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PROJECTED CHANGES IN CLIMATE AND EXTREME INDICES IN ILORIN, KWARA STATE, NIGERIA

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Article Info **Abstract**

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Purpose — This study examines the projected impact of climate change on rainfall, temperature, and climate extreme indices in Ilorin, Kwara State, Nigeria.
Methods — The study analysed rainfall and temperature extreme indices by considering eleven (11) climate change indices from the Expert Team on Climate Change Detection Monitoring Indices (ETCCDMI) using RClimdex in the R software package. With MAKESENS software, the magnitude and trends in rainfall and temperature extreme indices were calculated using the non-parametric Mann-Kendall test and Sen's slope estimator.
Findings — The study identified that most extreme rainfall indices were projected to decrease in the future (2020–2049), with the exception of consecutive dry days (CDD), which increased. The temperature extremes analysis shows an increasing trend in warm days (TX90p) and warm nights (TN90p), but a decreasing trend in cool days (TX10p) and cool nights (TN10p) for both the baseline and future periods.
Conclusion & Recommendation — These findings provide valuable insights into the anticipated changes in rainfall, temperature, and climate extreme indices, contributing to our understanding of the potential impacts of climate change on the study area and emphasizing the need for adaptive measures to address the projected challenges.

Keywords — RCMs, Rainfall, Temperature, Kwara State, Climate Extremes

Introduction

Climate change is a pressing global issue that has far-reaching effects on ecosystems, economies, and societies worldwide. The rise in climate-related extreme events poses a growing threat to the sustainability of socio-economic development. Extensive studies have been conducted across various regions, shedding light on the implications of temperature, rainfall patterns, and climate extremes indices for sustainable development (e.g., Sekele, 2013; Singh *et al.*, 2014; Alexander, 2016; Lelieveld *et al.*, 2016; Stott *et al.*, 2016; Shrestha *et al.*, 2017; Susanto *et al.*, 2020; Almazroui, 2020; Yaduvanshi *et al.*, 2021; Wilson *et al.*, 2022; Chemura *et al.*, 2022; Ankrah *et al.*, 2023).

These studies reveal that changes in temperature, rainfall patterns, and climate extreme indices have significant implications for sustainable development (Cramer *et al*., 2018; Lu *et al*., 2019; Agovino *et al*., 2019; Masson-Delmotte *et al*., 2022). Moreover, predictions indicate an increase in droughts and floods of unprecedented magnitude, posing threats to human and food security (Kotir, 2011; Parvin *et al*., 2015; Ebi and Bowen, 2016; Mbow *et al*., 2017; Alemu and Mengistu, 2019; Amoak *et al*., 2022; Pörtner *et al*., 2022).

Climate change projections suggest a decline in rainfall ranging from 0.5% to 40%, with an average of 10% to 20% by 2025, while other projections anticipate increases in rainfall and associated extreme events in West Africa (Kasei, 2014). Temperature analysis reveals a warming trend in Africa surpassing the global average, particularly across the continent (Nikulin *et al*., 2018). This warming trend is expected to persist and accelerate, increasing the frequency of extreme climate events (James and Washington, 2013; Niang, 2014). In Nigeria, like many other countries, the impacts of climate change are projected to be widespread and potentially devastating. Studies conducted by Abatan *et al*. (2018) and Abdussalam (2015) in Nigeria highlight significant trends in extreme temperature indices and temperature increases, particularly in southern Nigeria and during the winter season. However, rainfall-related indices show weak trends without spatial coherence.

General climate change projections for Nigeria, as suggested by the Intergovernmental Panel on Climate Change (IPCC, 2014), indicate a warming trend with increased daytime and nighttime temperatures. This poses risks such as heat-related illnesses, heightened water demand, reduced crop yields, and threats to agricultural production. Additionally, Nigeria may experience more intense rainfall events, increasing the risk of flooding and consequent damage to crops and infrastructure (IPCC, 2014). Climate change projections and extreme weather events pose significant concerns for Nigeria, given the vulnerability of its agriculture sector, which employs over 60% of the population and contributes about 30% to the Gross Domestic Product (GDP) (Adeola, 2018). Kwara State, a prominent agricultural hub, faces unique challenges due to its distinct geography and topography. Unfortunately, limited studies have specifically addressed climate projections and extreme indices in this region, hindering the understanding of local climate dynamics.

The absence of localized research and insufficient information on climate projections and extremes exacerbates the vulnerability of farmers and hampers the prediction and mitigation of devastating climate events (Ogundele *et al*., 2019). Consequently, this lack of knowledge impedes long-term sustainable development in the agriculture sector and the formulation of appropriate adaptation strategies for farmers and stakeholders.

To address this gap in knowledge, this study aims to analyze rainfall and temperature projections and their extreme indices in Ilorin, Kwara State, Nigeria. The findings of this study will contribute to the development of policies and programs aimed at promoting effective adaptation in the agricultural sector, not only in the study area but also across Nigeria and other countries sharing similar climatic and ecological characteristics as Kwara State.

Materials and Methods

Study Area

The study was conducted in Zone C of the Kwara State Agricultural Development Project (KWADP) in Kwara State, which falls under the southern Guinea Savanna agro-ecological zone of Nigeria (Figure 1). Geographically, Kwara State is located between latitudes 8° 05′ N and 10° 05′ N, and longitudes 2° 50′ E and 6° 05′ E, covering an area of about 32,500 km^2. The state shares a common internal boundary with Niger State in the north, Kogi State in the east, and Oyo, Ekiti, and Osun States in the south. The study area (Zone C) extends from latitudes 8° 05′ N to 9° 05′ N and longitudes 4° 20′ E to 5° 5′ E, covering an area of about 4,978.44 km^2. The area lies within a region described as having a tropical climate and is characterized by double rainfall maxima (Olanrewaju, 2009). The area experiences a rainfall regime from the end of March to October, with a mean annual rainfall ranging from 1000 mm to 1500 mm (Larbi *et al*., 2016). The temperature remains uniformly high, ranging between 25°C and 30°C throughout the wet season, except in July and August, when it reaches between 33°C and 34°C during the dry season. Relative humidity in the wet season ranges from 75% to 80% and approximately 65% in the dry season (NBS, 2009). Food crops produced in this area are mostly yam, cassava, water yam, sweet potato, maize, and sorghum, which constitute the main staple food aside from cereals.

