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Impacts of Climate Change on Groundwater Resources in a Semi-Arid Region: A Case Study of Damaturu, Yobe State

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Abstract: *In this study, the impact of climate change on groundwater was investigated. Vertical Electrical Sounding (VES) data obtained from the study area was used to characterize the subsurface lithology of the study area. Schlumberger electrode configuration was adopted for the study and five geoelectric layers were delineated. The delineated geologic layers are topsoil, clay, sand, sandy-clay, and sand. Precipitation and temperature data for thirty years (1991-2020) obtained from the Nigeria Meteorological Station Potiskum, were used to analyze the impact of climate variability on groundwater in the study area. The temperature and precipitation data were analyzed using the World Meteorological Organization (WMO) method. The geophysical survey results showed that the proximity of the first aquifer to the ground surface enhances the influence of high temperature on the groundwater. The first aquifer is semi-confined while the second aquifer is confined in the study area. The results of the analyzed precipitation data showed that the amount of precipitation in the study area has declined over the years. The results of the analyzed temperature data clearly showed that the study area is warming. The aquifers in the study area recharge by precipitation (rainfall) since there are no rivers or streams in the area. The decline in the amount of precipitation in the study area over the years has affected the aquifer recharge, leading to a reduction in the groundwater table. The effects of climate change on groundwater in the study area contributed to water scarcity, and the drying up of some wells and shallow boreholes in the study area. It has also contributed to the high cost of groundwater management in the area. The increasing trend in climatic variability in the study area may endanger the groundwater potential of the area if appropriate actions are not taken.*

Keywords: *Groundwater, temperature, precipitation, aquifer, climate change*

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1.0 Introduction

Groundwater is an important natural resource which is known for its freshwater supply. The role of groundwater in arid and semi-arid regions where there are little or no rivers and streams cannot be underestimated. Groundwater remains the only alternative water supply in areas where there is a scarcity of streams, lakes, ponds and rivers. The continuous increase in global temperature and the gradual reduction in annual precipitation mostly in semi-arid and arid regions over the years have directly enhanced the frequent occurrence of prolonged droughts. The increasing trend in extreme weather conditions such as heat waves, droughts and floods are the manifestations of climate change. Drought is a prolonged dry period in the natural climate without precipitation or rainfall. Drought has a great negative impact on both human and animal health, agriculture, economies, energy and the environment. Prolonged droughts are characterized by a lowering of water levels in the rivers, streams, ponds and the groundwater table (Moseki, 2017). In some cases, smaller streams, ponds and lakes often get dried up.

Climate change effect affects groundwater resources in many ways, such as reduction in soil moisture, increase in evapotranspiration, reduction in groundwater recharge, lowering of groundwater table and degradation of groundwater quality (Vasiljević *et al*., 2013). In most cases, prolonged drought has led to groundwater pollution thereby exposing people to water-related hazards as a result of the consumption of contaminated water. Climate change has been adjudged to be one of the factors contributing to desertification in both arid and semi-arid regions. Prolonged meteorological drought is responsible for groundwater drought. Groundwater drought occurs when the heads of the aquifer fall below critical level due to little or no recharge. Aquifers in arid or semi-arid regions are mostly recharged by precipitation (rainfall) due to the scarcity of rivers and streams. Lack of precipitation during drought has led to the extinction of some plants and crop species in the semi-arid region of Nigeria. This situation has led to increasing human migration due to drought.

In the semi-arid region of Nigeria, the increasing conflict between herders and farmers is exacerbated by the impact of drought in the region. Due to little or no precipitation, some plants that are used for animal feeds are almost going into extinction and this situation has prompted the herders to migrate southward for survival. Their migrations to new areas have caused severe rivalry between them and their new host communities as a result of competition over available land and water resources. This conflict has led to the destruction of many human lives and properties.

