FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 6 No. 4, August, 2022, pp 181 - 190
DOI: https://doi.org/10.33003/fjs-2022-0604-1062

GEOPHYSICAL AND HYDROCHEMICAL INVESTIGATION OF THE IMPACT OF CLIMATE CHANGE ON GROUNDWATER QUALITY: A CASE STUDY OF GASHUA, NORTHEAST NIGERIA

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ABSTRACT

In this study we investigated the impact of climate change on groundwater quality in Gashua northeast Nigeria. The results of the time series analysis of the meteorological data obtained from the area showed high variability in rainfall and temperature due to climate change. This variability is responsible for the extreme and erratic rainfall which cause flooding in the area. The flood water are associated with both organic and inorganic contaminants which infiltrate into the subsurface to pollute the groundwater. Geophysical and Hydrochemical methods were used to investigate the groundwater quality in the area. The results of the Vertical Electrical Sounding (VES) showed that the area is composed of five geoelectric layers which are; topsoil, clay, sand, sandy-clay and sand. The second layer which is clay enhances the retention of the flood water in the study area due to its proximity to the surface. Contaminated zones in the subsurface of the study area were identified as low resistivity areas with resistivity values ranging from 2 - 25 Ωm. The results of the hydro-chemical analysis of the groundwater samples showed that the groundwater is polluted. Based on the findings of this study, we recommend that a high capacity drainage system should be constructed in Gashua and its environs to protect the area from extreme flooding and groundwater pollution. Gashua river channel should be improved through excavation and river bank protection to accommodate floodwater.

Keywords: Gashua, climate change, temperature, rainfall, flood, contamination, groundwater

INTRODUCTION

The solar radiation from the sun provides the energy which constantly drives the earth. Any prolong perturbation in the energy balance of the earth is always associated with a change in the atmospheric and oceanic circulation, hydrologic cycle and groundwater recharge which culminate in climate change. The two major meteorological factors which determine climate dynamics are temperature and precipitation. Extreme temperature and lower rainfall are often associated with drought while extreme rainfall causes flooding, mostly in a semi-arid areas where the land surface is near uniform or in a flood plain. Floods are natural disasters that are caused by heavy rainfall or rapid melting snow and ice. Gashua is a town in northeastern Nigeria, which is plagued by annual flash flood because of its location within a flood plain in the Chad Basin part of Yobe State. Flash floods occur when there is more rain than the soil can absorb and the excess water can rise to a significant height above the ground surface. The flood water may take several days or weeks to drain into the soil. The flood water is often accompanied with organic and inorganic contaminants derived from domestic, agricultural and industrial wastes. As the flood water inundates the environment, the contaminants might infiltrate into the shallow aquifers to pollute the groundwater. De Lapaix *et al*., (2011) reported that there is a link between extreme rainfall and widespread of contaminant in soil. 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.

The increase in temperature in recent years and the gradual reduction in rainfall in arid and semi-arid regions are evidence of climate change. Erratic and extreme rainfall in the semi-arid region of Nigeria are characterized with flash floods which destroy farmlands, household properties and also causes environmental pollution. Flash flood in Gashua in recent years has become a regular feature, which had led to huge loss of farm produce and livestock. Many flood plains are known sinks to contaminants transported by floodwater. Temperature and precipitation variability are good indices of climate change which have direct bearing on drought and flash flood occurrence. The impact of climate change on water quality was not detailed in the 2007, Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC). However, many researchers have shown that climate change related flash flood affects both surface and groundwater quality in flood plains, mostly in coastal areas. (Delpla *et al*., 2009; Ayolabi, 2013; Ezekwe and Edoghotu, 2015; Ojolowo and Wahab, 2017).

The pollution of groundwater by contaminant infiltration in Agbara industrial estate was investigated by Mosuro et al., (2016) using electrical resistivity method and their results indicated that the contaminant had reached a depth of 10 m below the ground surface. Groundwater quality in Aule area of Akure was investigated using integrated geophysical methods and hydro-chemical analysis by Adelusi *et al*., (2013), their results showed that the groundwater in the area is polluted by petroleum products from a nearby filling station. The contaminant plume were delineated at a depth of 10 m below the ground surface. Waziri *et al*., (2009) reported that both surface and groundwater in Gashua and its environs are polluted. Agada *et al*., (2020) observed that leachate from the decomposition of solid waste contributes to the groundwater pollution in Gashua and its environs but the scope of the study was limited due paucity of fund. The demand for quality drinking water is increasing in Gashua, due to its rapid population growth. The high susceptibility of surface water to contamination has made the population to depend heavily on groundwater resources for both domestic and industrial consumption. Precipitation is the major source of groundwater recharge in semi-arid and arid regions (Small, 2005). Extreme precipitation often cause the pollution of shallow aquifer and makes the groundwater toxic for consumption. Microbial pollution often cause diseases such as Diarrheal and Cholera (Taylor *et al*., 2009). In developing countries, millions of people die annually due to the consumption of contaminated water (USEPA, 2001). The provision of adequate and quality drinking water is very important to good health and human development. In Sub-Saharan Africa, the provision of adequate quality drinking water has become a serious challenge due to inadequate financial resources and increasing climate variability. Increasing trends in flash flood and drought in semi-arid region of Nigeria has contributed to decline in groundwater quality and quantity (Agada and Yakubu, 2022). The problem of flooding is not limited to Gashua and its environs alone, it affects many parts of Nigeria, it is an annual scourge which occurs every rainy season. In recent years, more than 2.3 million people have been displaced with great economic damage by flood and about 363 lives were lost in Nigeria (Nwigwe and Emberga, 2014; Olanrewaju *et al*., 2019).

