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Investigation of the Impact of Drought on Groundwater: A Case Study of Yobe State, Nigeria

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ABSTRACT

Drought which occurs as a result of climate variability has devastating implications for human health especially in northeastern Nigeria, where it is known to cause malnutrition due to food and water shortage, epidemic (cholera and typhoid fever) and meningitis due to high temperatures. In view of the consequences of drought in the study area, this study investigated the impact of drought on groundwater in Yobe State, northeastern Nigeria using geophysical and meteorological data. The Vertical Electrical Sounding (VES) delineated five geologic layers, which are the topsoil, clay, sand, sandy clay and sand. Two aquifers were delineated in the study area, the first aquifer is unconfined and it is very close to the Earth surface in some areas within the study area, while the second aquifer is confined at a great depth. The temperature and the Actual Evapotranspiration analysis for the study area showed increasing trend which indicates significant loss of water from the ground. The first aquifer is mostly affected by drought due to its proximity to the Earth surface. The lowering of the water table and significant soil water loss in the study area manifested as low borehole yields during drought. Groundwater recharge for the period of the study (40 years) showed a decline trend. The droughts frequency and severity were evaluated using Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI). The results obtained showed that the study area had been involved in series of drought regimes, whose degree of impact ranged from moderate to extreme situations. Based on the findings of this study, it is recommended that more trees should be planted in the study area to reduce evaporation and evapotranspiration. More research and development activities should be encouraged to improve effective adaptability to drought and climate change in the study area.

Keywords:
Groundwater,
Evaporation,
Recharge,
Precipitation,
Temperature,
Climate.

INTRODUCTION

Drought is a natural disaster associated with great economic losses. Drought is one of the extreme weather conditions which manifest periodically as a result of climate change mostly in the semi-arid and arid regions of the world. It is a prolonged period of dry season characterized by lack of precipitation or rainfall. The impact of drought on ground water often manifest in terms of low ground water recharge, sea water intrusion in coastal areas, high temperatures and elevated evapotranspiration. Groundwater is a major important source of potable water in both semi-arid and arid regions especially where there were little or lack of alternative sources of water supply such as small rivers, streams, lakes and ponds. Drought is known to have serious impact on agriculture, food security, economies and the environment. An estimated 55 million people are affected by drought annually, and the impact is mostly felt by crops and livestock (WHO, 2023). Several anthropogenic activities have contributed to the increase in the concentration of greenhouse gases in the atmosphere (Gosain *et al*., 2006). These greenhouse gases have directly or indirectly contributed to the elevation of global temperature causing global warming (Agada, 2022).

Drought is characterized with rising temperature and extreme heat which leads to water shortages in the arid regions. A rising temperature is always associated with high evaporation and evapo-transpiration which elevates drought. Drought affects people's source of income, it increases the rate of disease and infection spread. It elevate communal crisis and mass migration due to economic losses, animal and crop failures. In some cases prolonged droughts are associated with groundwater pollution thereby exposing the populace to water related health hazards (Usman and Agada, 2024). The continuous increase in global carbon dioxide emissions and other related greenhouse gases through the consumption of fossil fuels will continue to elevate global temperatures and reduce annual precipitation. Droughts and its associated climate change are responsible for the frequent extreme weather conditions mostly experienced in recent times, especially in the semi-arid and arid regions.

Villhoth *et al*. (2013) reported that groundwater drought is the manifestation of meteorological drought in the subsurface. It is characterized by reduced groundwater storage, recharge and discharge. Mondal and Mujudmar, (2015) emphasized that the frequency and the intensity of droughts will increase in the future due to global warming from greenhouse gas emissions. The increasing rate of drought in semi-arid region of Nigeria has led to loss of economic activities, increase in crime rate, communal crisis, terrorism and banditry, thereby making life difficult for the populace. As a result of drought manifestation, an aquifer might dry out and eventually loss it's potential for recharge. The alteration of groundwater recharge mechanism could affect its sustainability. The variability in precipitation and temperature due to climate change could enhance the frequency and the intensity of drought in northern Nigeria. Wan *et al*. (2010) reported that wind speed has declined in many countries worldwide. Guo et al. (2011) also reported that the wind speed has declined by 29% in China.

Rainfall and temperature are the main factors which govern hydrological processes. Since rainfall and temperature are determinant factors of climatic conditions, the study of both climate indicators is very important to our ecosystem. An increasing temperature has severe impacts on the ecosystem. In most cases, it causes extreme weather events such as heat wave, sea level rise, melting of ice at the Polar Regions and diseases. Irregular pattern of rainfall are associated with flash floods, droughts, depletion of surface and groundwater levels and an increase in wildfire potential. MacDonald *et al*. (2005) reported that the benefits of groundwater is immense but there is limited knowledge on African groundwater resources and their response to climate change. The IPCC Fourth Assessment report review of climate model projections reveals a consistent progressive warming of the climate in all regions of Africa (Solomon *et al*., 2007). Conway (2011) observed that the increase in temperature will cause an increase in evapotranspiration as well as the increase in the intensity and variability of rainfall. This variability in rainfall will lead to high demand for groundwater.

In order to sustain groundwater supply, those factors which might limit its availability and supply need to be studied. Groundwater resources are mostly affected by climatic factors such as drought, evapotranspiration, desertification, temperature, precipitation and in general climate change. Hafmann *et al*. (2000) reported that an increase in evapotranspiration with a corresponding decrease in precipitation will lead to reduction in groundwater level.

Drought is associated with desertification. Desertification is both natural and anthropogenic, it is mainly caused by climate change. It is associated with the degradation of the ecosystem, soil erosion, and reduction in agriculture produce due to soil impoverishment. It is one of the environmental challenges in the northeastern Nigeria. The abysmal cutting of trees for energy source in the study area and animal overgrazing are also responsible for desertification. Desertification exposes the soil to enhanced solar radiation and thereby causing high soil evapotranspiration. Drought is a difficult natural phenomenon associated with significant loss of lives. In 1983, a severe drought in Sudan killed 150, 000 people and affected 8.4 million people. In 1991 about 8.6 million people were affected by drought (FAO, 2008).