Several research reports have shown that the continuous emission of Green House Gases (GHG) will increase the trend in drought-related water hazards and food shortage (IPCC, 2007; Taylor *et al* 2009; Agada and Sonloye, 2022; Agada and Habu, 2022). The main greenhouse gases causing climate change include carbon dioxide and methane. Climate change is not only associated with increasing global temperature, but its consequences are devastating. The consequences of climate change among others include intense drought, water scarcity, wildfires, flooding, melting of polar ice, catastrophic storms, rising sea levels and changes in biodiversity. Greenhouse gases are released into the atmosphere mainly through the combustion of fossil fuels. The availability of groundwater during meteorological drought in most cases is very helpful but in situations where the meteorological drought becomes prolonged both the quantity and quality of groundwater become compromised leading to groundwater drought.

Moseki (2017) observed that the change in frequency, intensity and pattern in precipitation as well as the e temperature change has strong implications for groundwater storage. It is evidence that groundwater recharge is often reduced during drought and this reduction puts enormous stress on the available groundwater resources. There is a growing interest in the impact of climate change and variability on groundwater (Cave *et al*., 2003) due to the shortage of water during drought and its effects on agriculture, industries and domestic consumption. Sukhija (2008) suggested that there should be regular monitoring of those parameters that influence the impact of climate change on groundwater resources.

A study by Cave *et al.* (2003) in South Africa showed that a 20% decrease in mean annual precipitation caused an 80% decrease in groundwater recharge in areas that are receiving 500mm precipitation per year or less. The results of their study showed that there is a strong relationship between the mean annual precipitation and the level of groundwater recharge in their study area. More than 70% of the African population depends on shallow or deep groundwater resources and therefore, any decrease in the groundwater recharge system will affect their domestic, agricultural and industrial outputs.

The increase in the depth of the groundwater table and the reduction in recharge will jeopardize many irrigation farming practices and the provision of water for both domestic and industrial purposes (Aizebeokhai, 2011). Damaturu is the capital of Yobe State and it is located in the semi-arid region of Nigeria. Reports from the Yobe State Water Corporation Board indicate that the groundwater table in some areas of the state has fallen below critical levels which has led to low borehole yield and the inability of some boreholes to produce water throughout the year. Hence the continuous depreciation of groundwater resources in the study area will seriously affect agricultural production because the communities around the study area are mainly agrarian. Considering the importance of groundwater to humans, agriculture, and industrial development, there is a great need to explore the relationship between groundwater resources and the changing climate.

Some many research reports have predicted that climate change will have devastating effects on groundwater resources (Thomsen, 1989; Jorgensen *et al*., 2010; Sophocleous, 2004; Warner, 2007; Kundzewicz et al., 2007; Bates *et al.*, 2008; Taylor et al., 2013). Both anthropogenic and natural climate variability are capable of affecting precipitation, evapotranspiration, soil water content, atmospheric water contents, lakes, rivers, streams and groundwater resources (Bates *et al*., 2008). Extensive variability in temperature and precipitation will have both direct and indirect effects on groundwater quantity and quality (Van Dijck *et al*., 2006; Bates *et al*., 2008; Agada and Yakubu, 2022). It has been established that large variability in precipitation often affects the quantity of groundwater in shallow aquifers (Hanson *et al*., 2006; Gurdak *et al*., 2007; Kundzewicz *et al*., 2007; Ouysse *et al*., 2010). Green *et al.* (2007) observed that a little change in the amount of precipitation in a given area may lead to a significant decline in groundwater recharge in that area. Emeka and Weltime (2008) observed that the groundwater in Damaturu contains a high concentration of iron. Given the challenges associated with groundwater in Damaturu and its environs, the need for the understanding of the impact of climate change on groundwater is very imperative to preserve and sustain groundwater resources in the study area. This study is focused on evaluating the impacts of climate change on groundwater resources in Damaturu and its environs. The outcomes of this study will help decision-makers and policymakers in Yobe State to take appropriate actions in protecting groundwater resources in Damaturu and its environs.

1.1 The Study Area

Damaturu is located at latitude 11.73^0 N and longitude 11.96^0 E within the Chad Basin (Fig. 2). The Basin is part of the African Phanerozoic Sedimentary Basins which were formed by the dynamic process of plate divergence (Maduabuchi *et al*., 2006). The Chad Basin extends to five (5) countries which are Nigeria, Chad Republic, Cameroon, Niger and Central African Republic. The Basin is located between latitude 11^0 N and 14^0 N and longitude 9^0 E and 14^0 E covering parts of Yobe State, Bornu State, and Jigawa State in Nigeria (Obaje *et al*., 2004). According to Barber and Jones (1965), the Chad Basin in Nigeria part is made up of both argillaceous and arenaceous rock materials. The Chad Basin consists of an upper aquifer, two (2) middle aquifers and lower aquifer (Maduabuchi *et al*., 2006). The Basin is composed of interbedded sands, clays, sandy clay lenses and silts (Obaje *et al*., 2004).

