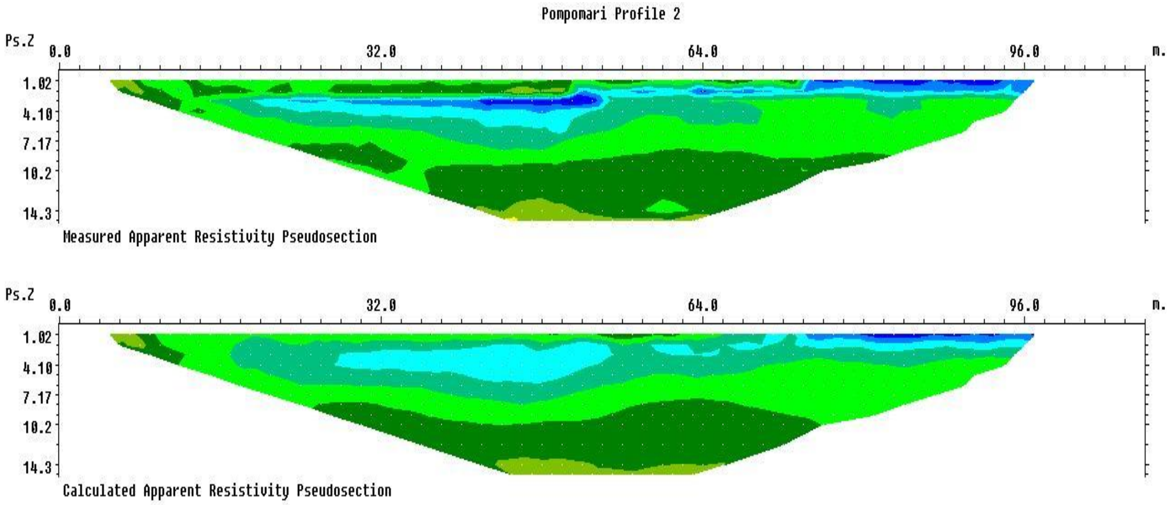


Figure 3a: Inverse resistivity model showing the presence of the contaminant plume in deep blue colour in the subsurface.

The contaminated region of the subsurface was marked with very low resistivity values which range from 12.0 to 27.0 Ωm.



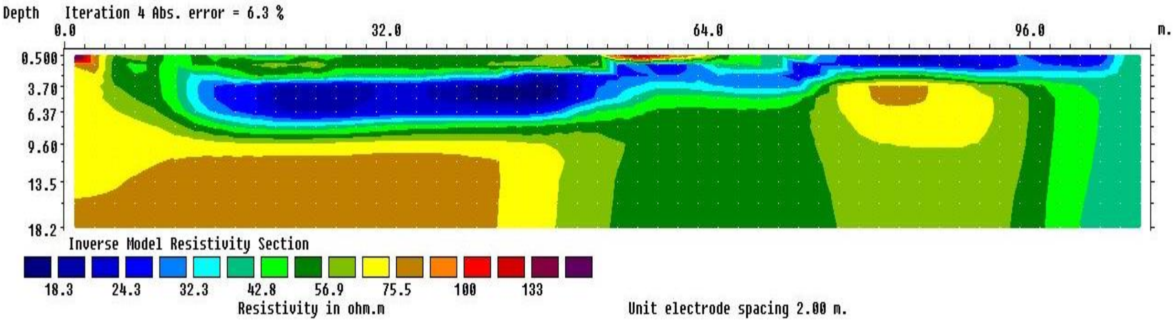


Figure 3b. Inverse resistivity model showing the spatial distribution of the contaminant plume.

The results of the 2D ERT imaging showed that the contaminant affects mostly the aquifers close to the surface (unconfine and semi-confine aquifers) in the study area. Water from shallow boreholes are in the study area are deemed to be contaminanted. The results of the hydro-chemical analysis shows the degree of the contaminantion of the groundwater in the study area (Table 2).