The Intergovernmental Panel for Climate Change (IPCC) stated that Africa will be affected by climate change as such that the warming will be 1.5 times the global average (Taylor *et al*., 2009). In recent times, the semi-arid and the arid regions of Africa is experiencing an increase in temperature caused by droughts and heat waves. These phenomena have strong influence on the pattern, frequency and intensity of rainfall which directly affect groundwater recharge. Groundwater recharge is significantly responsive to land use, geological settings, and climatic conditions. Hiscock and Tanaka (2006) observed that in Tokyo an increase of 3^{o}C in temperature of a shallow aquifer increases the depth of groundwater by 20 m due to the warming of the ground surface.

Jasper *et al*. (2006) observed that climate variability has profound effects on soil water content and temperature. Fan *et al*. (2007) reported that the Vadose-zone hydrology, shallow aquifer and water tables are affected by the variability in climatic factors. Aguilera and Murillo (2009) observed that climate variability will have numerous effects on groundwater recharge rates and mechanism. Thomsen (1989) noted that variability in precipitation would have substantial effects on recharge and groundwater levels. Taniguchi (2002) stated that temperature-depth profile in deep boreholes are useful tool for estimating ground-surface temperature and recharge, because climate variability is a function of subsurface thermal regime. Dettinger and

Earman (2007) noted that the potential effects of climate change on groundwater recharge and levels deserve more attention than the present responses. Abdulkadir *et al*. (2017) reported that the increase in the cases of air pollution due to high temperatures in northern region of Nigeria correlated with the rising causes of Meningitis in the area.

Research reports showed that Lake Chad and other lakes in northern Nigeria are drying up (Elisha *et al*., 2017; Dioha and Emodi, 2018). The Federal Ministry Environment (2014) reported that the effect of climate variability is mostly felt in the northeastern part of Nigeria where it is causing increase in temperature, less precipitation, loss of wetlands and rapid reduction of surface water. The variability in climatic conditions and drought has led to the displacement of many settlements and communities in the region (Federal Ministry of Environment, 2014; Matemilola, 2019). Sayne (2011) in his study reported that drought conditions in parts of northern Nigeria has caused reduction in the available drinking water leading to water scarcity. United State Geological Survey (2018) reported that groundwater decline caused by drought is real and it affects many places of the world.

Many international and national organization have through several programs and workshops supported and facilitated research activities towards providing adequate understanding on the impact of climate variability on groundwater resources. In a situation of uncertainties associated with climate change, sustainable groundwater resources will help to provide the need succor for the growing global population, agriculture and industrial activities. The study of the impact of drought on groundwater is very important in order to make provision for present and future effective management of groundwater resources.

Nigeria's climate has witnessed remarkable increase in temperature, drought, desertification, floods, irregular rainfall patterns and decline in rainfall in the semi-arid regions of Nigeria (Ebele and Emodi, 2016; Elisha *et al.*, 2017; Agada and Sonloye, 2022). The Federal Ministry of Environment in 2014 reported that Nigeria temperature has been increasing since 1980. Madu 2012, reported that the northern region of Nigeria is most vulnerable to climate change. Drought and desertification can undermine economic growth thereby leading to loss of jobs and unemployment. Desertification is one of the ecological problems affecting the semi-arid region of Nigeria with serious economic consequences. According to the Nigeria Meteorological Agency report (NiMet, 2020) the states that were affected by drought are Yobe, Sokoto, Zamfara, Kastina, Jigawa, Kebbi, and Borno. The extent and severity of drought and desertification in Nigeria has not been fully studied. In view of the effects of changes in temperature and rainfall on various hydrological processes, this study is focused on the study of drought and its impact on groundwater in the study area, since no such study has been carried out in recent times.

MATERIALS AND METHODS

Study Area

Yobe State is located within the semi-arid region of Nigeria, it lies between latitude $10^0$05'00''N and $13^0$03'00''N, and between longitude $9^0$06'00''E and $12^0$05'00''E. It has a total land surface area of about 47,153 square kilometers and has an annual mean temperature of about 32 ^oC. Major parts of the study are lies within the Chad Basin. The study area has tropical continental climate characterized by short rainy season (June - September) and long dry season (October – May), with high temperatures of about 39-45 ^oC. The annual rainfall amount ranged from 500-1000 mm. Yobe State has a population of about 3.4 million and its economy is based on agriculture.

