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APPLICATION OF GLOBAL CIRCULATION MODELS (GCMS) TO PREDICT RAINFALL AND TEMPERATURE VARIABILITIES IN KANO STATE, NIGERIA

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ABSTRACT
The study explored present and future climate scenarios of Kano using Global Circulation Models (GCMs). The metrological data from 12 locations were used for calibration of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). The historical record of 10 years was used for both temperatures and rainfall data which represent a period of 2010 to 2019. The future climate projections were made for 2041 to 2060 centered in the 2050s under RCP2.6 and RCP8.5 emission scenarios. The spatial analysis was conducted using the Inverse Distance Weighted (IDW) tool in an ArcGIS environment. The result shows that the temperature of Kano has increased relative to baseline condition by 1.025ºC (2.45%) and 4.6 ºC (10.98%) under RCP2.6 and RCP8.5 scenarios respectively. However, the annual rainfall was found to decrease from the historical amount by -37.9 mm (5%), and -68.2 mm (9%) under RCP2.6 and RCP8.5 emission scenarios. Moreover, the spatial analysis indicated that there was climate variability across the width and breadth of the state. The study concludes that the climate change effect will cause the temperature of Kano to rise considerably in the future with the consequences of decreased rainfall amount. The findings recommend that policymakers should deploy adaptation strategies to reduce the adverse effects that might be experienced.

Keywords: Climate Change, Representative Concentration Pathway (RCP), GCMs, CHIRPS

INTRODUCTION
Climate change is regarded as one of the most severe challenges facing the world today (Kang, Khan & Ma, 2009; Markus et al., 2017; Neal, Nearing, Vining, Southworth, & Pfeifer 2005). This problem drew the attention of international and multidisciplinary researchers and organizations to direct their efforts toward global environmental sustainability. Both global and regional climate changes are complex phenomena and human activities are the major influencing factors for their changes (Solomon et al., 2007). Therefore, climate change is undoubtedly a global issue of concern. It has been predicted that the trends of climatic variables include more hot days, heat waves, fewer cold days, and cold waves (Nasidi et al., 2023). These changes could lead to increasing global precipitations, a larger number of extreme events (flood and drought), and an overall devastating ecosystem (Stocker et al., 2013, 2014). Moreover, the global climate is already changing, and further changes are inevitable. For instance, during the last century from 1906 to 2005 the average global temperature rose by about 0.74ºC (IPCC, 2018). Similarly, existing climate studies have reported considerable increases in both temperature and rainfall. In the future, the average rainfall under all Representative Concentration Pathway (RCP) scenarios indicated higher temperatures and lower rainfall amounts to be received in the study location than in the historical period source. Therefore, study on climate change and its impact is paramount toward environmental sustainability and protection of both lives and properties globally.

Scarcity of rainfall is seriously affecting farming activities especially when the reduced rain was unexpected. Farmers in the northern state of Nigeria have recently experienced an abrupt shift in rainfall, particularly in Kano, Katsina, and Jigawa. These areas have reported considerable shifts in planting periods due to the unavailability of rainfall at the beginning of the rainy season which confused many farmers. Similar issues occurred during the harvesting period with consequences of low output and total yield loss in other places hit by the severe incidence Source. However, the study on this phenomenon has not been conducted so far intending to reveal the climate change effect on rainfall availability and its variability. This study focuses on a detailed investigation of the projection of rainfall and temperature in Kano state using Global Climate Models (GCMs).

Specifically, the study aims to; determine patterns of observed rainfall and temperature data for 30 years in Kano state for climate impact assessment, develop spatial and temporal climate variability models using GCMs and historical rainfall data under four greenhouse gas emission scenarios, make predictions of future climate change based on GCMs and local observed meteorological data under the RCP scenarios.

Both global and regional climate changes are complex phenomena and human activities are the major influencing factors for their changes (Ismail et al. 2021). The studies conducted by IPCC, 2018 working groups show that climate change has indicated positive and negative consequences in the future (Zhongwu et al., 2019).