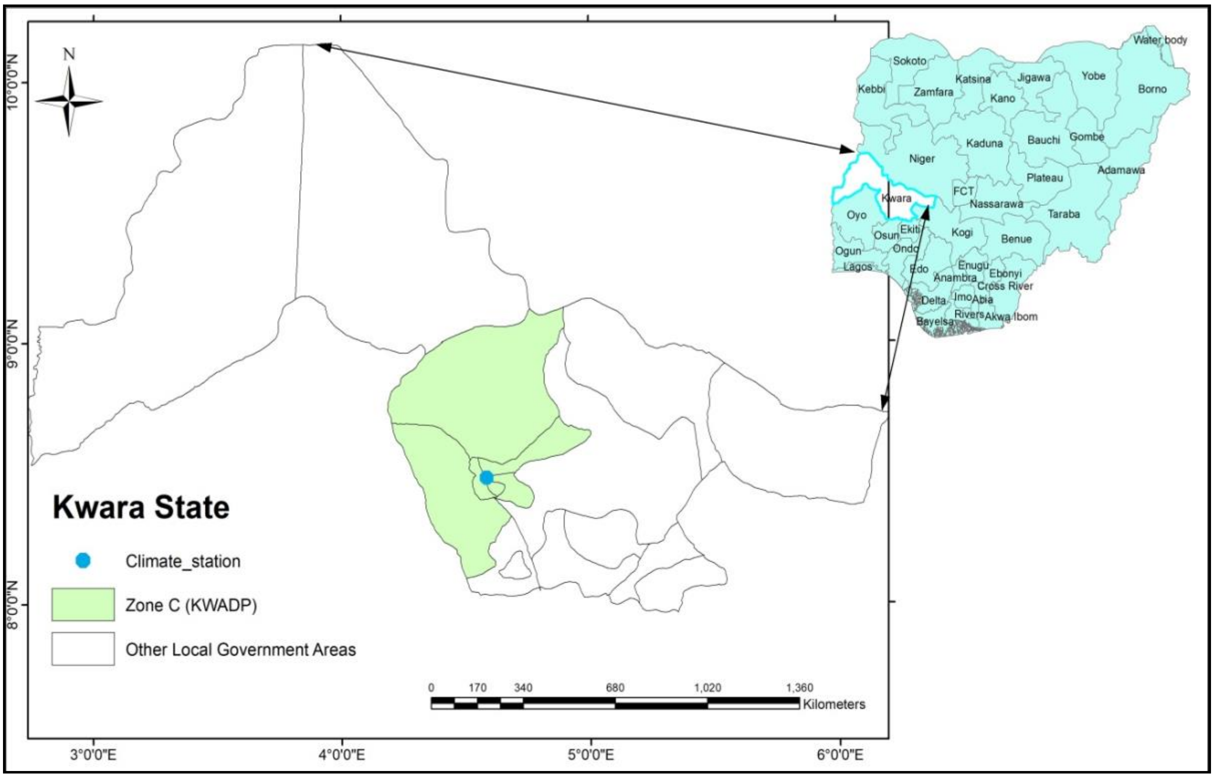


Figure 1: Map of Nigeria showing Zone C of Kwara State

Data Collection

Data on daily rainfall (mm) and maximum and minimum temperatures (°C), covering the period from 1981 to 2010, were collected from the Hydrology Section of the Lower Niger River Basin and Rural Development Authority in Ilorin, Kwara State, as well as from the Nigerian Meteorology Agency (NiMet) in Abuja. Data quality control was performed using Microsoft Excel and the Rclimdex package. The 12km resolution regional climate models' output from the Weather Research and Forecasting Model WRFv3.5.1, which was driven by the General Fluid Dynamics Laboratory Earth System Model (GFDL-ESM2M) and the Hadley Global Environment Model (HadGEM2-ES) for Representative Concentration Pathways (RCP4.5), was obtained from the West African Science Service Center on Climate Change (WASCAL) geoportal (Heinzeller *et al.*, 2016). The choice of RCP4.5 was driven by its realistic mitigation pathway, policy relevance, comparability with other scenarios, and availability of supporting data and models, as well as its role as a reference for a strong mitigation strategy (Van Vuuren *et al.*, 2011). It allows for a focused investigation of a potential future trajectory that aligns with the climate targets set by the Paris Agreement, which aims to limit global warming to around 2°C above pre-industrial levels. Furthermore, it has implications for policy and decision-making on various aspects of society, such as agriculture, water resources, ecosystems, and human health (Ibid.). The data from RCMs used in this study cover the baseline period (1981-2005) and the future period (2020-2049) for daily rainfall, minimum temperatures, and maximum temperatures.

Table 1: Description of the Regional Climate Models

GCM	RCM	Institution	Resolution
HadGEM2-ES	WRF-H	WASCAL / KIT/IMK-IFU	12km
GFDL-ESM2M	WRF-G	WASCAL / KIT IMK-IFU	12km

Data Analysis

Bias-Correction of RCMs Datasets

The biases in the rainfall and temperature outputs from the two RCMs were corrected using Local Intensity Scaling and Variance Scaling bias-correction methods found in the Climate Model Data for Hydrologic Modelling (CMhdy) tool (Rathjens *et al*., 2015). The Variance Scaling method was used to correct both the mean and variance of temperature time series (Chen *et al.*, 2011). Additionally, the Local Intensity Scaling method, known for effectively improving RCMs rainfall data, was employed to correct mean biases, wet-day frequencies, and intensities of rainfall (Schmidli *et al.*, 2007). For the future (2020-2049) climate analysis of the study area, an ensemble mean of the bias-corrected RCMs was utilized.

Climate Extreme Indices: Computation and Trend Analysis

Several indicators have been established by the Expert Team on Climate Change Detection Monitoring Indices (ETCCDMI) for understanding climate extremes and trends (Mouhamed *et al*., 2013). These indicators have been applied in various regions for the analysis of extreme events (N'TchaM'Po *et al.*, 2017; Larbi *et al*., 2021). Table 2 presents the eleven climate indices selected for this study, which were computed using RClimdex on the R programming software interface. The indices were calculated based on a common 30-year baseline for historical (1981-2010) and future (2020-2049) periods. In the analysis of extreme climate index trends, a non-parametric Mann-Kendall (MK) test and Sen's slope estimator were employed, which are widely used statistical methods for trend detection and quantification of hydro-climatic variables (Okafor *et al*., 2017). These analyses were conducted using MAKESENS software. The MK test (Equations 1 and 2) assumes a null hypothesis (Ho) of no trend, which is tested against the alternative hypothesis (H_1) of the presence of a trend (Önöz and Bayazit, 2003). The null hypothesis (H_0) is rejected when $|Z_s| \geq Z_{\alpha/2}$ at a significance level of $\alpha = 0.05$. The standard normal test statistic Z_s (Equation 2) indicates a trend in the data series, with a positive or negative value indicating increasing or decreasing trends, respectively.

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} \mathrm{Sgn}(X_j - X_k) \qquad (1)$$

$$Z_s = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}}, for\ s > 0 \\ 0, for\ s = 0 \\ \dfrac{S+1}{\sqrt{VAR\ (S)}}, for\ s < 0 \end{cases} \qquad (2)$$

Table 2. Climate Extreme Indices

Indices	Descriptive Name	Definition	Units
RX5day	Max-5-day rainfall amount	Annual maximum consecutive 5-day rainfall	mm
R99p	Extremely wet days	Annual total rainfall on the days when daily PRCP > 99th percentile	mm
R20mm	Number of very heavy rainfall days	Annual counts of days when PRCP ≥ 20mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with PRCP ≥ 1mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with PRCP< 1mm	days
TX90p	Warm days	Percentage of days when Tmax > 90th percentile	days
TN90p	Warm nights	Percentage of days when Tmin > 90th percentile	days
TX10p	Cool days	Percentage of days when Tmax < 10th percentile	days
TN10p	Cool night	Percentage of days when Tmin < 10th	days

		percentile	
TXx	Warmest day	Annual maximum value of the daily max temperature	°c
TNx	Warmest night	Annual maximum value of daily min temperature	°c

Results and Discussion

Temperature and Rainfall Projections

Figures 2 and 3 display the time series of the ensemble mean projection of monthly and annual mean rainfall and temperature for Ilorin under the RCP4.5 climate change scenario, relative to the baseline period.

