FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 02, January, 2026, pp 237 – 244
DOI: https://doi.org/10.33003/fjs-2026-1002-4519

MODELLING CURRENT AND FUTURE IMPACTS OF CLIMATE CHANGE ON MAIZE YIELD IN KANO STATE, NIGERIA

***[1]Maryam Shuaibu Hassan, [2]Amos Tiereyangn Kabo-bah and [3]Isah Usman Hassan**

[1]Pan African University Institute of Water and Energy Sciences including Climate Change. Tlemcen, Algeria.
[2]Civil and Environmental Engineering Department, University of Energy and Natural Resources (UENR), Sunyani, Ghana.
[3]Department of Geography, Federal College of Education (Technical) Bichi. Kano, Nigeria.

*Corresponding authors' email: maryammusty30@gmail.com

ABSTRACT
IPCC predicts that climate change will have an impact on agriculture in the future and increase the risk of hunger and water scarcity, with the need to expand agricultural output to feed an estimated nine billion people by 2050. Agricultural system in Kano State depends largely on natural rainfall as the main source of crop production, and thus, exposed to spatial and temporal variability of the climatic parameters of rainfall and temperature. This study used the SDSM tool to downscale current and future temperature and precipitation scenarios in Kano State, Nigeria using data obtained from NASA power for current scenarios and GCM's CMIP5 for the future scenarios. The results showed an increase in temperature and wet day's percentages in the future through the RCP8.5, which might impact the maize yield positively or negatively. A non-parametric statistic using Mann-Kendall and Sen.'s slope estimator alongside simple linear regression was conducted on the observed data to check the trend of temperature and precipitation over the years, at the same time the regression analysis was done to check whether the dependent variable (maize) can be affected by the independent variables (temperature and precipitation). The findings showed that precipitation has no significance on maize yield, but temperature has slight significance on the level of maize yield in the study area. Therefore, for future climate projections, it is recommended that other variables such as soil moisture, crop varieties, irrigation and climate-smart agricultural practices be considered for effective increase in maize yield in the study area.

Keywords: SDSM, Rcps, Climate Parameters, Maize Yield, Non-Parametric Statistics, Kano

INTRODUCTION

Every populated area on the planet is already experiencing the effects of climate change, with human activity responsible for many of the known changes in weather and climatic extremes (IPCC, 2021).The IPCC also predicts that climate change will have an impact on agriculture in the future and increase the risk of hunger and water scarcity. Coupled with changes in consumer habits, the effects of climate change, and the increasing scarcity of water and land by 2050, the world will need to expand agricultural output to feed an estimated nine billion people (Akpoti et al., 2022; Knox et al., 2012). More focus has been placed on the effects of climate change that account for uncertainty in climate projections and the adaptation of crops to climate change(Zhang et al., 2017). Researchers needs effective and timely response knowledge on how climate change may affect crop output (Lobell & Burke, 2010). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), climatic factors like extreme heat, heavy rain, CO2 emissions, and cyclones are adversely influencing many facets of agriculture, including food production, distribution, and prices(Chandio et al., 2022). Researchers agree that global climate change can have an impact on the production yields of crops and is an issue that must be addressed for attaining food security.

The subtropics will become drier than the moist tropics, and Africa is projected to experience larger mean annual warmth than the global annual average warming in all seasons. This susceptibility has been attributed to the continent's high rates of poverty, poor capability for adaptation, reliance on rain-fed agriculture, and weak institutional and economic capacity (Cairns et al., 2013). According to some reports, Africa's food security is now threatened by climate variability. Sub-Saharan African nations are particularly vulnerable to future climate change on a global scale. In recent decades, temperatures in Africa have risen at a rate that is a little quicker than the average global temperature increase, thereby increasing food insecurity through crop yield decrease all over the continent(Asfew & Bedemo, 2022; Bello, 2021; Kourat et al., 2022; Wang et al., 2018; Yeboah et al., 2022).

Due to its heavy reliance on rain-fed agriculture and a number of uncertainties surrounding crop production's responses to climate change, Nigeria as an African nation is projected to be particularly vulnerable to the effects of climate change (Durodola & Mourad, 2020). Because of fast population increase, declining wealth, long-term climate change, and climate variability, Nigeria is frequently experiencing food shortages, famine, and water scarcity. Furthermore, with the typical annual crop grown in Nigeria being maize, numerous studies have indicated that the rise in temperature, fluctuating rainfall, droughts, and floods will have an impact on maize yield because Nigerian farmers rely heavily on rainfall for its production (Olomola & Nwafor, 2018; Otekunrin et al., 2019). Agricultural system in Kano State depends largely on natural rainfall as the main source of crop production, and thus, exposed to spatial and temporal variability of the climatic parameters of rainfall which was indirectly affected by soil degradation from use of Agrochemicals (I. U. Hassan; Y. I. Garba; A. Hussain, 2025) and temperature in the study area whose distribution is critical in affecting crop growth and its production (Olomola & Nwafor, 2018). The highest rainfall months in the study area are; July and August, resulting in relative dryness in the rest of the months alongside crops lost if the rainfall is too high within the rainy months. Similarly, temperature prove to have significant influence on crop yield in the study area(Bello, 2021). Rain-fed farming was the main source of Kano State's agricultural productivity, and the people's primary activity is farming, with a focus on sorghum, millet, rice and maize crops, alongside vegetables like tomatoes, peppers, onions etc. The local governments in the states where most smallholder farmers are found include; Rano, Bunkure, Garunmalam, Warawa, kura, Karaye, Rogo, and Shanono local governments(Nazifi et al., 2021).

