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Rainfall and Temperature Variations in a Dry Tropical Environment of Nigeria

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ABSTRACT

This study examines long-term rainfall and temperature variations over a dry tropical environment in Nigeria. An assessment of the variations of these weather variables showcases the extent of climate change limits and corresponding effects on the biotic environment. Rainfall and temperature data were obtained from Nigerian Meteorological Agency for a period of 31 years (1991-2020) for Kano and Katsina States. Descriptive statistics were used to determine the degree of variability of the weather variables across spatial domains. Results showed that there is a sharp contrast in mean annual rainfall amounts of 1154.1 mm and 569.6 mm for Kano and Katsina located in the dry continental and semi-arid climate zones of Nigeria respectively. It is revealed that the month of August had the highest mean monthly rainfall for both areas i.e. 359 mm and 194 mm with little or no trace during the dry season. The sharp difference in rainfall amount across spatial domains of the near similar climate zones shows that the Inter-tropical Discontinuity (ITD) does not completely overwhelm the northern band of Nigeria in August. The least variable monthly rainfall was in August and July with coefficient variations (CV) of 40% and 47% for Kano and Katsina. The months of February and March had the highest CV of 557% and 273% for the respective areas. In the examined areas the wet and dry seasons are from June-September and October-May respectively. The index of rainfall variability and drought intensity for the areas ranged from 0.85-0.95 and 45% indicating moderate variability and drought respectively. Mean annual temperature values are 33.4 °C and 33.8 °C for Kano and Katsina. The study recommends a proper climate observing scheme, most especially for agrarian practices so as to ensure profitable outputs for human sustainability.

Keywords: Rainfall; Air temperature; Climate change; Kano State; Katsina State

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1. Introduction

Rainfall and temperature are major climatic factors that impact the semi-arid zone of tropical West Africa. A distinct wet season exists from June to September when there is a southward retreat of the bands of low pressure known as the Inter-tropical Discontinuity (ITD). Variations in rainfall and air temperature for any region arise from the energy interactions between the surface layer and the lower atmosphere including the dominant air mass that characterizes the region [1]. The variation of rainfall pattern is vital as it determines the onset, cessation and extent of seasons as well as an important component of climate and hydrological systems [2-4]. Rainfall changeability is slight in humid regions of the wet tropics and most variable in dry and sub-humid areas. The sub-humid areas are the most vulnerable since small negative deviations from the mean rainfall may cause widespread crop failure and famine as frequently happens in the area. Minimal rainfall deviations indicate that the average amount for any specified catchment is steady while large deviations denote extensive variations in the average rainfall amount. A given amount of rainfall may be termed consistent if it can be expected to be corresponded to or surpassed some chosen probability level.

Nigeria characterised by a low-lying is principally placed within the warm and humid tropics close to the equator which induces a high ambient temperature pattern [5] and this near equatorial position boosts the high-temperature condition observed over the area all through the year. As noted by Ayoade [2], Nigeria's latitudinal position as well as solar elevation which is large at low latitudes contributes to the high-temperature range. Temperatures over the dry tropical zone of Nigeria have increased over the last decades, in line with an increase in global temperatures [6,7]. The impact of global warming on rainfall in the zone remains challenging to assess in a climate that is vulnerable to vital variation at spatial-temporal scales. Future soil suitability for major crops is expected to be affected by climate change; in particular beans, maize and millet production might face declines and require cropping system transformations. This study evaluated the rainfall and temperature deviations between two close areas (Kano and Katsina) both at the northern tip of Nigeria, however, under the influence of different climate zones.