Moreover, the patterns of some climate variables of the climate system were expected to include more hot days and heat waves in some regions, while in other regions there were fewer cold days and cold waves. This may include a rise in global rainfall and temperature, a greater number of severe events (flood and drought), and a catastrophic overall ecosystem (Nasidi et al., 2023). There are clear convictions that the global environment is already changing and that more changes are unavoidable. For example, the average global temperature rose by about 0.74ºC over the last century from 1906 to 2005 (IPCC, 2018). Recently, the IPCC report has demonstrated convincing evidence of increasing global average sea level. It was estimated that, over the 20th century the total global mean sea level rose by 12.22 cm due to the melting of snow cover and mountain glaciers (Azim et al., 2016). It was also identified that, over the past century, changes have occurred in terms of amount, intensity, frequency, and types of precipitation (IPCC, 2014). Moreover, it was reported that the future of the earth's surface temperature is projected to increase in the range of 1.1 ^oC to 6.4^oC by the end of 2100 century.

MATERIALS AND METHODS

Study Location

The research was conducted at Kano state, Nigeria which is located within the latitudes 12°21'14.98"N to 10°40'36.73"N, and the longitudes of 7°54'34.59"E to 8°49'52.09"E. The study location was situated at an average altitude of 464 m above sea level with a maximum temperature of 32^oC and a minimum temperature of 20.9^oC. The location of each data source is presented in Figure 2. There were exactly 12 metrological stations used in this study Figure 1. Firstly, a ten-year record of rainfall and temperature data from 2010 to 2019 was extracted from each metrological station and projected for the future under climate change scenarios (Nasidi et al., 2015). Moreover, the information on each metrological station considered in this work is presented in Table 1.

Table 1: Location of the Metrological Stations in Kano State

S/N	Meteorological Station	Latitude	Longitude
1	Dawakin Tofa	12.126639°	8.365795°
2	Gabasawa	12.157542°	8.880392°
3	Danbatta	12.440403°	8.631471°
4	Kunchi	12.502058°	8.271067°
5	Shanano	12.050467°	7.991014°
6	Rogo	11.532801°	7.821018°
7	Garun Malan	11.683721°	8.371808°
8	Tudun Wada	11.248235°	8.400954°
9	Sumaila	11.344954°	8.880821°
10	Doguwa	10.812175°	8.704325°
11	Gaya	11.861894°	8.999282°
12	Fagge	12.031512°	8.521469°

