

Figure 6. Precipitation Distribution in 2021.

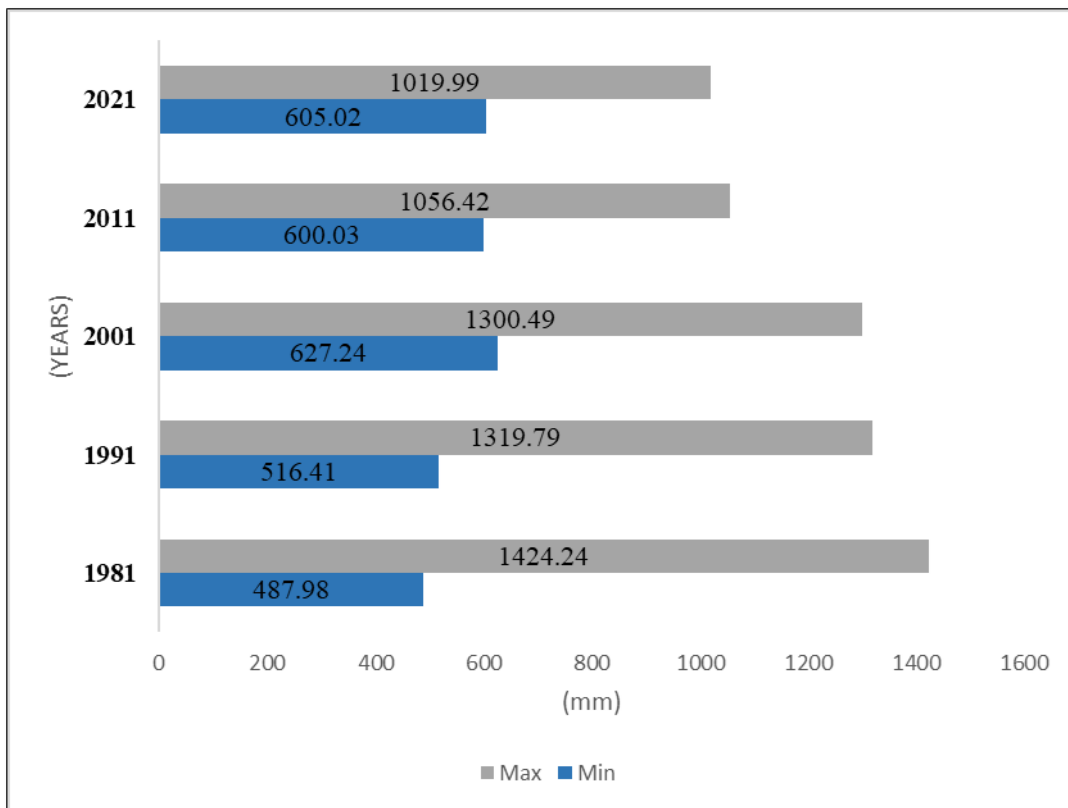


Figure 7. Summary of temporal variation of precipitation Distribution from 1981-2021.

Figure 1 shows the variability in precipitation over the study area. There was a decrease of 193.7mm in the mean annual precipitation between 1981 to 1983, from 1002.8 mm to 809.1mm. However, there was an upward fluctuation from 1983 to 1987 where the precipitation reached 876.5mm in 1987. The area showed an abrupt rise in precipitation between 1987 and 1988 where it reached 1012.7mm before a decline in 1989 (976.9mm) and 1990 (827.6mm). The precipitation was observed to be on the increase though with several fluctuations reaching the highest peak amount of 1093mm in 1996 but this upward trend was not sustained as there was a gradual but steady fluctuation below the 1996 threshold with the lowest amount of precipitation (773.9mm) recorded over the basin in 2014. Another sharp rise in the annual rainfall was recorded in the basin up till 2016 where it recorded 982.3mm and a downward trend which ended the study period with 790.7mm in 2021. This result in the Upper Benue River Basin is congruent with the studies of Trenberth (2011) and National Oceanic and Atmospheric Administration [NOAA] (2021) which observed a direct influence of global warming on precipitation as increased heating leads to greater evaporation and thus surface drying, thereby increasing the intensity and duration of drought. This observed fluctuation in the precipitation regime of the study area can be attributed to the effect of climate change in the area. Precipitation intensity and frequency can be impacted by climate change. Oceans that are warmer cause more water to evaporate into the atmosphere. More moisture-laden air can produce more intense precipitation when it flows over land or merges with a storm system (NOAA, 2021). The map in figure 2 to fig. 6 presents the yearly variabilities in precipitation over the Upper Benue River Basin.