Fig. 2: Map of Nigeria showing Damaturu the study area. The aquifer characteristics of the Chad Basin ranged from unconfined and semi-confined to confined (Agada *et al*, 2021). The thickness of the aquifers increases towards the centre of the basin (Agada and Yakubu, 2022). The aquifers recharge mainly from rainfall.

2.0 Materials and Methods

The electrical resistivity method involving Schlumberger configuration was used in this study to determine the depth of the groundwater and delineate the subsurface layers and the aquifer thickness of the study area. The acquired Vertical Electrical Sounding (VES) data were initially interpreted manually using the partial curve marching technique and the obtained results were modelled using WINRESIST version 1.0, to obtain the true resistivity of the various subsurface layers and their thicknesses. Temperature and precipitation data for a period of thirty (30) years (1991-2020) were obtained from the Nigeria Meteorological Agency station Potiskum, Yobe State. The temperature and precipitation data were analyzed using the World Meteorological Organization method (WMO, 2006; Hayes *et al*., 2011). Both Standardized Precipitation Index (SPI) and Standardized Temperature Anomaly Index (STAI) were used to assess the temperature and precipitation variability. These methods have been extensively used around the world for the analysis and characterization of precipitation, temperature, and drought-related events (Hayes *et a*l., 2011; WMO, 2012).

2.1 Theory

The Standard Anomaly Index (SAI) was calculated using,

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

Where, x_i is the mean temperature of the year and x_m is the long-term mean temperature. σ

is the standard deviation of the annual maximum temperature for the long term. Periods below the long-term average were considered cooling periods and periods above the long-term average were considered warming periods. The standard anomaly index of the temperature was compared to the threshold risk levels (Table 1).

Table1. Standard Anomaly Index (Source: Marck, 2015)

S/N	Event	Interpretation
1	SAI ≥ 2.0	Extremely hot
2	SAI $\geq 1.5 < 2$	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 hot
6.	SAI $\leq -1.5 > -2.0$	Very cold
7.	SAI ≤ -2.0	Extremely cold

The Standardized Precipitation Index (SPI) is based on Gamma Distribution Function (GDF). The probability density function of the gamma distribution is defined as,

$$g\ (x) = \frac{1}{\beta^{\mu}\Gamma(\mu)} x^{\mu-1} e^{-\frac{x}{\beta}} \quad \text{for } x > 0 \quad (2)$$

Where $\mu > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, $x > 0$ is the amount of precipitation, and $\Gamma(\mu)$ is the gamma function. The parameters μ and β are estimated using the following expressions.

$$\bar{\mu} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (3)$$

and

$$\bar{\beta} = \frac{\bar{x}}{\bar{\mu}} \quad (4)$$

where $\bar{x}$ is the mean precipitation and A is given by

$$A = In\ (\bar{x}) - n^{-1} \sum In(x) \quad (5)$$

Integrating equation (1) for x, and using the estimates of μ and β, we obtain a cumulative probability G(x) of a given amount of precipitation for a given time scale as,

$$G(x) = \int_0^x g(x)dx = \frac{1}{\bar{\beta}^{\bar{\mu}}\Gamma(\bar{\mu})} \int_0^x x^{\bar{\mu}}\ e^{-\frac{x}{\bar{\beta}}} dx \ (6)$$

Assuming $t = \frac{x}{\bar{\beta}}$, and substituting it into (6), we have,

$$G(x) = \frac{1}{\Gamma(\bar{\mu})} \int_0^x t^{\bar{\mu}-1} e^{-1} dt \quad (7)$$

Equation (7) is the incomplete gamma function. The gamma distribution function is not defined for $x = 0$. The probability of zero precipitation $q = p(x = 0) > 0$, is positive. Hence, the cumulative probability becomes,

$$F(x) = q + (1 - q)G(x) \quad (8)$$

Where $F(x)$ is the true probability of non-exceedance and q is the probability of $x = 0$. If ϕ is the sample size and η is the number of zeros in the sample, then q can be estimated as,

$$q = \frac{\phi}{\eta} \quad (9)$$

The transformation of the cumulative probability distribution $F(x)$ will yield the standard precipitation index (Somè *et al*., 2013). The SPI values and their interpretations are shown in Table 2.