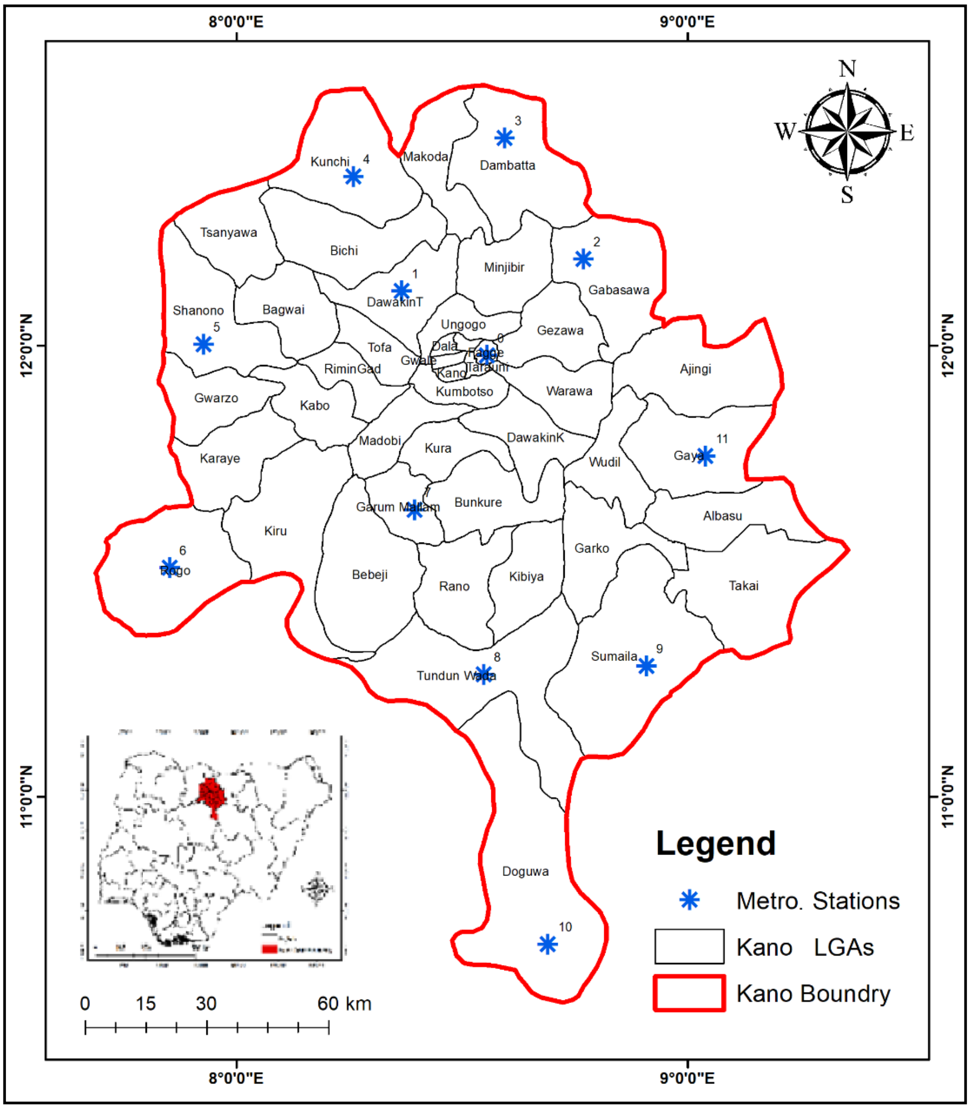


Figure 1: Map of the Study Area

Downscaling the Global Circulation Model for Local Impact Assessment

The data obtained from the selected locations were downscaled to represent the local climate of Kano state using a statistical downscaling approach and validated with gauged stations. The statistical method of downscaling refers to the modification of the GCM output in such a way that the statistical characteristics of the output are consistent with the statistical characteristics of the fine-scale climate data taken from the climate stations (Nasidi et al. 2020). In this study, the statistical downscaling method used involved a two-step process. The processes involved the development of statistical relationships between local climate variables, and the application of such relationships to the output of the global climate model to simulate future local climate characteristics in Kano state.

The downscaling process of the climate data in this work was accomplished through the change factor method. The procedure entails several mathematical steps to estimate the empirical cumulative distribution functions (CDFs) for future GCM (GCM_f) and baseline (GCM_b) for all the scenarios (Matonse et al., 2011). In an additive CFM, one calculates the arithmetic difference between a GCM variable derived from a current climate simulation and the one derived from a future climate scenario taken at the same GCM grid location. This difference is then added to observed local values to obtain the modeled future values. This method is typically used for downscaling of temperature (Akhtar et al., 2008) if the GCM produces a reasonable estimate of the absolute change in the value of a variable regardless of the accuracy of the GCM's current climate simulation. Similarly, a multiplicative change factor (CF) is calculated in the same process except that the ratio, rather than the arithmetic difference, between the future and current GCM simulations is calculated. That is, the observed values are then multiplied by the CF instead of adding. This method assumes that the GCM produces a reasonable estimate of the relative change in the value of a variable and is typically used for downscaling the precipitation GCM data. The procedure to calculate a single CF, additively or multiplicatively is that the first step is to estimate the mean values of GCM simulated baseline and future climates (equations 1 and 2).

$$\overline{\mathrm{GCMb}} = \sum_{i=1}^{Nb} \frac{\mathrm{GCMb_i}}{\mathrm{Nb}} \quad (1)$$

$$\overline{\mathrm{GCMb}} = \sum_{i=1}^{Nf} \frac{\mathrm{GCMb_i}}{\mathrm{Nf}} \quad (2)$$

GCM_b and GCM_f represent the values from a GCM baseline and GCM future climate scenario, respectively. Also, $\overline{\mathrm{GCMb}}$ and $\overline{\mathrm{GCMf}}$ are the mean values from a GCM baseline and GCM future scenario for the designated temporal domain. N_b and N_f are the number of values in the temporal domain of the GCM baseline and GCM future scenario.