As indicated in **Figure 2**, for the year 1981, the annual precipitation ranged from 487.98 mm to 1424.24mm. The spatial pattern observed indicates a northward decrease in the amount of precipitation over the study area. It is evident that precipitation in the basin decreases with increasing latitude. From latitude 7° 15 N to about latitude 8° 35N in 1981, the precipitation distribution was between 1,233.33mm to 1,424.24mm and also on the eastern flank of the basin close to 9° 00 N. However, the precipitation decreased between latitude 8° 35 N to long 9° 45 N (1,049.75mm- 12,233.32mm). Further North, the precipitation decreased between latitude 9° 39N to about latitude 10° 55N (689.93-873.5mm) and this trend continued till the uppermost north of the basin with precipitation distribution of between 487.98 to 689.92mm. This agrees with Huang, Sun, Xue & Zhang [18] in Mongolia, northern China. The result of the findings in **Figure 3** reveals that the northward decline in the annual rainfall pattern for 1991 remains persistent with slight variation in comparison to 1981. The range of rainfall was between 516.41mm to 1319.79 mm. The result here shows that precipitation

decreased with increasing latitude towards the north. In 1991, between Latitude 7° 15N and 8° 35N, the precipitation was between 1,181.17 to 1,319.79mm. However, this further decreased between 1,048.85mm to 1,181.16mm between latitude 8° 35N to latitude 9° 40N at the eastern flank of the basin. Further north between Latitude 9° 40N to 10° 15N, the precipitation was between 907.08mm to 1, 048.84mm. This trend is sustained decreasing further till the upper part of the basin to 516.4mm to 736.9mm. This agrees with Huang, Sun, Xue & Zhang [18] in Mongolia, northern China.

As presented in **Figure 4**, the minimum range stood at 627.24mm -769.81mm, a significant increase from the previous two epochs (1981 and 1991). The maximum range was between 1142.09mm - 1300.49mm, depicting declining values from previous years. The result here shows that precipitation decreased with increasing latitude towards the northern part of the study area. In 2001, between latitude 7° 15N and 8° 35N, the precipitation was between 1,142.09 to 1,300.49mm. However, this further decreased between 1,018.00mm to 1,142.08mm between latitude 8° 35N to latitude 9° 40N at the eastern flank of the basin. Further north between latitude 9° 40N to 10° 15N, the precipitation was between 901.83mm to 1, 017.99mm. This trend is sustained decreasing further till the upper part of the basin to 627.24mm to 769.81mm. This agrees with Huang, Sun, Xue & Zhang [18] in Mongolia, northern China. For the year 2011, as seen in **Figure 5**, the minimum range stood at 600.03 mm - 682.36 mm, while the maximum range values recorded 934.73mm - 1056.42mm. This indicates a further decline from the previous periods. The spatial pattern however remained consistent with slight variations. The result here shows that precipitation decreased with increasing latitude towards the north pole. In 2011, between Latitude 7° 15N and 8° 35N, the precipitation was between 935.73 to 1,056.42mm. However, this further decreased between 843.45mm to 934.72mm between latitude 8° 35N to latitude 9° 40N at the eastern flank of the basin. Further north between Latitude 9° 40N to 10° 15N, the precipitation was between 753.96mm to 843.44mm. This trend is sustained decreasing further till the upper part of the basin to 600.03mm to 682.36mm. This agrees with Huang, Sun, Xue & Zhang [18] in Mongolia, northern China.