For the purpose of this study, analysis of long-term data series was done in order to predict the influence of climate change drivers on maize yield in the study area. Temperature and rainfall data (1981-2021) were downloaded, calibrated, optimized and validated for a sensitivity analysis of their impact on maize yield value per hectare (1981-2021) for current and future projections in Kano State Nigeria.

MATERIALS AND METHODS

Study Area

This study was carried out on Kano State, Nigeria, where maize production is predominant with large percentage of smallholder farmers. Kano State is situated between latitudes 10° 3' and 12° 37' N and longitudes 7° and 90° E. It borders Katsina state to the northwest; Jigawa state to the northeast and Bauchi and Kaduna states to the south, the state has an altitude of 500m to 750m above sea level (http://www.kanostate.net). As Northern Nigeria's commercial hub, its overall land area of 20, 760 square kilometers, with 1,754,200 hectares of fertile agricultural land, of which 86,500 are solely Fadama land. Grazing lands also cover around 75,000 hectares (Irohibe & Agwu, 2014). The rainy season, which typically lasts from April to September with 134.4mm of annual precipitation, begins after the dry season, which typically lasts from October to April. The occurrence of peak rainfall, peak runoff, and peak discharge starts from beginning of July and August indicating highlights of the climatic parameters. Between 800 and 900 millimeters of rain on average per year fall in the area. Kano has exceptionally productive soils, which Olofin (2016) describes to be due to both effective user management practices and harmattan dust, which scatters minerals that enrich the soils. Because of the state's fertile soil, a variety of foods can be produced in large quantities(Tukur et al., 2018).

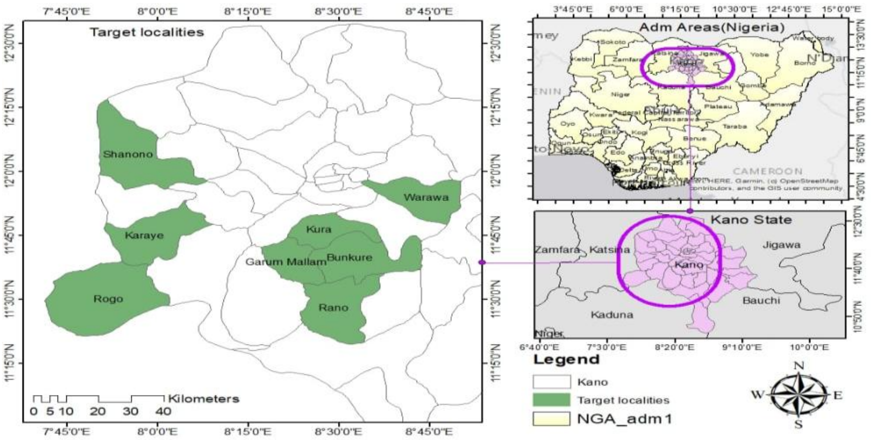

Figure 1: GIS Generated Map of the Study Area and the Maize Crop Major Producers

Demographics

Kano State is ranked 2nd most populous in Nigeria. According to United Nations (UN) Kano State, Nigeria statistics 2022, Kano State population amounts to 11,151,624 as at 2022, with a projection of about 20,647,647 by 2050. And 75% of the populace are into agriculture (NPC, 2007). Maize is grown in many parts of Nigeria but the northern part dominates all other regions with Kano and Kaduna States taking higher percentages(NAZİFİ et al., 2021). Murphy, (2010) indicated that growing maize by smallholder farmers can overcome food insecurity in their households. These smallholder farmers make up to 80% of farmers in Northern Nigeria, and they produced substantial percentage of food consumed by Nigerians particularly maize crop. Maize (Zea mays) is a staple food for a large part of the population around the Globe and is of great socio-economic importance in the Sub-Saharan Africa (FAO, 2013). It is one of the most heavily cultivated cereal crop globally, and one of the main cereal crops of West Africa and the most important cereal food in Nigeria(Onuk E. G.; Ogara I. M.; Yahaya H.; Nannim N., 2010). In order to grow, maize needs soils that are deep, medium-textured, well-drained, fertile, and have a pH range of 5.5 to 8.0 (I. U. Hassan; Y. I. Garba; A. Hussain, 2025). Since the majority of farmers in the nation adopt rain-fed agriculture, abnormalities in the onset, frequency, and intensities of rainfall are another issue threatening maize output in the nation. Maize cultivation is getting increasingly challenging as a result of crop output and climatic uncertainty. Low maize yields have a significant impact on the food security and income of smallholder farmers throughout the nation and in the study area(Durodola & Mourad, 2020).