Secondly, the calculation of additive and multiplicative change factors (*CF*add, *CF*mul) (equations 3 and 4).

$$\mathrm{CFadd} = \overline{\mathrm{GCMf}} - \overline{\mathrm{GCMb}} \quad (3)$$

$$\mathrm{CFmul} = \overline{\mathrm{GCMf}} \,/\, \overline{\mathrm{GCMb}} \quad (4)$$

Finally, to obtain Local Scaled future values (LS_{fmul}, i and LS_{fadd}, i) by applying CF_{add} and CF_{mul} (equations 5 and 6).

$$\mathrm{LS_{add,i}} = \mathrm{LOb_i} + \mathrm{CF_{add}} \quad (5)$$

$$\mathrm{LS_{add,i}} = \mathrm{LOb_i} \times \mathrm{CF_{mul}} \quad (6)$$

Where LOb_i are observed values of the meteorological variable (at the i^{th} time interval) at an individual meteorological station or are the averaged meteorological time series for a watershed for the designated temporal domain. LS_{fadd}, i and $LS_{fmu,\,i}$, i are values of future scenarios of the variable obtained using additive and multiplicative formulation of CFM. Figure 2 presents a flow diagram for the downscaling process used in this study to project future climate scenarios.

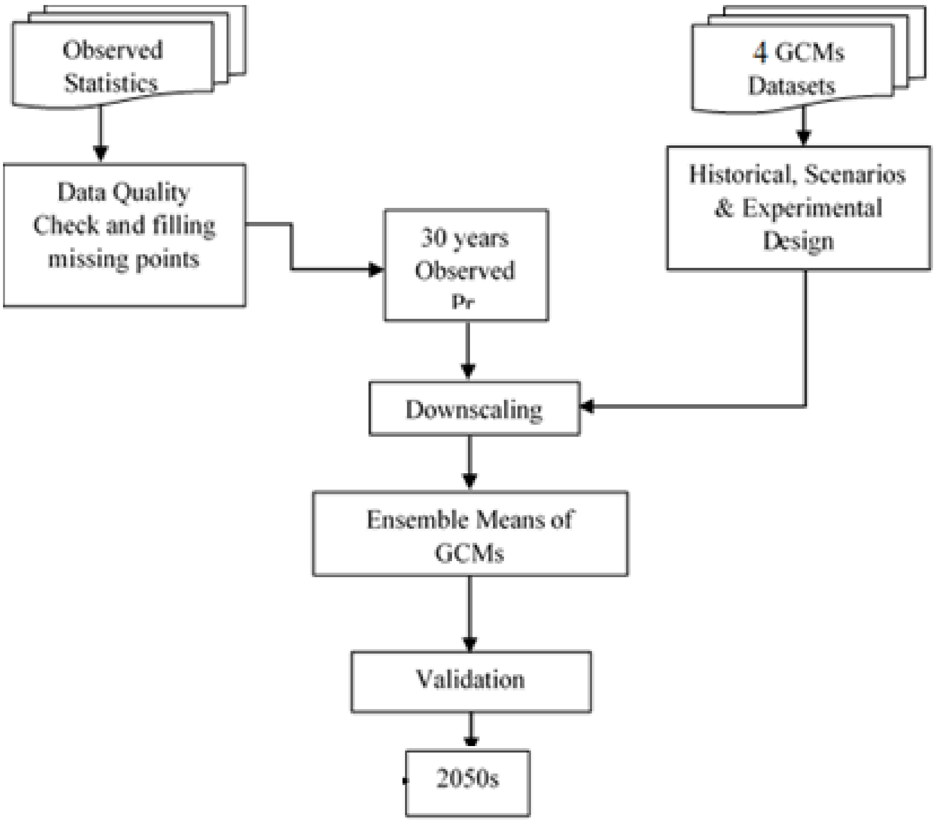


Figure 2: Flowchart of Climate Prediction through the Statistical Downscaling Process

Spatial and temporal climate variability in northern Nigeria

The study used Geographic Information System (GIS) and Remote sensing data to develop spatial and temporal variations of climate data across the span of Kano state. The senility and geospatial information of each data collection point will be recorded and analyzed using GIS software.