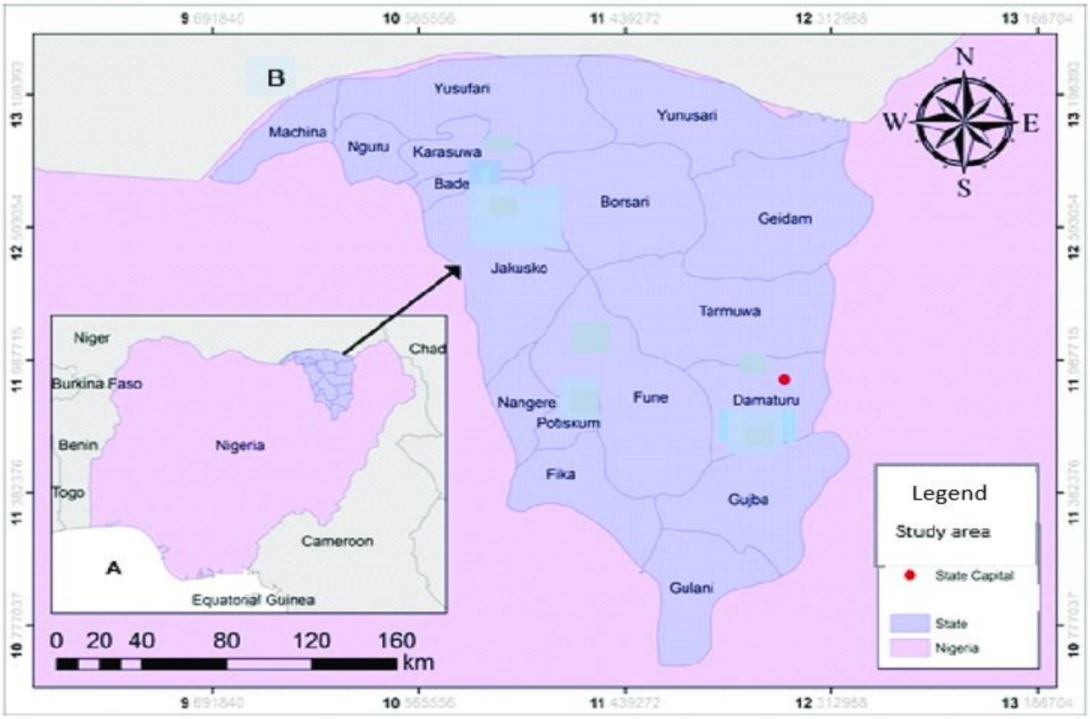


Figure 1: Map of Nigeria showing the study area (Source: Ali *et al*., 2022)

In this study, Meteorological data from Nigeria Meteorological station, Nguru and TerraClimate datasets were used to investigate how drought affects groundwater in Yobe State. Precipitation and temperature data of forty years (40) were obtain from the NiMet station. The Terraclimate datasets includes both climatic and environmental parameters that are associated with drought such as: Actual Evapotranspiration (AET), Wind speed, Palmer Drought Severity Index (PDSI) and Precipitation. Some hydrogeological parameters such as groundwater recharge and evapotranspiration were determined to evaluate the impacts of drought on groundwater in the study area. The TerraClimate data were obtained from https://www.climatologylab.org/terraclimate.html.

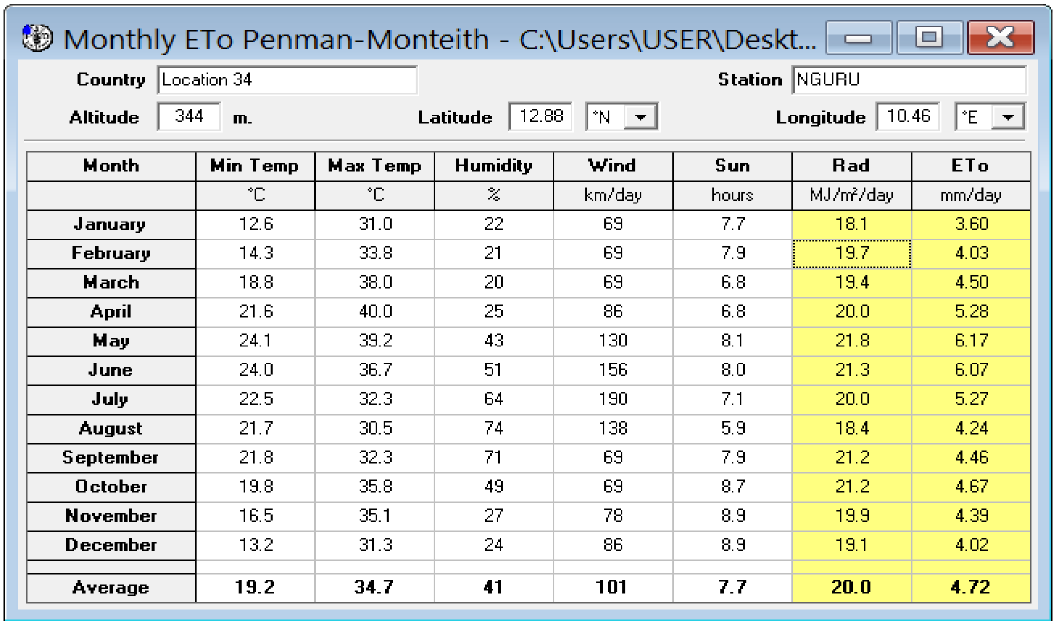
TerraClimate is a global gridded data of meteorological and water balance variables from 1958 to present. Its fine spatial resolution, global extent, and long standing are unique combination that enhances the reliability of the climate data it provides. In addition to providing maximum and minimum temperatures, Terraclimate also provide derived variables such as Actual Evapotranspiration (AET), Palmer Drought Severity Index (PDSI) and vapor pressure deficit. In order to understand the impact of the drought on groundwater in the study area, five (5) Vertical Electrical Sounding (VES) were carried out to delineate the depth to groundwater in the study area using Schlumberger configuration.

Evapotranspiration (ET)

Evapotranspiration is a process whereby water is lost from water bodies, ground and plant surfaces into the atmosphere. Water evaporates from various surfaces such as rivers, soils, lakes and vegetation. Evapotranspiration is the flux of water from the earth surface to the atmosphere under the action of radiant energy. It involves both evaporation and transpiration processes and it occurs simultaneously. It plays a vital role in the energy budget of the climate system. Evaporation increases with increasing temperature (Roderick *et al*., 2007; Sheffield *et al*., 2012). Evapotranspiration is a combine effects of solar radiation, air temperature, humidity and wind speed. It is an important part of the climate and water cycle. The evapotranspiration of the study area was estimated using CROPWAT software version 8.0 (Figure 2) which is based on FAO Penman Monteith formula (Gong *et al*., 2006).

