Evaluation of Geospatial Climatic Variation and Aridity trend of the Jigawa State, Nigeria

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Abstract:- This study investigated evaluation of geospatial climatic variation and aridity increase, high risk zone with annual seasonal variation for a period of thirty years (30 years) from 1990 to 2020 in Jigawa State. Climatic data for this work are global data sources, which include; Tropical Application of Meteorology Satellite (TAMSAT) and NASA Earth observatory. Temperature data was acquired from NASA Earth observatory while precipitation data and evapotranspiration data were obtained from TAMSAT respectively. The seasonal variation of Jigawa State was investigated using an excel spread sheet to compare precipitation and temperature in the extreme Jigawa north and Jigawa south of the areas was also analyzed to find a critical environmental factor in determining the evolution of natural vegetation by considering the water stress which may occur during reduction of vegetation cover. Results showed that there was higher evapotranspiration and temperature but less precipitation in the northern part of Jigawa state. The rate of evapotranspiration is also high from 2011 to 2020. Aridity ranges for the Jigawa state are characterized by very high aridity and very low aridity. Aridity is very high in the extreme north of Jigawa, with an aridity value of 0.20 and a land area of 9,062.7 km^2 or 39 percent (%) land mass; aridity is very low in the extreme south of Katsina, with a value of 0.40 and a land area of 5,044.5 km^2 or 22 percent (%) land mass. There is more precipitation in southern Jigawa than in the northern part. On the other way round, the temperature is higher in northern Jigawa than in the southern part.

Keywords:- *Climatic variation, aridity increase, TAMSAT, remote sensing and GIS.*

I. INTRODUCTION

Jigawa State is confronted with climate variability challenges as a result of the ever-increasing need for growth, development, socioeconomic, and other inducements by human activities that affect the basic components of the environment. Climate change cannot bring a piece of land to a desertified state by itself, but it may modify the critical thresholds, so that the system can no longer maintain its equilibrium (Williams, M.A.J. and R.C. Balling, 1996). The global environmental issues that we are experiencing today are the result of anthropogenic activities that are unique to each ecosystem, and Jigawa as an ecology community is not immune to this environmental problem. The climate of Jigawa state has shown a considerable temporal and spatial shift in its variability and change from 1990 to 2020 (Climate Research Unit website, 2017). Therefore, there is some area sensitivity to low rainfall and high temperatures, while other areas are sensitive to low vegetation cover, low resistance of vegetation to drought and water deficit, that lead to aridity, which is a long term climatic phenomenon, (Agnew C. and W. Anderson, 1992). Climate variability constitutes a serious environmental problem facing mankind. Prominent among the consequences of climate variability is aridity, which in turn affects agriculture, rainfall and temperature distribution, devastating ecosystems and deficiency in water supply. Climatic conditions are now a global issue that has been recognized by both the national and international community. Climatic variability exerts a strong influence on the relevant socioeconomic sector and livelihood in the Jigawa State where the aridity (drying condition) has been on the increase. The escalating variability in rainfall distribution pattern may lead to deforestation and degradation of natural resources in Jigawa. These cumulative effects of rapid depletion of natural resources and variability in the distribution pattern of rainfall have drastically affected the quality of biotic and abiotic components in Jigawa, most especially the northern part of the state. Rainfall is the principal nourishment for the terrestrial ecosystem in the world, at the same time, a requirement for animals and plants to survive. Then, any challenge of unsteady recurring rainfall has adversely affected the moisture quality of the zone, thereby triggering aridity.

Small changes in the driving forces, such as climate change or change in land use, tend to cause change in the equilibrium system of the environment. This little change caused either by climatic factors or land use changes leads to some changes in communities, most especially fragile ecosystems. Therefore, climate variability is expected to cause damage to more vulnerable zones in the world because the prevailing weather conditions may lead to adverse effects so that the soils remain bare, creating conditions for flood and erosion. One of the critical environmental factors caused by climatic conditions is aridity. Aridity is a critical environmental factor in determining the evolution of natural vegetation by considering water stress which may cause reducing vegetation cover (Maliva, R., and T. Missimer, 2012).

A. Statement Of The Problems

Before now, aridity has been monitored using primitive methods of monitoring like interviews, administering questionnaires, traces of historical background, which is not really reliable and cannot provide an accurate description of the aridity of an area at a given scale. Satellite remote sensing has many reliable ways of monitoring environmental problems like aridity. Observation satellite can provide a complete survey of an area; show the distribution pattern of aridity and sources of aridity problem, determine any relationship between aridity and ecological features that can contribute to aridity and assist in determining where effort should focus so as to decrease the level of aridity in the area (Michael P., K. et al, 2005).

B. Justification

Satellite remote sensing can serve as a powerful technology that provides input data for monitoring, measurement, mapping and modeling of environmental aridity within the domain of the Geographic Information System. So also, the fundamental analytical function of GIS based statistics in spatial analyst tools, most especially Covariance in Inverse distance weighted (IDW) that limits the error of bias etc. are commonly used during the environmental data analysis process for mapping, monitoring and modelling of aridity. However, Remote Sensing and Geographical Information System (GIS) can provide a platform that is capable of integrating climatic parameters with other relevant data or associated features, which will help measuring, monitoring and mapping aridity so as to address the problem.

C. The Objectives Of The Study Are

- Estimation of climatic quality data from satellite sensor measurement of Jigawa state over a long period.
- Determination of the spatial and temporal pattern of the climate of Jigawa state over a period of Thirty one year's start from 1990 to 2020.
- Determination of the Jigawa climatic variable over a long period.
- Determination of the spatial pattern of aridity index of the Jigawa state.
- Determination of the contribution of climate variability to the degree of aridity in Jigawa state.

