

Sokoto Journal of Geographical Studies (SJGS)



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Sokoto Journal of Geographical Studies
Department of Geography
Faculty of Social and Management Sciences
Sokoto State University, Sokoto
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TREND ANALYSIS OF AGROCLIMATIC PARAMETERS AND CROP YIELDS IN SOKOTO STATE NORTHWEST NIGERIA

Yohanna Yunusa¹, A. T. Umar² & Isah Hamisu³

¹Address: 6 Omotayo Oresanya Street Ojokoro Village Ikorodu Lagos State, Nigeria or Institutional Affiliation: Department of Geography, Usmanu Danfodiyo University, Sokoto, Nigeria

^{2&3}Department of Geography, Usmanu Danfodiyo University, Sokoto, Nigeria



Corresponding Author's Email: yyohanna19@gmail.com

Abstract

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This study examined the trends and variability of climate parameters and crop yields in Sokoto State, northwest Nigeria, recognizing the importance of climate in agricultural production. Secondary data on temperature, precipitation, humidity, solar radiation, and wind speed were obtained from NASA archives, while crop yield data for maize, millet, rice, and sorghum were sourced from national agricultural databases including NAERLS, NFRA, and NBS. Trend analysis was employed to assess trends and patterns over the 15-year period. Results revealed positive trends with intermittent fluctuations across all climate parameters, projected to persist in the near future. Maize, millet, and sorghum showed increasing yield trends, whereas rice exhibited a slight decline during the study period. Owing to fluctuations observed, the study concludes that continuous monitoring of climatic variables and adaptive crop management strategies are essential for sustainable agricultural development. It recommends integrating climate-smart agriculture and long-term planning frameworks to enhance resilience and ensure food security in the region.

Keywords: Crop Yield, Time Series Analysis, Food Security.

Introduction

Climate refers to the long-term patterns and averages of meteorological elements such as temperature, rainfall, wind, and humidity in a defined region (Ayoade, 2004). Unlike weather, which captures short-term atmospheric behavior, climate is measured over extended periods typically 30 years or more and directly influences critical sectors such as agriculture (Adejuwon, 2004). In semi-arid regions like Sokoto State, the impacts of climatic variability are especially profound due to the fragile environmental conditions for crop production (Williams *et al.*, 2018).

Key climatic variables affecting agricultural productivity include temperature, precipitation, humidity, solar radiation, and CO₂ levels. These parameters influence crop physiological processes including germination, nutrient uptake, disease resistance, and photosynthesis. Extreme weather—such as heatwaves, droughts, and heavy rainfall can cause substantial yield losses. While global research (e.g., IPCC, 2014) has emphasized the significance of climate variability, the local trends of these parameters and their relation to agricultural yields remain under-examined.

In Sokoto State, agriculture depends on climatic conditions, with food crops such as millet, maize, sorghum, and rice forming the staple base (Mundi, 2008; Tahir, 2014). However, the semi-arid climate with its unpredictable rainfall and temperature extremes poses significant

threats to productivity. While farmers frequently report reduced yields and shifting planting seasons, these claims lack supporting empirical trend data at the regional level.

There is a pressing need for localized studies that document the annual and seasonal shifts in climate parameters and corresponding crop yields. This study seeks to fill this gap by systematically analyzing meteorological and agricultural yield data over a 15-year period (2008–2022) to identify significant patterns and inform long-term planning for food security in Sokoto State.

Materials and Method

Study Area

Sokoto State is located in the extreme North-West Sudano - Sahelian Savannah ecological belt of Nigeria. The State is located between Latitude Latitudes $11^{\circ} 03'$ and $13^{\circ} 50'$ N and Longitude Equator and Longitudes $4^{\circ} 14'$ and $6^{\circ} 40'$ E of the Greenwich Meridian (Abubakar, 2006). It occupies 25,973 square kilometers. Sokoto State shares its borders with Niger Republic to the North, Zamfara State to the East, Kebbi State to the South-East and Benin Republic to the West (Figure 1). It has its headquarters in Sokoto with twenty-three (23) Local Government Areas (LGAs). As of 2024 it has an estimated population of more than 6.3 million (Sani, Muhammad & Barau, 2025).