As reflected in **Figure 6**, annual minimum precipitation values were 605.02mm - 688.02mm, while the maximum values recorded a range of 910.97mm - 1019.99mm. The result here shows that precipitation decreased with increasing latitude towards the north pole. In 2021, between latitude 7° 15N and 8° 35N, the precipitation was between 910.97mm to 1,019.99mm. However, this further decreased between 837.74mm to 910.96mm between latitude 8° 35N to latitude 9° 40N at the eastern flank of the basin. Further north between Latitude 9° 40N to 10° 15N, the precipitation was between 764.51mm to 837.73mm. This trend is

sustained decreasing further till the upper part of the basin to 605.02mm to 688.02mm. While there has been fluctuating minimum values, the maximum values remained steadily on the decline. This agrees with Huang, Sun, Xue & Zhang [18] in Mongolia, northern China.

As presented in **Figures 2-7** is a summary of the variation in precipitation, and it shows that there is a consistent decrease in the maximum values of precipitation for the study period. From 1981, the precipitation amount dropped from 1424.24mm to 1019.99mm in 2021, marking a significant difference of 404.25mm. On the other hand, minimum precipitation values have been on the increase from 487.98mm in 1981 to 605.02mm in 2021, marking an increase of 117 mm. On the whole, the overall ranges for the years considered have been seen to be on the decline northwards and overtime. This is the footprint of rainfall uncertainty. This result is congruent with the studies of Odjugo [19] which observed rainfall decreases of 1350mm

from 1941-1970 to 1276mm from 1970-2002. Similarly, a recent study by Abaje and Oladipo [20] in Kaduna, in the Northwest region of Nigeria also showed a similar decrease in the trend of rainfall from 1971 to the late 1990s, however, their result showed a little increase in rainfall over Kaduna between 1991 to 2016. Additionally, the study agrees with Dike [21] whose study on intensification of summer rainfall over Nigeria in the recent decades shows that the Sahel region is experiencing decreasing wet-day rainfall frequency but increasing intensity leading to flooding in the region.

Spatial and Temporal Variation of Temperature in Upper Benue River Basin

The spatio-temporal variation in temperature for the study area is presented in **Figure 8** and each of the 4 decades covered is presented spatially on a map (**Figures 9-13**) and summarized in **Figure 14** which indicated the dynamics of annual temperature over the study area for the periods of 1981-2021.

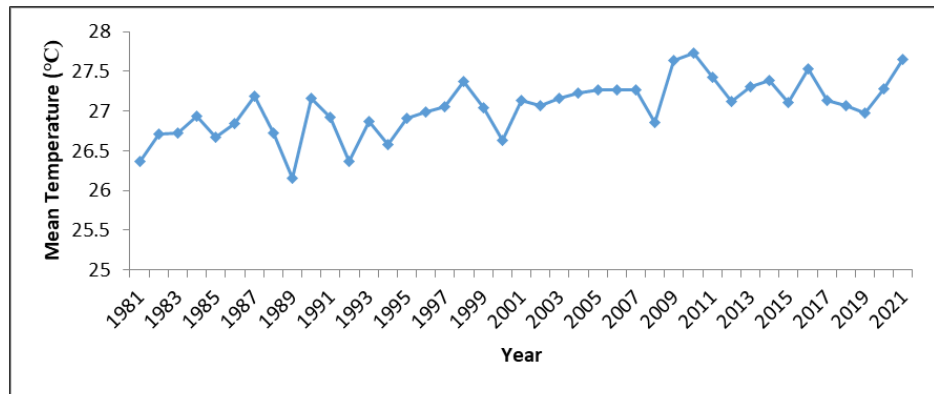


Figure 8. Trend of Temperature in the Upper Benue River Basin.

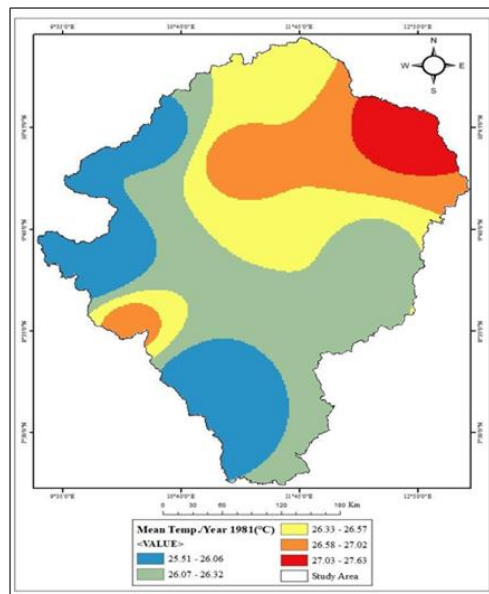


Figure 9. Temperature Distribution in 1981.