II. STUDY AREA AND METHODOLOGY

A. Jigawa Study Area

Jigawa is Geographic located in the northwestern part of the country between latitudes 11.00°N to 13.00°N and longitudes 8.00°E to 10.15°E. It has a total population of 318,234 according to the 2006 population census. Jigawa State borders Kano and Katsina to the west, Bauchi and Yobe State to the east. To the north, Jigawa shares an international border with The Republic of Niger, which is a unique opportunity for cross-border trading activities. Jigawa State has a land mass of about 23,154 km²

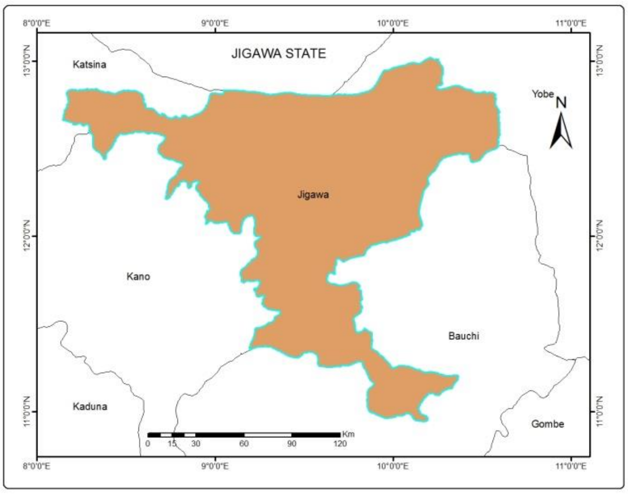

Fig. 1: Study Area Map

B. Climate And Vegetation

The climate of Jigawa State is the tropical wet and dry type (tropical continental climate) classified by Koppen climate. Rainfall is mostly between May and September with a peak in August (Abaje, I.B., et al, 2012). During the wet season, there is high humidity and the temperature is moderate. The dry season lasts from October to April, with very low humidity and extreme temperatures. During the season, there is significant Harmattan caused by the north east trade wind, which is why the most evaporation occurs during the dry season. The vegetation of the area is the Sudan Savanna type, which combines the characteristics and species of both the Guinea and Sahel Savanna (Abaje, I. B. 2007).

III. METHODOLOGY

Data Set: Data from Climate research unity (CRU) from 1990 to 2020, my NASA data and TAMSAT was used to estimate annual precipitation, annual mean temperature and evapotranspiration analysis for Jigawa state twenty years.

Climatic Data from sensor: Climatic data comprises of annual precipitation in millimeters (mm), Annual mean temperature degree Celsius (^{0}C) and evapotranspiration between 1990 and 2020 from satellite sensor-based used for mapping and modeling of Climate Variability and Aridity Index of Jigawa State.

A. Method

The methodology adopted for this study (shown in figure 2) is divided into four main stages. The stages include data collection, data processing, data analysis and the production of a high zone risk aridity map.

Annual Precipitation: The total values of monthly rainfall data obtained from sensor data for a given year were added together to form annual precipitation (i.e. total rainfall from January to December).

Annual Mean Temperature (i.e. total temperature from January to December divided by 12 months): The total values of monthly temperature acquired for a year were added up and divided by 12 to form annual mean temperature (i.e. total temperature from January to December divided by 12 months).

Data analysis/determination of aridity: The interpolation criteria applied for the data provided in this study was Inverse Distance Weight (IDW). The Aridity Index was calculated from precipitation, annual mean temperature and evapotranspiration to examine the high zone risk aridity of Jigawa. Various aridity indices have been developed and used by different researchers. In this study, the data collected was subjected to the De Martonne's (1926) Aridity Index model calculated as:

$$\mathbf{AI} = \frac{P}{T+4} \quad \textbf{Equation}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\textbf{1}$$

Where P is precipitation in meter (m) and T is mean temperature in degree Celsius (^{0}C).

Class	Aridity Index
Cold	> 0.65
Humid	>0.65
Dry Sub-Humid	0.50-0.65
Semi-arid	0.20-0.50
Arid	0.5-0.05
Hyper Arid	<0.05
Dry-land	<0.065
Susceptible dry lands	0.05-0.065

Table 1: Categories of Aridity Index based [8]

Trend in variation: Long and short seasonal variations were carried out in excel spread sheet to observe dry and wet season and also long year’s variability.

IV. RESULTS AND DISCUSSION

Results

The results of analysis of the climatic data recorded from satellite sensor measurement for different points of climatic quality parameters over Jigawa State include; precipitation and temperature obtained from satellite data based on performed analysis of climatic variability and aridity index in Jigawa State.

Figure 3 shows the long term annual mean temperature of Katsina state from 1990 to 2019. The least annual mean temperature recorded in this period was 23 ^{0}C in 1997 and the highest temperature recorded was 30 ^{0}C in 2016. In this curve, the temperature in degree Celsius (^{0}C) is on the vertical axis and year on the horizontal axis. It can also be deduced to the steady increase in temperature from 1997 to 2016.