2. Materials and methods

2.1 Study area

The climate of the study domains are classified by Koppen's climate pattern as *Aw* (wet and dry tropical continental with a mono-modal rainfall pattern) and *BSh* (a climate domain that has the characteristics of both the Sahara Desert and tropical wet and dry climate i.e. semi-arid zone, with more of a dry condition). **Figure 1** shows the map of both Kano and Katsina with part of Katsina bordering the Niger Republic. Subsidence prevails almost all year round with respect to the high-pressure area being influenced by the Saharan Desert bearing dry tropical continental air mass. The mean ambient temperature for both diurnal and annual ranges is large from 20 °C to 25 °C [2]. Lower and higher temperatures are recorded during December—January and March—April with 12 °C and 40 °C being the extreme low and high respectively. Ayoade [2] noted that August is recorded as a peak rainfall period with a mean range of 215-250 mm and intermittent or irregular nature of rainfall that spans between May-September exists in the area [8,9]. According to Mamman et al. [10], the mean annual minimum and maximum range for 262-956 mm. Rainfall amount for Kano and Katsina are 416-1872 mm and due to the domains' distance and position from the influence of rain-bearing air mass from the Atlantic Ocean, longer dryer spells persist from October to May when there is a retreat of the ITD towards the coast in September. The extensive dyer days sustained by a mean sunshine diurnal range of 8-11 hours increases the evapotranspiration rate thereby enhancing drought and desertification of the area [11]. The cloudiness index for the area is less than 0.45 while the mean surface solar radiation across seasons is greater than 280 W/m^2 [12]. The dryer atmosphere retains less amount of water vapour to a percentage range of 18%-63%. The study area exhibits a typical feature of the Sahel Savannah environment where there is less vegetation with a vast landmass that increases surface wind speed with a mean range of 1.5-12 m/s.

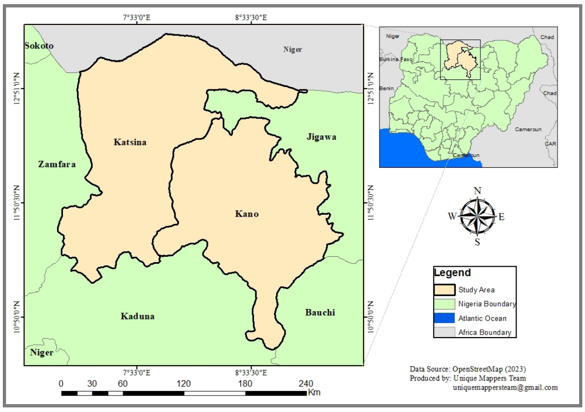

Figure 1. Map of study areas.

2.2 Rainfall and temperature data

A 31-year mean monthly rainfall and temperature data for Kano and Katsina from 1990-2020 were acquired from the Nigerian Meteorological Agency and analysis was done using Microsoft Excel Spreadsheet 2016. Statistical tools were engaged to determine the seasonal spatial variations of the retrieved climate data. Oyegoke et al. [13] indicated that statistical techniques of analysis are essential normally to precisely evaluate rainfall data for effective planning and for future forecasts regarding proficient and operative water resources management. The coefficient of variation (CV) was used to examine the extent of rainfall variation. The method is given as:

$$CV = \sigma/\bar{x} \quad (1)$$

where: σ is the rainfall standard deviation and $\bar{x}$ is the mean rainfall and CV is the coefficient of variation. The 10, 50 and 90 percentiles are the index of rainfall changeability used in climatological studies and according to Ayoade [14] it is as follows:

$$(90\% - 10\%)/50\% \quad (2)$$

where greater than 1.75 is extreme variability; 1.50-1.75 is very high variability; 1.25-1.50 is high variability, 1.00-1.25 is moderately high variability; between 0.75-1.00 is moderate variability; 0.50-0.75 is moderately low variability; < 0.05 is low variability. The measure of drought intensity was analysed using the percentage derivation below the mean, with the following categories: 11-25 (slight drought), 26-45 (moderate drought), 46-60 (severe drought) and more than 60 (disastrous drought).