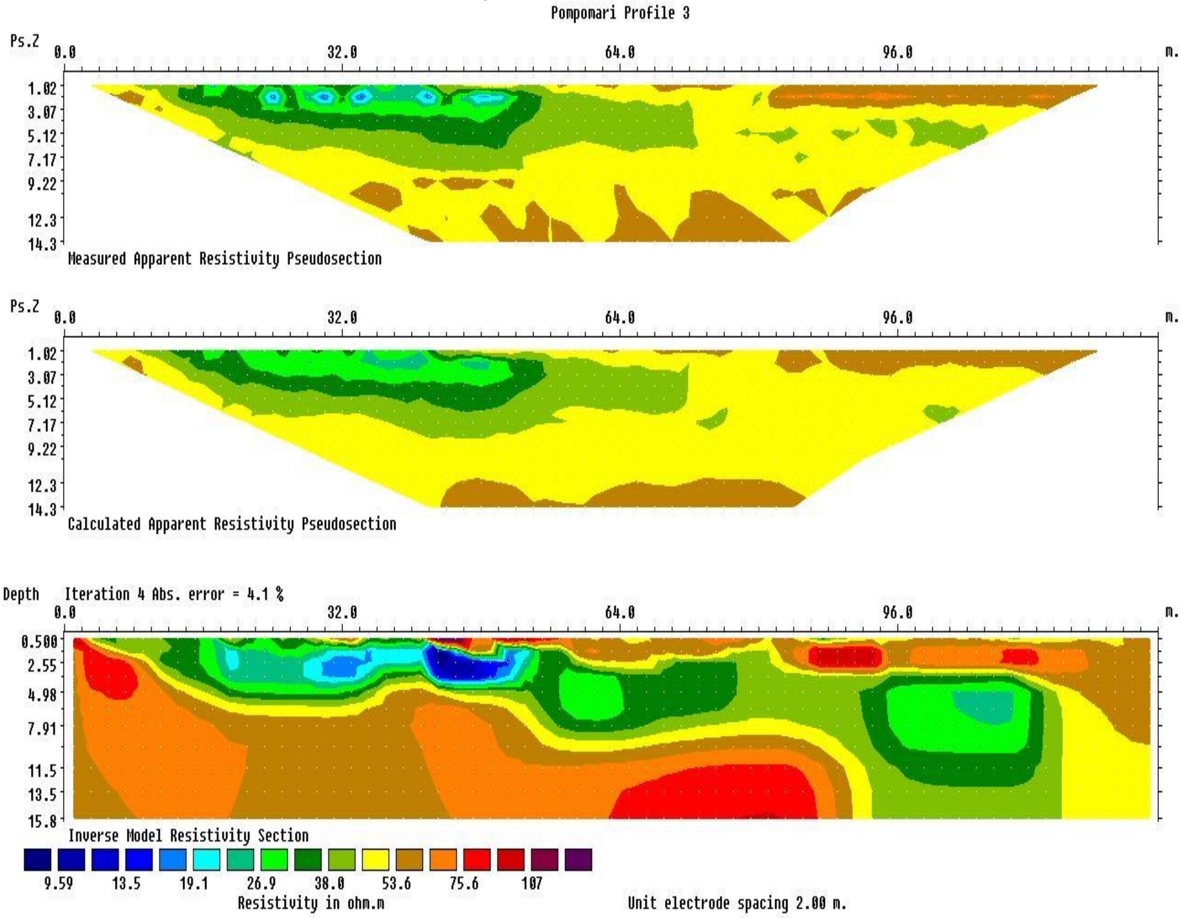


Figure 3c: Inverse resistivity model showing the presence of the contaminant plume in deep blue colour in the subsurface. The contaminated region of the subsurface was marked with very low resistivity values which range from 3.0 to 12.0 Ωm. The results of analyzed water samples was compared with the World Health Organization Standard (Table 2).

Table 2 Water sample analysis results

Parameter	**Wet season heavy metal concentration (*mg*/L)**			**P.I**	**Dry season heavy metal concentration (*mg*/L)**			**P.I**	**WHO Guidelines (*mg*/L)**
	Min	**Max**	**Ave**		**Min**	**Max**	**Ave**		
Cadmium	0.020	0.050	0.036	3.60	0.065	0.185	0.046	4.60	0.010
Lead	0.015	0.026	0.019	1.90	0.001	0.362	0.025	2.50	0.010
Iron	0.250	1.500	1.000	3.33	0.330	2.140	1.220	4.10	0.300
Arsenic	0.012	0.040	0.090	9.00	0.014	0.050	0.040	4.00	0.010
Chromium	0.040	0.080	0.056	1.12	0.043	0.066	0.083	1.70	0.050
Copper	0.150	0.720	0.876	0.44	0.037	0.817	0.411	0.20	2.000

Min = minimum; Ave = average; Max = maximum; P.I = Pollution index.