Data Sources

Temperature and rainfall data was downloaded from with the NASA Langley Research Centre (LaRC) website. This Agro climatology Archived data is designed to provide web-based access to industry-friendly parameters formatted for input to crop models (NASA Power Project, https://power.larc.nasa.gov/). This study uses NASA power data because of its usefulness in data scarce regions like the study area(Gulacha & Mulungu, 2017; Gunaratne M.D.N, De Silva S.H.N.P, 2022; Z. Hassan & Harun, 2011; Marzouk, 2021). Maize yield data of Nigeria was downloaded from the FAO website (https://www.fao.org/faostat/en/#data) ranging from 1961 to 2021. Due to constraints of obtaining the same dataset of the study area, an estimation of 30% out of the total estimated value obtained from FAO was used, this is because a study shows that Kano State produces approximately 30% of the country's maize grain each cropping season(NAZİFİ et al., 2021).

However in order to develop the future scenarios, data was downloaded from the Canadian Climate Data and Scenarios website with simulations from 2006 to 2100. CMIP5 statistical downscaling was used to downscaled climate scenarios and predictors in the study area through the adoption of the RCPs instead of the recent SSPs as a result of the robustness of the initial scenarios.

Methods

Current Climate Scenarios

A general table showing the maize yield data obtained from FAO website, 2022, with the estimated 30% assumed for the study area was used for analysis of the dependent variable. Historical meteorological data from 1981 to 2021 were used to observe the climate parameters of temperature and precipitation and to analyze their impact on the maize crop yield. For this study, maximum temperature, minimum temperature and percentage of wet day's precipitation as the major climate parameters for assessing historical climate impacts on crop yields were selected. Daily mean maximum and minimum temperatures and monthly wet day's percentage precipitation were calibrated, modelled and statistically compared using the Statistical Downscaling Model (SDSM 4.2 version), this software was used because of its advantage as par the time and logistics constraints during the research period and also the ability to check the sensitivity analysis of the software. The observed data obtained from NASA Power was used to model current scenarios.

Future Climate Scenarios

The CMIP5 retrieved data was used to model future scenarios. RCP2.6, RCP4.5, and RCP8.5 were the three emission trajectory predictions that were available for the future climate modelling. The RCP with the lowest emission scenario is the RCP2.6. RCP4.5 represented a stabilizing scenario, whereas RCP8.5 represented a 'Business as usual' radiative forcing trajectory that was always rising. With the use of these multi-model ensembles, we were able to examine changes in maize yield in the future while taking into account both parametric and climatic uncertainties of temperature and precipitation. For the calibration of the model, data from 1981 to 2021 was used, while 2006 to 2100 was used for the future prediction. During the calibration, the downscaled parameters from the GCM which acted as the predictors were used iteratively to select the best predictor variables for the temperature and precipitation. For ease of graphing and representation, the final outputs from SDSM were exported to excel software.

Man-Kendall Test, Sen.'s Slope and Simple Linear Regression

The data collected over the period were analysed using Man-Kendall's non-parametric tests. Prior studies showed that the non-parametric Mann-Kendall test is the most widely used test and several researchers have adopted this approach to understand the trends in the temperature and precipitation parameters(Aswad et al., 2020; Kamal & Pachauri, 2018) For rainfall trends, Aswad et al., 2020 used the same to understand monthly and annual rainfall trend in Sinjar District, Iraq.

For this study the Mann-Kendall (non-parametric) test was performed to determine if there were upwards, downwards, or no trends in the temperature and rainfall trends of the chosen area. And for this data set the formula is provided by the following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

Where:

N: numbers of data points

x_j And x_i are annual values in years j and i, j > 1

And Sign $(x_j - x_i)$ calculated using the equation:

$$sign\ (x_j - x_i) = \begin{cases} -1\ if\ (x_j - x_i) < 0 \\ \ \ 0\ if\ (x_j - x_i) = 0 \\ +1\ if\ (x_j - x_i) > 0 \end{cases}$$

The Sen.'s slope estimator can also be used to determine the strength of a trend. It is discovered that the Sen. (1968) slope estimator is an effective tool for developing linear relationships. Sen.'s slope was a very important tool over regression's slope because it is less affected by large data series errors and outliers. The mean of all pair-wise slopes for every pair of points in the dataset was found to represent the slope of the Sen.(Aswad et al., 2020). This test was originally developed in 1968 for the performance of checking the statistical trend of different variables. However, in recent times in climate change studies (Durodola & Mourad, 2020) have adopted it in their studies. In this study however, the test was also used for checking the performance of each of the variables' trend were the R2 and RMSE significance were analysed.

Lastly, a simple linear regression model was done for the observation of temperature and rainfall data against the maize yield data. A linear regression analysis is a parametric tool and one of the most widely used methods to detect a pattern in data series(Aswad et al., 2020; Lobell & Burke, 2010). For this study regression analysis was used to determine the impacts of climatic elements such as; rainfall and temperature, as the independent variables, and the maize yield as the dependent variable. Furthermore, the simple linear regression was done to determine which climatic variable has more effects on the crop yield in the study area.

RESULTS AND DISCUSSION

Temperature

Results from the observed and modelled temperature (Tmax) showed the hottest months to be March to June with a variation of 40.7° to 45° respectively for the observed and modelled years. At the same time, the RCPs indicated the same months as the hottest, with RCP 2.6 recording slightly lower than RCP 4.5. But for RCP 8.5 being the worst scenario of 'Business as Usual' it recorded a very high temperature variation of 47.1° to 49.2° in the months of April and May indicating those months not favorable for growing maize generally (Lizaso J. I.; Rodriguez A.; 2018) and therefore in the study area too.