There is very limited research on the effect of climate change on groundwater quality in the semi-arid region of Nigeria. In order to fill the knowledge gap, this study was focused on unraveling the dynamics of groundwater quality and contamination associated with flash floods in Gashua, a semi-arid region of Nigeria. Surface meteorological data, hydro-chemical analysis of the groundwater samples and geophysical investigation were deployed to carry out this study. The aim of this study is to investigate the impact of climate change on groundwater quality in Gashua and its environs and to make appropriate recommendations for its mitigation base on the findings of this study.

MATERIAL AND METHODS

The study area

Gashua is a town in Yobe State, northeastern Nigeria (Fig. 1), it is situated close to the convergence of Hadeija and Jama'are rivers in 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). Gashua has a population of about 125, 000 according to 2006 National population census results. Gashua climate is known to have a characteristic 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. Greater part of Gashua lies within the flood plain. Topographically, Gashua is relatively a lowland area which contribute to the flooding of Gashua and its environs (Fig. 6).

Data Acquisition

Meteorological data such as temperature and precipitation data were collected for a period of thirty (30) years (1990 – 2020) from Nigerian Meteorological station Nguru which is very close to Gashua, and the data were analyzed to determine if climate change has contributed to the flooding of the study area. Groundwater samples were collected during both dry and rainy seasons and they were analyzed hydro-chemically to ascertain their quality with reference to United States Environmental Protection Agency (USEPA) and World Health Organization 2017 standards. Thirty-two (32) water samples were collected in Gashua and its environs and they were analyzed to determine the presence of lead, cadmium, chromium, iron, copper and arsenic and their concentrations in the water samples.

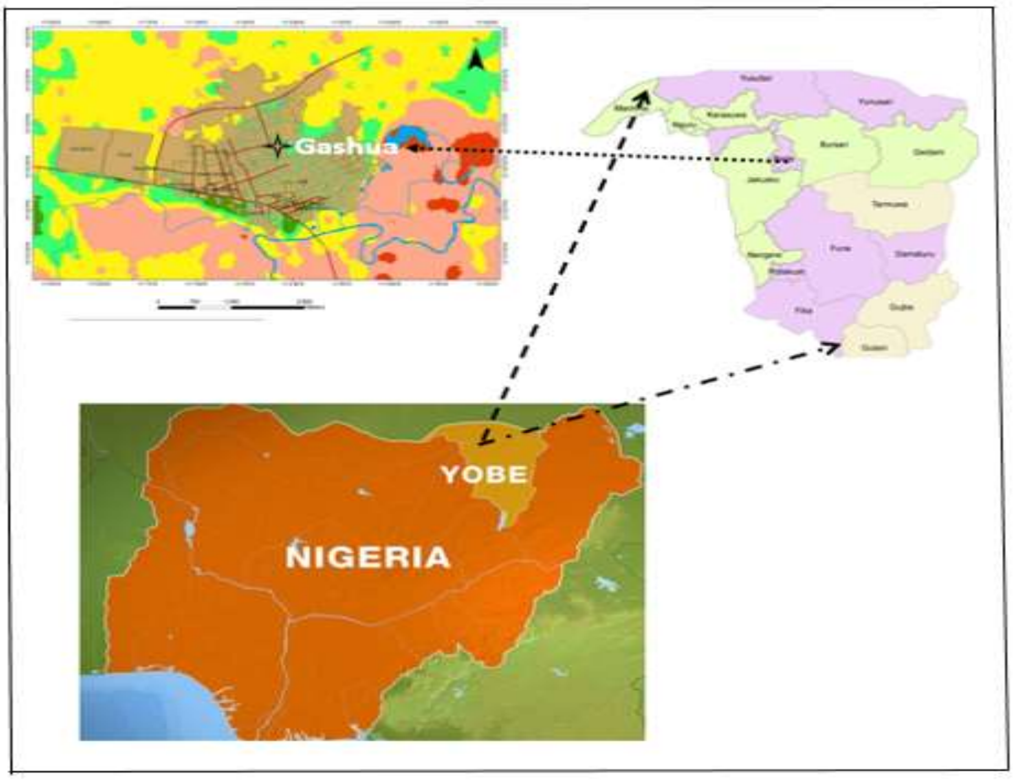


Figure 1: Map of Nigeria showing Gashua the study area.

Figure 2: Geological map of Nigeria showing the location of Gashua in the Chad Basin (Obaje *et al.*, 1999).

Electrical resistivity surveys which involves 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.

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.

Data Processing.