Prediction of Future Climate using GCMs and Local Observed Gauged Data under RCP Scenarios

Future predictions of climate were achieved through the application of a GCM under representative concentration pathways. The climate prediction was conducted flowing the process as shown by the flowchart in Figure 2 above. The periods considered were from 2010 to 2019 as the baseline, whereas the projection was from 2041 to 2060 which is centered in the 2050s. This climate data was further calibrated and downscaled to represent a Kano local scale climate. Furthermore, the projections were made based on the two Greenhouse Gas (GHG) emission scenarios. These are categorized as low-emission scenarios (RCP2.6) and high-emission scenarios (RCP8.5) respectively.

RESULTS AND DISCUSSION

Baseline and Projected Climates

The baseline temperature and projections under two different scenarios are presented in Table 1. It shows that future temperatures increase significantly. The temperature rise was more pronounced under RCP8.5 which was considered a worse scenario (IPCC, 2014). The study found that the temperature of Kano will rise by about 1.025 ^{o}C (2.45%) in the 2050s under the RCP2.6 scenario (Table 1). Similarly, the change in the temperature will be more pronounced under the RCP8.5 scenario by 4.593 ^{o} C (10.98%) over the same durations. This projection of high temperatures is very common in several studies conducted in the same region (Shanono, Lawan, and Nasidi, 2022; Sun, Jiang, Liu, Chang, & Zhang, 2018). Another study conducted by Nasidi (2023) revealed that that would be a continuous rise in temperature till the end of the 21st century.

Table 2: Baseline and Projected Temperatures in Kano State

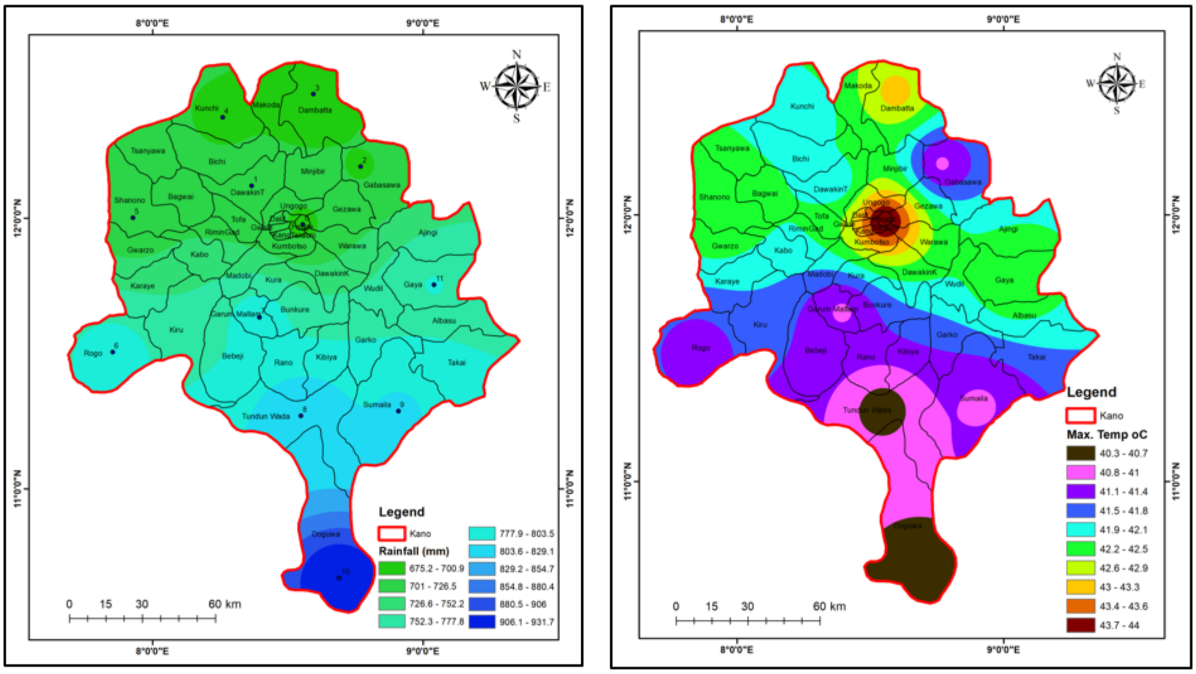
FID Station	Meteorological Station	Precipitation (mm)		
		Baseline	**RCP2.6**	**RCP8.5**
1	Dawakin Tofa	44.0	45.1	48.8
2	Gabasawa	42.0	43.0	46.6
3	Danbatta	41.0	42.4	45.5
4	Kunchi	43.0	43.9	47.7
5	Shanano	42.0	42.8	46.6
6	Rogo	42.5	43.4	47.2
7	Garun Malan	41.3	42.1	45.8
8	Tudun Wada	41.0	42.0	45.5
9	Sumaila	40.5	42.1	45.0
10	Doguwa	41.0	42.0	45.5
11	Gaya	40.3	41.7	44.7
12	Fagge	42.5	42.9	47.2
	Average	**41.76**	**42.8**	**46.3**