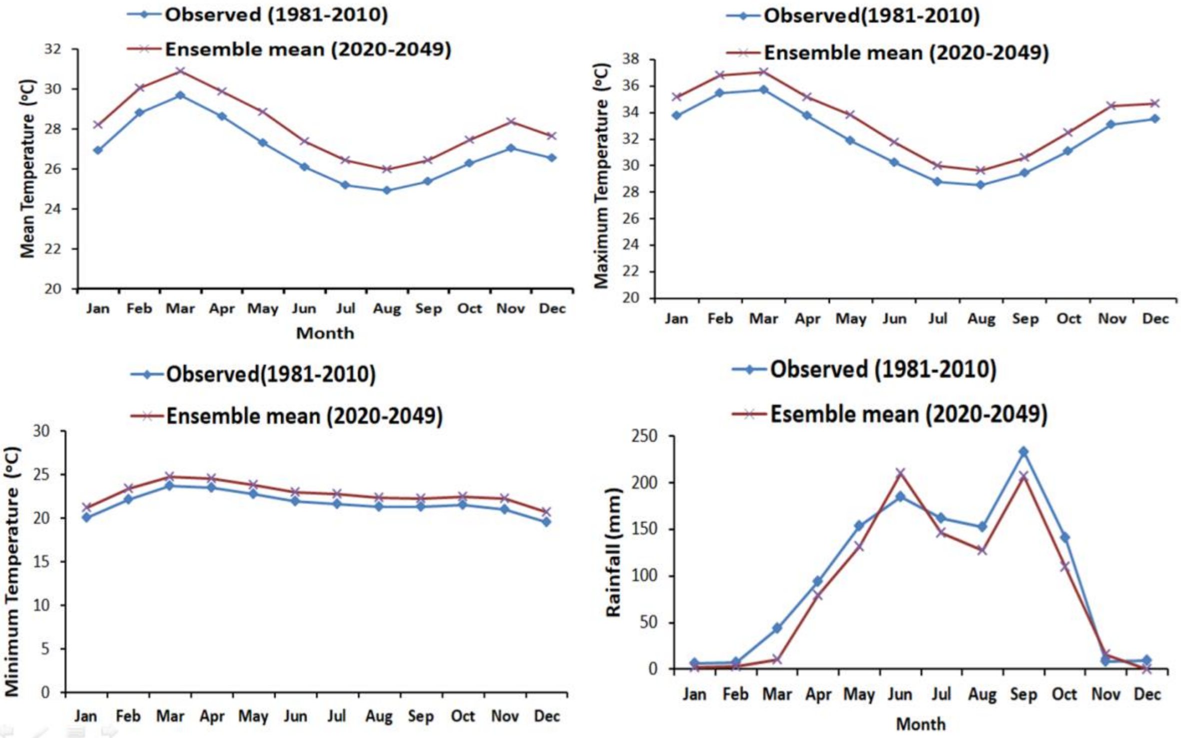


Figure 2: Mean monthly temperature and rainfall projections for Ilorin based on the ensemble mean under the RCP4.5 scenario

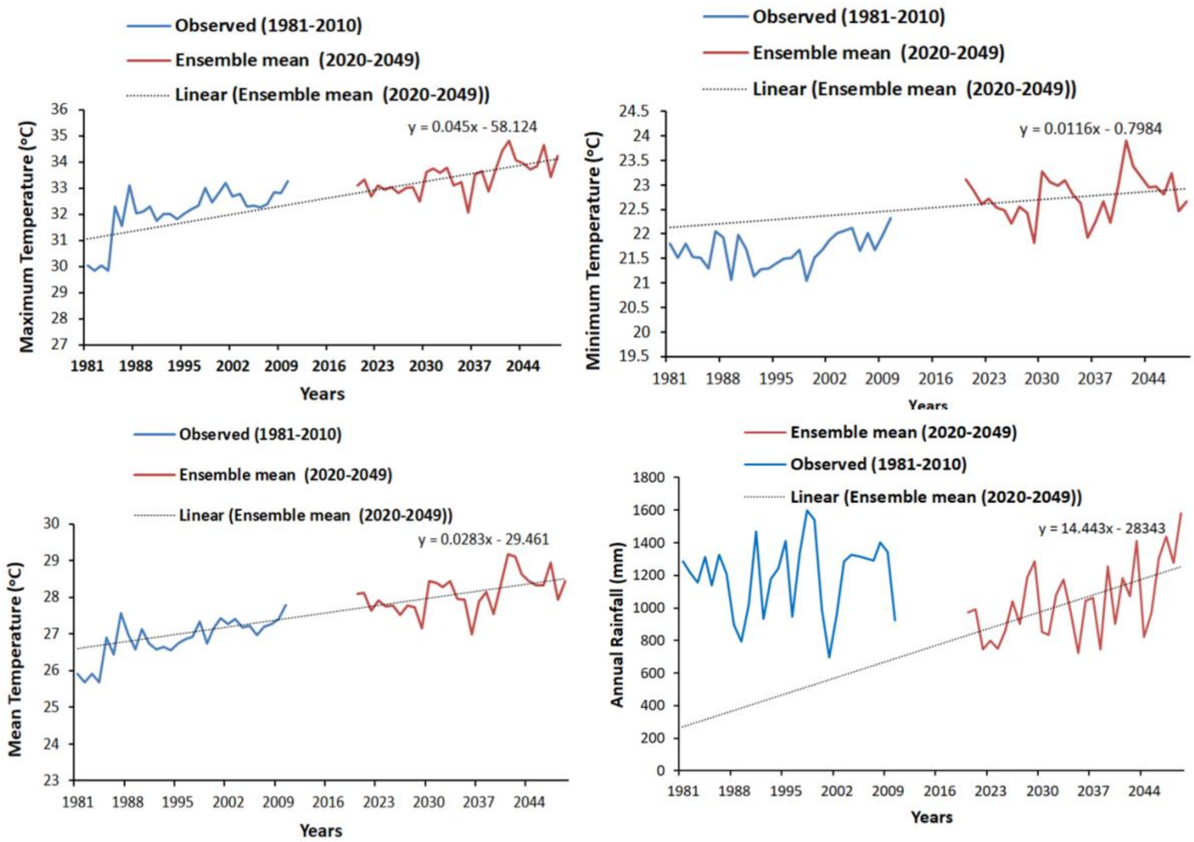


Figure 3: Mean annual temperature and rainfall projections for Ilorin based on the ensemble mean under the RCP4.5 scenario

On a monthly scale, as shown in Table 3, the mean monthly temperature is projected to increase by 1.2°C for both the rainy season (AMJJASO) and the dry season (NDJFM). This finding aligns with Coumou *et al.*'s (2013) study on the global increase in record-breaking monthly mean temperatures. Their study suggests an 80% chance of mean monthly temperature increases in most countries in Africa due to climate change impacts, such as prolonged heatwaves. These temperature increases will have implications for agriculture and other climate-dependent sectors. Additionally, other studies indicate that the rise in mean monthly temperature not only affects people's livelihoods but also has adverse effects on health, as the number of malaria cases is expected to increase over time (Antwi-Agyei *et al.*, 2014; Ampadu *et al.*, 2018; Agyekum *et al.*, 2021).