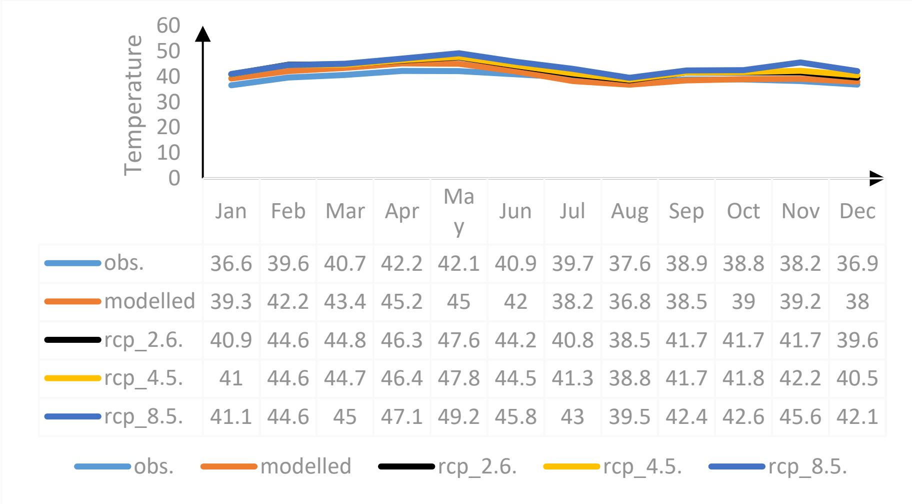

Figure 2: Tmax Showing Observed, Modelled & RCPs (2006-2100)

For Tmin, the observed and modelled data showed January recording 0° indicating that it is the coldest month followed by December with 6.94°. Similarly, the RCPs showed the same trend with an unusual trend where both RCP 4.5 and RCP 8.5 records almost the same temperature with just a few degrees points variation between them, but nonetheless, January remains the coldest month, therefore, slightly suitable for maize cultivation.

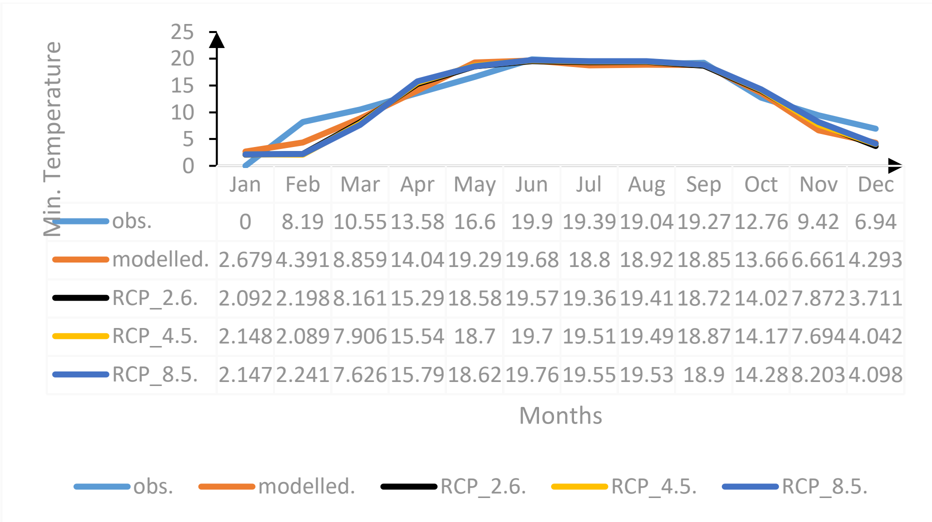

Figure 3: Tmin Showing Observed, Modelled & RCPs (2006-2100)

Table 1 presented the magnitude of annual temperature patterns obtained from the Mann-Kendall test, the slope estimator from Sen, and the p-values. Other months have been neglected because there is no statistical significance in them according to the p-values. The Sen.'s slope estimator in figure 3.1c showed decrease and increase trends over the years with a major negative fall around 1989 (-26.3) and a major rise around 2010 (27.9). But conclusively, the R^2 showed 46.63% temperature trend impact over the years. This trend has an impact on maize yield in the study area, as studies showed that slight rise in temperature has a significant impact on the yield of some cereal crops including maize.

Table 1: Annual and Monthly Temperature Trend Analysis with Significance Level (α) = 5%.