3. Results and discussion

Results as shown in **Figure 2** indicate the average monthly values of rainfall in Kano and Katsina in the dry continental (Koppen's *Aw*) and semi-arid (Koppen's *BSh*) climate zones of Nigeria respectively. The study areas recorded rainfall values of less than 50 mm from October to April. This shows the extent of the dry season for the areas with 0 mm rainfall from November to March. The rainiest month for the areas was in August with peak values of 194 mm and 359 mm for Katsina and Kano. The percentage contributions of the peak rainy month for the areas to the overall amount were 34% and 30% for Katsina and Kano respectively (**Figure 3**). The highest difference for the climate indicator pattern was during the dry season for the months of February and March where the CVs were 557% and 273% for Kano and Katsina respectively. The lowest spatial variability was experienced in July and August i.e. (CVs of 40 and 47 %) for the respective areas (**Figure 4**). The high coefficient of variations for the dry season showed the complete dominance of the dry continental air mass in Kano for the month of February (with rainfall amount of 0.3 mm) and in Katsina for the month of March (with a rainfall amount of 1.5 mm). It showed that, there was little encroachment of the rain-bearing moist maritime air mass for the areas. The complete dominance of moist maritime air mass during the rainy season indicates the lowest spatial variability for the climate indicator.

Also, as shown in **Figure 5**, there is a distinct spatial difference in the average annual rainfall spread in Kano and Katsina from 1990 to 2011. Kano experienced a dominant rainfall domain for the specified years and Katsina experienced the only dominance for the zone in 2015. The year 2020 shows a similar trend for both areas, however, indicating a back shift for the Kano rainfall pattern when compared to that for Katsina. This shows that the study areas in the same climate zone varied in spatial rainfall values, however both areas have no strong relationship with the El Nino Southern-Oscillatiom (ENSO) associated with convective rainfall across the equatorial Pacific Ocean as investigated by Hashidu and Badaru [15]. Mohammed et al.; Abaje et al. [16,17] highlighted in studies of rainfall patterns in Kano (1914-2013) and (1911-2010) respectively that there was an improvement in the moisture condition for the area during the last two decades when compared to the past. As shown in **Figure 5**, there was a lower rainfall amount in Katsina from 1990-2003 when compared to 2004-2011. A study conducted by Suleiman et al. [18], showed that the above mean rainfall amount was observed from the year 2000 upward. Also, Yamusa and Abdulkadir [19] disclosed that while mean yearly rainfall, onset dates of the wet season as well as yearly minimum and maximum temperature were increasing; the cessation dates and length of the wet season were decreasing. As noted by Adeleke and Orebayo [20], if there is an increase in maximum and mean temperature as well as the onset of rains, then rainfall amount will increase and vice-versa. The index of rainfall variability for the areas ranged from 0.85-0.95 and this shows moderate rainfall variability for the areas.

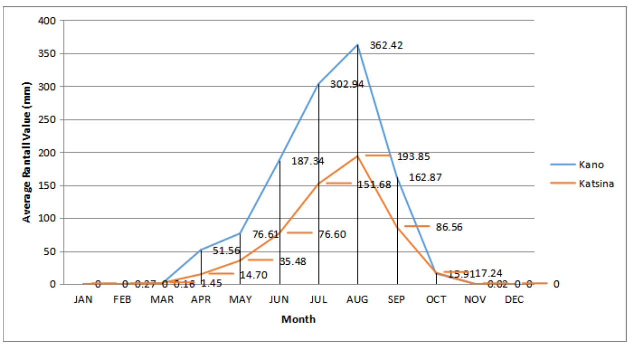

Figure 2. Average rainfall values for the study areas.