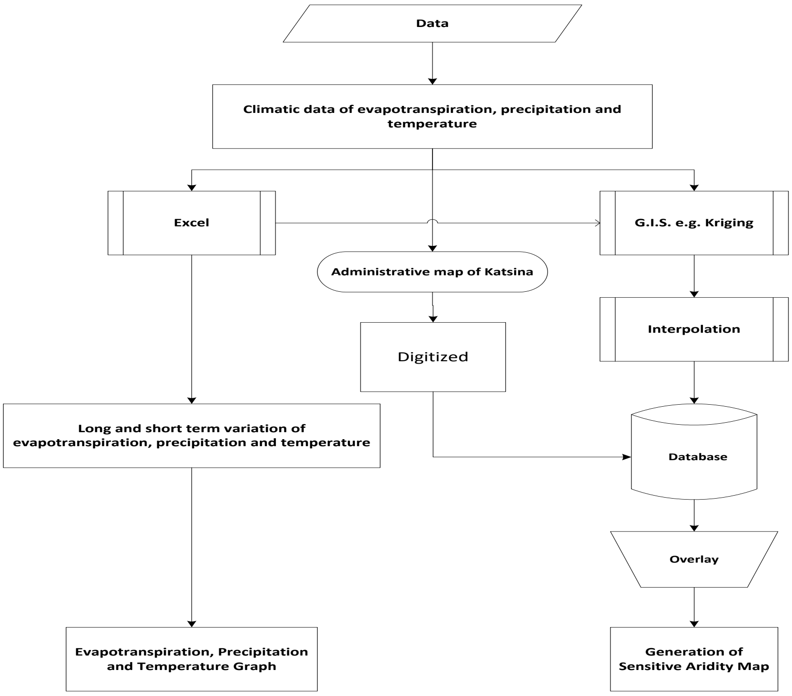

Fig. 2: Methodology flowchart

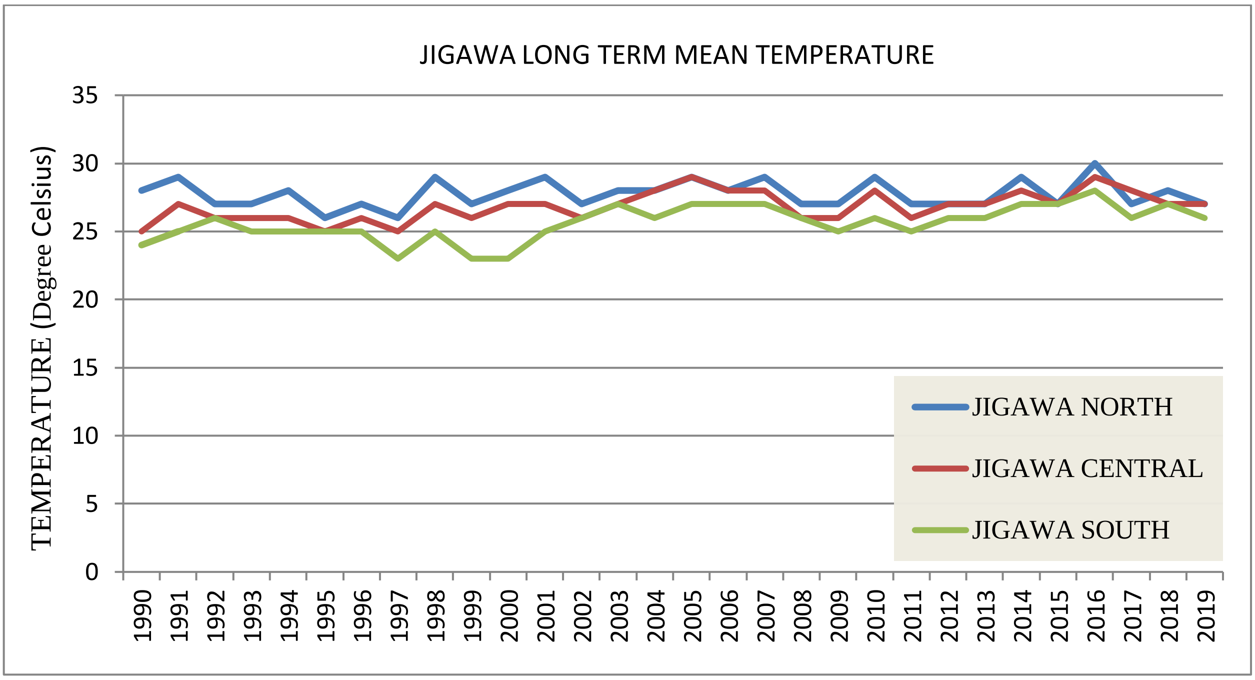

Fig. 3: Jigawa Long Term Mean Temperature

Figure 4 shows the temperature anomaly trend of Katsina state from 1990 to 2019. This chart shows that the temperature was not as high in the first and part of the second decade, from 1990 to 2005. In 2016, the last decade's temperature is high and it continues to rise. This rise in temperature plays a significant role in dryness in a fragile ecosystem.

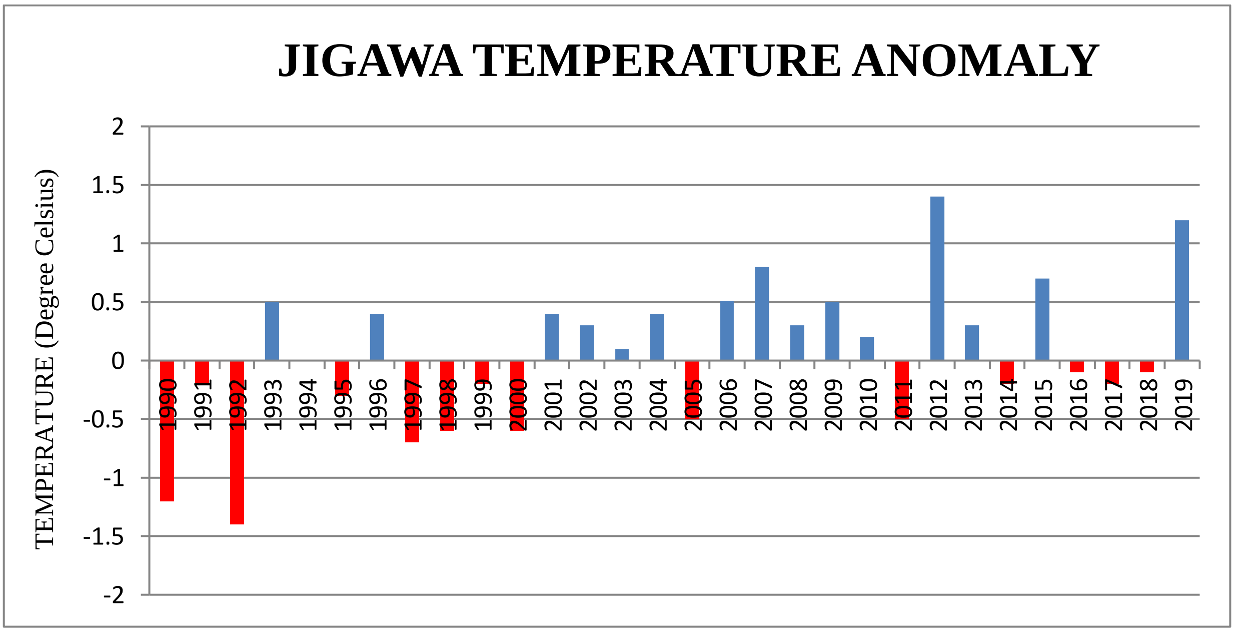

Fig. 4: Jigawa Temperature Anomalies

Figure 5 shows the long term curve of Jigawa State annual precipitation or rainfall, which comprises of Jigawa central, north and south from 1990 to 2020. The vertical axis represents annual rainfall in millimeters (mm) while the horizontal axis represents the year. The highest annual rainfall in Jigawa south is 1040 mm in 2019 and its least annual rainfall was 789 mm in 1993. Jigawa central recorded the highest value of annual rainfall of 629 mm in 2019 and the least value of annual rainfall of 468 mm in 2000. Jigawa north zone recorded the highest annual rainfall of 470 mm in 2019 and the least annual rainfall of 369 mm in 2014.