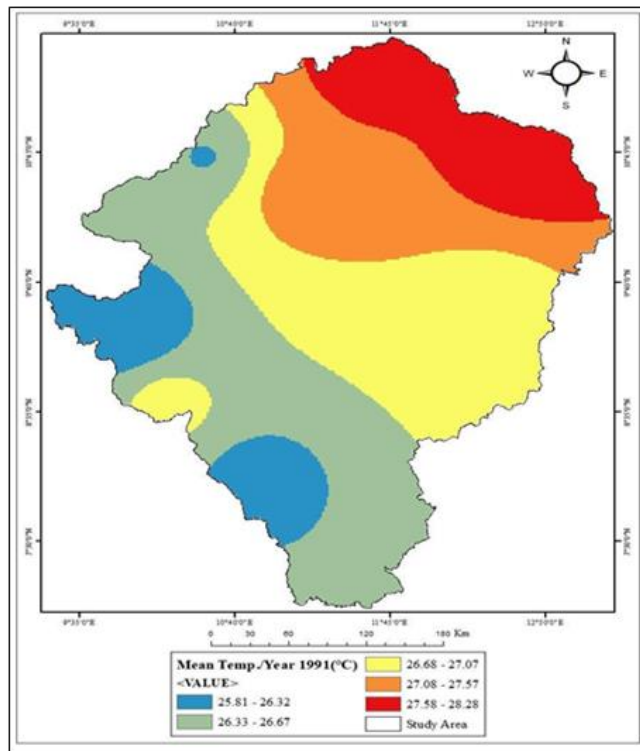


Figure 10. Temperature Distribution in 1991.

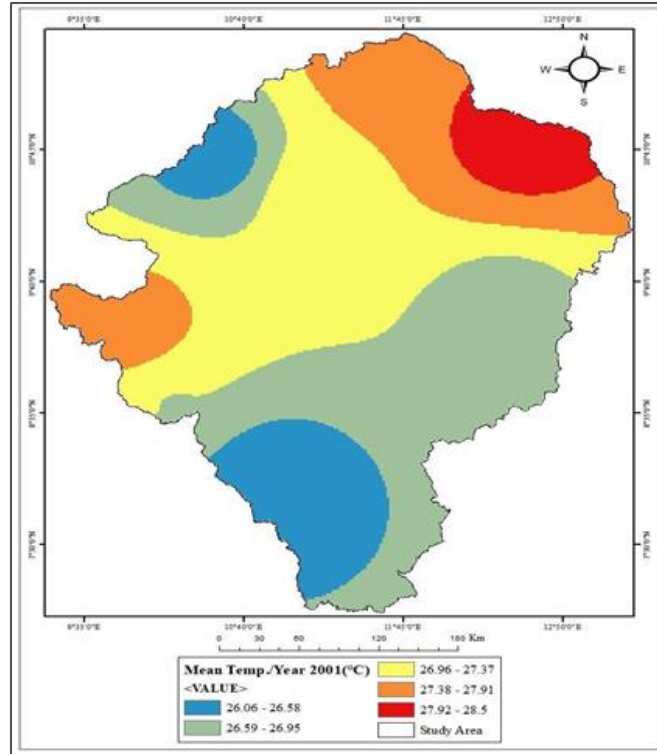


Figure 11. Temperature Distribution in 2001.