Time series analysis and basic statistics were used to evaluate the temperature and precipitation data. The Standard Anomaly Index (SAI) was calculated using equation (1),

$$SAI = \frac{x_i - x_m}{\sigma} \qquad (1)$$

where, x_i is the mean temperature or precipitation for each year and x_m is the long-term mean temperature or precipitation. σ is the standard deviation of the annual temperature or precipitation for the long term. Periods below the long-term average were considered cooling periods for the temperature analysis and dry periods for the precipitation analysis. The periods above the long-term average were considered warming periods for the temperature analysis and wet periods for the precipitation analysis. The standardized anomaly index of the temperature was compared to the threshold risk levels in table 1 and the standardized precipitation index were compared with the threshold risk levels in table 2.

Table 1. Standardized Temperature Anomaly Index (Source: Marck, 2015)

S/N	Event	Interpretation
1	$SAI \geq 2.0$	Extreme hot
2	$SAI \geq 1.5 < 2.0$	Very hot
3	$SAI \geq 1.0 < 1.5$	Moderately hot
4	$SAI < 1.0 > -1.0$	Near normal
5	$SAI \leq -1.0 \; > -1.5$	Moderately cold
6	$SAI \leq -1.5 > -2.0$	Very cold
7	$SAI \leq \; -2.0$	Extremely cold

Table 2. SPI values and their interpretation (Source: Koudahe *et al.*, 2017)

SPI Value	Interpretation
≥ 2.0	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.99 to -0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
≤ 2.0	Extremely dry

The acquired Vertical Electrical Sounding (VES) data were modeled using IP2WIN software to obtain the subsurface layer resistivity and thickness values. The ERT data were interpreted using RES2DINV software to delineate the distribution of the contaminant plume in the study area.

RESULTS AND DISCUSSION

The time series analysis of both the maximum and minimum temperature data of the study area showed an increasing temperature trend (Figs. 3 and 4), which is an indication that the area is warming at a faster rate due to climate change. This warming effect has impacted the groundwater recharge and storage capacities negatively due to increase in evapotranspiration and high demand for water consumption. The high demand for groundwater supply exerts intense pressure on the groundwater resources in the area. Over pumping of groundwater in order to meet the demand for water supply reduces groundwater storativity and the hydraulic conductivity of the aquifer and could lead to a structural deformation of the aquifer with resultant contamination of the groundwater. The rate of borehole failure in recent times in the study area is a good indication of the effect of climate change on groundwater in the area.

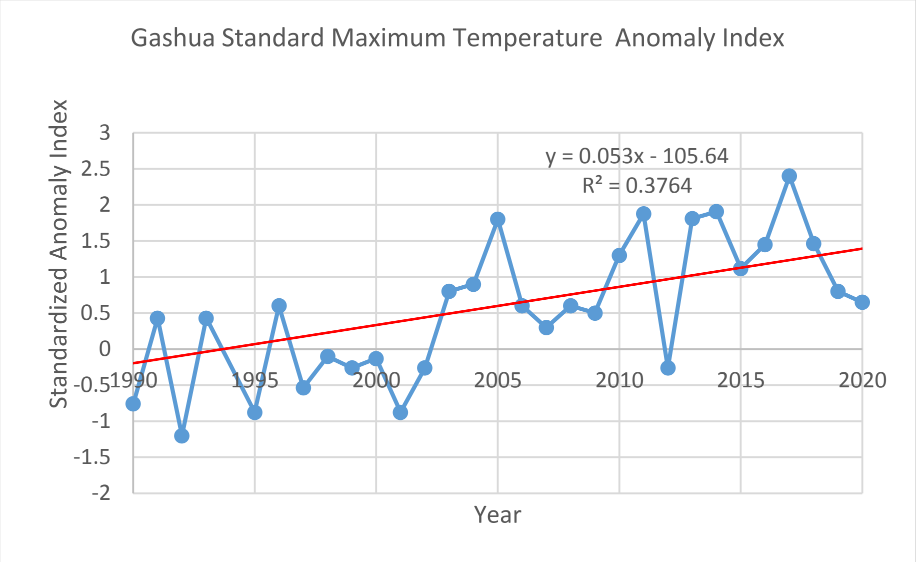


Figure 3: Standardized maximum temperature anomaly index of the study area for thirty years, showing an increase in temperature trend. This increasing trend in maximum temperature over the years has affected both the recharge and the quality of groundwater in the area.

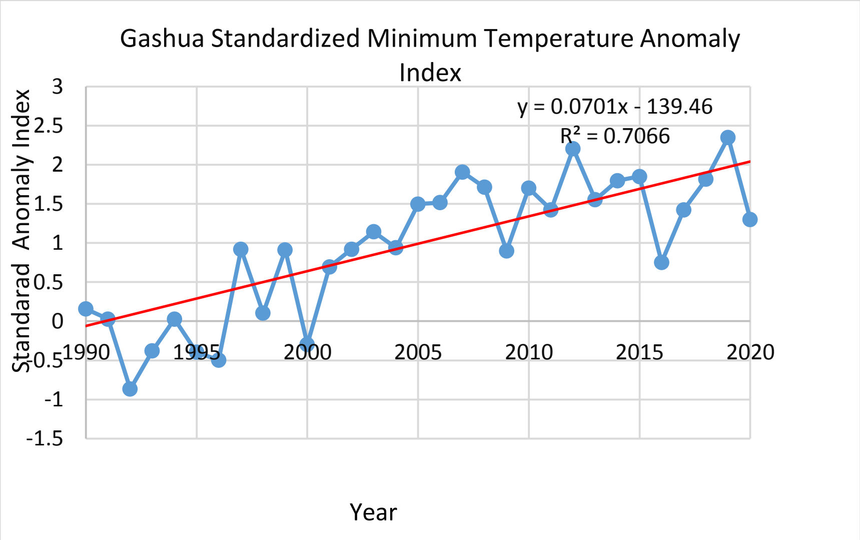


Figure 4: Standardized minimum temperature anomaly index of the study area for thirty years, showing increasing trend in temperature. This increasing trend in minimum temperature is a manifestation of climate change.