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \quad (1)$$

where, ET_O = reference evaporation rate (mmd^{-1}); T = mean air temperature (^oC); u_2 = wind speed (ms^{-1}) at 2m above the ground; R_n= net radiation at the crop surface, $MJm^{-2}d^{-1}$; G = soil heat flux density $MJm^{-2}d^{-1}$; e_s = saturation vapour pressure, KPa; e_a= actual vapor pressure, KPa; $e_s - e_a$ = saturaturion vapor pressure deficit, KPa, γ = Psychrometric constant, KPa $^oC^{-1}$, $\Delta =$ slope of saturation vapor pressure curve.



Country: Location 34
Station: NGURU
Altitude: 344 m.
Latitude: 12.88 °N
Longitude: 10.46 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	12.6	31.0	22	69	7.7	18.1	3.60
February	14.3	33.8	21	69	7.9	19.7	4.03
March	18.8	38.0	20	69	6.8	19.4	4.50
April	21.6	40.0	25	86	6.8	20.0	5.28
May	24.1	39.2	43	130	8.1	21.8	6.17
June	24.0	36.7	51	156	8.0	21.3	6.07
July	22.5	32.3	64	190	7.1	20.0	5.27
August	21.7	30.5	74	138	5.9	18.4	4.24
September	21.8	32.3	71	69	7.9	21.2	4.46
October	19.8	35.8	49	69	8.7	21.2	4.67
November	16.5	35.1	27	78	8.9	19.9	4.39
December	13.2	31.3	24	86	8.9	19.1	4.02
Average	**19.2**	**34.7**	**41**	**101**	**7.7**	**20.0**	**4.72**

Figure 2: Monthly ET$_O$ for the study area

Precipitation Analysis

The precipitation data were analyzed using the Standardized Precipitation Index (SPI) which is based on Gamma Distribution Function (GDF).

The probability density function of the gamma distribution is defined as,

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

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 distribution. The gamma distribution parameters μ and β for each station and time scale are estimated using the following expressions.

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

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

Where,

$$A = In\,(x)\text{-}n^{-1}\sum In(x) \qquad (5)$$

and n = number of precipitations observed.

Integrating equation (1) with respect to 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,

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

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

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

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,

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

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 zero in the sample, then q can be estimated as,

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

The transformation of the cumulative probability distribution $F(x)$ will yield the standard precipitation index. The SPI values and their interpretations are shown in table 2.

Table 1: SPI values and their interpretation

SPI Values	Interpretation
−2.0 and less	Extremely dry
−1.5 to −1.99	Severely dry
−1.0 to −1.49	Moderately dry
−0.99 to +0.99	Near normal
1.0 to 1.49	Moderately wet
1.5 to 1.99	Very wet
2.0 and above	Extremely wet

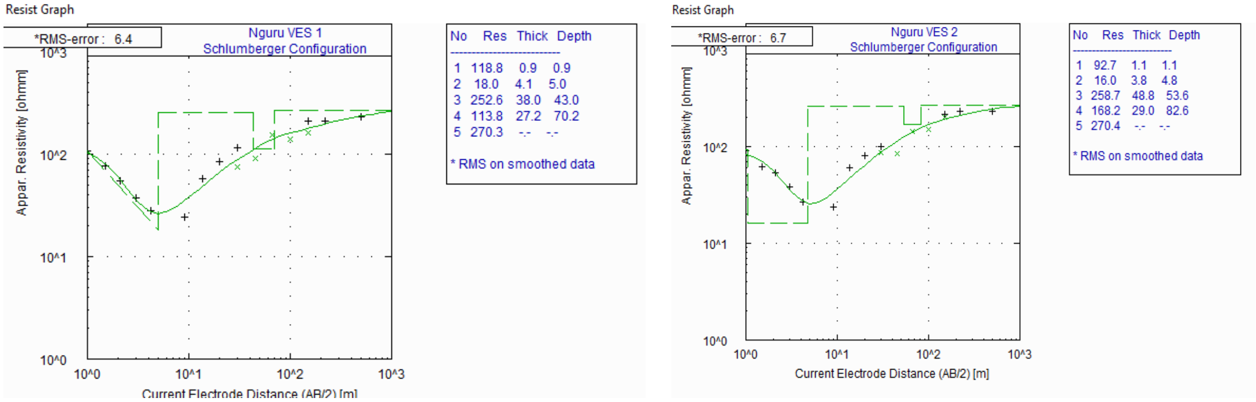
(Source: Koudahe *et al*., 2017)

RESULTS AND DISCUSSION

The proximity of groundwater to the Earth surface will determine the rate at which it is been impacted by drought and high daily temperature. The Vertical Electrical Sounding (VES) results from the study area delineated five (5) geological layers. The first geologic layer is the topsoil which is composed of a mixture of sand, clay and plant remains. It has resistivity values which range from 69.4 to 199.7 Ωm (Table 1). The topsoil has an average depth of 0.88 m. The second layer in the study area is a thin clay formation, whose resistivity values ranged from 16.0 to 25.3 Ωm. The average thickness of the second layer is 4.9 m. The third layer is a sand formation and it is the first aquifer in the study area. The first aquifer is both unconfined and semi-confined in some places within the study area. The forth layer is a sandy-clay formation which overlays the fifth layer which is the second aquifer in the study area. The resistivity values of the fourth aquifer ranged from 113.8 to 130.0 Ωm (Table 1). The second aquifer is confined and cannot be easily affected by drought.

The proximity of the first aquifer to the Earth surface enhances the impact of drought on groundwater in the study area, leading to low groundwater table and frequent borehole failures. The inferred decline in groundwater level in the study area is in consonance with the USGS (2018) report on the reduction of groundwater in many parts of the world due to drought and the observation of Fan *et al.* (2007), that the Vadose-zone hydrology, shallow aquifer and water tables are affected by climatic variability. The HA-curves are the dominant geoelectric curves obtained from the VES sounding (Figure 3).