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

SPI Values	*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*

3.0 Results and Discussion

The electrical resistivity survey results showed that five geologic layers were delineated in the study area. The results were interpreted with the aid of existing borehole logs from nearby sites. The subsurface layers delineated include the topsoil, clay, sand, sandy clay, and sand (Table 3). The average resistivity of the first layer is 148.8 Ωm and its resistivity varies from 15.1 to 232.0 Ωm. The average thickness of the first layer is 1.0 m (Table 3). The second layer is characterized by low resistivity values and it has an average resistivity of 58.2 Ωm and its resistivity varies from 25.4 to 98.2 Ωm indicating that it is a clay formation. The second layer has an average thickness of 9.1 m. The third layer has resistivity values ranging from 156.0 to 832.5 Ωm. Its average resistivity is 306.8 Ωm and it has an average thickness of 51.7 m and a depth of 61.6 m (Table 3). The typical curves obtained in the study area are shown in Fig. 3.

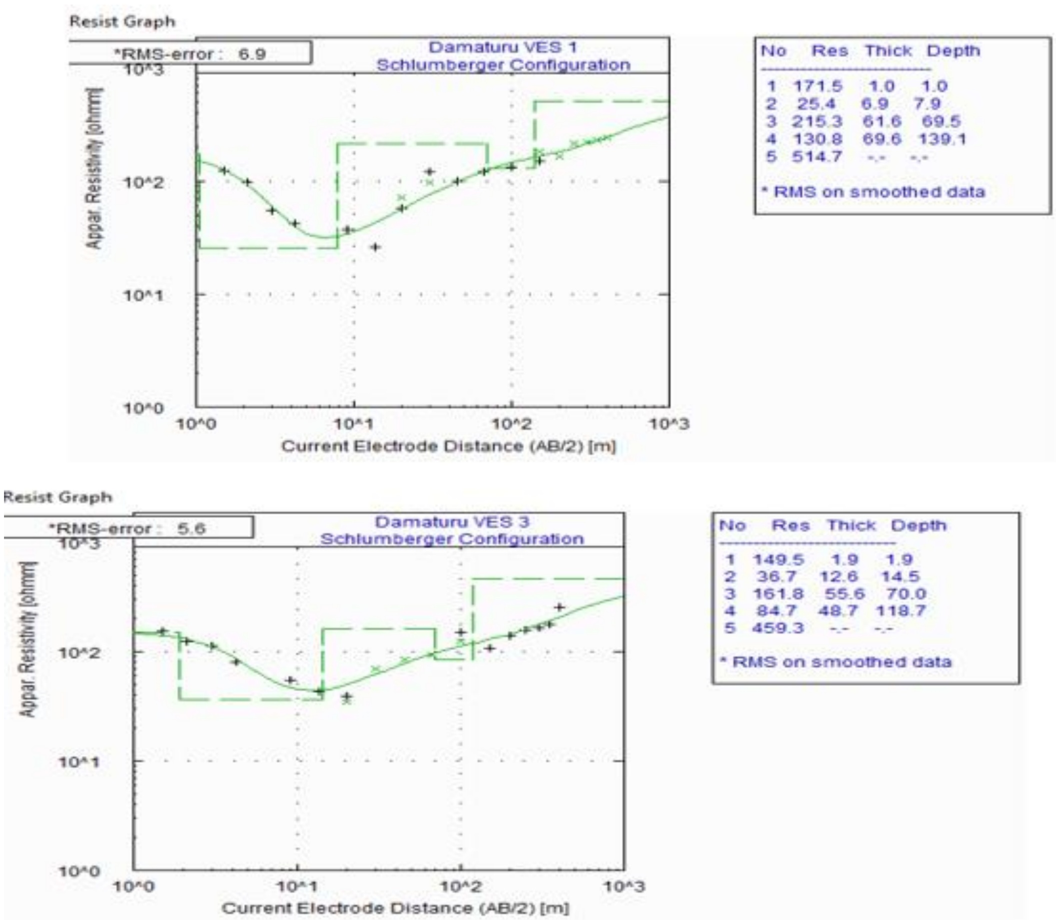

Fig. 3: Typical curves obtained from the study area.