Table 3: Mean seasonal rainfall and temperature projections for Ilorin, Kwara State under RCP4.5 Scenario

Climate Variable	**AMJJASO Season**		**NDJFM Season**	
	1981-2010	**2020-2049**	**1981-2010**	**2020-2049**
Maximum temperature (°C)	30.53	31.93 (1.39)	34.31	35.63(1.34)
Minimum temperature (°C)	21.96	23.02 (1.06)	21.27	22.41(1.14)
Mean temperature (°C)	26.25	27.47 (1.2)	27.79	29.0 (1.2)
Rainfall (mm)	160.02	144.16 (-4.5%)	14.95	6.39(-57.0%)

NB: Values in brackets indicate the changes that had occurred over the two periods.

Table 4: Mean annual rainfall and temperature projections for Ilorin, Kwara State

Climate Variable	Baseline (1981-2010)	RCP4.5 (2020-2049)	Change (%)
maximum temperature (^oC)	32.08	33.45	1.37
minimum temperature (^oC)	21.66	22.76	1.09
mean temperature (^oC)	26.85	28.10	1.23
rainfall (mm)	1194.9	1041.1	-12.87%

The maximum temperature is projected to increase by 1.39°C (rainy season) and 1.34°C (dry season), which is higher in both seasons compared to the increase in minimum temperature of 1.06°C (rainy season) and 1.14°C (dry season). This finding is consistent with the minimum and maximum temperature trends observed globally, as studied by Easterling *et al.* (1997), which show that both rainy and dry seasons are likely to be characterized by high maximum temperatures due to the impacts of climate change and climate variability. The mean annual temperature is projected to increase by 1.3°C in the future (2020-2049). This increase is accompanied by a warming trend of 0.02°C per year (Figure 3). In the future (2020-2049), the annual maximum temperature is projected to increase by 1.37°C at a faster rate of 0.045°C per year compared to the increase in minimum temperature of 0.01°C per year. A study by Engelbrecht *et al.* (2015) suggests that the rate of increase in maximum temperatures is relatively higher than that of minimum temperatures across countries on the African continent, which supports the findings of this study. According to Misra (2014), these observed increases in minimum and maximum temperatures have implications for hydrological regimes, with varied impacts on crop yield, water productivity, and food security across most countries in Africa. Regarding rainfall, the research findings indicate a projected decrease of 12.87% in mean annual rainfall for the future compared to the baseline period (Table 4). This decrease suggests that the study area may experience reduced rainfall in the coming years. However, it is important to note that changes in rainfall patterns in the study area may not be uniform across the country. As observed by Shiru and Park (2020) under two scenarios, RCPs 4.5 and 8.5, while some regions of Nigeria, such as the Northwest, may experience a decrease in annual rainfall, others may see an increase, leading to spatial variations in rainfall patterns.

The peaks of the rainy season were observed to increase by 5% for the month of June, implying a potential intensification of rainfall events during that period. On the other hand, there was a decrease of 2% in the peaks of the rainy season month for September, indicating a potential decrease in rainfall intensity during that time. These findings highlight the variable nature of rainfall patterns in the area. The mean monthly rainfall over the study period was found to decrease by 4.5% during the rainy season and by a significant 57.0% during the dry season. These decreases in rainfall align with previous studies that indicate future projections of a shorter rainy season and growing season in West Africa, along with an extension of torrid, arid, and semi-arid climate conditions (Sylla *et al*., 2016a; Sylla *et al*., 2016b). These changes in rainfall can be attributed to global climate change impacts, including alterations in temperature and surface water supply (De Wit and Stankiewicz, 2006). The observed decrease in rainfall patterns raises concerns about the availability of freshwater resources, not only in the study area but also globally. This decrease in rainfall has implications for water management and potential conflicts over water resources (Unfried *et al*., 2022). As rainfall becomes more variable and potentially decreases in the study area, the overall availability of freshwater resources may be further strained.

Projected Changes in Climate Extreme Indices

Rainfall Indices

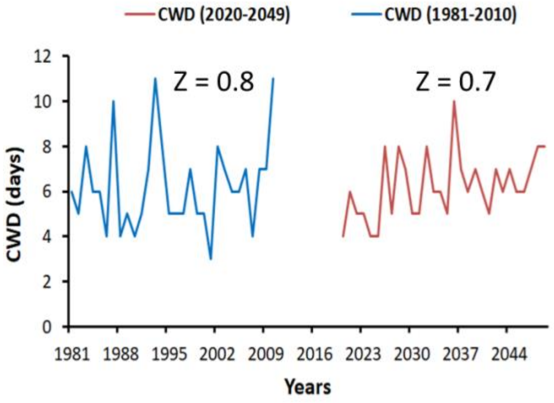
The results of the Mann-Kendall trend test statistics for the extreme rainfall indices over the baseline and future periods are presented in Table 5 and Figure 4. The findings suggest that most of the rainfall indices are projected to decrease in the future, with the exception of consecutive dry days (CDD), which shows an increase of 53%. Specifically, the annual maximum consecutive 5-day rainfall is observed to decline at a rate of 1.04mm/year. This decline indicates a decreasing trend in prolonged heavy rainfall events, which can have implications for water availability and management in the study area and other regions of Nigeria. It is important to note that consecutive wet days (CWD) exhibit a decreasing trend, while consecutive dry days

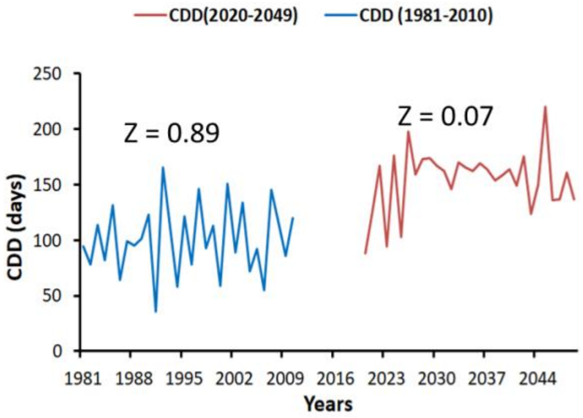
(CDD) display a slight increasing trend, although it is not statistically significant. The decrease in consecutive wet days may adversely affect aquatic ecosystem productivity (Benavides-Gordillo *et al.*, 2019), and changes in rainfall patterns can impact agriculture and livestock production in rangeland ecosystems (Alkemade *et al.*, 2013). With fewer consecutive wet days, the availability of water for crops, grazing lands, and livestock can be compromised, posing challenges for food security and livelihoods. Furthermore, the observed trends in rainfall indices have implications for renewable groundwater supplies in communities (Döll, 2009). As consecutive dry days increase and rainfall decreases, the replenishment of groundwater sources may be negatively affected. This situation can pose threats to water security, particularly when adequate climate change adaptation measures are not implemented.