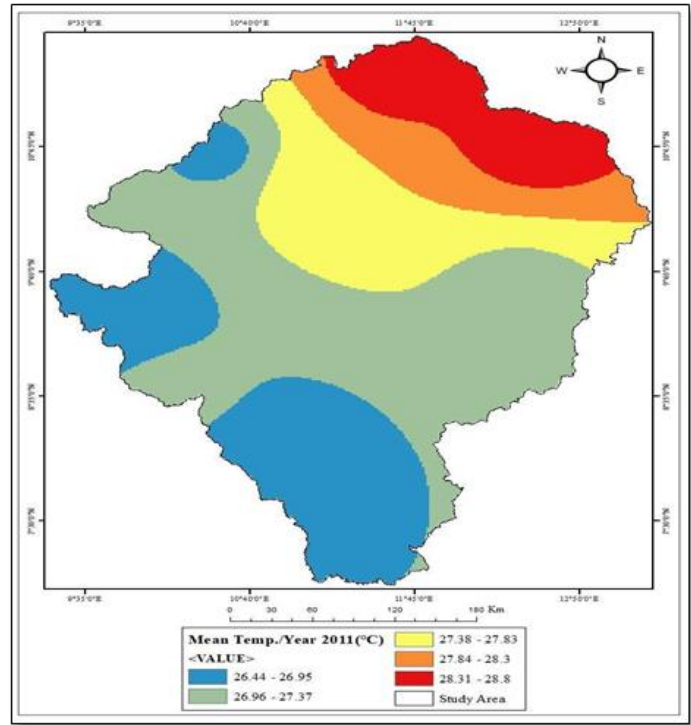


Figure 12. Temperature Distribution in 2011.

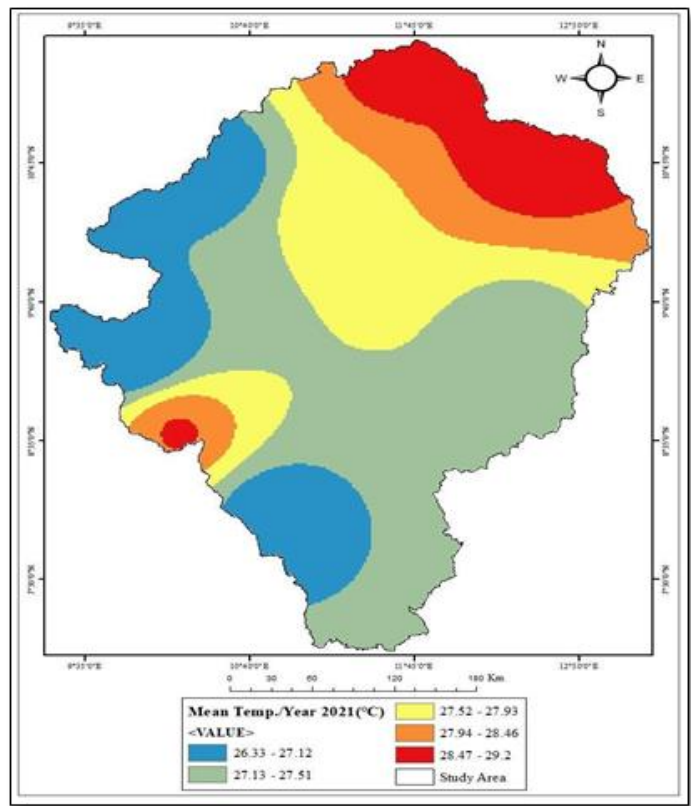


Figure 13. Temperature Distribution in 2021.