Table 3: Results of the Vertical Electrical Sounding (VES)

VES	Layer Resistivity (Ωm)					Layer Thickness (m)				Depth (m)			
	$\rho 1$	$\rho 2$	$\rho 3$	$\rho 4$	$\rho 5$	$h1$	$h2$	$h3$	$h4$	$d1$	$d2$	$d3$	$d4$
1	171.5	25.4	215.3	130.8	514.7	1.0	6.9	61.6	69.6	1.0	7.9	69.5	139.1
2	15.1	98.2	832.5	38.0	158.3	0.7	1.5	51.1	100	0.7	2.1	53.2	153.1
3	149.5	36.7	161.8	84.7	459.3	1.9	12.6	55.6	48.7	1.9	14.5	70.0	118.7
4	232.0	39.9	570.0	115.0	290.0	0.9	6.4	30.8	74.2	0.9	7.3	38.1	112.3
5	190.0	65.3	319.0	110.6	273.2	0.8	10.6	44.0	74.8	0.8	11.4	55.4	130.2
6	117.5	84.0	208.0	118.5	247.7	0.9	12.6	67.7	80.4	0.9	13.5	80.5	160.9
7	154.0	55.2	213.4	106.2	200.8	1.1	11.5	40.0	56.3	1.1	12.6	52.6	108.9
8	125.4	76.0	190.3	119.7	301.4	0.7	12.0	61.2	50.6	0.7	12.7	73.9	124.5
9	114.1	25.4	156.0	101.5	282.1	0.9	10.6	56.6	67.4	0.9	10.6	67.2	134.6
10	219.0	75.4	195.5	120.2	340.3	1.3	6.2	48.3	49.8	1.3	7.5	55.8	105.6
Average:	148.8	58.2	306.1	104.5	306.8	1.0	9.1	51.7	67.2	1.0	10.0	61.6	128.8

The resistivity values of the third layer indicate that it is a sandy formation. It is shallow in some parts of the study area and moderately deep in other parts of the study area. It is the first aquifer in the study area and it is considered to be semi-confined. The fourth layer resistivity ranged from 38.0 to 130.8 Ωm with an average value of 104.5 Ωm. The fourth layer has an average thickness of 67.2 m (Fig. 4). Its resistivity characteristics indicate that it is a sandy-clay formation. The VES results obtained in this study correlated well with existing borehole logs from the study area. The fifth layer has resistivity values which ranged from 158.3 to 514.7 Ωm. It has an average resistivity value of 306.8 Ωm, which indicates that it is a sandy formation. The average thickness of this layer was not estimated but it is the second aquifer in the study area and it is confined.

The geologic sequence of the subsurface layer of the study area is shown in the geoelectric section below (Fig. 3).