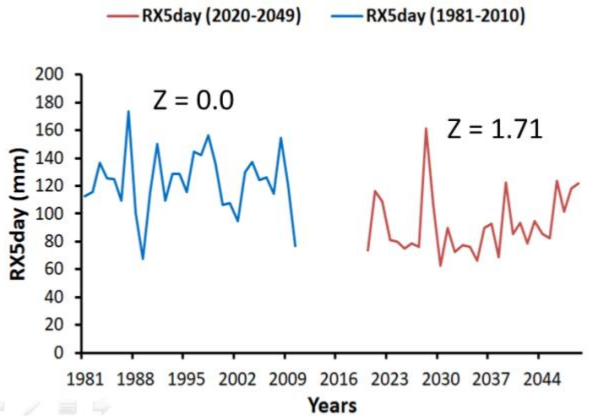
Table 5: Projected Changes in Rainfall Extreme Indices in Ilorin, Kwara State

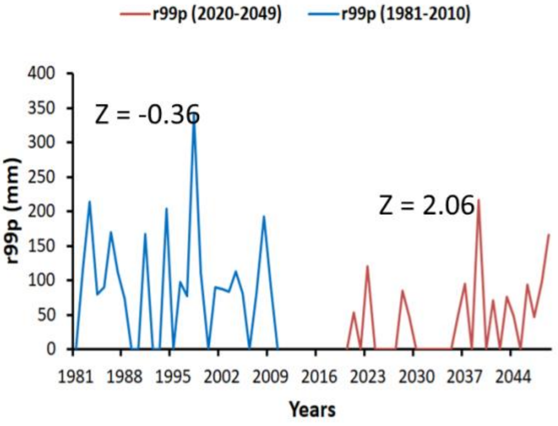
Descriptive names (Units)	**Baseline (1981-2010)**	**Ensemble (2020-2049)**	**Change**
Consecutive wet days, CWD (days)	6.2 (0.01)	5.4(0.07)	-0.8(12.9%)
Consecutive dry days, CDD (days)	100.7 (0.44)	154.3 (0.33)	53.5 (53%)
Max-5-day rainfall amount, RX5day (mm)	122.8 (0.02)	92.0 (0.65)	-30.0 (25%)
Extremely wet days, R99p (mm)	89.1(0.00)	42.3 (0.02*)	-46.7(52%)
Number of very heavy rainfall days, R20 (days)	20.3 (0.04)	9.2 (0.09)	-11.0 (54%)

Values in the bracket indicate Sen's slope; negative/positive value indicates a decrease/increase in trend respectively; * means statistically significant at 5% level









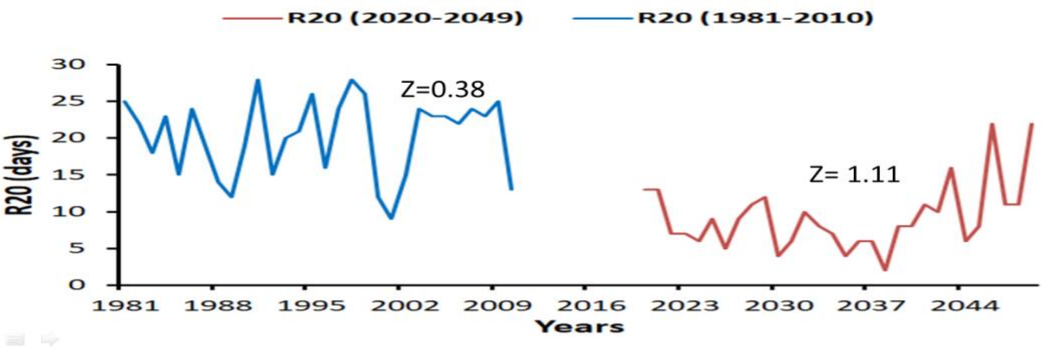


Figure 4: Extreme rainfall Indices in Ilorin for the baseline line (1981-2010) and Future (2020-2049) periods with Man-Kendall trend statistics (Z)

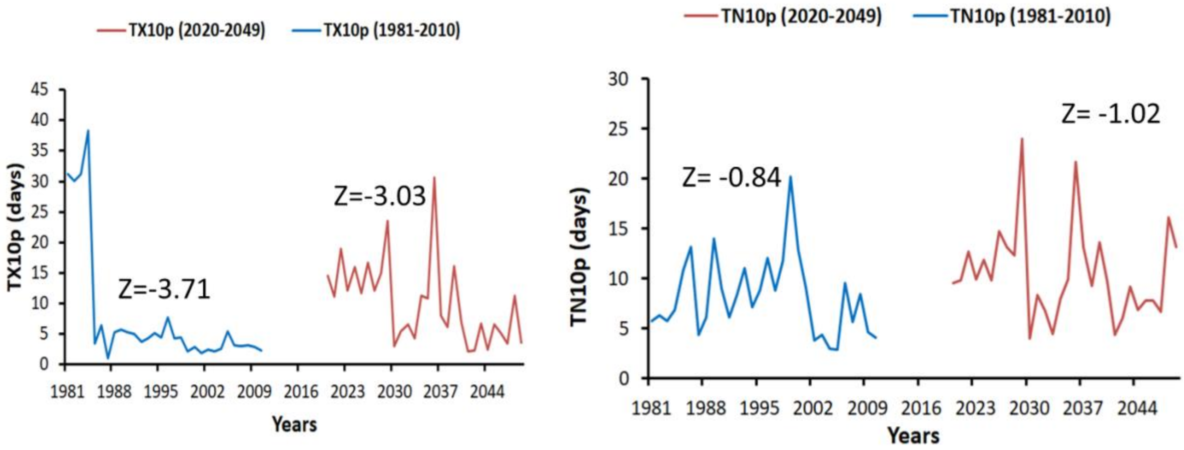
Temperature Indices

The analysis of temperature extreme indices shows a significant increasing trend in the annual number of warm days (TX90p) and warm nights (TN90p) in the future period of 2020-2049 (Table 6 and Figure 5).