Series\Test	Jan	Mar	May	Jul	Nov	Dec	Annual
Kendall's tau	0.254	0.411	0.217	0.289	0.389	0.306	0.500
p-value	0.020	0.000	0.048	0.009	0.000	0.005	<0.0001
Sen's slope	0.029	0.029	0.012	0.017	0.029	0.029	0.018

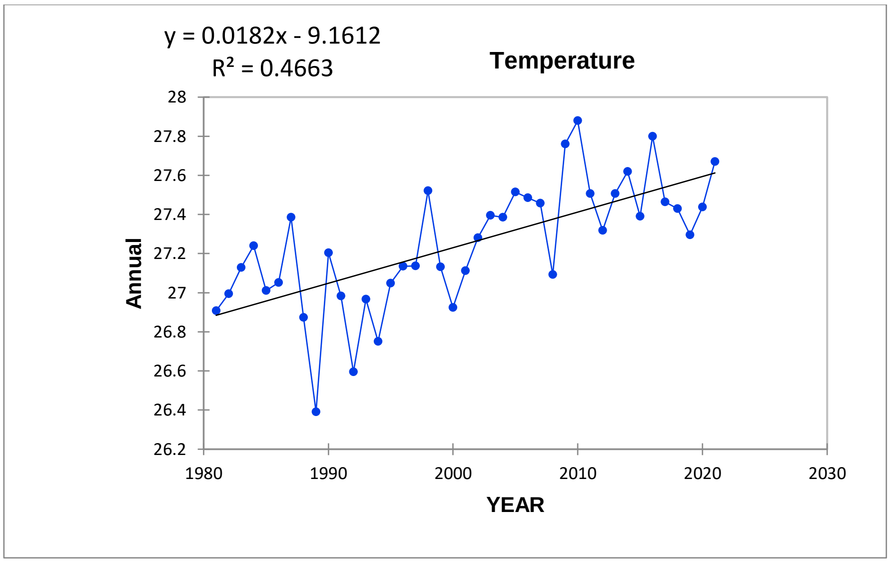

Figure 4: Temperature Sen.'s Slope and Linear Regression

Precipitation

Precipitation analysis for the observe and modelled data showed July and August recording the highest percentage of wet days as 88.3% and 90.7% respectively, this amount to an equivalent of a high millimeter of rainfall within the months making them the most suitable months for maize cultivation in the study area so as to increase the yield. The RCPs hypothesis showed January to March as dry months with no rainfall. But RCP8.5 predicted an extension of October to December to receive an amount of 38.1 to 14.3% of wet days respectively, thereby giving farmers additional cultivation time so as to increase the yield.

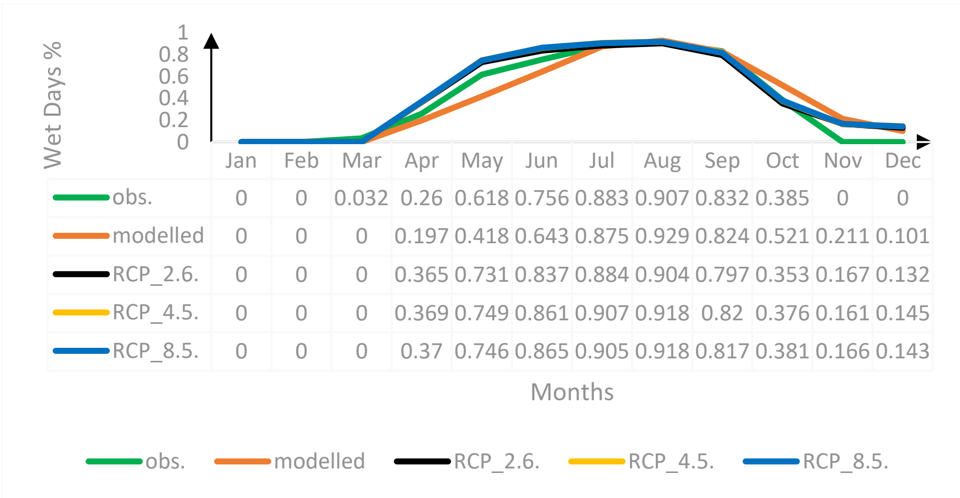

Figure 5: Wet Days % Observed, Modelled & RCPs (2006-2100)

Table 2 presented the magnitude of annual rainfall patterns obtained from the Mann-Kendall test, and the slope estimator from Sen. From the table, the annual data trend is decreasing as both the slope estimator of the Sen and the tau (Z) values of Kendall were negative in the months of March, April, May and July. Likewise, there are positive (increasing) trend for months of January, February, June, August and November, because the Sen's slope and Kendall's tau (Z) values were both positive. Other months are neglected because the p-value showed slight significance in the trend. The value of R^2 in figure 3.2b showed that only 16.54% of rainfall has an impact on maize yield in the study area.

Table 2: Annual and Monthly Rainfall Trend Analysis with Significance Level (α) = 5%

Series\Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Nov	Annual
Kendall's tau	0.068	0.068	-0.039	-0.061	-0.015	0.205	-0.110	0.110	0.200	0.276
p-value	0.537	0.537	0.728	0.582	0.902	0.061	0.317	0.317	0.067	0.011
Sen's slope	0.029	0.054	-0.037	-0.094	-0.033	0.659	-0.345	0.421	0.140	0.261

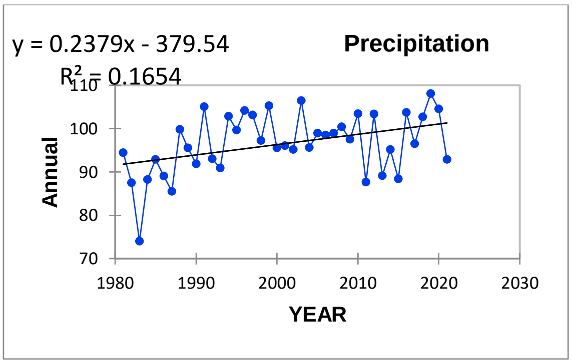

Figure 6: Rainfall Sen.'s Slope and Linear Regression

Maize Yield Results

Based on the assumed maize yield data from FAOSTAT (2022) Nigeria's data, 1983 recorded the lowest yield of 2912hg/ha while 2009 recorded the highest yield of 6588.3hg/ha. For 1983, the yield might be affected by the amount of rainfall received that year, as it shows the lowest amount over the observed years, but as for 2009 all climate parameters of rainfall and temperature remain the same as other months, therefore the increased yield might be due to other factors.