Drought is a period of prolonged low rainfall, leading to a shortage of water. The results of the time series analysis of the annual rainfall for a period of thirty (30) years showed that the area has been affected by series of drought episodes and the precipitation trend is declining due to climate change (Fig. 5). The results of the analysis of the precipitation data indicates that there were droughts in 1990, 1992, 1993, 1996, 2001, 2003, 2008, 2016, 2017, 2018, and 2019 in the study area which have contributed to the depletion of the quantity and quality of the groundwater in the study area (Fig. 5).

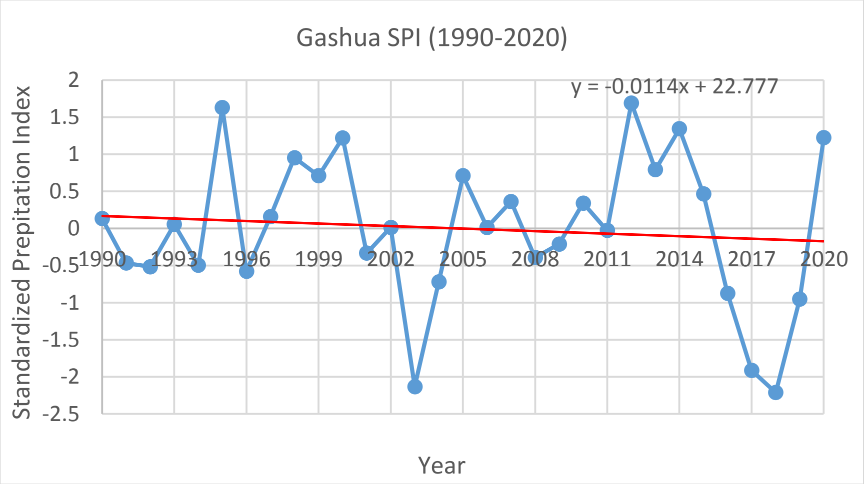


Figure 5: The standardized precipitation index of the study area for thirty years showing a decreasing precipitation trend in the area.

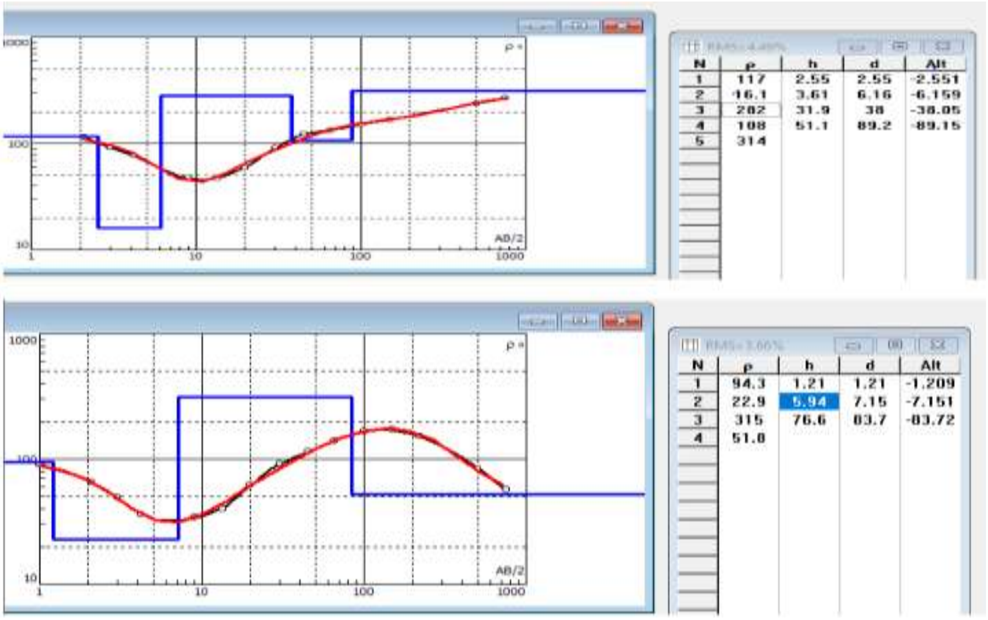
The precipitation timing has become erratic and unpredictable as such that farming activities have been greatly disrupted in recent years. The standard precipitation index of the study area showed that the rainfall in Gashua and its environs has declined in recent years and this declination in the amount of rainfall has reduced the recharge of the groundwater in the area. The rainfall pattern in the area has become erratic due to climate change. The groundwater in the study area has been affected by the amount of precipitation in the area. The erratic rainfall are often extreme and are accompanied with flashflood which in most cases inundate the area (Fig. 6).

Figure 6: Flash flood scene in Gashua.