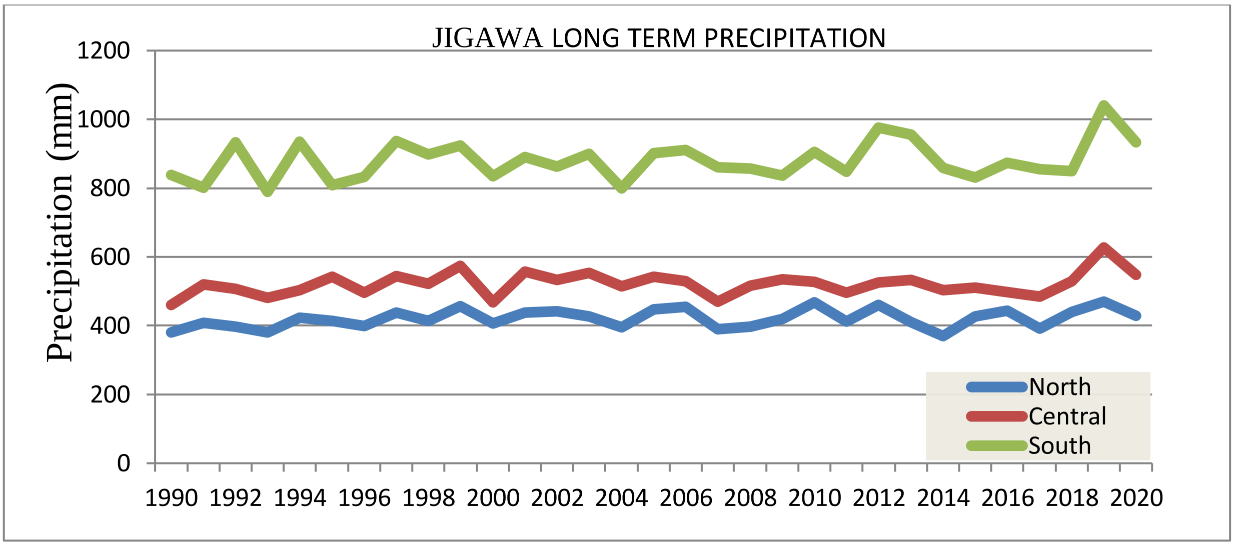

Fig. 5: Jigawa Long Term Precipitations

Figure 6 shows the precipitation anomaly trend of Jigawa State from 1990 to 2020. The year 2019 showed excess precipitation of 185 mm and next to it is 2012 with precipitation in excess of 120 mm. The last decade, from 2014 to 2018, saw a decrease in precipitation, which is a lack of rainfall that can cause aridity in an area.

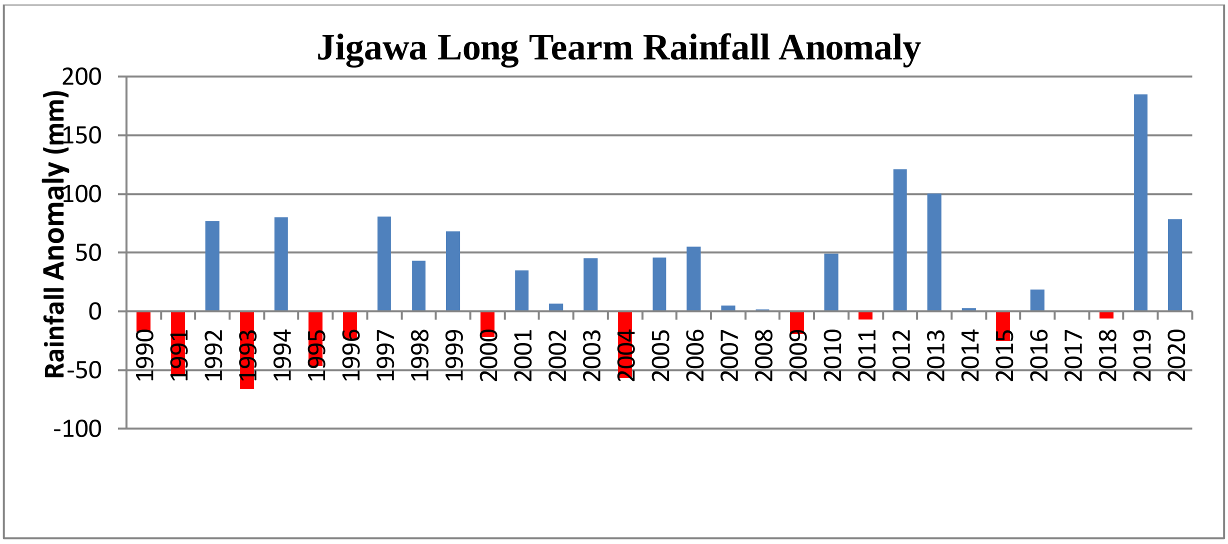

Fig. 6: Jigawa Rainfall Anomalies

Figure 7 depicts the long-term mean–evapotranspiration amount in mm/day, which gradually increases northward. *Babura, Birinwa, Garawa, (approx. 80%), Gumel, (approx.60%), Guri*and a part of*Gwiwa*, have a long term mean-evapotranspiration that varies between 62.56mm/day to about 65mm/day. *Kauguma and Kazaure (50-60%), Musawa* (approx. 50%) and little of *Kiri-Kasamma*, have a long term mean-evapotranspiration between 65.01mm/day and 68mm/day. For most parts of *Madori, Maigatari*and a small part of *Malam* and *Sule-Tankankar*, plus a very tiny part of *Yankwashi*, the long term mean-evapotranspiration amount falls between 68.01mm/day and 70mm/day.

In the far interior part, that is, areas like *Roni, Garki* and part *of Taura, Ringim, Miga (up north),* and*Auyo, Kafin Hausa, Jahun (down south),* the long term mean-evapotranspiration amount falls between 70.01mm and 73 mm per day. In the far exterior part of *Jigawa* (i.e. Jigawa South), for places like *Dutse, Kiyawa, Buji, Bimikudu and Gwaram,* the long term mean-evapotranspiration amount ranges between 73.01mm and 76mm per day.

The distribution of evapotranspiration in the state is linked with the temperature pattern exhibited. A seasonal increase in the degree of dryness was made evident by the increase in evapotranspiration during the dry season of the state *(November – April, figure 7)* with the northern part losing more moisture at a higher rate (73.1 to 76 mm/day) compared to the southern part (62.56 to 65 mm/day), following the temperature distribution in the state. The significant increase in evapotranspiration in the last decade can be attributed to increasing vegetation depletion (Abaje, I.B., et al, 2014).