Table 3 presented the results of regression of maize yield as the dependent variable, and precipitation as independent variable. The p-value indicated that rainfall has no significance on maize yield over the studied years. The ANOVA table can be summarized as;

$F (1, 38) = 6.65, p = 0.800059$

Table 3: Coefficients of Maize Yield and Precipitation

	Coefficients	Standard Error	t Stat	P-value
Intercept	397.8646	1559.94322	0.255051	0.800059
Variable 1	41.50936	16.1000913	2.578207	0.013932

Table 4 presented the results of regression of maize yield as the dependent variable, and temperature as independent variable. The p-value indicated that temperature has significance on maize yield over the studied years. The ANOVA table can be summarized as;

$F (1, 38) = 16.148, p = 0.000267$

Table 4: Coefficients of Maize Yield and Temperature

	Coefficients	Standard Error	t Stat	P-value
Intercept	26.23805	0.252376	103.964	2.85E-48
Variable	0.000227	5.64E-05	4.018568	0.000267

Figure 3 showed the simple linear regression scatter plot of temperature and precipitation on the maize yield as the dependent variable. The R^2 showed only 14.89% precipitation impact on maize yield, meaning that it has no significant impact on the value of yield per hectare. At the same time, 29.8% temperature impact on maize yield was observed indicating that temperature has a significant impact on the value of yield per hectare in the study area. All these parameters were correlated including all the outliers present in the data.

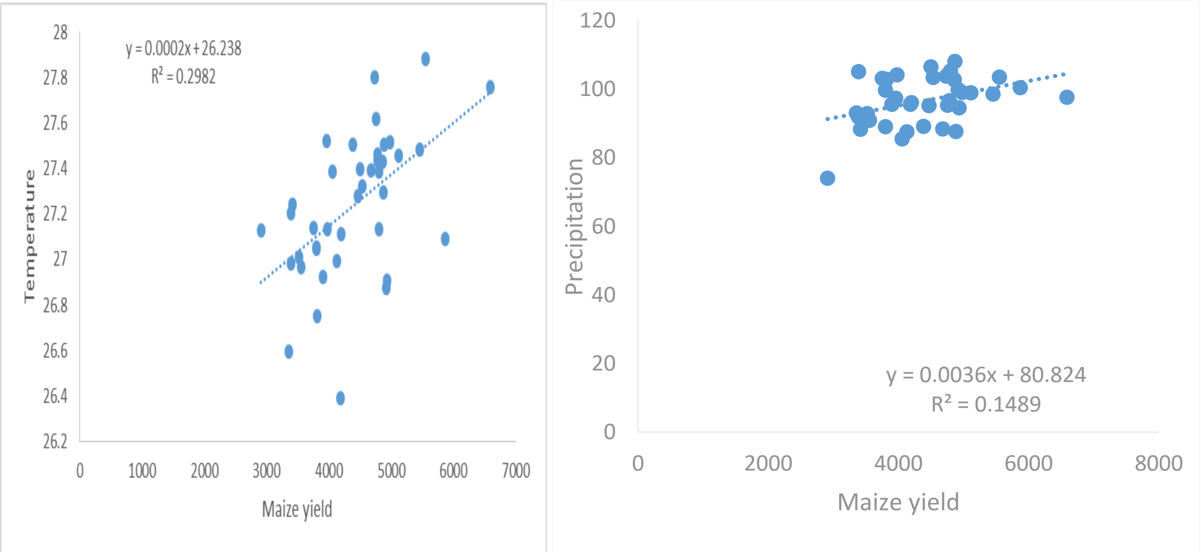

Figure 7: Temperature and Precipitation Regression Scatter Plot over the Dependent Variable (Maize yield)

Discussions

Contrary to some previous studies (Irohibe & Agwu, 2014; Luka Fitto Buba, Nura Isyaku Bello, Hamza Ahmad Isiyaka, Muhammad Alhaji, Tijjani abdulahi Yahaya, 2021; Olomola & Nwafor, 2018; Onuk E. G.; Ogara I. M.; Yahaya H.; Nannim N., 2010; Otekunrin et al., 2019; Tukur et al., 2018), this study found that there was no statistical significance between precipitation and maize yield in Kano state, but temperature showed a significance impact on the maize yield over the observed years in the study area, with other factors such as soil moisture, PH level, crop variety and planting time remaining constant. When compared to other studies findings(Asfew & Bedemo, 2022; Durodola & Mourad, 2020; Srivastava et al., 2018), temperature becomes the major climatic parameter affecting maize yield which becomes similar with the study area findings. For future predictions, the multi-model ensembles showed that there will be increase in temperature and precipitation, based on the RCP8.5 trajectory, rainfall months will extend further with three more raining months, meaning that cropping season will increase, thereby increasing maize yield in the study area. Similarly, the temperature will be increased significantly based on the RCP8.5 trajectory, this also goes in-line with findings of some studies (Kogo et al., 2019; Roudier et al., 2011; Yin & Leng, 2021).