The results of this study showed that drought is associated with low yield of groundwater in shallow boreholes and high demand for water, which confirms the report of Sayne (2011) on the reduction of available drinking water in northern Nigeria by drought.



No	Res	Thick	Depth
1	118.8	0.9	0.9
2	18.0	4.1	5.0
3	252.6	38.0	43.0
4	113.8	27.2	70.2
5	270.3	-.-	-.-

No	Res	Thick	Depth
1	92.7	1.1	1.1
2	16.0	3.8	4.8
3	258.7	48.8	53.6
4	168.2	29.0	82.6
5	270.4	-.-	-.-

Figure 3: Typical geoelectric curve obtained from the study area

Table 2: Vertical Electrical Sounding Results

VES	ℓ1	ℓ2	ℓ3	ℓ4	ℓ5	*h1*	*h2*	*h3*	*h4*	*D1*	*D2*	*D3*	*D4*
1	118.8	18.0	252.8	113.8	270.3	0.9	4.1	38.0	27.2	0.9	5.0	43.0	70.2
2	92.7	16.0	258.7	168.2	270.4	1.1	3.8	48.8	29.0	1.1	4.8	53.6	82.6
3	107.5	23.9	229.1	119.0	350.1	0.8	5.0	36.0	39.1	0.8	5.8	41.8	80.9
4	69.4	30.6	266.3	125.4	293.5	0.7	6.0	41.2	44.6	0.7	6.0	47.9	92.5
5	199.7	28.7	272.0	130.2	311.5	0.9	5.7	37.4	45.0	0.9	6.6	44.0	89.0

Maximum Temperature Anomaly Index

The maximum temperature anomaly index of the study area showed an increasing trend (Figure 4). The increasing trend of the maximum temperature is an indication that there is a continuous loss of water from the study area through evaporation and evapotranspiration, this observation is in conformity with the report of the Federal Ministry of Environment (2014) on the loss of wetlands and reduction in of surface water in the area. Water from both surface and subsurface (shallow depth) are released into the atmosphere due to elevated temperature in the study area. The maximum temperatures in the year 1984, 1987, 2003, 2004, 2005, 2006, 2008, 2009, 2010, 2011, 2013, 2014, 2015, 2016, 2017 and 2019 were remarkably high and have impacted the groundwater in the study area (Figure 4).

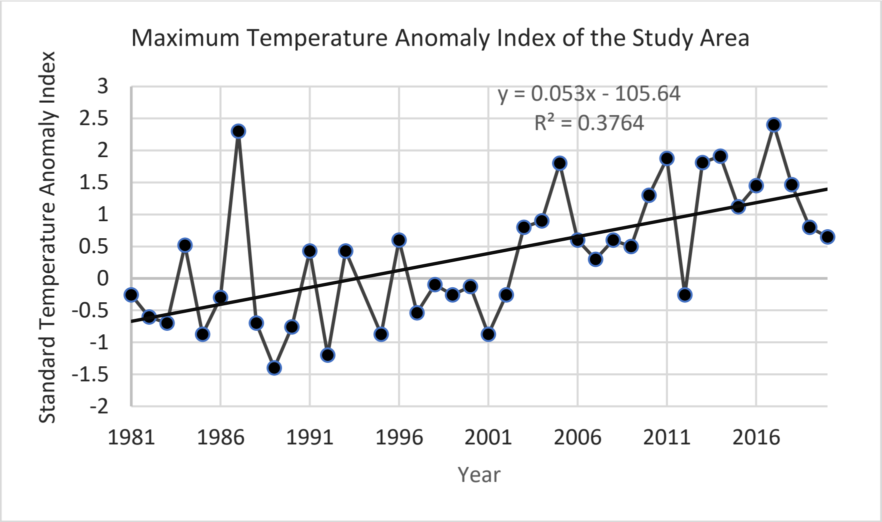


Figure 4: Maximum Temperature Anomaly Index of the Study area

The time series of the minimum temperature between1981-2020 in the study area showed an increasing trend, which is an indication of prolong groundwater loss in the area (Figure 5).

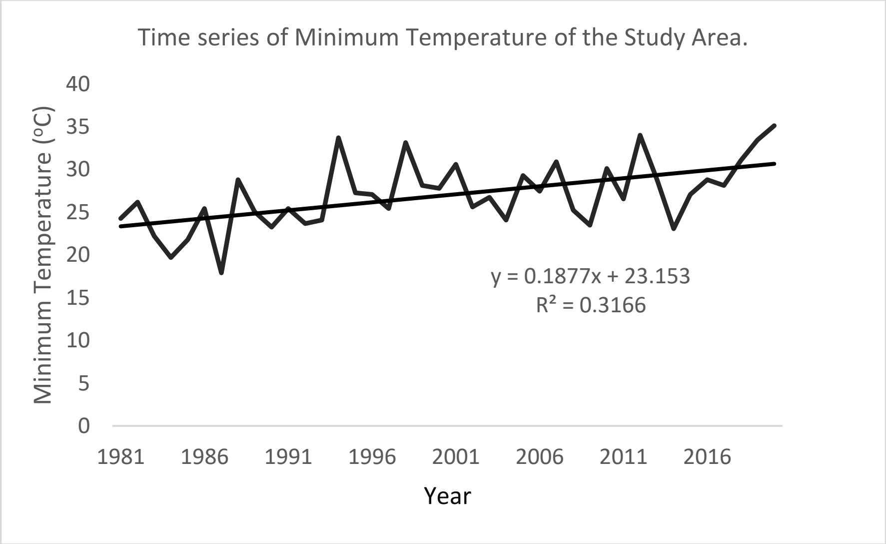


Figure 5: The time series of the minimum temperature of the study area

Actual Evapotranspiration (AE)

The results of the actual evapotranspiration in the study area showed that during the years 1982, 1983, 1989, 1996, 1998, 2016 and 2019 there were remarkable high evapotranspiration (Figure 6) which were influenced by droughts and other climatic factors such as enhanced solar radiation, temperature, relative humidity and wind speed. Under high temperature condition, the amount of energy required for evaporation is low. The relative humidity of the atmosphere also influences evapotranspiration.