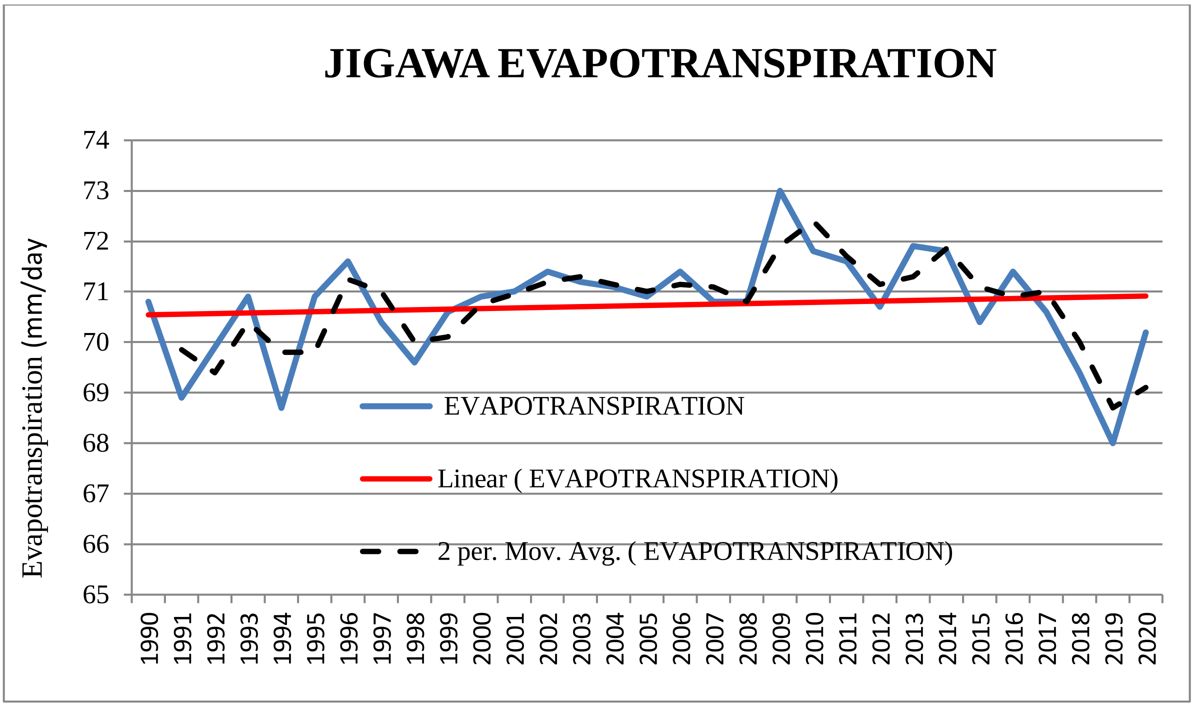

Fig. 7: Jigawa long term Evapotranspiration

Figure 8 shows the monthly evapotranspiration trend of Jigawa state. The least evapotranspiration is observed in the month of August and the highest evapotranspiration is experienced in the month of April.

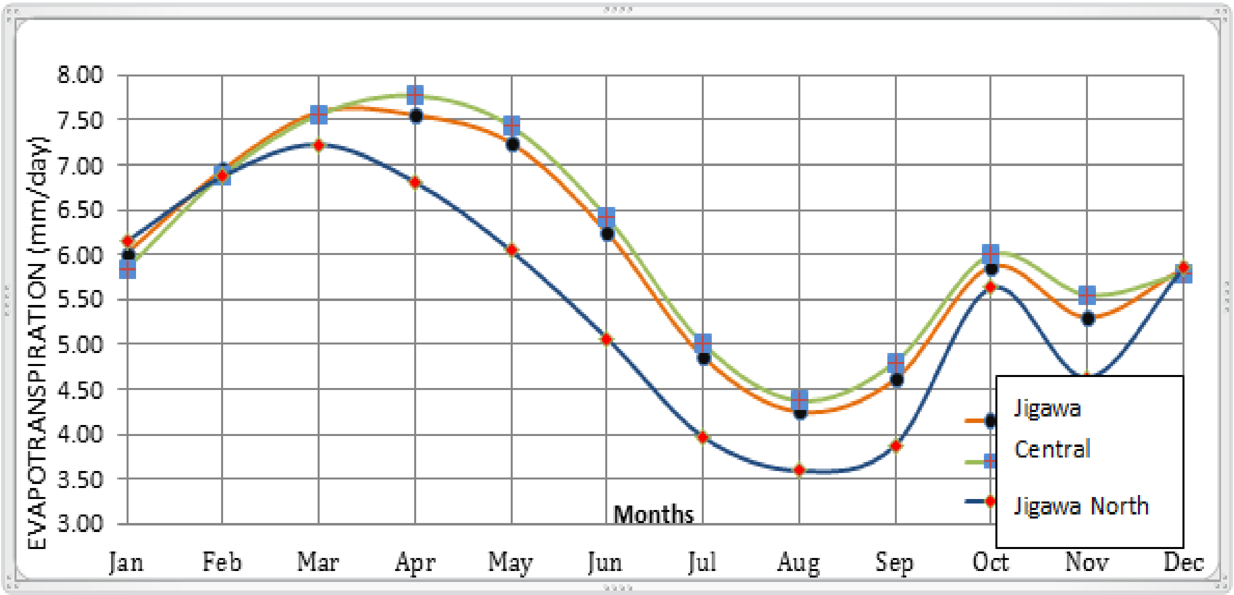

Fig. 8: Jigawa Monthly Evapotranspiration

Figure 9 shows the long term mean aridity of Jigawa State from 1990 to 2020. From the curve, aridity is on the vertical axis and year on the horizontal axis. It can be observed that the linear series of the curve showed an increase from 0.28 to 0.39 and this increase has been happening from 1990 to 2020.