Furthermore, this study explored the characteristics of rainfall in the 2050s period which it found substantial changes caused by climate change. It shows that the amount of precipitation will reduce relative to the baseline condition under climate scenarios (Table 2). The precipitation was found to be reduced by 37.9 mm (5%) toward the end of the 2050s period under the RCP2.6 scenario Table 3. However, the reduction in precipitations is further exacerbated by 9% for the same period under the worse climate scenario (RCP8.5). Nevertheless, several studies projected a drop in rainfall amounts in some regions and an increase in other regions in the future (Aich et al., 2016; Trzaska & Schnarr, 2014; Wu et al., 2017). Additionally, a decrease in rainfall amount is very common in tropical areas such as Kano state as reported by several scientists (IPCC, 2013, 2014).

Table 3: Baseline and Projected Precipitation in Kano State

FID Station	Meteorological Station	Precipitation (mm)		
		Baseline	**RCP2.6**	**RCP8.5**
1	Dawakin Tofa	696.4	-34.8	-62.7
2	Gabasawa	701.2	-35.1	-63.1
3	Danbatta	699.2	-35.0	-62.9
4	Kunchi	675.2	-33.8	-60.8
5	Shanano	695.2	-34.8	-62.6
6	Rogo	710.8	-35.5	-64.0
7	Garun Malan	785.9	-39.3	-70.7
8	Tudun Wada	788.7	-39.4	-71.0
9	Sumaila	826.3	-41.3	-74.4
10	Doguwa	805.9	-40.3	-72.5
11	Gaya	931.7	-46.6	-83.9
12	Fagge	778.5	-38.9	-70.1
	Average	**757.9**	**-37.9**	**-68.2**

Moreover, the spatial variation of climate information at the baseline period is presented in Figure 3. The rainfall variations reveal that the northern part of Kano will receive lesser rainfall amount compared to the southern part at baseline (2010 – 2019). Although the changes are not so magnanimous at the baseline period, still noticeable changes were observed. However, a temperature of over 43°C was expected to be received in the metropolitan city of Kano. Simply due to reasons such as deforestation, burning of excessive fossil fuel, and high population density with overcrowded structures and public infrastructures. Furthermore, these anthropogenic activities contribute significantly to the amount of greenhouse gas emissions which lead to temperature rise and indirectly affect the rainfall behavior of any given catchment area (Nasidi et al., 2020).