Table 6: Projected Changes in Temperature Extreme Indices in Ilorin, Kwara State

Descriptive names (Units)	**Baseline (1981-2010)**	**Ensemble (2020-2049)**	**Change**
Warm days, TX90p (days)	7.3 (3.53)	10.5 (0.403*)	3.1 (42%)
Warm nights, TN90p (days)	7.1 (3.27*)	10.5 (0.255*)	3.4 (47%)
Cool days, TX10p (days)	7.7 (-0.177*)	10.2 (-0.378*)	2.4 (31%)
Cool night, TN10p (days)	8.2 (-0.06)	10.5 (-0.07)	2.3 (28%)
Warmest day, TXx (°c)	38.9 (0.01)	40.3 (0.01)	1.4 (3%)
Warmest night, TNx (°c)	26.3 (0.02)	28.0 (0.029)	1.7 (6%)

Values in bracket indicate Sen's slope; negative/positive value indicates a decrease/increase in trend respectively; * means statistically significant at 5% level



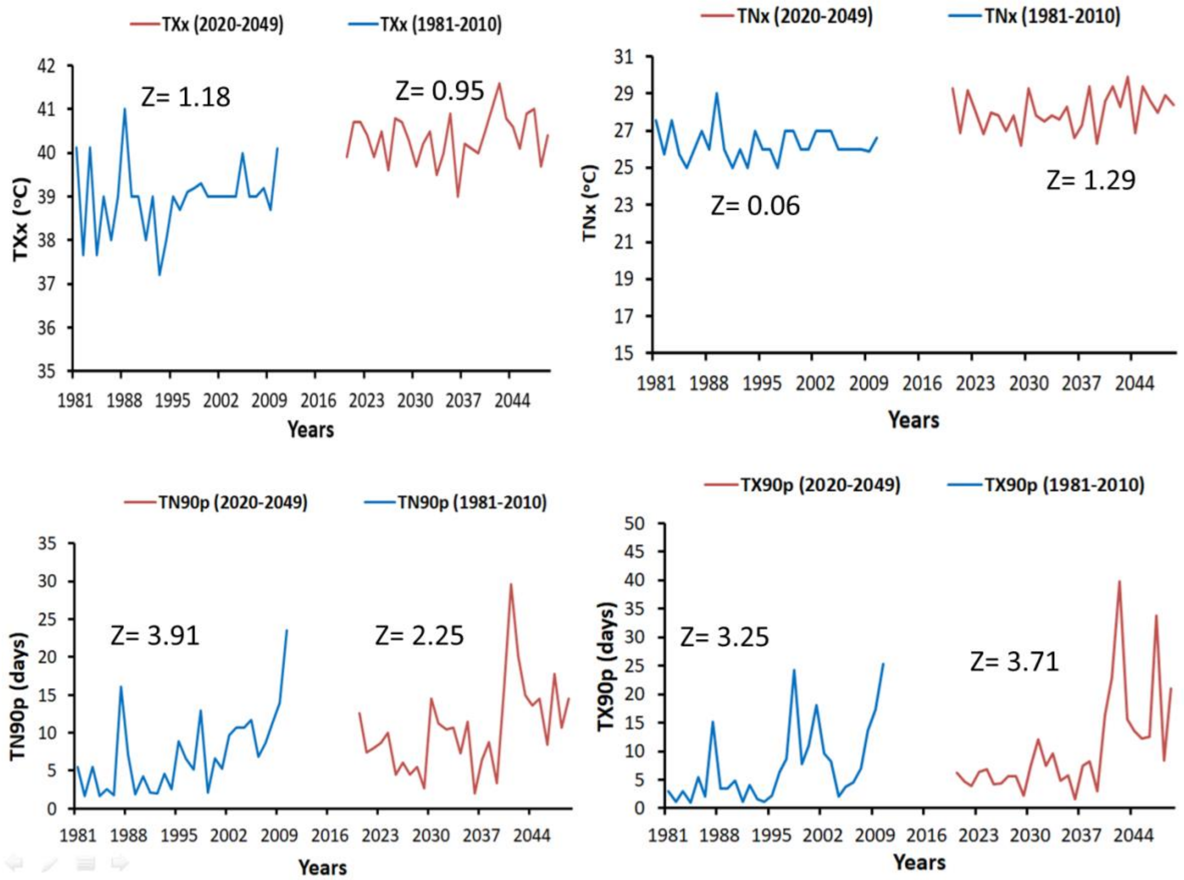


Figure 5: Extreme temperature indices in Ilorin for the baseline line (1981-2010) and Future (2020-2049) periods with Man-Kendall trend statistics (Z)

Decreasing trends were observed for cool days (TX10p) and cool nights (TN10p), with the trend for cool days being significant in both the historical and future periods. This indicates that both nighttime and daytime temperatures are getting warmer, which aligns with the findings of Abdussalam's study (2015) conducted in the north-western part of Nigeria. The findings are also consistent with other previous studies that indicate a general warming trend in Nigeria, projecting an increase in average temperatures for both daytime and nighttime (Akinsanola and Ogunjobi, 2014; Ragatoa *et al*., 2018; Gbode *et al*., 2019). Shiru *et al*.'s study (2020) specifically suggests that temperature increases are expected to be more pronounced in the northern regions of Nigeria, including the Northwest, compared to the southern regions. The annual maximum values of daily minimum temperature (TNx) and maximum temperature (TXx) are projected to increase by 1.7°C and 1.4°C, respectively, in the future. The Mann-Kendall (MK) test indicates an increasing trend in TNx (0.02°C/year) and TXx (0.01°C/year) for both the baseline and future periods. This indicates a higher warming of nighttime temperatures compared to daytime temperatures, which aligns with the findings of Abatan *et al*.'s study (2018) on trends in extreme temperature indices across Nigeria.

The higher nighttime temperatures in the area can have far-reaching implications for various sectors, especially the energy sector, as the population may resort to higher energy consumption through the use of cooling devices such as air conditioners and fans. Additionally, the population without access to energy may be at risk of heat-related diseases. The analysis of extreme indices provides evidence of significant changes in the occurrence of extreme climate events, particularly regarding temperature, over the past decades (1981-2010). In general, the study area exhibits significant changes in climate extremes, especially in relation to temperature. These findings are consistent with Auwal *et al*.'s study (2022), which suggests that heatwaves and extremely high temperatures are likely to become more frequent in Nigeria, resulting in increased risks to human health, agriculture, and water resources. Auwal *et al*. (2022) further posit that heatwaves are expected to increase in intensity and duration in Nigeria, posing risks to human health and increasing energy demands for cooling.

Conclusion and Recommendation

The study assessed the impact of climate change under the RCP4.5 scenario on rainfall, temperature, and their extreme indices in Ilorin, Kwara State. The ensemble mean of the regional climate model analysis of rainfall and temperature projections for the area shows a drier and warmer climate in the future, 2020-2049. Extreme climate indices analysis revealed a decrease in most of the extreme rainfall indices in the future, 2020-2049, except for consecutive dry days (CDD), which shows an increase. The temperature extreme indices, on the other hand, show significant increasing trends in the future, especially with the percentile-based indices. There has been a warming trend over the past decades, mostly dominated by an increase in the daily minimum temperature, though not significant. Among other challenges, the projected changes could lead to water scarcity, decreased agricultural productivity, and increased health risks. It is, therefore, crucial for policymakers in Kwara State and other areas with similar climatic conditions to take action to build the resilience of the communities to be able to adapt to the effects of climate change and the changing conditions to minimize their impact on the population and the local economy. This should include the dissemination of climate information and various adaptation strategies to ensure future food security in the area.

References

Abatan, A.A., Abiodun, B.J., Gutowski, W.J., & Rasaq-Balogun, S.O. (2018). Trends and variability in absolute indices of temperature extremes over Nigeria: linkage with NAO. *International Journal of Climatology,* 38, 593–612. doi:10.1002/joc.5196.

Abdussalam, A. F. (2015). Changes in indices of daily temperature and precipitation extremes in northwest Nigeria. *Science World Journal*, 10(2), 18-26.

Adeola, R. A. (2018). Climate variability and Nigerian agriculture: A review. *Journal of Environmental Managemen*t, 221, 195-213.