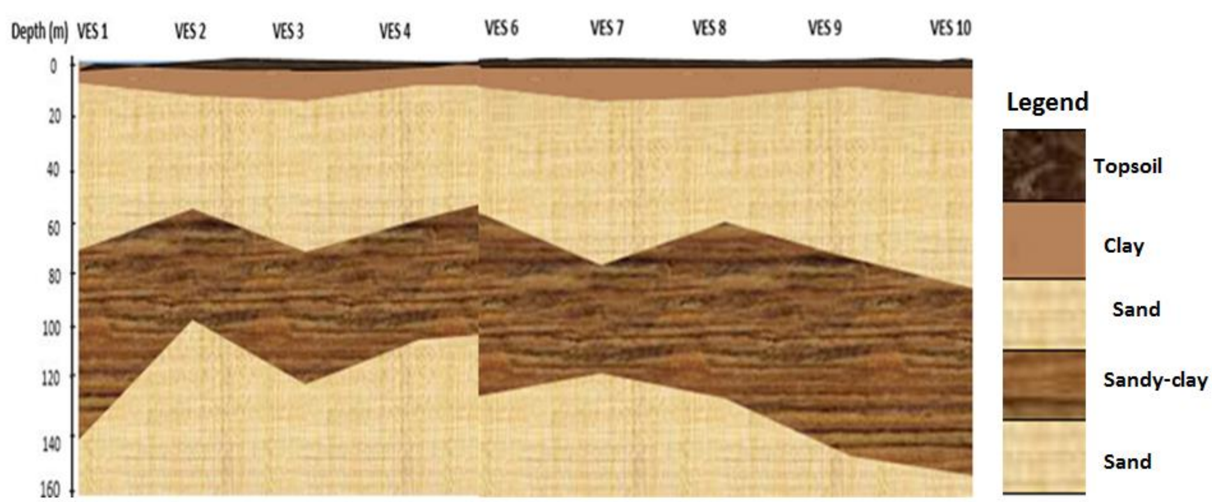

Fig. 3: Geoelectric section of the study area.

The geologic sequence of the subsurface layers (Fig. 3) was used to deduce how the groundwater in the study area could be influenced by variability in climatic conditions. The groundwater in the study area is mainly recharged by rainfall since there were no rivers and streams in the study area. The rainwater reaches the aquifer through fractures or by infiltration through the micro-pores overlying the aquifer formation (Fig. 3). Considering the proximity of the first aquifer to the surface (Fig. 3), a prolonged drought episode would have direct effects on both the groundwater quality and quantity in the study area. Shallow aquifers are known to be prone to contamination by leachate and floods. The situation in the study area is not exempted as some research reports have shown that the groundwater from the first aquifer in the study area is contaminated by trace metals (Waziri *et al*., 2009; Emeka and Weltime 2008; Agada and Yakubu, 2022).

The declining trend in the amount of precipitation in the study area (Fig. 4) is a clear indication that the groundwater table in the study area is gradually decreasing and the situation has led to borehole failures and drying of wells in some parts of the study area.

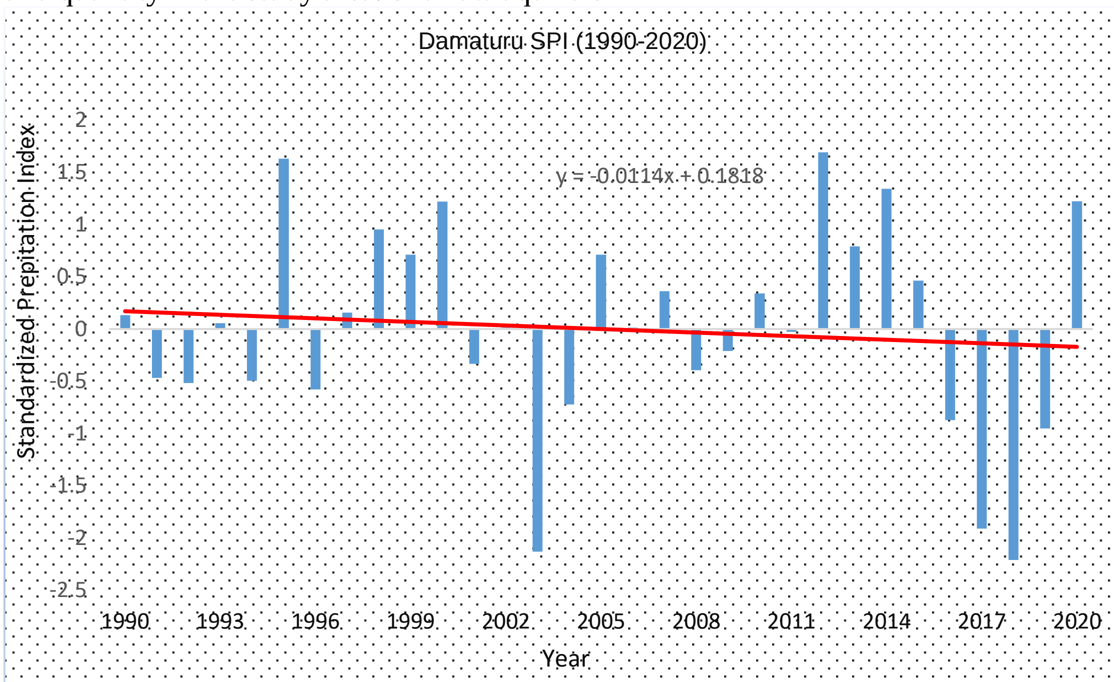

Fig. 4: Standardized precipitation index of Damaturu (1990-2020).