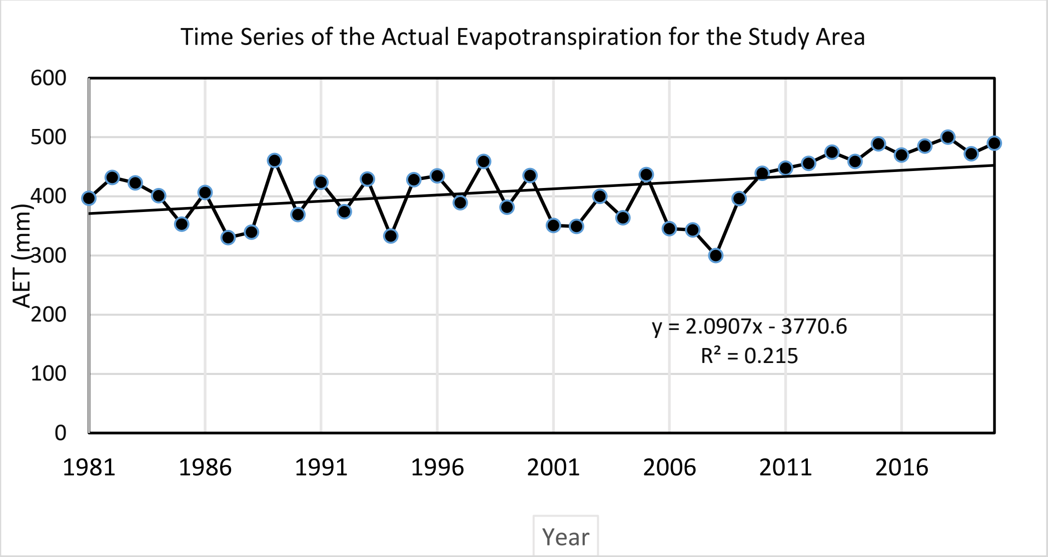


Figure 6: Time series of the Actual Evapotranspiration for the study area

The results of the Actual Evapotranspiration (AE) obtained from the study area showed an increasing trend (Figure 6). This increase in the trend of Actual Evapotranspiration (AE) contributes to the prevalence of seasonal drought in the study area. The first aquifer in the study area which is semi-confined and shallow, is associated with increasing groundwater evapotranspiration which leads to lowering of groundwater table. More groundwater is lost into the atmosphere through the process of evapotranspiration as they rise to the earth surface.

Groundwater Recharge

The time series of groundwater recharge in the study area showed a decreasing trend (Figure 7). The periods of drought in the study area showed remarkable low groundwater recharge in the study area. The intermittent periods of drought are characterized with low groundwater recharge (Figure 7). This observation is in consonance with the report of Hofmann *et al.* (2000), which stated that an increase in evapotranspiration with a corresponding decrease in precipitation will lead to reduction in groundwater level due to low recharge. The negative groundwater recharge trend in the study area is an indication that the groundwater in the area is gradually diminishing due to drought and climate change (Fig. 7).

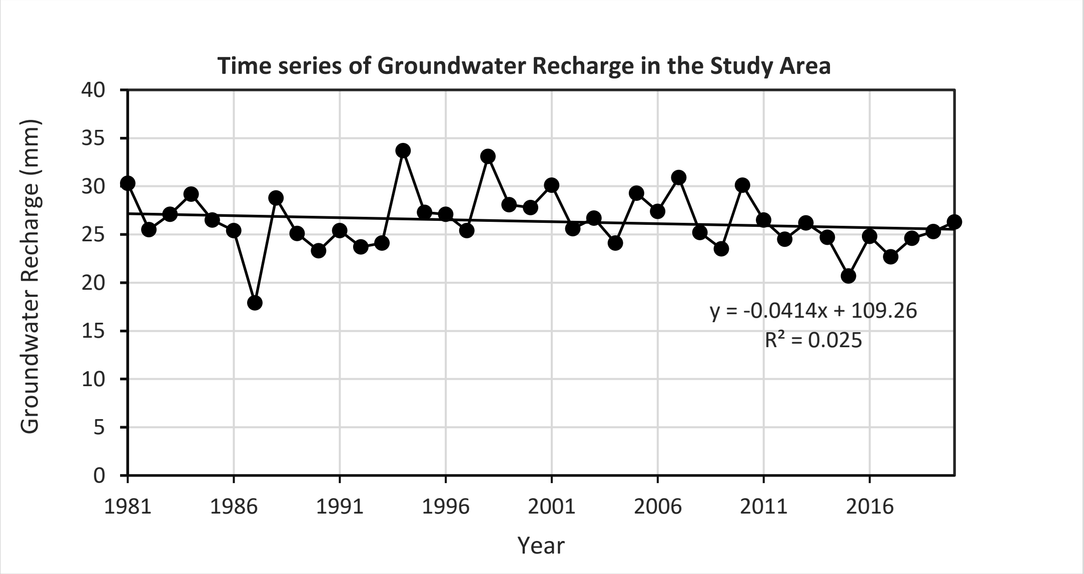


Figure 7: Time series of groundwater recharge in the study area

Wind Speed

The time series analysis of the wind speed in the study area showed a remarkable decline in trend (Fig. 8). This result is in agreement with the reports of Wan *et al*. (2010), which noted that wind speed has declined in many countries worldwide. It is also similar to the observation of Guo *et al*. (2011) which stated that wind speed has decrease by 29% in China. The reduction in the wind speed can be attributed to rising levels of carbon dioxide and the warming of the Earth poles which leads to melting of the ice at the poles. The declined wind speed cold affect plant production in the study area and energy production worldwide. The wind speed was higher in the northern part of the study area where there were less vegetation cover and it decreases down to the south where the vegetation cover is much (Fig. 9).