The flood water inundates the area and it always come with both organic and inorganic contaminants of domestic, agricultural and industrial extractions to pollute the groundwater.

The overflowing of the Hadeija and Yobe rivers exacerbates the flooding events in the Gashua floodplain. Typical curves such as HA and HK were obtained in the study area (Fig. 7).

The Vertical Electrical Sounding (VES) results obtained from the electrical resistivity survey showed that the study area is composed of five geoelectric layers, which are; the topsoil, clay, sand, sandy-clay, and sand (Fig. 8).



N	ρ	h	d	Alt
1	117	2.55	2.55	-2.551
2	16.1	3.61	6.16	-6.159
3	282	31.9	38	-38.05
4	108	51.1	89.2	-89.15
5	314			

N	ρ	h	d	Alt
1	94.3	1.21	1.21	-1.209
2	22.9	5.94	7.15	-7.151
3	315	76.6	83.7	-83.72
4	51.8			

Figure 7: Typical VES curves obtained from the study area.

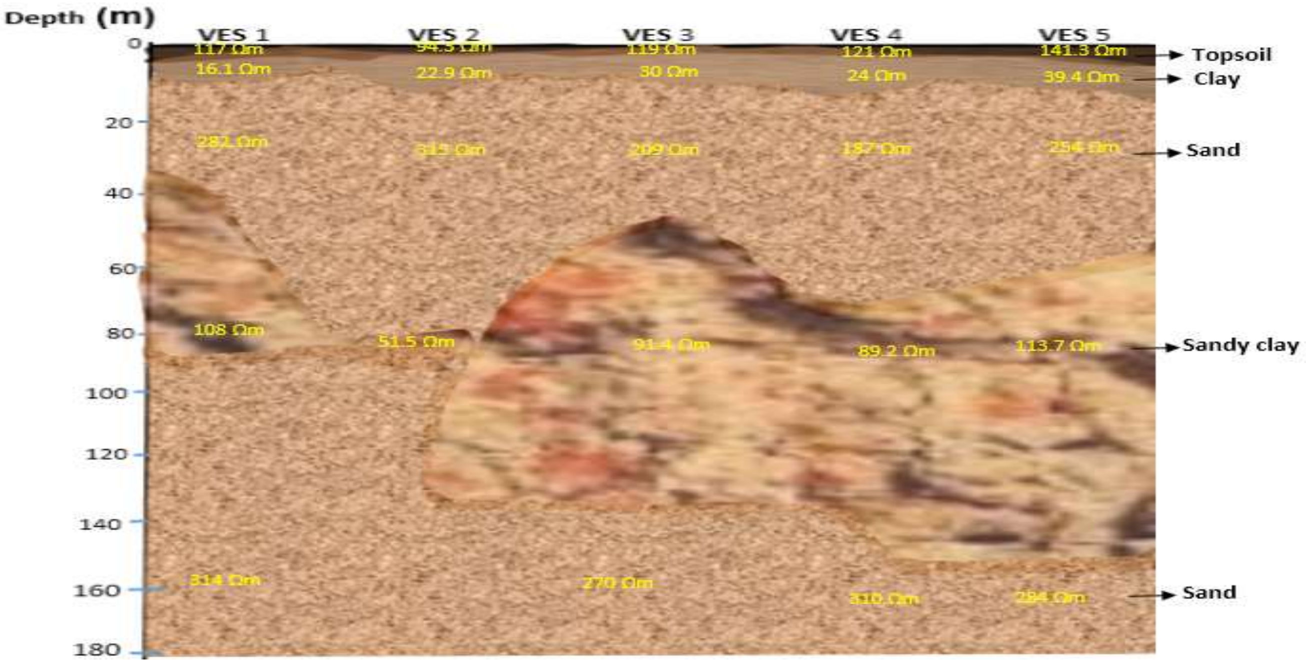


Figure 8: Geoelectric section of VES 1-5 showing the various subsurface layers in the study area.

The Vertical Electrical Sounding (VES) results were compared with an existing borehole log in the study area and the results showed good correlation. The first layer is the topsoil and it has resistivity values ranging from 83.0 to 185.0 Ωm and a thickness which range from 0.7 to 2.5 m (Table 3). The second layer is a clay formation whose resistivity range from 16.0 to 46.9 Ωm and has a thickness which range from 3.60 to 8.30 m (Table 3). The clay layer influences the water retention capacity of the area and thereby positively influences the flood activity in the study area. The third layer has resistivity value which range from 182.0 to 329.0 Ωm and a thickness value which range from 31.90 to 76.6 m. The third layer is a sandy aquifer in which most hand dug wells and shallow boreholes are drilled. This aquifer is prone to contamination considering its proximity to the surface. It is semi-confined in some places within the study area. The fourth layer is characterized by resistivity value which range from 51.5 to 121.2 Ωm and has the thickness which range from 51.5 to 93.0 m. It is a sandy-clay layer which over lays the fifth layer. The fifth layer has resistivity which range from 214.0 to 342.0 Ωm. It is a sandy layer which is the second aquifer in the study area but its thickness was not determined (Table 3).

The Electrical Resistivity Tomography (ERT) results showed that the dissolved contaminants infiltrate into the subsurface and were mapped as low resistivity plume. The contaminant plume were indicated in deep blue color in the inverse resistivity model as shown in figures 9a to 9c. The contaminant seeps into the aquifer and 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.