The temporal variation in annual temperature is presented in Fig. 9. Despite annual and decadal variability across the entire study area, temperature has generally increased over the study period. However, between 1950s and 1960s, a reduction in temperature was reported and a positive trend witnessed thereafter up to date. It is worth noting that there has been a significant positive change in the recent past, from 1990s to 2000s (Fig. 10). The overall increase can be attributed to the ongoing global warming, coupled with other meso-scale factors, such as land use and land cover changes.

CONCLUSION

Modelling future climate change impacts on crop yields such as maize is very important in order to project variability that might cause increase or decrease in the yield thereby curtailing food insecurity. This study used the SDSM tool for downscaling current and future temperature and precipitation scenarios in Kano State, Nigeria using data obtained from NASA power for current scenarios and GCMs CMIP5 for the future scenarios. The results showed an increase in temperature and wet day's percentages in the future, which might impact the maize yield positively or negatively. A non-parametric statistics was conducted using Mann-Kendall and Sen.'s slope estimator alongside simple linear regression on the current data to check the trend of temperature and precipitation over the years, at the same time the regression analysis was done to check whether the dependent variable (maize) can be affected by the independent variables (temperature and precipitation). The findings showed that precipitation has no significance on maize yield, but temperature has slight significance on the level of maize yield in the study area. Therefore, for future climate projections, it is recommended that other variables such as soil moisture, crop varieties, irrigation and cropping time considering climate-smart practices be considered for effective increase in maize yield in the study area.

REFERENCES

Akpoti, K., Groen, T., Dossou-Yovo, E., Kabo-bah, A. T., & Zwart, S. J. (2022). Climate change-induced reduction in agricultural land suitability of West-Africa's inland valley landscapes. *Agricultural Systems*, *200*. https://doi.org/10.1016/j.agsy.2022.103429

Asfew, M., & Bedemo, A. (2022). Impact of Climate Change on Cereal Crops Production in Ethiopia. *Advances in Agriculture*, *2022*. https://doi.org/10.1155/2022/2208694

Aswad, F., Yousif, A. A., Ibrahim, S. A., & Aswad, F. K. (2020). Trend Analysis Using Mann-Kendall and Sen's Slope Estimator Test for Annual and Monthly Rainfall for Sinjar District, Iraq The advancement of computer aid in hydrology and water resources engineering View project Water Managment View project TREND ANALYSI. In *Journal of University of Duhok* (Vol. 32, Issue 2). https://www.researchgate.net/publication/343787766

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. In *Food Security* (Vol. 5, Issue 3, pp. 345–360). https://doi.org/10.1007/s12571-013-0256-x

Chandio, A. A., Jiang, Y., Fatima, T., Ahmad, F., Ahmad, M., & Li, J. (2022). Assessing the impacts of climate change on cereal production in Bangladesh: evidence from ARDL modeling approach. *International Journal of Climate Change Strategies and Management*, *14*(2), 125–147. https://doi.org/10.1108/IJCCSM-10-2020-0111

Durodola, O. S., & Mourad, K. A. (2020). Modelling maize yield and water requirements under different climate change scenarios. *Climate*, *8*(11), 1–26. https://doi.org/10.3390/cli8110127

Gulacha, M. M., & Mulungu, D. M. M. (2017). Generation of climate change scenarios for precipitation and temperature at local scales using SDSM in Wami-Ruvu River Basin Tanzania. *Physics and Chemistry of the Earth*, *100*, 62–72. https://doi.org/10.1016/j.pce.2016.10.003

Gunaratne M.D.N, De Silva S.H.N.P, A. R. (2022). Can NASA Power Climatic Data Fill the Gap of Climatic Data Required for Agriculture and Forest Ecosystems Modeling? *Proceedings of the 26th International Forestry and Environment Symposium*, 21.

Hassan, Isah Usman; Yusuf Idris Garba and Adamu Hussain (2025). Effects of Agrochemicals and their Impact on Soil Quality in part of Sudan Savannah Zone of Northwestern Nigeria. *FUDMA Journal of Sciences (FJS)*, *9*(3), 7–14. https://doi.org/https://doi.org/10.33003/fjs-2025-0903-2693

Hassan, Z., & Harun, S. (2011). Statistical Downscaling for Climate Change Scenarios of Rainfall and Temperature. *United Kingsom-Malaysia-Ireland Engineering Science Conference 2011 (UMIES 2011)*, *January*. https://doi.org/10.13140/RG.2.1.2336.9446

IPCC. (2021). Climate Change 2021: The Physical Science Basis - Summary for the Policymakers (Working Group I). In *Climate Change 2021: The Physical Science Basis.*