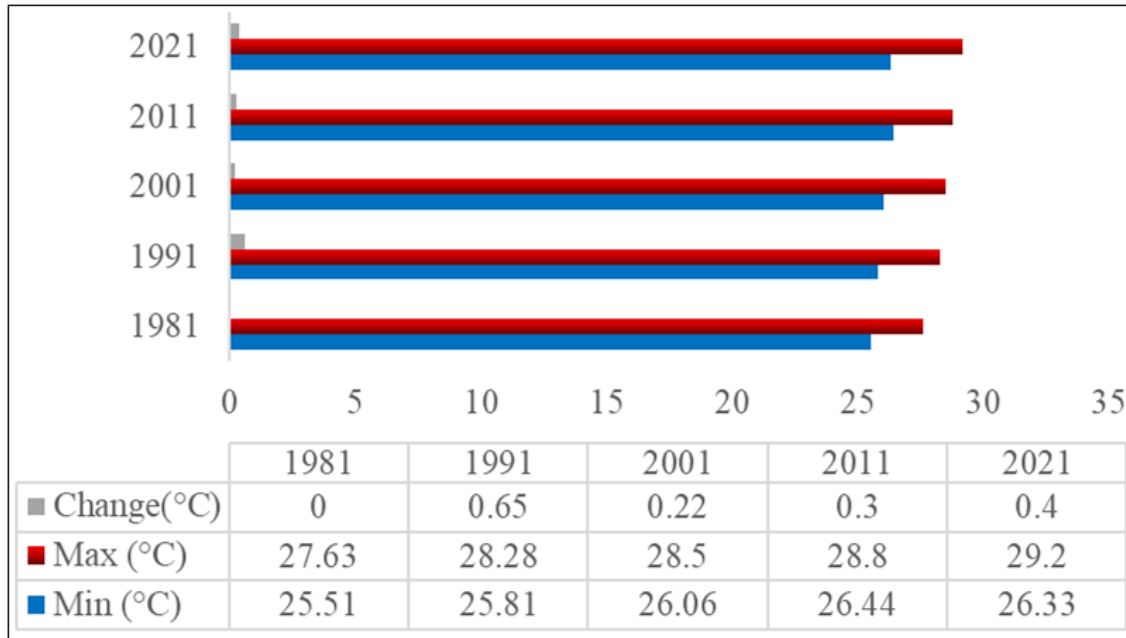


Figure14. Summary of temporal variation of temperature.

The **Figure 8** shows that in 1981, the mean annual temperature in the Upper Benue River Basin was 26.4°C, which rise to 26.7°C in 1982 and 1983 respectively. The temperature further increased to 26.9°C in 1984 and decreased to 26.7°C in 1985. From 1985 to 1987 an increasing trend was observed from 26.8°C in 1986 to 27.2°C in 1987. However, there was a sharp decrease from 26.7°C in 1988 to 26.2°C in 1989. A surge in temperature to 27.2°C was recorded in 1990 but a decline in 1991 (26.9°C) and 1992 (26.4°C). From 1992 to 2021, the temperature has been on a steady but staggering increase reaching highest peak of 26.9°C in 1993, 27.4°C in 1998, 27.1°C in 2001, 27.3°C in 2007, 27.7°C in 2010 and 27.6°C in 2021 respectively. The visual display of the changes in temperature distribution over the basin is shown on maps in **Figures 9-13**.

Looking at the spatial pattern of the temperature in 1981, as seen in **Figure 9**, it can be deduced that the northern part of the study area is characterized by relatively higher temperatures and it decreases westwards and southwards.

Finding of the study from **Figure 11** show the temperature of the basin for the year 2001. In 2001 temperatures were relatively cooler between latitude 7°15N to about 8° 25N and the southwestern part of the basin. The result also indicates a marked difference in the spatial pattern, relative to the previous years. The result here shows that temperature does increase with increasing latitude towards the north pole although temperatures are relatively higher on lower latitude especially close to the equator. Because the angle of radiation varies depending on the latitude, surface temperatures on average are warmer in the northeast side of the Upper Benue River Basin. In 2011 temperatures were

relatively cooler between latitude 7°15N to about 8° 25N and the southwestern part of the basin.

Figure 13 shows the change in spatial spread of temperature across the study area, the maximum value for the year 2021 remains the highest compared to the previous decades. The result shows that temperature increased also with increasing latitude in the basin.

As presented in **Figure 14**. It can be deduced that the maximum annual average temperatures recorded for the four decades considered **Figures 9-13** has been on the increase from 27.63°C in 1981 to 29.2°C in 2021 with a difference of 1.57°C. The highest flux of 0.65°C was recorded between 1981 and 1991, followed by the period between 2011 and 2021 with 0.4°C. This result is corroborated by the findings of the study by Abaje and Oladipo [20] whose study in Kaduna showed an increasing trend over the last two decades. Similarly, this result agrees with Mbanjeude [22] which posited that the north experiences a dry season with high temperatures reaching 38°C monthly. In March, 2022, the Nigerian Meteorological Agency, NiMet had predicted a rise in temperature particularly over the Northern part of the country [23].