The inhabitants of the study area confirmed that the situation was different some years ago. The dried wells were functional about forty (30) years ago. The decrease in borehole yields and the drying up of some wells in the study area can be attributed to the impacts of climate change on groundwater. This observation is in agreement with the reports of some researchers that large variability in precipitation often affects the quantity of groundwater in shallow aquifers (Hanson *et al*., 2006; Gurdak *et al*., 2007; Kundzewicz *et al*., 2007; Ouysse *et al*., 2010). An analysis of the temperature data obtained from the study area showed that the study area is warming due to an increasing trend in the temperature of the study area (Fig. 5).

The increasing trend in the minimum temperature of the study area is an indication that the area is warming due to climate change. Both the maximum and minimum daily temperatures of the study area indicated that the area is warming due to climate change. The results of the analysis of the precipitation data showed that there were periods of droughts during the years under study (Fig. 4).

The droughts of 1991, 1992, 1994, 1996, 2001, 2003, 2004, 2008, 2009, 2016, 2017, 2018 and 2019 (Fig. 4) might have directly impacted the groundwater resources negatively in the study area. When droughts are severe it might take groundwater a very long time to recover. The study area and its environs may continually witness an increase in climatic variability leading to groundwater vulnerability in the study area. The increase in desertification in the study area by anthropogenic activities such as overgrazing, deforestation, and bush burning will lead to more droughts which will have a significant impact on groundwater in the study area.

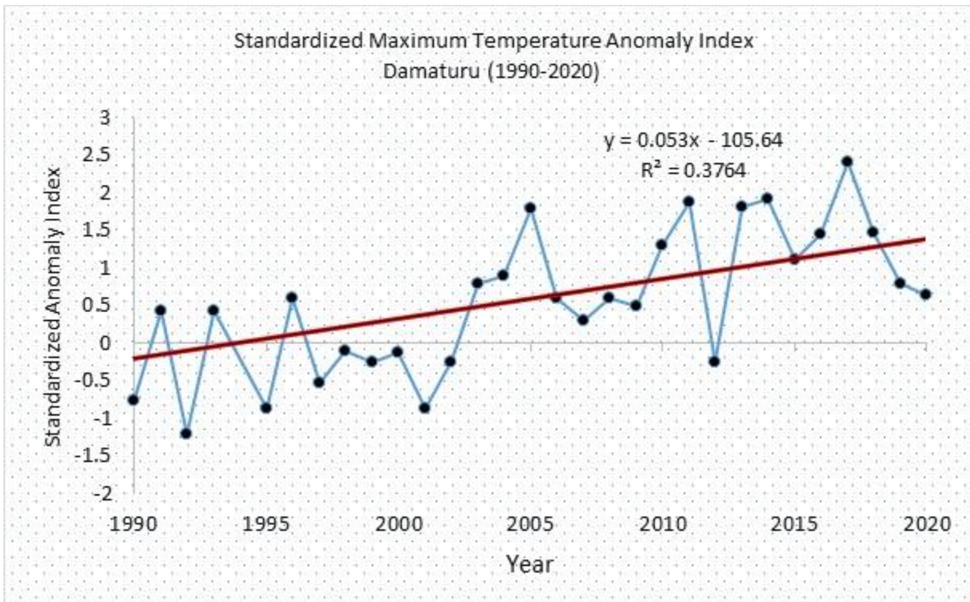

Fig. 5: Standardized Maximum Temperature Anomaly Index of Damaturu (1990-2020) The Standardized Maximum Temperature Anomaly Index (Fig. 5) shows that the maximum temperature of the study area is increasing.