Irohibe, I. J., & Agwu, A. E. (2014). Assessment of food security situation among farming households in rural areas of Kano State, Nigeria. *Journal of Central European Agriculture*, *15*(1), 94–107. https://doi.org/10.5513/JCEA01/15.1.1418

Kamal, N., & Pachauri, S. (2018). Mann-Kendall Test - A Novel Approach for Statistical Trend Analysis. *International Journal of Computer Trends and Technology*, *63*(1), 18–21. https://doi.org/10.14445/22312803/ijctt-v63p104

Knox, J., Hess, T., Daccache, A., & Wheeler, T. (2012). Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters*, *7*(3). https://doi.org/10.1088/1748-9326/7/3/034032

Kogo, B. K., Kumar, L., Koech, R., & Langat, P. (2019). Modelling Impacts of Climate Change on Maize (<i>Zea mays</i> L.) Growth and Productivity: A Review of Models, Outputs and Limitations. *Journal of Geoscience and Environment Protection*, *07*(08), 76–95. https://doi.org/10.4236/gep.2019.78006

Kourat, T., Smadhi, D., & Madani, A. (2022). Modeling the Impact of Future Climate Change Impacts on Rainfed Durum Wheat Production in Algeria. *Climate*, *10*(4). https://doi.org/10.3390/cli10040050

Lobell, D. B., & Burke, M. B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agricultural and Forest Meteorology*, *150*(11), 1443–1452. https://doi.org/10.1016/j.agrformet.2010.07.008

Luka Fitto Buba, Nura Isyaku Bello, Hamza Ahmad Isiyaka, Muhammad Alhaji, Tijjani abdulahi Yahaya, A. H. (2021). Impact of climate variability on the yield of staple grain crops in Wudil local government area, Kano State, Nigeria. *Turkish Journal of Food and Agriculture Sciences*, 37–44. https://doi.org/10.53663/turjfas.980135

Marzouk, O. A. (2021). Assessment of global warming in Al Buraimi, sultanate of Oman based on statistical analysis of NASA POWER data over 39 years, and testing the reliability of NASA POWER against meteorological measurements. *Heliyon*, *7*(3), e06625. https://doi.org/10.1016/j.heliyon.2021.e06625

NAZİFİ, B., BELLO, M., SULEİMAN, A., & SULEİMAN, M. S. (2021). Impact of Contract Farming on Productivity and Food Security Status of Smallholder Maize Farmer's Households in Kano and Kaduna States, Nigeria. *International Journal of Agriculture, Environment and Food Sciences*, *5*(December), 571–579. https://doi.org/10.31015/jaefs.2021.4.17

Olomola, A. S., & Nwafor, M. (2018). *Nigeria agriculture sector performance review*.

Onuk E. G.; Ogara I. M.; Yahaya H.; Nannim N. (2010). Economic Analysis of Maize Production in Mangu Local Government Area of Plateau State, Nigeria. *Patnsuk Journal*, *6*(December), 15–25.

Otekunrin, O. A., Otekunrin, O. A., Momoh, S., & Ayinde, I. A. (2019). How far has Africa gone in achieving the zero hunger target? Evidence from Nigeria. *Global Food Security*, *22*(February), 1–12. https://doi.org/10.1016/j.gfs.2019.08.001

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, *21*(3), 1073–1083. https://doi.org/10.1016/j.gloenvcha.2011.04.007

Srivastava, A. K., Mboh, C. M., Zhao, G., Gaiser, T., & Ewert, F. (2018). Climate change impact under alternate realizations of climate scenarios on maize yield and biomass in Ghana. *Agricultural Systems*, *159*, 157–174. https://doi.org/10.1016/j.agsy.2017.03.011

Tukur, A. I., Nabegu, A. B., Umar, D. A., Olofin, E. A., & Azmin Sulaiman, W. N. (2018). Groundwater condition and management in Kano region, Northwestern Nigeria. *Hydrology*, *5*(1), 1–21. https://doi.org/10.3390/hydrology5010016

Wang, J., Vanga, S. K., Saxena, R., Orsat, V., & Raghavan, V. (2018). Effect of climate change on the yield of cereal crops: A review. In Climate (Vol. 6, Issue 2). MDPI AG. https://doi.org/10.3390/cli6020041

Yeboah, K. A., Akpoti, K., Kabo-bah, A. T., Ofosu, E. A., Siabi, E. K., Mortey, E. M., & Okyereh, S. A. (2022). Assessing climate change projections in the Volta Basin using the CORDEX-Africa climate simulations and statistical bias-correction. *Environmental Challenges*, *6*. https://doi.org/10.1016/j.envc.2021.100439

Yin, X., & Leng, G. (2021). Modelling global impacts of climate variability and trend on maize yield during 1980–2010. *International Journal of Climatology*, *41*(S1), E1583–E1596. https://doi.org/10.1002/joc.6792

Zhang, Y., Zhao, Y., Wang, C., & Chen, S. (2017). Using statistical model to simulate the impact of climate change on maize yield with climate and crop uncertainties. *Theoretical and Applied Climatology*, *130*(3–4), 1065–1071. https://doi.org/10.1007/s00704-016-1935-2

World Bank. World Bank Group Database 2019. https://data.worldbank.org/country/nigeria https://populationstat.com/nigeria/kano,