Rainfall of Kano at Baseline

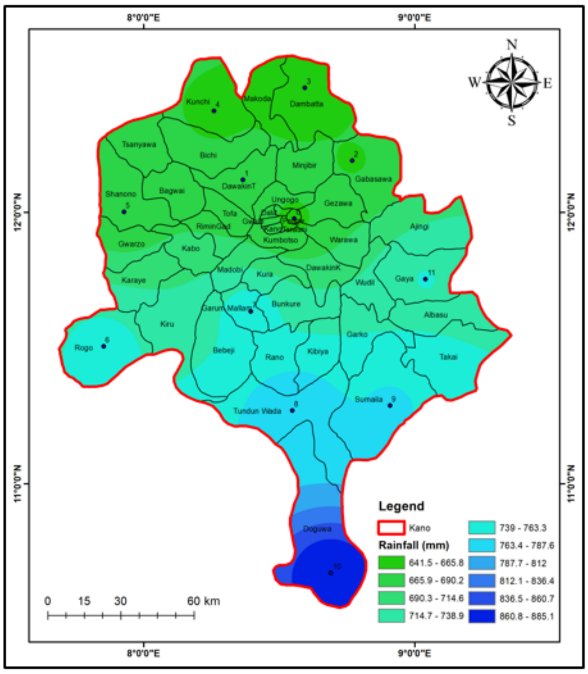
Tempreture of Kano at Baseline

Figure 3: Baseline Climate of Kano (2010 – 2019)

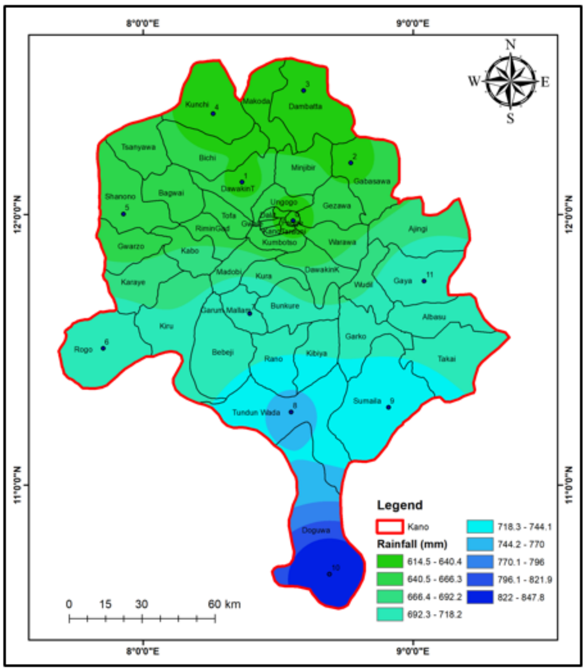
Spatial Projection of Climate at Kano Regions

Rainfall Projection to 2050

In this study, the behavior of rainfall was analyzed and presented to show the distribution pattern of rainfall according to climate change circumstances. Figure 4 reveals the projected rainfall amounts for 20250 under both RCP2.5 and RCP8.5 emission scenarios. In both projection scenarios, the pattern of rainfall distributions remains almost the same over the spatial area of the Kano geographical space, except that, the amount of the expected precipitation varied considerably. Southern region particularly Doguwa local government is projected to have a higher amount, even though future rainfall is anticipated to diminish in the future (Abubakar et al., 2022; M. Nasidi et al., 2020; N. M. Nasidi et al., 2019, 2023). On the other hand, areas such as Danbatta, Makoda, and Kunchi are expected to account for lesser rainfall amounts compared to the race surface area of the entire state. Thus, these climate scenarios were consistent with global assumptions in such a way that equatorial regions face higher extreme events compared to other regions that are further away.