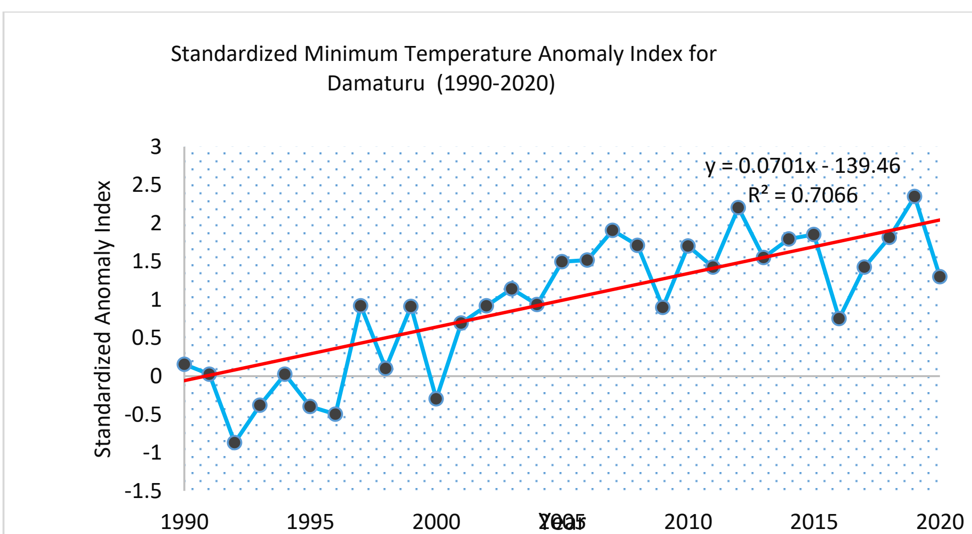

Fig. 6: Standardized minimum temperature anomaly index of Damaturu (1990-2020)

The devastating effects of climate variability on groundwater resources in the study area have led to increase in the cost of groundwater development and water supply in the area. Access to portable water has become more difficult due to the reduction in groundwater recharge and the lowering of the groundwater table. The prevailing situation due to climatic variability has led to food insecurity and significant losses in agriculture. The results of this study have shown that groundwater is vulnerable to climate change and variability.

4.0 Conclusion

In this study, the impact of climate change on groundwater resources was investigated in Damaturu, a semi-arid region of Nigeria. The geophysical investigation results revealed that the study area and its environs were composed of five geoelectric layers which are: the topsoil, clay, sand, sandy-clay, and sand. The third layer which is a sandy formation is the first aquifer in the area and it is semi-confined. The first aquifer in the study area is highly susceptible to the effects of increasing temperature trends and declining rainfall in the study area because of its proximity to the surface. The results of this study showed that climate change has affected the hydrologic cycle of the study area, through increasing temperature, high evapotranspiration and reduced rainfall. The increase in the temperature of the study area has contributed to changes in the rainfall pattern and timing in the study area. The increasing temperature in the study area contributes to frequent extreme weather events (flood, drought, and heat waves) in the study area. These extreme weather events posed significant stress on the groundwater resources of the area. They also contribute to water scarcity and the high cost of groundwater exploitation in the area.

Some of the boreholes sited within the first aquifer in the study area are faced with challenges of low yields and degrading quality. This situation has culminated in borehole failures in the study area.

Given the findings of this study, there is an urgent need for effective long-term planning to properly manage and secure the groundwater resources in the study area.

The understanding of the impact of climate change on groundwater resources is very important to human survival. Based on the findings of this study, the following are recommended.

(i) There should be adequate education and training to sensitize the public in the study area and its environs on the impact of climate change on groundwater resources. Such education will help to reduce some activities such as deforestation, bush burning, emission of greenhouse gases and overgrazing which contribute directly or indirectly to climate change. Bush burning, overgrazing and deforestation are agents of desertification and desertification contributes to climate change.

(ii) Research on the impact of climate change on groundwater resources and the environment should be encouraged.

(iii) Regulatory standards should be established to protect the groundwater resources from anthropogenic contamination.

(iv) Afforestation and good groundwater management should be encouraged to reduce groundwater losses from evaporation.

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