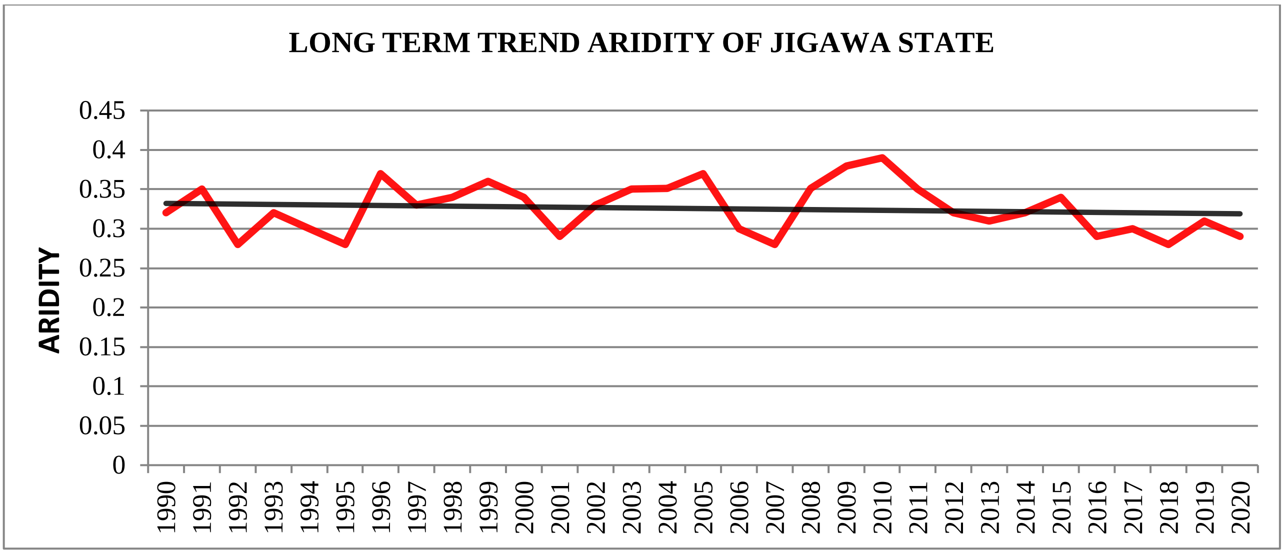

Fig. 9: Long Term Trend Aridity of Jigawa

Figure 10 shows the Jigawa temperature map of 2019. The distribution pattern of the map showed an area with high degrees Celsius and low degrees Celsius in Jigawa state as we can see the values or colour arrangement of the map. Plants in this area may not develop well because of high temperatures; exposure of plants to extreme temperatures may limit the ability of plants to produce fruit because high temperatures affect the process of fertilization and also affect the ability of crops to produce. These, on the other hand, have a consistent negative impact on plants. Categories of temperature classes, a class are expressed in area in kilometer square (km^2) and percentage (%) area in Table 3 below and area in (%) also expressed in the pie chart in Figure 11 below. Classes 26–27 take up the most percentage area, while classes 28–29 take up the least.

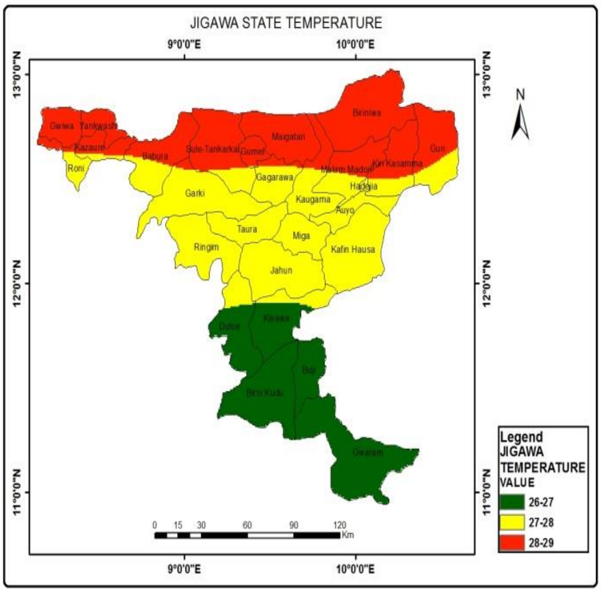

Fig. 10: Jigawa Temperature Map

S/N	Classes	Area (km^2)	Area (%)
1	26 to 27	5344.6	23
2	27 to 28	10215.1	33
3	28 to 29	7594.3	44

Table 2: Jigawa Temperature Class

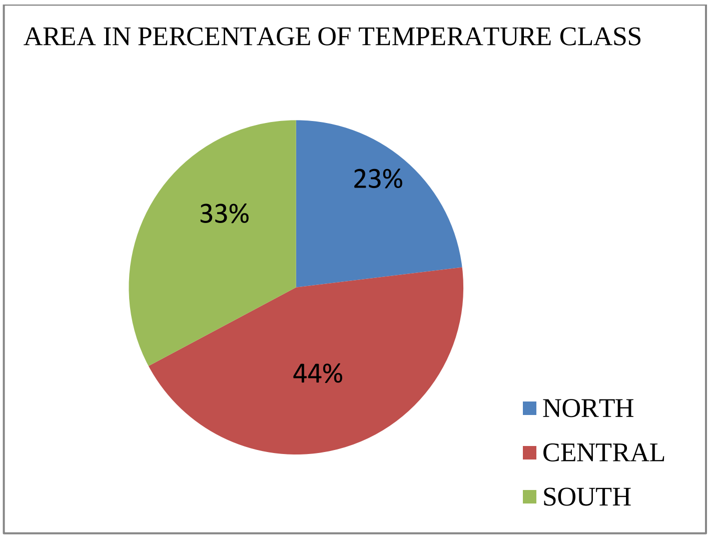

Fig. 11: Percentage Distribution of Temperature Class

Figure 12 shows the result of the precipitation map of Jigawa with the distribution of precipitation across the state. As we can see, the distribution pattern of rainfall or precipitation showed some parts of Jigawa with high precipitation of 936 mm and other parts with low precipitation of 590 mm. That is, the southern part and northern part of the state. So, there is more precipitation in the southern part than the northern part of Jigawa. For this purpose, soil in this part with low rainfall may be prone to environmental challenges like drought, aridity, degradation etc. Categories of precipitation classes, a class are expressed in area in kilometer square (km^2) and percentage (%) area in Table 1 below and area in (%) also expressed in the pie chart in Figure 13 below. Class 455 to 588 takes up the most percentage area, while class 719 to 913 takes up the least.

