

SPATIO-TEMPORAL ANALYSIS OF RAINFALL AND TEMPERATURE (1984–2019) AND ITS IMPLICATIONS FOR DESERTIFICATION IN NORTHERN SOKOTO STATE, NIGERIA

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ABSTRACT

This study analysed the spatio-temporal variability of rainfall and temperature across five Local Government Areas (LGAs) in northern Sokoto State, Nigeria (Gudu, Tangaza, Illela, Gada, and Sabon Birni), between 1984 and 2019. The study area is highly vulnerable to desertification, and due to the limited availability of ground-based meteorological observations, satellite-derived climate datasets were employed. Rainfall data were obtained from the PERSIANN Climate Data Record (PERSIANN-CDR), while temperature data were derived from the ERA5 reanalysis dataset. Spatial patterns were analysed using kriging interpolation in ArcMap 10, while temporal trends were assessed using the Mann-Kendall non-parametric trend test and Sen's slope estimator. Results indicate an overall increase in annual rainfall, although considerable spatial and inter-annual variability was observed across the study area. Also, temperature exhibited significant temporal fluctuations, with a marked warming trend during the latter part of the study period. The combined effects of temperatures and erratic rainfall patterns are likely to intensify evapotranspiration, reduce soil moisture availability, and accelerate land degradation, thereby increasing the vulnerability of northern Sokoto State to desertification. The study highlights the need for climate-adaptive land-use planning and sustainable agricultural practices and evidence-based environmental management strategies to enhance resilience in northern Sokoto State.

Keywords: Climate variability; Desertification; Remote sensing

INTRODUCTION

Desertification remains one of the most critical environmental challenges in semi-arid regions of Sub-Saharan Africa, with severe implications for food security, livelihoods and ecosystem stability (UNCCD, 2017). In Nigeria, northern frontline states such as Sokoto are particularly vulnerable due to pronounced climatic variability, fragile ecosystems and increasing anthropogenic pressures. Desertification in these areas manifests through declining soil fertility, reduced vegetative cover and persistent land degradation, adversely affecting rain-fed agriculture and pastoral livelihoods (Dregne, 2002).

Northern Sokoto State lies within the Sudan Savanna ecological zone and experiences a tropical dry-wet climate characterized by marked seasonal variability. The region is prone to wind and water erosion, a situation exacerbated by irregular rainfall patterns and rising temperatures (Ati et al., 2009; Lawal & Shehu, 2024). Understanding long-term trends and spatial patterns of key climatic variables such as rainfall and temperature is therefore essential for assessing desertification risks and informing sustainable land management strategies, particularly in the context of climate

change (IPCC, 2021).

However, comprehensive climate analyses in this region are constrained by the sparse distribution and inconsistent operation of meteorological stations. Remotely sensed and reanalysis climate datasets offer viable alternatives for climate assessment in data-scarce environments. The PERSIANN-CDR rainfall product and ERA5 temperature dataset have been widely applied and validated across Nigeria for hydrological and drought-related studies (Jibrillah et al., 2018; Adedeji et al., 2020).

This study therefore examines the spatio-temporal patterns of rainfall and temperature in five northern LGAs of Sokoto State from 1984 to 2019. Specifically, it analyses spatial variability, evaluates long-term trends, and discusses the implications of observed climatic changes for desertification and agricultural sustainability in the region.

MATERIALS AND METHODS

Study Area

The study covers five Local Government Areas (LGAs) located in northern Sokoto State, Nigeria: Gudu, Tangaza, Illela, Gada and Sabon Birni. The area lies approximately between latitudes 12°58'N and 13°28'N and longitudes 4°08'E and 5°29'E, covering about 10,870 km². It shares an international boundary with the Niger Republic to the north and west and is regarded as one of the zones most susceptible to desertification in the state.

The climate is tropical wet-and-dry, with three distinct seasons: the cool, dry Harmattan season (November–February), the hot, dry season (March–May), and the rainy season (June–September). Annual rainfall is generally low and highly variable, while temperatures are persistently high. The population is predominantly Hausa and Fulani, with subsistence farming and livestock rearing forming the major economic activities (NPC, 2006).

Data Sources

Rainfall data for the period 1984–2019 were obtained from the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks Climate Data Record (PERSIANN-CDR), a satellite-derived rainfall product with a spatial resolution of 0.25° × 0.25° (Ashouri et al., 2015). The dataset was accessed through the Center for Hydrometeorology and Remote Sensing (CHRS), University of California, Irvine (<https://chrsdata.eng.uci.edu/>) and downloaded on [insert date of data retrieval]. PERSIANN-CDR is specifically developed for long-term climate studies and has been widely validated for hydro-climatic analyses in data-scarce regions. Temperature data for the same period were obtained from the ERA5 reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) (Hersbach et al.,

2020). The dataset was accessed through the Copernicus Climate Data Store (CDS) (<https://cds.climate.copernicus.eu/>) and downloaded on [insert date of data retrieval]. ERA5 provides consistent, high-resolution gridded climate variables suitable for regional climate variability and trend analyses.