The water samples analysis results showed that the concentration of cadmium ranges from 0.020 to 0.05 mg/L with an average value of 0.036 mg/L during the wet season. The pollution index of cadmium during the wet season was 3.60. The concentration of cadmium in the groundwater during the dry season range from 0.065 to 0.185 mg/L with an average of 0.046 mg/L (Table 2). The pollution index of cadmium during the dry season was 4.6. The average value of cadmium in the water samples was higher than the World Health Organization guideline value of 0.010 mg/L during both wet and dry seasons (Table 2). The pollution index of cadmium in both seasons clearly indicate that the groundwater is polluted by cadmium. The average concentration of lead in the water samples during the wet season was 0.019 mg/L and its concentration in the water samples range from 0.015 to 0.026 mg/L (Table 2). The value of lead in the water samples during the dry season range from 0.010 to 0.362 mg/L and its average value was 0.025 mg/L. The average values of lead in the water samples during both wet and dry seasons were both above the WHO guideline of 0.010 mg/L (Table 2) which indicates that the water is contaminated. The pollution index of lead in both seasons were 1.9 and 2.5 respectively and this shows that the water is polluted by lead. The average values of iron in the water samples for both wet and dry seasons were 1.0 mg/L and 1.22 mg/L respectively. And these values were higher than the WHO guideline value of 0.3 mg/L. (Table 2). The pollution index of iron for both seasons in the groundwater were 3.3 and 4.1 respectively. These values showed that the groundwater is polluted by iron. The average value of arsenic in the water samples for both wet and dry seasons were 0.09 mg/L and 0.04 mg/L respectively. These values are more than the WHO guideline value of 0.01 mg/L (Table 1). The pollution index for both wet and dry seasons were 9 and 4 respectively. These values showed that the groundwater in the area are polluted by arsenic. The pollution index of chromium for both seasons were 1.12 and 1.7 (Table 1). These values indicated that the groundwater in the study area is polluted by chromium. The average concentration of copper in the groundwater for both wet and dry seasons were 0.876 mg/L and 0.411 mg/L respectively. The pollution index of copper in the groundwater of the study area were 0.44 and 0.2 for the wet and dry seasons respectively. The pollution index values of copper in both seasons clearly showed that the concentration of copper in the groundwater in the study area is within the acceptable level (Table 1).

The presence of those heavy metals in elevated concentration in the drinking water in the study area requires an urgent intervention, due to their health implications. In general, the results of this study showed that the groundwater in Pompomari is contaminated. The slight higher concentration of contaminants observed during the dry season could be attributed to increase in evaporation and hydro-chemical reactions. Majority of the contaminants were brought by flood from both far and near places. The contamination is more prominent in shallow aquifers where the groundwater table is nearer to the surface and vulnerable to contaminants from dissolved ions, metals, and nitrates. The presence of contaminants in the groundwater of the study area constitute health hazards which are associated with diseases such as kidney failure, cancer, diarrhea, lung damage, and nausea. Therefore, the area needs a high capacity drainage system that will facilitate the redirection of the flood run-off. Boreholes for groundwater supply in the study area should be drilled to at least a depth of 100 m or more into the second aquifer for quality groundwater exploitation.

The contaminants in the groundwater, obviously constitute severe health hazards to both human and animals. The results of this study is in consonance with the findings of Waziri *et al*., 2009; Emeka and Weltime, 2008; and Sani *et al*., 2018. The results of this study will help policy and decision makers in Damaturu, Yobe State, to take proactive measures against groundwater pollution in the study area.

CONCLUSION

This study investigated groundwater pollution in Pompomari area of Damaturu using geophysical and hydro-chemical methods. The findings of the study showed that the area is composed of five geo-electrical layers such as topsoil, clay, sandy clay, sand and clay. The fourth layer constitute the aquifer in the study area. Although in some areas the second layer serve as semi-confined aquifer and it is highly susceptible to contamination while the fourth layer is the second aquifer and it is confined. The results of the electrical resistivity tomography showed that the contaminants came through the flood water to converge in the study area and infiltrate into the subsurface to pollute the groundwater resources in the area. The contaminants were delineated as low resistivity plume in the subsurface of the study area. The contaminants spread spatially in the area as they infiltrate into the subsurface. The results of the analyzed water samples showed that the water is contaminated by heavy metals whose concentration are higher than the World Health Organization standard guidelines. Efficient waste management system should be encouraged to avoid the infiltration of leachate into the subsurface

RECOMMENDATION

Based on the findings of this study, the following suggestions will help to mitigate the effect of groundwater pollution in Pompomari.

i. Deeper borehole drilling and regular groundwater monitoring should be encouraged in the study area.
ii. The consumption of water from wells and shallow boreholes in the study area should be stopped to avoid infections due to consumption of contaminated water.

CONFLICT OF INTEREST

The authors declared that there are no competing interests.

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Plate 1: The field crew with the two authors (4th and 5th persons) L-R.

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