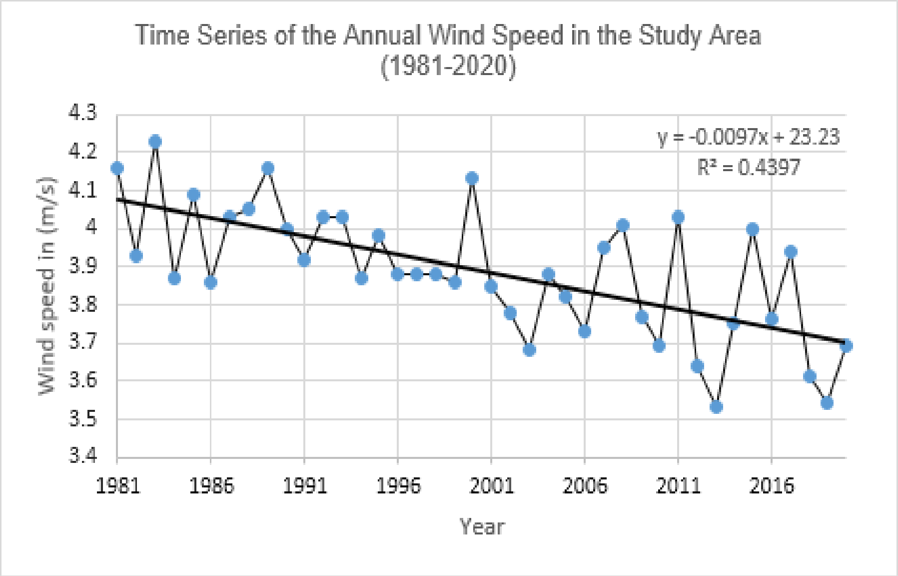


Figure 8: Time series of the annual wind speed in the study area

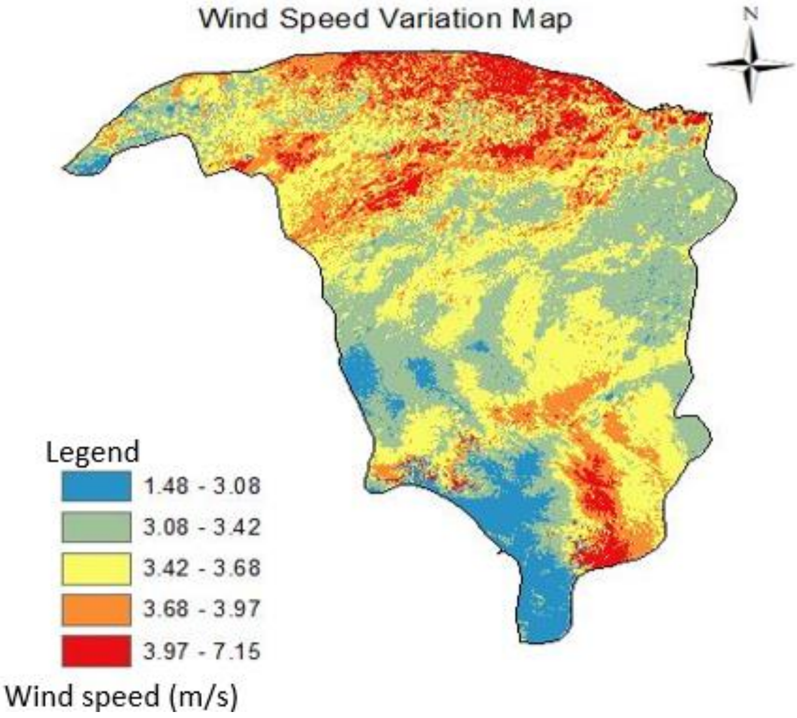


Figure 9: Wind speed variation map of the study area

The time series analysis results of the surface runoff in the study area showed an increased trend. The increasing trend indicates that significant amount of the precipitation in the study area do not infiltrate into the subsurface to recharge the groundwater (Fig. 10).

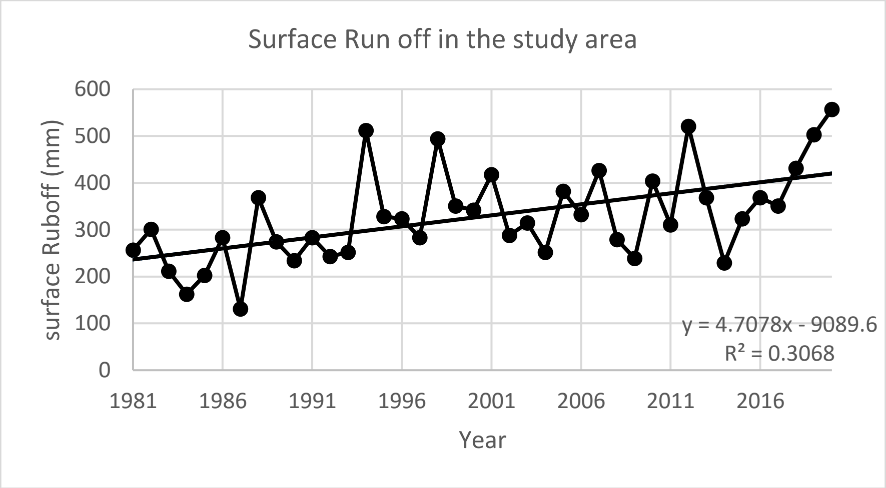


Figure 10: Time series analysis results of the surface runoff in the study area

The increased surface runoff contributes to flooding and water pollution in the study area.