RCP2.6 Scenario

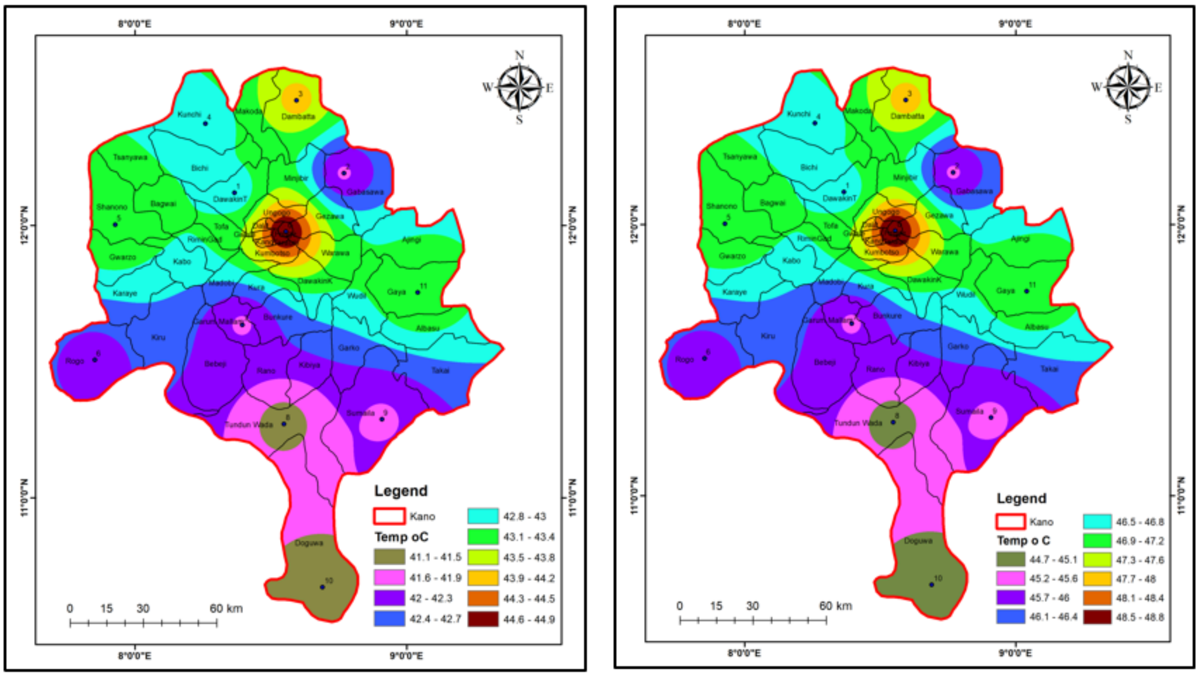


RCP8.5 Scenario

Figure 4: Projected Rainfall at 2050

Temperature Projection to 2050

Temperature projection in Kano state followed a similar spatial trend to the rainfall, except that it is increasing relative to the baseline condition. The metropolitan area is projected to be the hottest region in the state with a temperature higher than 48 ^{o}C under the RCP8.5 scenario (Figure 5). Although the variability of the temperature was random and irregular, however, most regions are expected to receive more heat waves in future reference to the baseline situation. Nasidi et al., (2023) reported that there is high temperatures in tropical areas were most likely to occur and will continue to rise until the end of the 21st century. Similarly, irregular patterns of temperature variability were often projected in most climate change analyses. Babel and Plangoen, (2015) reveal a significant rise in temperature in the next sixty years in all climate scenarios. This outcome was confirmed by several studies (Aich et al., 2016; Switzman et al., 2017; Wu et al., 2017). In addition, Kano state regions fall within the semi-arid zone which is characterized by harsh weather conditions. This considerable temperature rise could be attributed to anthropogenic activities such as deforestation, the release of excessive greenhouse gases, and a lack of adherence to protection measures. This shows that the climate change effect will cause the temperature of Kano to rise considerably in the future with the consequences of decreased rainfall amount. This is shown by the climate change projections using the GCMs. For example, the temperature is projected to increase by 4.8 ^{o}C relative to the baseline condition by 2050 under 8.5 RCP, while rainfall ought to reduce by 62.7 mm.



RCP 2.6 Scenario **RCP8.5 Scenario**

Figure 5: Projected Temperature of Kano at 2050

CONCLUSION

The study concludes that Kano state is experiencing higher temperatures with diminishing rainfall amounts throughout the state. Moreover, the spatial analysis indicated that there was climate variability across the width and breadth of the state. The considerable temperature rise could be attributed to anthropogenic activities such as deforestation, the release of excessive greenhouse gases, and the lack of adherence to climate adoption measures.

RECOMMENDATION

The study recommends that policymakers should deploy adaptation strategies to reduce the adverse effects that might be caused.

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