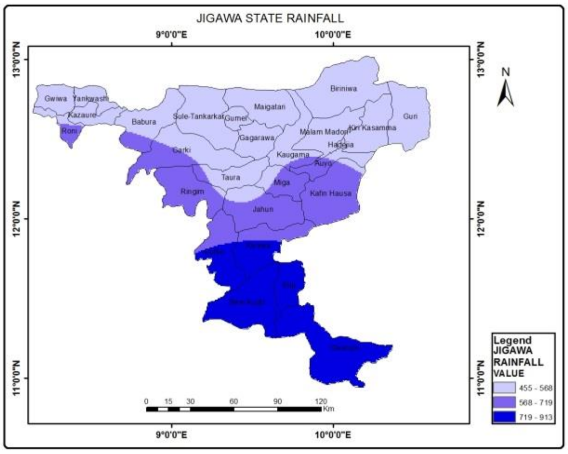

Figure 12 Jigawa Rainfall Map

S/N	Classes	Area (km^2)	Area (%)
1	455 to 588	12494.1	54
2	588 to 719	5709.5	25
3	719 to 913	4950.4	21

Table 3: Jigawa Rainfall Class

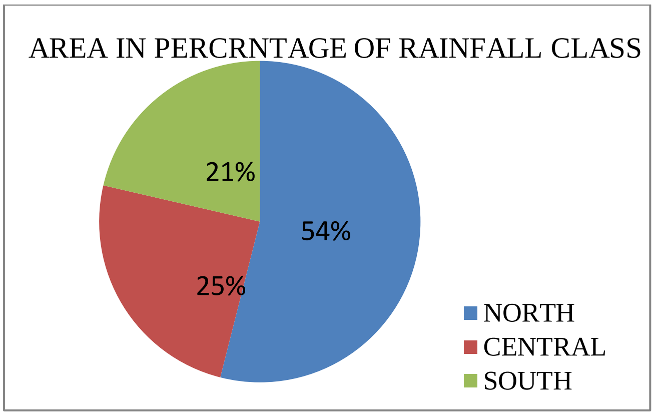

Fig. 13: Jigawa Rainfall Class in Percentage

From the aridity map in Figures 14, Table 4 and Figure 15, a significant part of northern Jigawa shows proneness to aridity. The map shows the distribution of aridity in Jigawa. Using the United Nations Environmental Programme Aridity Index classification, the whole of Jigawa falls under the semi-arid index (0.20 to 0.50). The northernmost part of Jigawa exhibits a 0.20 to 0.24 index, which makes the area more prone to aridity. The northernmost areas are more susceptible to aridity. These sub regions similarly exhibited high evapotranspiration, high temperature and low precipitation. The pattern of aridity, which is a combination of the different contributing factors of temperature, precipitation variation and the rate of evapotranspiration across the state, can be accounted for by climate variability and change, human activities like deforestation, excessive felling of trees, overgrazing by livestock and uncontrolled farming, all of which contribute immensely to soil aridity (Abdulkadir, A., et al, 2013). Classify Jigawa as one of the extremely deficient moisture effectiveness zones in northern Nigeria. Evidently, there is an increasing aridity in the state which accounts for the shrinking of surface reservoirs (Sawa B.A., et al, 2015). The Central Jigawa is around 0.24 to 0.31 and that of the southern part of the state is 0.31 to 0.40.

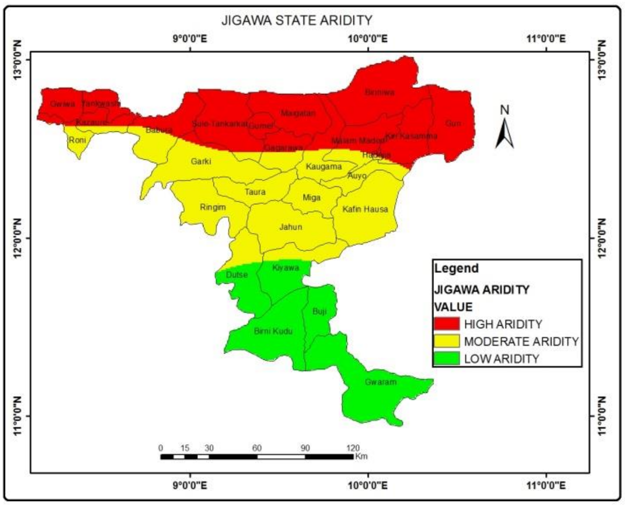

Fig. 14: Jigawa Aridity Map

S/N	Classes	Area (km^2)	Area (%)
1	0.20-0.24	9,062.7	39
2	0.24-0.31	9,046.8	39
3	0.31- 0.40	5,044.5	22

Table 4: Jigawa Aridity Class

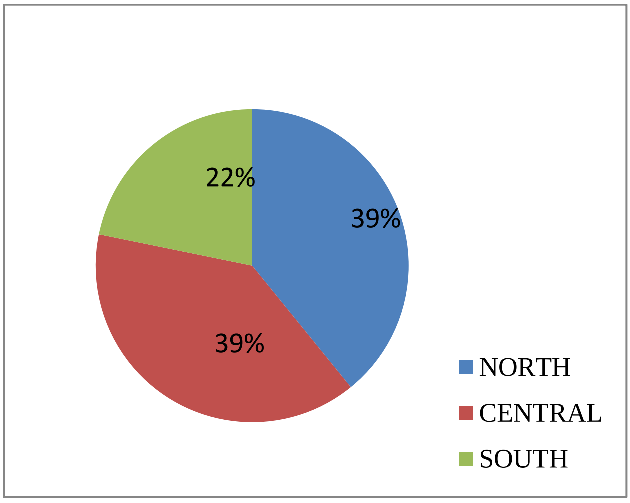

Fig. 15: Aridity Distribution Class in Percentage

V. DISCUSSION

According to the trend and aridity growth rate analysis and results of the entire factor reveals short, middle, and long term variation above, there is less precipitation in the dry season than in the wet season, as well as more precipitation in the southern part of Jigawa State than the northern part, and less precipitation in the last decade of precipitation anomalies (2011 to 2020). The lowest precipitation recorded for both northern and southern Jigawa was 379 and 789 mm in 1993. The highest ever rainfall recorded for Jigawa north for the period of this study was 470 mm and for Jigawa south was 1040 mm. It will happen in 2019. The northern parts of the Jigawa state, which are constantly increased by low precipitation of climatic conditions through the involvement of human activities like; excessive felling of trees, overgrazing and uncontrolled farming and overgrazing by livestock, can contribute immensely to soil aridity. During the course of this analysis, it was observed that the annual peak value of precipitation was the month of August and the least value was the month of March.

The temperature in the dry season is higher than in the wet season as observed in Figures 3 and 4. This supported (Abaje, I. B., et al, 2012). The temperature Celsius (^{0}C) in the northern part of Jigawa is more than the temperature in the southern part of Jigawa State. Temperatures in the entire Jigawa state rose from 2011 to 2017, as shown in Figure 3. The highest temperature in northern Jigawa is 30 ^{0}C, and that of the southern part is 28 ^{0}C, both in 2016. The lowest temperature in northern and southern Jigawa is 26 ^{0}C and 23 respectively in 1997 for the period of this investigation. The temperature of the state (Figure 10) has risen from 26 to 29 degrees Celsius (^{0}C), which is about 3.0 (^{0}C). Rising temperatures must have an adverse impact on ecosystems of the area in several ways; longer drying season, water deficit, increased rate of evaporation, diseases like meningitis and measles, heat waves, variation in the hydrological cycles are expected to have a negative effect on habitat. Higher temperatures as observed above can contribute to high evaporation of soil and water bodies in the area, which in turn leads to soil aridity in extreme Jigawa north.