Table 3: 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_5	d_1	d_2	d_3	d_4
1	117.0	16.1	282.0	108.0	314.0	2.5	3.6	31.9	51.1	2.5	6.2	38.0	89.2
2	94.3	22.9	315.0	51.5	-	1.2	5.9	76.6	-	1.2	7.1	83.7	-
3	119.0	30.0	209.0	91.4	270.0	1.1	4.8	51.0	81.0	1.1	5.9	56.9	137.9
4	121.0	24.0	187.0	89.2	310.0	1.3	7.2	67.7	63.0	1.3	8.5	76.2	139.2
5	141.3	39.4	254.0	113.7	284.0	2.0	5.6	54.0	93.0	2.0	7.6	61.6	154.6
6	131.0	42.6	182.0	121.2	315.0	1.5	8.3	45.0	87.0	1.5	9.8	54.8	141.8
7	83.0	37.0	329.0	118.0	291.0	0.9	7.5	61.0	59.0	0.9	8.4	69.4	128.6
8	144.0	28.5	274.0	101.0	314.0	0.7	6.9	55.0	72.0	0.7	7.6	62.6	134.6
9	105.0	38.0	285.0	92.0	214.0	1.2	7.8	49.0	70.0	1.2	9.0	58.0	128.0
10	185.0	46.9	327.0	117.5	342.0	1.3	8.1	56.0	64.0	1.3	9.4	65.4	129.4

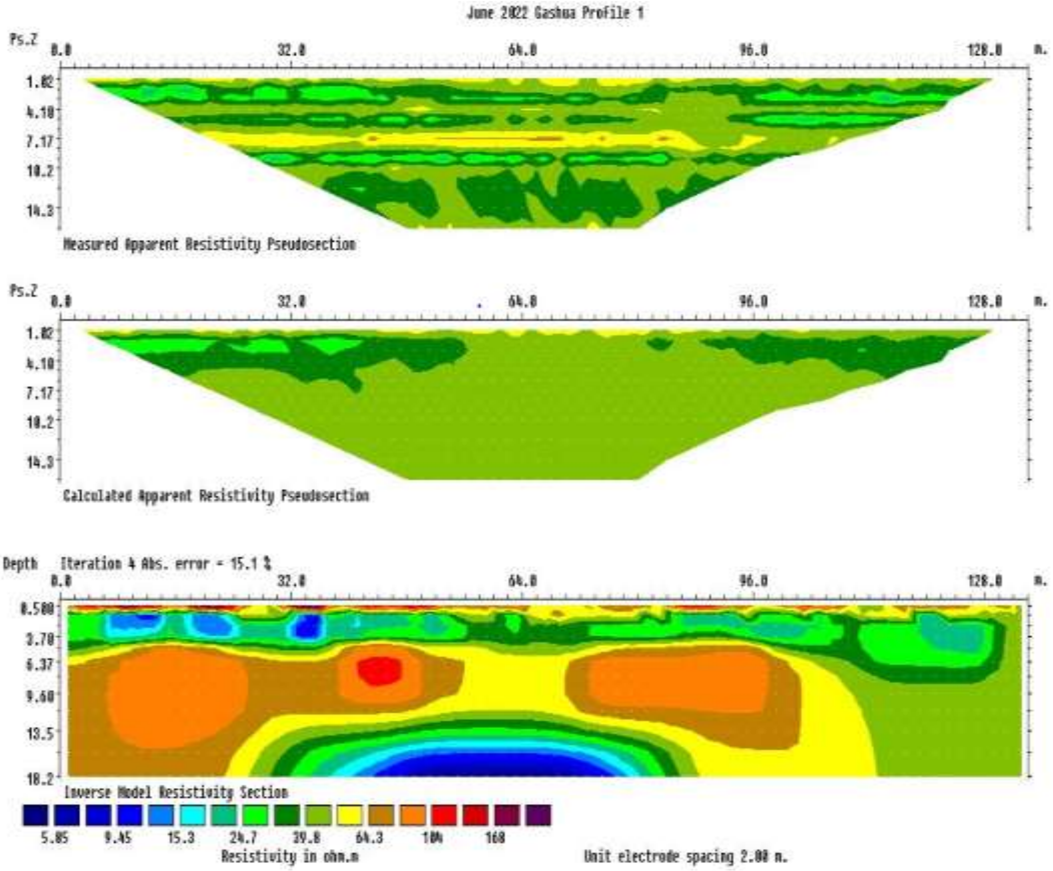


Figure 9a: Inverse resistivity model showing the presence of the contaminant plume in deep blue colour in the subsurface. The contaminants are characterized by very low resistivity values that range from 2-5 Ωm which distinguishes them from the surrounding rocks. The result shows that the contaminants have impacted the aquifer.