Annual rainfall totals and mean annual temperature values were extracted for the study area. To examine spatial variability, three benchmark years (1984, 2002 and 2019) were selected to represent the early, mid and recent phases of the 35 years. These years were chosen to facilitate spatial comparison while minimizing redundancy in map presentation.

The extracted point data were imported into ArcMap 10. Geostatistical interpolation using the ordinary kriging technique was applied to generate continuous spatial distribution maps for rainfall and temperature. Kriging was selected for its ability to account for spatial autocorrelation and provide unbiased estimates with minimum variance.

Trend Analysis

To assess long-term temporal trends in rainfall and temperature, the Mann-Kendall (MK) non-parametric test was employed. The MK test is widely used in climatological studies because it does not require the data to be normally distributed and is robust against outliers. Sen's slope estimator was applied to quantify the magnitude and direction of detected trends. Statistical significance was evaluated at the 5% confidence level.

RESULTS AND DISCUSSION

The interpolation maps revealed significant spatio-temporal variability in both rainfall and temperature over the 35 years. Rainfall showed an overall trend of increasing total amount but with shifting spatial patterns. In 1984, the highest average rainfall (545.375 mm) was concentrated in Tangaza and Gudu, while Illela and Gada received the lowest (344.163 mm). By 2002, the highest recordings (609.848 mm) remained in Tangaza and Gudu, but the area of moderate rainfall expanded. In 2019, the spatial pattern shifted markedly, with Sabon Birni, Illela, and Gada receiving the highest rainfall (up to 702.191 mm), while Gudu and Tangaza transitioned to moderate levels. The Mann-Kendall test indicated a statistically significant increasing trend in annual rainfall over the study period ($p < 0.05$), while Sen's slope revealed a positive but modest rate of increase.

Temperature patterns were more erratic. The highest average temperature in 1984 was 39°C, concentrated in Illela, Sabon Birni, and Gudu. A notable decline occurred in 2002, with the highest average at only 34°C in Gudu. However, by 2019, temperatures increased sharply, reaching 41°C in Gudu and Illela. This fluctuation aligns with global observations of increased climatic volatility (IPCC, 2021; Forster et al., 2023).

The discussion centers on the implications of this variability for desertification. The erratic and inconsistent distribution of rainfall, coupled with rising peak temperatures, intensifies evapotranspiration and soil moisture stress. Total rainfall may increase in some years, but its timing and distribution become less reliable for rain-fed agriculture, a finding consistent with Ati et al. (2009) and Bahiru et al. (2020). The high temperatures recorded in 2019 exacerbate drought conditions, accelerating soil degradation and reducing vegetative cover, thereby increasing susceptibility to wind erosion (Singh et al., 2023; Iwuchukwu et al., 2023). This highly irregular climatic pattern directly threatens agricultural yields and disrupts crop phenology, confirming the observed relationship

between climate and declining agricultural productivity, with associated impacts on biodiversity (Zhu et al., 2022).

CONCLUSION

This study has demonstrated the significant temporal and spatial variability in rainfall and temperature patterns in northern Sokoto State between 1984 and 2019. The analysis reveals an overall increase in annual rainfall but with considerable inter-annual and spatial inconsistency. More critically, temperature regimes show marked fluctuation, with a sharp increase observed in recent years. This erratic climatic behavior, characterized by unreliable rainfall distribution and rising temperatures, is a principal driver of environmental degradation in the region. It contributes to soil moisture deficit, loss of vegetation cover, and increased soil erosion, thereby accelerating desertification. Consequently, these climatic factors pose a direct and substantial threat to the sustainability of agricultural land use and productivity in this vulnerable semi-arid zone.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. Farmers should be encouraged and supported to adopt Climate-Smart Agriculture (CSA) practices such as conservation agriculture, use of drought-resistant and early-maturing crop varieties, and efficient water harvesting techniques to enhance resilience against rainfall variability and high temperatures.
2. The government and relevant agencies should invest in densifying the network of automated weather stations across the state to complement satellite data for more precise local-scale climate monitoring and early warning systems for drought and desertification.
3. Concerted efforts should be made to implement community-based afforestation and reforestation projects using native, drought-tolerant species to restore vegetative cover, combat wind erosion, and improve microclimates.
4. Findings on climatic trends should be integrated into local and state-level development planning, particularly in agricultural extension services and land-use policy, to ensure proactive adaptation and sustainable resource management.