Standardized Precipitation Index (SPI)

There were droughts between 1991 and1994, 2001 and 2004, 2008 and 2009, and between 2016 and 2019. The droughts of 2003, 2017, and 2018 were extreme (Fig. 11). The results showed that the precipitation in the study area for the past 30 years (Fig. 11) were unusual and has affected the groundwater in the study area. The precipitation variability has both economic and environmental implications. The SPI analysis revealed distinct period of negative and positive values in which negative values indicate occurrence of drought and positive values imply no drought.

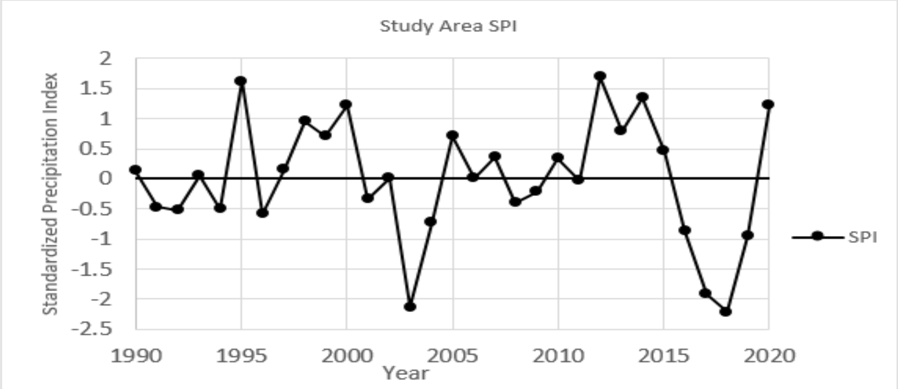


Figure 11: Standard Precipitation Index (SPI) for Drought intensity assessment of the study area

The SPI results showed that the frequency of dry periods (severely and extremely dry) increased in the last decade (Fig.11). There is a possibility of consistent increase in frequency of dry periods and extreme temperature occurrence in the near future in the study area, which could increase the rate of wind erosion in the area.

Palmer Drought Severity Index (PDSI)

The PDSI results of the study area showed that there has been an intermittent drought in the study area (Figure 12), but extreme drought were observed in the years of 1988, 1987, 2007, 2008, 2009, 2012, 2013, 2014, 2015 and 2020 (Figure 12). In view of the fact that the aquifers in the study area are mainly recharged by rainfall, these drought episodes have obviously affected the groundwater recharge and potential in the study area, due to low precipitation during the drought seasons.

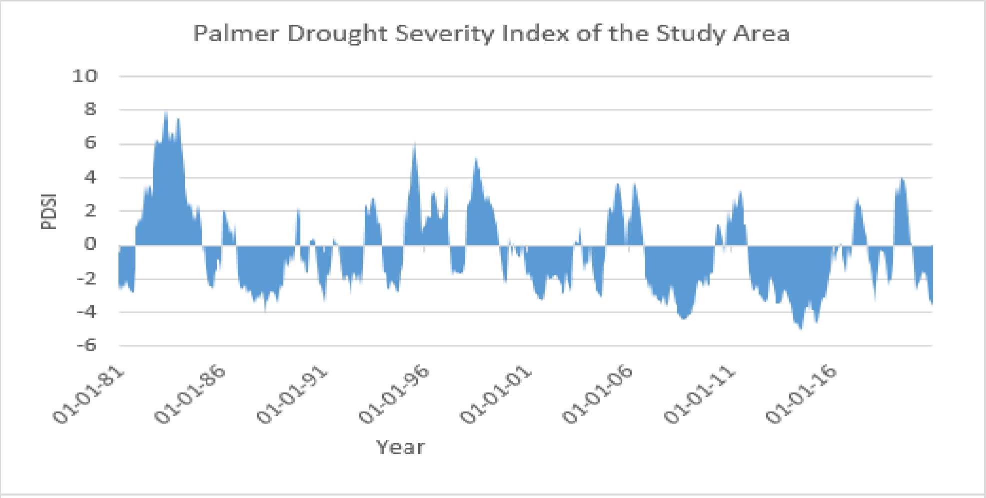


Figure 12: The Palmer Drought Severity Index (PDSI) of the study area

CONCLUSION

This study investigated the impact of drought on groundwater in Yobe State. Both geophysical and meteorological data were used to carry out the study. The geophysical investigation delineated two aquifers in the study area. The first aquifer is shallow and it might have been affected by severe and extreme droughts in the study area. The scond quifer is confined and it is located at a greater depth where it is secured from the Earth surface thermal dynamics. The change in the pattern of rainfall, frequency, intensity and temperature in the study area had significant impact on the groundwater resources as they are characterized with high evaporation and evapotranspiration. Therefore, understanding the impact of drought on groundwater will be heplful in overcoming the challenges imposed on groundwater by climate variability. Finally, the increased variablity in temperature, evapotranspiration, and precipitation as observed in the study area will have divers effects on the aquifers in Yobe State and other semi-arid areas at large. Considering the stress imposed on groundwater by drought and other climatic factors, it is imperative to protect the groudwater resources, because any small change in groundwater recharge and discharge will have both environmental and economic consequences. Based on these reasons, the following are recommended: there should be more research and development activities directed toward improving effective adaptability responses to drought and climate change in the study area and other semi-arid and arid regions, in view of the fact that groundwater demand will increase in the furture due to climate variability, groundwater monitoring and evaluation should be encourage to improve the understsnding of both community and stakeholders in groundwater management, tree planting should be encouraged by both communities and stakeholders in groundwater management in order to reduce carbondioxide, evaporation, and evapotranspiration, boreholes for domestic and industrial water supply should be drilled to the second aquifer in the study area to overcome the challenges of water scarcity and low borehole yield during drought.

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