Trend of Climatic Variability using Mann Kendall and Sen’s Slope Estimator

Having presented the outcome of the spatial and temporal variation of precipitation and temperature, this section tests the statistical significance of the trend of each variable using a fusion of the Mann Kendall and Sen’s slope estimation statistical analysis. The outcomes are presented in subsequent sessions (**Tables 1 & 2**).

Table 1. Mann Kendall and Sen’s Slope Estimator Test for Precipitation (1981-2021).

Summary statistics for Precipitation							
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Mean Rainfall	41	0	41	674.312	1144.759	937.010	105.008
Mann-Kendall trend test /Two-tailed test (Mean Rainfall):							
Kendall's tau: 0.112							
S: 92.000							
Var(S): 7926.667							
p-value (Two-tailed): 0.307							
Alpha: 0.050							
Sen's slope:							
	Value	Lower bound (95%)	Upper bound (95%)				
Slope	1.527	-1.516	4.479				
Intercept	-2088.868	-7995.311	3987.113				

As reflected in **Table 1**, the Mann Kendall and Sen’s slope estimator analysis for precipitation shows that for the whole study period (1981-2021), the lowest recorded values for precipitation were 674.3 mm while the highest recorded annual average stood at 1144.8 mm, with an overall mean of 937mm and standard deviation 105mm. However, while

Kendall's tau and Sen’s slope values stood at 0.112 and 1.527 respectively, the outcome of p-value (Two-tailed) test of significance is 0.307. As the computed p-value is greater than the significance level alpha=0.05, This implies that there is no significant trend in average annual precipitation over the time of study.

Table 2. Mann Kendall and Sen’s Slope Estimator Test for Temperature (1981-2021).

Summary statistics for temperature							
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
26.35875	40	0	40	26.155	27.734	27.060	0.337
Mann-Kendall trend test / Two-tailed test (26.35875):							
Kendall's tau	0.476						
S	371.000						
Var(S)	7365.667						
p-value (Two-tailed)	<0.0001						
Alpha	0.050						
Sen's slope							
	Value	Lower bound (95%)	Upper bound (95%)				
Slope	0.020	0.012	0.025				
Intercept	-12.932	-17.971	-4.822				

As shown in **Table 2**, the Mann Kendall and Sen's slope estimator test for trend of temperature reveals that with a P value <0.05 and a slope value of 0.02, there was a significant trend in temperature for the period under study. This result agrees with Frimpong, Korantengand Molkenhth [24] as their study's Mann Kendall and Sen's slope revealed significant trends in the annual and seasonal (dry and wet seasons) in minimum temperature in the Accra and Kumasi Metropolis in Ghana. They further posited the observed increase in temperature might lead to an increased rate of heat-stressed diseases and an overall rise in urban warming in both cities. The findings emphasize the importance of assessing temperature trends and indices in light of worries about climate change and its impact in the northern part of Nigeria.

CONCLUSION

The study has examined climate change and variability in the Upper Benue River Basin Nigeria. The study used climatological data (precipitation and temperature) for 41 years acquired from the gridded climatological data of the website. This was downscaled to match the extent of the basin using map. The findings of the study reveal high variability in precipitation in the basin from 1093mm in 1996 to 773.9mm in 2014. The findings of the study also reveal that mean annual temperature in the basin has been on rise from of 26.4°C in 1981 to 29.2°C in 2021.

RECOMMENDATIONS

Based on the findings of the study, the following recommendations are made;

- i. There is the need for the integration of existing weather station data from in-situ observation with the gridded satellite data for a better and robust climate picture of the basin.
- ii. There is need to increase the number of functional ground weather station with state-of-the-art equipment in the basin to increase the generation and dissemination of climate information to farmers and other users in the country.
- iii. There is need to reduce deforestation and fuelwood exploitation in the basin as a way of protecting vegetation cover and adapting to climate change in the area.

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