Evapotranspiration in northern Jigawa is higher than in southern Jigawa because of the high temperature and low precipitation experienced in this area. During the dry season, evapotranspiration is high, most especially in the northern part of the state. Figure 7 and 8, long term mean and monthly evapotranspiration Figure 7 shows that there has been a significant increase in evapotranspiration over the last decade, specifically from 2010 to 2020, indicating a water shortage that may result in a decrease in vegetation cover. Figure 9 depicts the long-term trend of aridity, which indicates that there will be more aridity from 2011 to 2020.The decreasing value in figure 9 means that the increase in aridity of a place is inversely proportional to the value of the analysis. There is evidence of sensitive to aridity in some parts of Jigawa because of the range of value in Figure 14, which is between 0.2 and 0.40. 0.2 values is the area that is sensitive to high aridity, while 0.40 values is the area sensitive to low aridity. This high aridity value is due to the area's low precipitation and high temperature, whereas areas with low aridity are due to a sufficient amount of precipitation and low temperature.

Increased aridity can have an arbitrary effect on the soil by altering the PH of the soil. Soil PH increases with increasing aridity and temperature, and tends to have negative effects on soil organic matter. Decreasing soil with climatic conditions can be attributed to the aridity inducing decline of soil water availability and vegetation cover both directly or indirectly. In addition, reduced vegetation cover, together with increased temperature, enhances soil erosion that can remove fine, nutrient particles from the soil. Aridity induced reductions in availability of soil water will limit plant production capacity in Jigawa state, most especially the northern part of the state. The increasing aridity could further increase the rate of evaporation into the atmosphere and would result in reducing the stream flow in the river, causing water shortages or insufficient livelihood and crops. This may also lead to lower yields of agricultural produce and lead to some species extinction. As shown in Figures 10, 12, and 14, the southern part of Jigawa state, which is still favourable in terms of climate, is being pressed by extreme weather from the northern part of the state.

There is evidence of pressure on land in Jigawa state's transition area (i.e. the central part), as well as some strategic resources such as forested areas and water bodies. Climate variation is an important environmental factor in ecosystems. Therefore, climate variation may affect the ecological community in different ways.

VI. CONCLUSION

It can be concluded that the Aridity Index (AI) is a simple tool that allows analyzing the magnitude of the aridity and drought phenomena all over the Jigawa state territory for a reasonable number of years (1990 to 2020). In addition to the absolute values and relevant climate classifications, the aridity index has allowed researchers to verify geographical characteristics and differences as well as the occurrence of the climate variations in the state. Climatic variables aided in the observation of high precipitation, low temperature, and low evapotranspiration in the southern part of Jigawa State, resulting in very low sensitivity to aridity, whereas high evaporation and low precipitation resulted in very high sensitivity to aridity in Jigawa north. Lower precipitation in Jigawa north, together with high temperature, high evapotranspiration and low value of precipitation make the area prone to aridity and will have a direct negative impact on livelihood and ecosystem in the northern part of the state. Although, Jigawa people may not be directly responsible for climate variability and aridity problems in the state, they are prone to greater impacts of variability because their economies are highly dependent on natural resources that are sensitive to climate in addition to the fewer resources. The options they have are to combat the impacts of climate variability and aridity in the area. Inhabitants of Northern Jigawa state may likely face catastrophes, and extreme weather events are likely to become more intense and more frequent with higher global temperatures affecting crops, water supplies and increased spread of diseases among other impacts.

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REFERENCES

[1.] Williams, M.A.J. and R.C. Balling, (1996): Inter actions of desertification and climate. London: Arnold. xiv + 276 pp. £50.00 cloth. ISBN: 0 340 63217 8.

[2.] Climate Research Unit website, (2017). www. cru.uea.ac.uk http://www. tamsat.org.uk/ data-subset/data

[3.] Agnew C. and W. Anderson, (1992). Water in the arid realm. Routledge: London. The Palmer drought severity index: Limitations and assumptions. Journal of Climate and Applied Meteorology, 23(5615), 1100–1109.

[4.] Maliva, R., and T. Missimer, (2012) Arid Lands Water Evaluation and Management, Environmental Science and Engineering, Springer-Verlag Berlin Heidelberg.

[5.] Michael P., K. Theodora, B. David, B. Asbjorn, H. Gerard, S. Gavin, R. Adrianos and S. Nicolaos, (2005). Remote Sensing and GIS as Pollution model Validation and Emission Assessment Tools. Proceedings the 10 Int. Confrence on Harmonisation within atmospheric Dispersion modelling for Regulation Purposes.

[6.] Abaje, I. B., O. F. Ati, and E. O. Iguisi, (2012). Changing climatic scenarios and strategies for drought adaptation and mitigation in the Sudano-Sahelian Ecological Zone of Nigeria.

[7.] Abaje, I. B. (2007). Introduction to soils and vegetation. Kafanchan: Personal Touch Productions.

[8.] United Nations Environment Programme (UNEP 1997). World atlas of desertification 2ED. UNEP, London.

[9.] Abaje, I.B., B.A. Sawa, O.F. Ati, (2014). Climate Variability and Change, Impacts and Adaptation Strategies in Dutsin-Ma Local Government Area of Katsina State, Nigeria. Journal of Geography and Geology, 6(2), 103-110.

[10.] Abdulkadir, A., M.T. Usman, A.H. Shaba, S. Saidu, (2013). An Appraisal of the Eco-climatic Characteristics in Northern Nigeria. African Journal of Environmental Science and Technology, 7(8), 749 – 750. doi: 10.5897/AJEST12.161

[11.] Sawa B.A., O.F. Ati, I.A., Jaiyeoba, E.O. Oladipo, (2015).Trends in Aridity of the Arid and Semi-Arid Regions of Northern Nigeria. Journal of Environment and Earth Science, 5(10), 61-68

[12.] Abaje, I. B., Ati, O. F., &Iguisi, E. O. (2012). Changing climatic scenarios and strategies for drought adaptation and mitigation in the Sudano-Sahelian Ecological Zone of Nigeria.