Agovino, M., Casaccia, M., Ciommi, M., Ferrara, M., & Marchesano, K. (2019). Agriculture, climate change and sustainability: The case of EU-28. *Ecological Indicators*, 105, 525-543.

Agyekum, T. P., Botwe, P. K., Arko-Mensah, J., Issah, I., Acquah, A. A., Hogarh, J. N., Dwomoh, D., Robins, T. G., & Fobil, J. N. (2021). A Systematic Review of the Effects of Temperature on Anopheles Mosquito Development and Survival: Implications for Malaria Control in a Future Warmer Climate. *International Journal of Environmental Research and Public Health*, 18(14), 7255. doi:10.3390/ijerph18147255

Akinsanola, A.A., & Ogunjobi, K.O. (2014). Analysis of rainfall and temperature variability over Nigeria. *Global Journal of Human-Social Science: B Geography, geo-sciences, Environmental Disaster Management*, 14(3), 1-17.

Alemu, T., & Mengistu, A. (2019). Impacts of climate change on food security in Ethiopia: adaptation and mitigation options: a review. In Climate Change-Resilient Agriculture and Agroforestry: *Ecosystem Services and Sustainability* (pp. 397-412).

Alexander, L.V. (2016). Global observed long-term changes in temperature and precipitation extremes: A review of progress and limitations in IPCC assessments and beyond. *Weather and Climate Extremes*, 11, 4-16.

Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J., & Jeuken, M. (2013). Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.1011013108.

Almazroui, M. (2020). Changes in temperature trends and extremes over Saudi Arabia for the period 1978–2019. *Advances in Meteorology*, 1-21.

Amoak, D., Luginaah, I., & McBean, G. (2022). Climate change, food security, and health: Harnessing agroecology to build climate-resilient communities. *Sustainability,* 14(21), 13954.

Ampadu B., Boateng E.F., Abassa M.A. (2018). Assessing Adaptation Strategies to the Impacts of Climate Change: A Case Study of Pungu–Upper East Region, Ghana. *Environmental and Ecological Research*, 6, 33–44. doi:10.13189/eer.2018.060.

Ankrah, J., Monteiro, A., & Madureira, H. (2023). Extreme Temperature and Rainfall Events and Future Climate Change Projections in the Coastal Savannah Agroecological Zone of Ghana. *Atmosphere*, 14(2), 386.

Antwi-Agyei, P., Stringer, L. C., & Dougill, A. J. (2014). Livelihood adaptations to climate variability: Insights from farming households in Ghana. *Regional Environmental Change*, 14, 1615-1626. doi:10.1007/s10113-014-0597-9.

Auwal, A. H., Bello, N. I., Alhaji, M., & Baba, K. A. (2022). Assessment of heatwave intensity and associated human responses in Kano Metropolis Northwestern Nigeria (2001-2020). *International Journal of Energy Applications and Technologies*, 9(3), 55-63.

Benavides-Gordillo, S., Farjalla, V. F., González, A. L., & Romero, G. Q. (2019). Changes in rainfall level and litter stoichiometry affect aquatic community and ecosystem processes in bromeliad phytotelmata. *Freshwater Biology*, 64(8), 1357-1368.

Chemura, A., Nangombe, S. S., Gleixner, S., Chinyoka, S., & Gornott, C. (2022). Changes in Climate Extremes and Their Effect on Maize (Zea mays L.) Suitability Over Southern Africa. *Frontiers in Climate*, 4, 890210. doi:10.3389/fclim.2022.890210.

Chen, I. C., Hill, J. K., Ohlemüller, R., Roy, D. B., & Thomas, C. D. (2011). Rapid range shifts of species associated with high levels of climate warming. Science, 333, 1024–1026. doi:10.1126/science.1206432.

Coumou, D., Robinson, A., & Rahmstorf, S. (2013). Global increase in record-breaking monthly-mean temperatures. *Climatic Change*, doi:10.1007/s10584-012-0668-1.

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J. P., Iglesias, A., Lange, M. A., Lionello, P., Llasat, M. C., Paz, S., & Peñuelas, J. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change*, 8(11), 972-980.

De Wit, M., & Stankiewicz, J. (2006). Changes in surface water supply across Africa with predicted climate change. *Scienc*e, doi:10.1126/science.1119929.

Döll, P. (2009). Vulnerability to the impact of climate change on renewable groundwater resources: A global-scale assessment. *Environmental Research Letters*, doi:10.1088/1748-9326/4/3/035001.

Easterling, D. R., Horton, B., Jones, P. D., Peterson, T. C., Karl, T. R., Parker, D. E., Salinger, M. J., Razuvayev, V., Plummer, N., Jamason, P., & Folland, C. K. (1997). Maximum and minimum temperature trends for the globe. *Science*, 277(5324), 364-367.

Ebi, K. L., & Bowen, K. (2016). Extreme events as sources of health vulnerability: Drought as an example. *Weather and Climate Extremes*, 11, 95-102.

Engelbrecht, F., Adegoke, J., Bopape, M.J., Naidoo, M., Garland, R., Thatcher, M., McGregor, J., Katzfey, J., Werner, M., Ichoku, C., & Gatebe, C. (2015). Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environmental Research Letters*, 10(8), 085004.

Gbode, I.E., Adeyeri, O.E., Menang, K.P., Intsiful, J.D., Ajayi, V.O., Omotosho, J.A., & Akinsanola, A.A. (2019). Observed changes in climate extremes in Nigeria. *Meteorological Applications*, 26(4), 642-654.

Heinzeller, D., Junkermann, W., Kunstmann, H., Heinzeller, D., Junkermann, W., & Kunstmann, H. (2016). *Anthropogenic Aerosol Emissions and Rainfall Decline in Southwestern Australia: Coincidence or Causality?* J. Clim., 29, 8471–8493. doi:10.1175/JCLI-D-16-0082.1

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, & L.L. White (Eds.)]. Cambridge University Press.

James, R., & Washington, R. (2013). Changes in African temperature and precipitation associated with degrees of global warming. *Climatic Change*, 117(4), 859-872.

Kasei, R.A. (2014). Modelling in the Semi-Arid Volta Basin of West Africa. *Intech open*, 2(64). doi:10.5772/32009.

Kotir, J.H. (2011). Climate change and variability in Sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security. *Environment, Development and Sustainability*, 13, 587-605.

Larbi, I., Bessah, E., Nyamekye, C., Amuzu, J., Okafor, G.C., Kwawuvi, D., & Asare, Y.M. (2021). Changes in length of rainy season and rainfall extremes under moderate greenhouse gas emission scenario in the Vea catchment, Ghana. *Journal of Water and Climate Change*.

doi/10.2166/wcc.2021.316/874844/jwc2021316.pdf

Larbi, I., Gana, A.S., Nmadu, J.N., Okhimamhe, A.A., & Hima, M.B.G. (2016). Evaluation of root and tuber crop yield under the changing climatic condition in Kwara State, Nigeria. *Asian Journal of Economics, Business and Accounting*, 1(2), 1-9. doi:10.9734/AJEBA/2016/28441

Lelieveld, J., Proestos, Y., Hadjinicolaou, P., Tanarhte, M., Tyrlis, E., & Zittis, G. (2016). Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. *Climatic Change*, 137(1), 245-260.