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APPENDIX1: Rainfall distribution of the study area in the year 1984

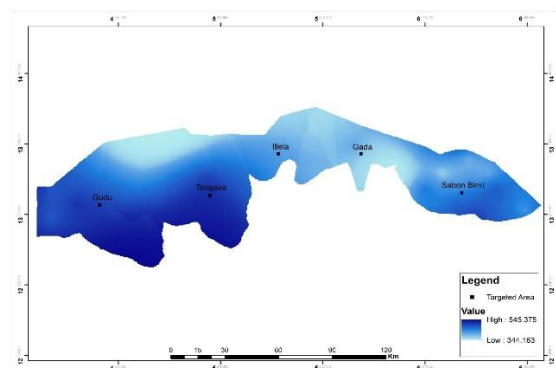


Figure 1: Rainfall distribution of the study area in the year 1984

APPENDIX 2: Rainfall distribution of the study area in the year 2002

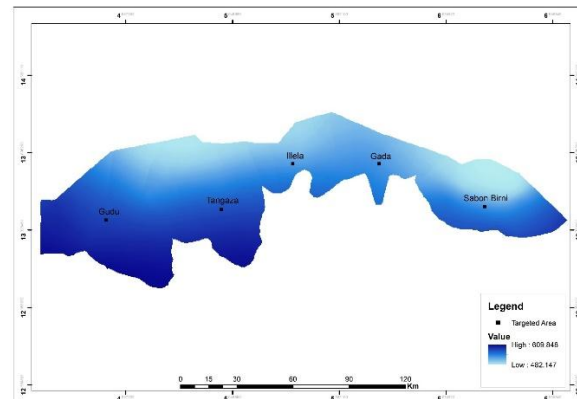


Figure 2: Rainfall distribution of the study area in the year 2002

APPENDIX 3: Rainfall distribution of the study area in the year 2019

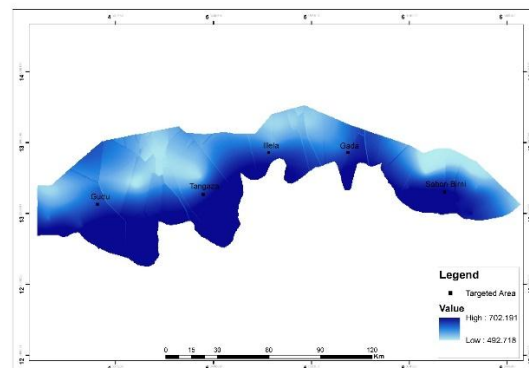


Figure 3: Rainfall distribution of the study area in the year 2019

APPENDIX 4: Temperature distribution of the study area in the year 1984

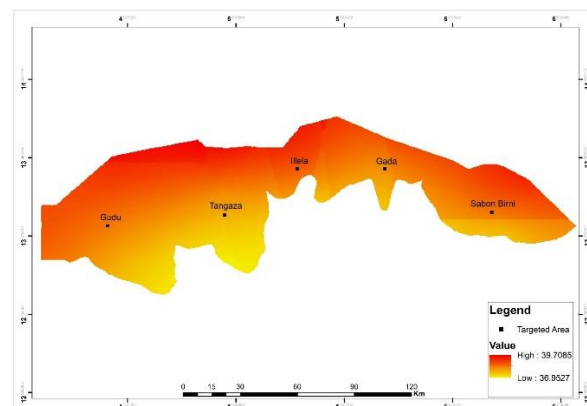


Figure 4: Temperature distribution of the study area in the year 1984

APPENDIX 5: Temperature distribution of the study area in the year 2002

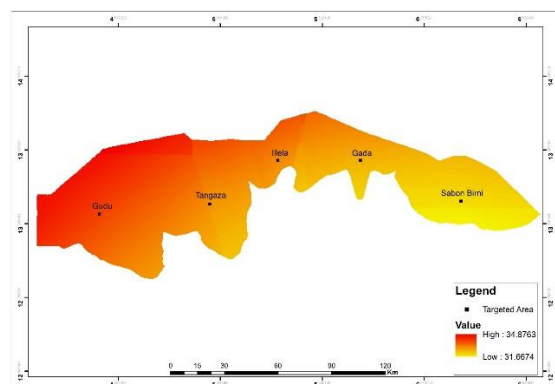


Figure 5: Temperature distribution of the study area in the year 2002

APPENDIX 6: Temperature distribution of the study area in the year 2019

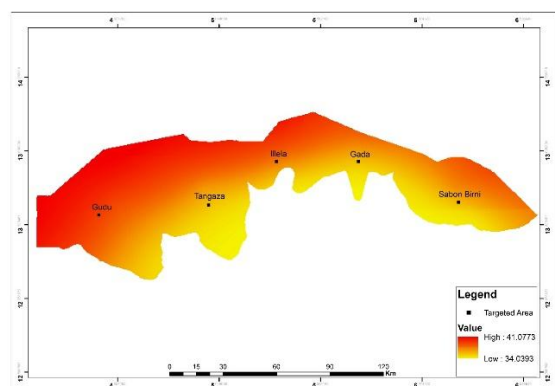


Figure 6: Temperature distribution of the study area in the year 2019