The moderate rainfall variability indicates the study domain's location far inland which impedes its constant impact on the Ocean's maritime air. Fabeku and Okogbue [8] and Ogungbenro and Morakinyo [21] highlighted that the mean yearly rainfall amount for the Sahel zone where the study area belongs is from 150 mm to about 1000 mm for the zone. This variability makes the climatic region to be susceptible to heightened actual evapotranspiration which enhances drought especially for Katsina. It has been emphasized that the early cessation of rainfall trend in Katsina is due to the early retreat of the ITD from the area. As disclosed by Yaya et al. [22], the moderate drought condition that exists within the study environment is associated with the late start of the wet season and its early termination. This early cessation as noted by Atedhor [23] impacts soil moisture deficiency that induces forced harvest of crops from the study area most especially rice yield [24]. Peter et al. [25] highlighted that the major crop cultivated in the study environment includes: cowpea, soya beans, cotton, sorghum, millet, etc. The drought index for the areas which was analysed from the percentage rainfall derivation below the mean indicated about 45% for the areas. This shows that there is a moderate drought index experienced in the zone. Ati et al. [26] examined meteorological drought and temperature in the Sudano-Sahelian zone of Nigeria from 60-year and 40-year rainfall and temperature data respectively. It was revealed using the Bhalme and Mooley Drought Index (BMDI) that mild to moderate drought exists in the zone. Cases of droughts according to Dada [27] can be attributed to shifting weather forms exhibited through the consistent accumulation of surface layer heat fluxes, atmospheric fluctuations resulting in reduced rainfall and low rain cloud resulting in greater evaporation rates. It was also emphasised that the ensuing impacts of drought are intensified by anthropogenic happenings. These happenings include grassland clearing and burning, overgrazing and disadvantaged cropping systems, which decrease water holding of the soil, and inappropriate conservation methods leading to soil deficiency. Furthermore, it was specified that numerous flora and fauna kinds are vanishing in the drought-inclined area of Kano and Maiduguri. Activities such as land degradation, bush burning and desertification had impacted the productivity and diversity of flora and fauna in the areas [27,28].

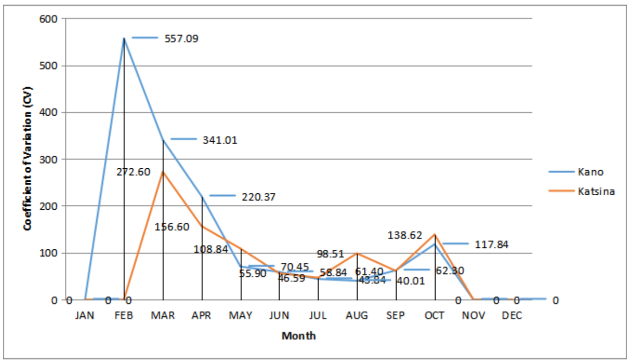

Figure 3. Average percentage contribution of monthly rainfall to annual total value.

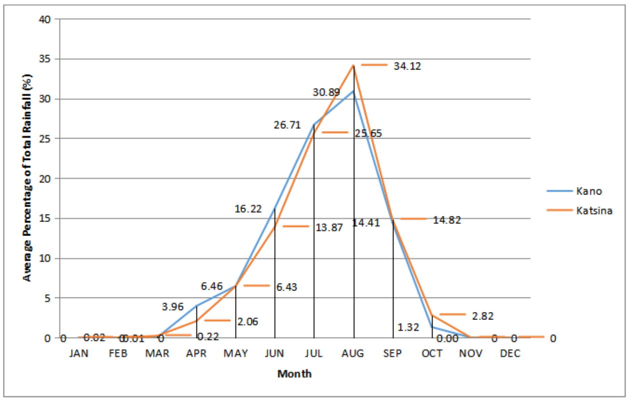

Figure 4. Rainfall coefficient of variation (CV) for study areas.

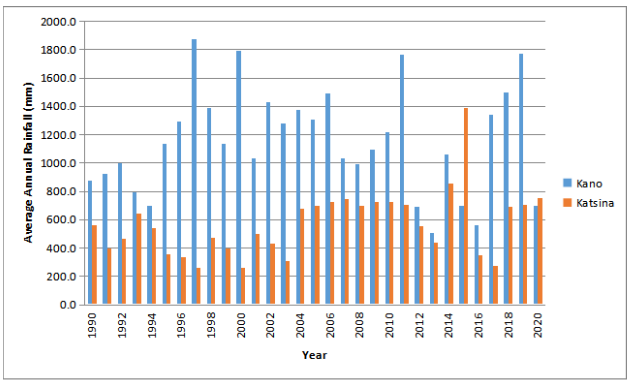

Figure 5. Average annual rainfall values for study areas.