Lu, S., Bai, X., Zhang, X., Li, W., & Tang, Y. (2019). The impact of climate change on the sustainable development of regional economy. *Journal of Cleaner Production*, 233, 1387-1395.

Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., & Shukla, P.R. (2022). *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. Cambridge University Press.

Mbow, H.O.P., Reisinger, A., Canadell, J., & O'Brien, P. (2017). *Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SR2)*. Ginevra, IPCC, 650.

Misra, A.K. (2014). Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment*, 3(1), 153-165.

Mouhamed, L., Traore, S.B., Alhassane, A., & Sarr, B. (2013). Evolution of some observed climate extremes in the West African Sahel. *Weather Clim*. Extrem., 1, 19–25.

N'TchaM'Po, Y., Lawin, E., Yao, B., Oyerinde, G., Attogouinon, A., & Afouda, A. (2017). Decreasing Past and Mid-Century Rainfall Indices over the Ouémé River Basin, Benin (West Africa). *Climate*, 5, 74. doi:10.3390/cli5030074.

National Bureau of Statistics (NBS). (2009). *Commercial Agriculture Development Project (CADP).* NBS/CADP Baseline Survey Report.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2014). Africa. In V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, & L.L. White (Eds.), Climate Change 2014: *Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1199-1265).* Cambridge University Press.

Nikulin, G., Lennard, C., Dosio, A., Kjellström, E., Chen, Y., Hänsler, A., Kupiainen, M., Laprise, R., Mariotti, L., Maule, C.F., & van Meijgaard, E. (2018). The effects of 1.5 and 2 degrees of global warming on Africa in the CORDEX ensemble. *Environmental Research Letters*, 13(6), 065003.

Ogundele, O.O., Fosu, M., & Amikuzuno, J. (2019). Farmers' Perceptions of Climate Change and Variability in Nigeria: The Role of Knowledge, Perceived Exposure, and Socio-demographics. *Journal of Agricultural Extension*, 23(2), 30-44.

Okafor, C.G., Jimoh, O.D., & Larbi, I. (2017). Detecting Changes in Hydro-Climatic Variables during the Last Four Decades (1975-2014) on Downstream Kaduna River Catchment, Nigeria. *Atmospheric and Climate Sciences*, 7(2), 161-175. https://doi.org/10.4236/acs.2017.72012

Olanrewaju, R.M. (2009). *Effect of climate on Yam Production in Kwara State*, Nigeria. Environmental Issues, Department of Geography and Environmental Management, University of Ilorin, Ilorin.

Önöz, B., & Bayazit, M. (2003). *The power of statistical tests for trend detection*. Turk. J. Eng. Environ. Sci., 27, 247–251.

Parvin, G.A., Fujita, K., Matsuyama, A., Shaw, R., & Sakamoto, M. (2015). Climate change, flood, food security and human health: cross-cutting issues in Bangladesh. *In Food Security and Risk Reduction in Bangladesh* (pp. 235-254).

Pörtner, H.O., Roberts, D.C., Adams, H., Adler, C., Aldunce, P., Ali, E., Begum, R.A., Betts, R., Kerr, R.B., Biesbroek, R., & Birkmann, J. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Geneva, Switzerland: IPCC.

Ragatoa, D.S., Ogunjobi, K.O., Okhimamhe, A.A., Francis, S.D., & Adet, L. (2018). A trend analysis of temperature in selected stations in Nigeria using three different approaches. *Open Access Library Journal*, 5(2), 1-17.

Rathjens, H., Oppelt, N., Bosch, D.D., Arnold, J.G., & Volk, M. (2015). Development of a grid-based version of the SWAT landscape model. Hydrol. *Process*., 29, 900–914. doi:10.1002/hyp.10197.

Schmidli, J., Goodess, C.M., Frei, C., Haylock, M.R., Hundecha, Y., Ribalaygua, J., & Schmith, T. (2007). Statistical and dynamical downscaling of precipitation: An evaluation and comparison of scenarios for the European Alps. J. *Geophys. Res. Atmos*., 112, 4105. doi:10.1029/2005JD007026.

Shiru, M. S., & Park, I. (2020). *Comparison of ensembles projections of rainfall from four bias correction methods over Nigeria. Water*, 12(11), 3044.

Shiru, M.S., Shahid, S., Dewan, A., Chung, E.S., Alias, N., Ahmed, K., & Hassan, Q.K. (2020). *Projection of meteorological droughts in Nigeria during growing seasons under climate change scenarios*. Scientific reports, 10(1), 1-18.

Shrestha, A.B., Bajracharya, S.R., Sharma, A.R., Duo, C., & Kulkarni, A. (2017). Observed trends and changes in daily temperature and precipitation extremes over the Koshi river basin 1975–2010. *International Journal of Climatology*, 37(2), 1066-1083.

Singh, D., Tsiang, M., Rajaratnam, B., & Diffenbaugh, N.S. (2014). Observed changes in extreme wet and dry spells during the South Asian summer monsoon season. *Nature Climate Change*, 4(6), 456-461.

Stott, P.A., Christidis, N., Otto, F.E., Sun, Y., Vanderlinden, J.P., van Oldenborgh, G.J., Vautard, R., von Storch, H., Walton, P., Yiou, P., & Zwiers, F.W. (2016). Attribution of extreme weather and climate-related events. Wiley Interdisciplinary Reviews: *Climate Change*, 7(1), 23-41.

Susanto, J., Zheng, X., Liu, Y., & Wang, C. (2020). The impacts of climate variables and climate-related extreme events on island country's tourism: Evidence from Indonesia. *Journal of Cleaner Production*, 276, 124204.

Sylla, M.B., Elguindi, N., Giorgi, F., & Wisser, D. (2016b). Projected robust shift of climate zones over West Africa in response to anthropogenic climate change for the late 21st century. *Climatic Change*, 134(1-2), 241-253.

Sylla, M.B., Nikiema, P.M., Gibba, P., Kebe, I., & Klutse, N.A.B. (2016a). Climate Change over West Africa: Recent Trends and Future Projections. In J. Yaro & J. Hesselberg (Eds.), *Adaptation to Climate Change and Variability in Rural West Africa* (pp. 35-54). Springer. https://doi.org/10.1007/978-3-319-31499-0_3

Unfried, K., Kis-Katos, K., & Poser, T. (2022). Water scarcity and social conflict. *Journal of Environmental Economics and Management*, 113, 102633.

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.F., & Masui, T. (2011). The representative concentration pathways: An overview. *Climatic Change*, 109(5-31).

Wilson, A.B., Avila-Diaz, A., Oliveira, L.F., Zuluaga, C.F., & Mark, B. (2022). Climate extremes and their impacts on agriculture across the Eastern Corn Belt Region of the US. *Weather and Climate Extremes*, 37, 100467.

Yaduvanshi, A., Nkemelang, T., Bendapudi, R., & New, M. (2021). Temperature and rainfall extremes change under current and future global warming levels across Indian climate zones. *Weather and Climate Extremes*, 31, 100291.