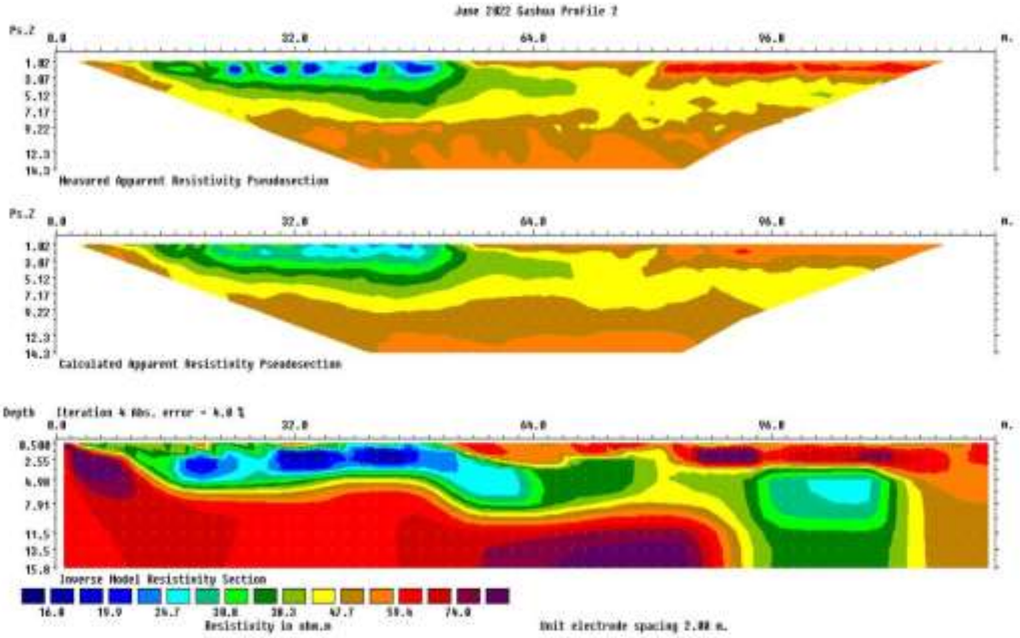


Figure 9b: Inverse resistivity model showing the spatial distribution of the contaminant plume.

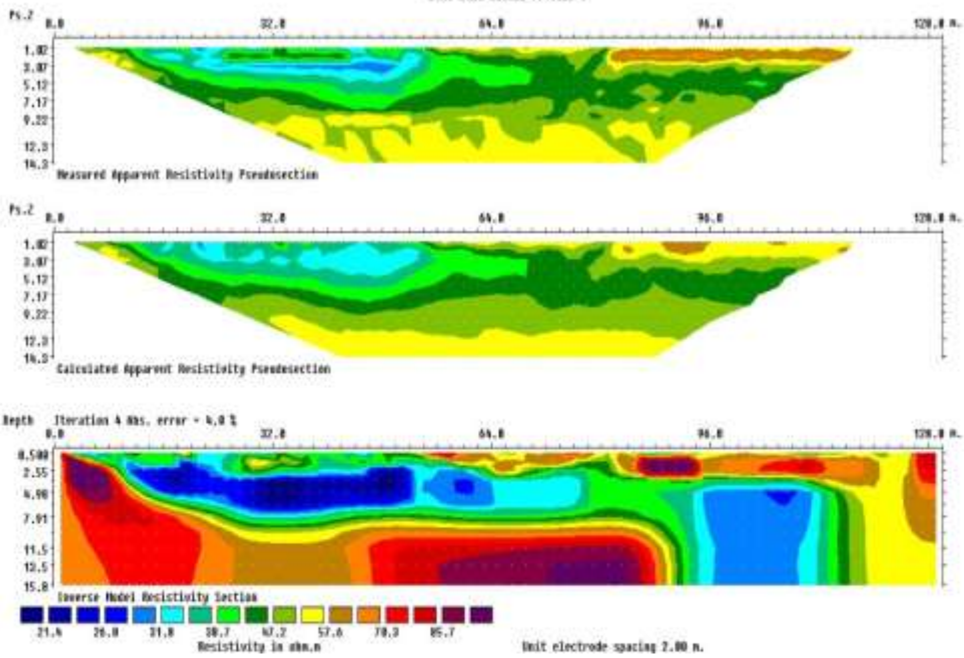


Figure 9c: Inverse resistivity model showing the contaminant plume migration into the aquifer.

The continuous deposition and sedimentation of contaminants transported from different sources to Gashua floodplain by flood water will continue to enhance the toxicity of the groundwater as a result of increasing trend of climate change if the problem is not resolved.

Table 4: Water sample analysis results

Parameter	Wet Season heavy metal concentration (mg/L)				Dry Season heavy metal concentration (mg/L)				WHO Guidelines
	Min	**Max**	**Ave**	**Stdev**	**Min**	**Max**	**Ave**	**Stdev**	
Cadmium	0.018	0.057	0.034	0.013	0.054	0.169	0.049	0.032	0.010
Lead	0.010	0.024	0.017	0.004	0.001	0.962	0.067	0.102	0.010
Iron	0.200	1.600	1.000	0.405	0.300	2.240	1.280	0.463	0.300
Arsenic	0.013	0.040	0.070	0.308	0.013	0.050	0.040	0.025	0.010
Chromium	0.030	0.090	0.046	0.015	0.041	0.566	0.103	0.092	0.050
Copper	0.085	0.920	0.476	0.108	0.035	0.917	0.333	0.120	2.000

Min = minimum; Ave = average; Max = maximum; Stdev = standard deviation.