Results as shown in **Figures 6 and 7** indicate the pattern of air temperatures for the study areas. It is shown that annual air temperatures are high for the period considered with ranges from 31-34 °C and 32-35 °C for Kano and Katsina respectively. On average, higher temperatures of range 36-38 °C are recorded from March to May for the areas with April being the hottest month and December being the coolest month. The high-temperature pattern which cuts through both the end of dry and the beginning of wet seasons shows that the zone is found in the high-pressure zone where air subsidence dominates. Akinsanola and Ogunjobi [29] observed that the air temperature is typically high and low during the wet and dry seasons respectively and this makes temperature deviation lower at the coast than in the northern domain of Nigeria. The study domain is majorly influenced by the dry and stable continental air from across the Saharan desert. This trend makes the zone fall under the Sudan-Sahel climate region of Nigeria with a latitude from 11° to 13° [30]. On the monthly average, the difference between the maximum highest temperatures and lower temperatures is 10 °C for the study areas. This high-temperature peak range shows the effect of climate change anomaly arising from excessive heating of the earth's surface where more heat is experienced and less rainfall is observed. This implied that the high variability of average monthly temperatures can affect plant growth and development. It can also affect the comfort index of human endeavors across the areas [31]. An assessment of the aridity index of Katsina has shown that its northern axis is within the arid zone while the southern axis falls in the semi-arid zone with an index of 0.26 and 0.49 respectively with an overall aridity increase from years 2000 to 2016 [32]. The study further highlighted a significant increase in actual evapotranspiration in Katsina. Ibrahim et al. [33] observed in a study conducted that extremely high and low ambient temperature has been noted to support the survival of mosquitoes in Katsina. It was highlighted that sharp deviations of temperature changes enhanced 77% of severe malaria cases for an infant with occurrence between the months of May-September. It was recommended that adequate medical care be offered to children less than 5 years old.

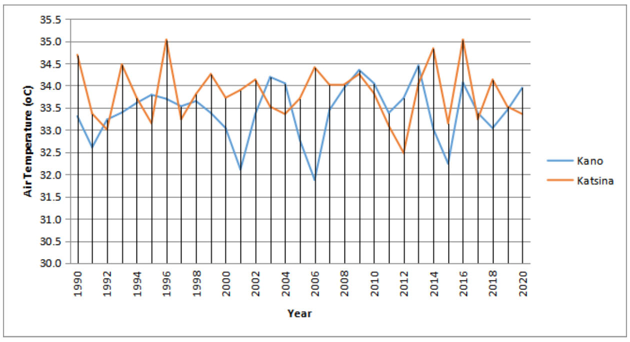

Figure 6. Average annual air temperature values for study areas.

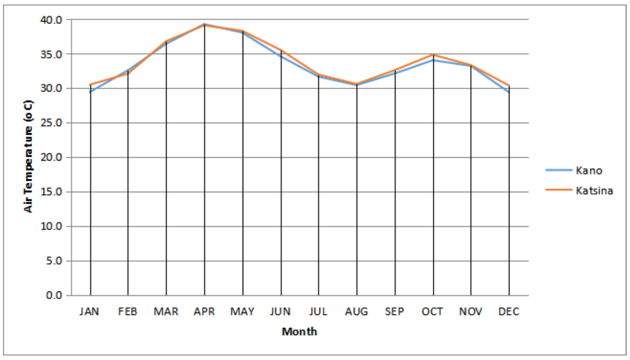

Figure 7. Average monthly air temperature values for study areas.

4. Conclusions

This study surveyed the rainfall and temperature variations for Kano and Katsina areas domiciled in the Sudan zone of Nigeria. An assessment of the variability of the weather variables considered shows that climate change limits and impacts the liveable environment. Study findings show that there is moderate rainfall variation with a low rainfall pattern especially for Katsina as compared to Kano and also a moderate drought pattern for the areas. The evaluated drought pattern may degenerate to a severe category if conservation practices are not put in place. Average monthly maximum temperatures for the areas ranged from 29-39 °C. This high-temperature peak shows the effect of climate change arising from excessive heating of the earth's surface where more heat is experienced and less rainfall observed. This climate pattern will definitely impact the dominant agricultural practices that prevail in the study areas with subsequent effects on the economic development of the region. The study recommends a proper climate observing scheme, most especially for agrarian practices so as to ensure profitable outputs for human sustainability.

Conflict of Interest

There is no conflict of interest.

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