The results of the chemical analysis of the water samples showed that the concentration of cadmium ranges from 0.018 to 0.057 mg/L with an average value of 0.034 mg/L during the wet season and its concentration during the dry season range from 0.054 to 0.169 mg/L with an average of 0.049 mg/L (Table 4). 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 4). The average concentration of lead in the water samples during the wet season was 0.017 mg/L and its concentration in the water samples range from 0.010 to 0.024 mg/L. The value of lead in the water samples during the dry season range from 0.001 to 0.962 mg/L and its average value was 0.102 mg/L. The average values of lead in the water samples during both wet and dry seasons are both above the WHO guideline of 0.010 mg/L (Table 4) which indicates that the water is contaminated. The average values of iron in the water samples for both wet and dry seasons are 1.0 mg/L and 1.28 mg/L respectively. And these values were higher than the WHO guideline value of 0.3 mg/L. (Table 4). The average value of arsenic in the water samples for both wet and dry seasons are 0.07 mg/L and 0.04 mg/L respectively. These values are more than the WHO guideline value of 0.01 mg/L (Table 4).

The concentration of chromium in the water samples range from 0.030 to 0.090 mg/L during the wet season and its average value is 0.046 mg/L (Table 4). The concentration of chromium in the water samples during the dry season range from 0.041 mg/L to 0.566 mg/L. The average concentration of chromium in the water samples during dry season was 0.103 mg/L. The average value of chromium in both wet and dry seasons was higher than the WHO guideline of 0.050 µg/L. The average values of chromium in the water samples indicate that the water is polluted. The concentration of copper in the water samples range from 0.085 to 0.920 mg/L during the wet season, and its average value was 0.476 mg/L. During the dry season, the concentration of copper in the water samples range from 0.035 to 0.333 mg/L. The average concentration of copper in the water samples for both dry and wet seasons are below the WHO guideline value of 2.0 mg/L (Table 4) and these values indicate that the concentration of copper in the water samples is within the acceptable limit. The availability of these trace metals in elevated concentration in the drinking water constitute serious health hazards as some of them are carcinogenic.

In general, the overall results showed that the groundwater in Gashua and its environs are polluted. The slight higher concentration of contaminants observed during the dry season could be attributed to increase in evaporation and hydro-chemical reactions. The results of the analyzed groundwater samples indicate that the groundwater is contaminated by trace metals and other contaminants brought by flood water 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 from various sources. The presence of contaminants in elevated concentration in the groundwater constitute health hazards which are associated with diseases such as kidney failure, cancer, diarrhea, lung damage, and nausea.

CONCLUSION

This study investigated the impact of climate change on groundwater quality in Gashua and its environs. The findings of the study showed that the area is composed of five geo-electrical layers such as topsoil, clay, sand, sandy clay and sand. The third and the fifth layers constitute the aquifers in the area. The first aquifer is semi-confined and it is highly susceptible to contamination while the second aquifer is confined. The variability in temperature and precipitation due to climate change has caused intense flash flood occurrence in the study area in recent years which has degraded the quality of the groundwater in the area. The results of the electrical resistivity tomography indicated that the contaminants transported from many different places by the flood water converge and infiltrate into the subsurface in Gashua 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 sediments and percolates into the subsurface to pollute the groundwater. The clay layer which is close to the surface enhances the retention of the flood water and exacerbate the flood risk. The results of the analyzed water samples showed that the water is contaminated by trace metals whose concentration are elevated and they constitute severe health hazards. Some of which are carcinogenic. The concentration of the contaminant in the groundwater is higher during dry season than the rainy season due to evaporation caused by increase in temperature. The flooding in the area is mostly exacerbated by the over flowing of the Hadeija and Yobe rivers during extreme rainfall. In view of the findings of this study, the provision of good drainage system in Gashua and its environs will help to alleviate the occurrence of flood in the area. Considering the increase in the occurrence of water related diseases in the study area (Sani et al., 2018), there is need for regular monitoring of groundwater quality in the Gashua and its environs to avert health complications associated with the consumption of contaminated water. The results of this study is in consonance with the findings of Waziri et al., 2009 and Agada et al., 2020. The results of this study will help policy and decision makers to take proactive measures to overcome the threat of climate change on groundwater quality in the study area.

RECOMMENDATION

Based on the findings of this study, the following suggestions will help to mitigate the effect of climate change on groundwater quality in Gashua and its environs.

i. The State Environmental Protection Agency (EPA) should establish a flood forecasting and warning system in the study area.
ii. The river channel should be improved to accommodate the flood water through excavation and bank protection.
iii. High capacity drainage system should be constructed in Gashua and its environs to facilitate the redirection of the flood run-off through the use of floodwalls and flood gates.
iv. Afforestation should be encouraged in the study area in order to reduce the variability in temperature.
v. Efficient waste management system should be encouraged to avoid the infiltration of leachate into the subsurface.

CONFLICT OF INTEREST

The authors declared that there are no competing interests.

ACKNOWLEDGEMENT

We acknowledge the support of Tertiary Education Trust Fund (TETFund) and the management of Yobe State University Damaturu for providing financial support for the accomplishment of this study. We also appreciate Nigerian Meteorological Agency (NiMet) Abuja for the meteorological datasets used in this study.

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