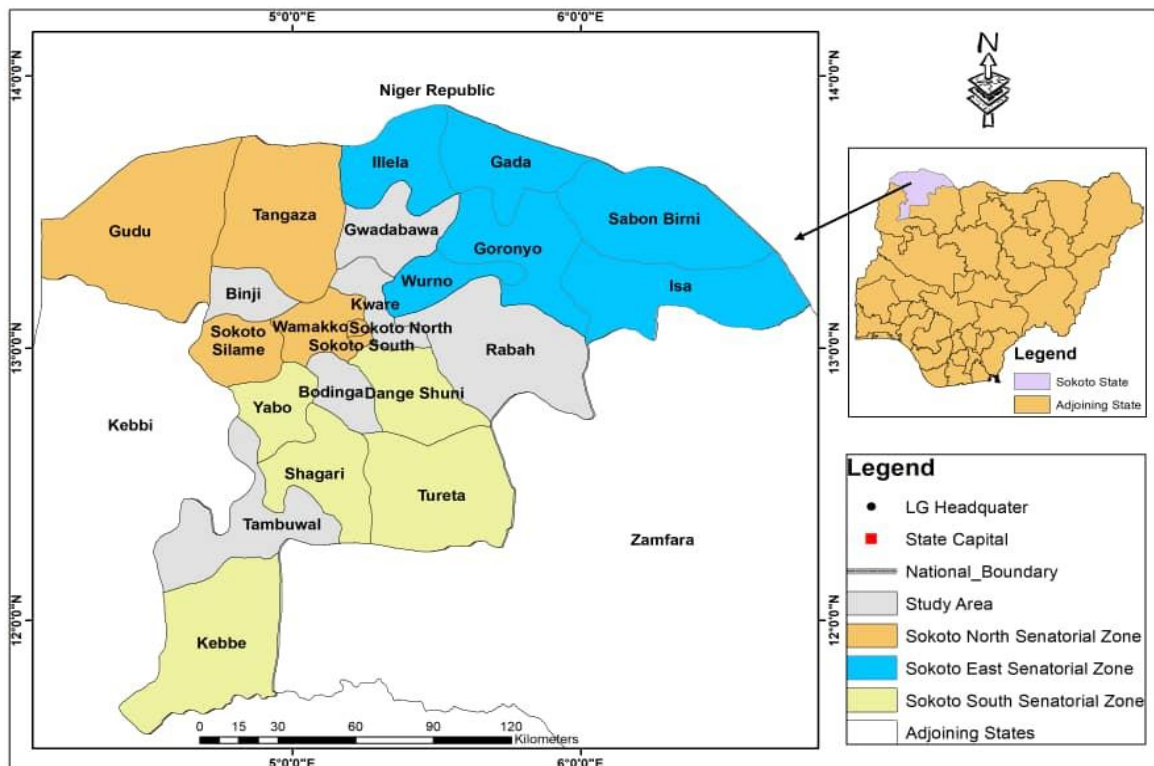


Figure 1 Map of the Study Area

Sources of Data

Annual Climatic data on maximum temperature, minimum temperature, rainfall, relative humidity, radiation, and wind, was collected from National Aeronautics and Space Administration (NASA), (2008 - 2022). This was in accordance with Azare (2014), who reported that, precipitation, solar radiation, wind, temperature, relative humidity and other climatic parameters affect and solely determine the global distribution of crops and livestock and their

yields or outputs. Corresponding 15-years crop yield data in annual Tone or yield per hectare was collected for four (4) varieties of major food crops (sorghum, maize, millet, rice) from a Publication by National Agricultural Extension and Research Liaison Services (NAERLS) and National Food Reserve Agency (NFRA) of Federal Ministry of Agriculture and Water Resources in collaboration with National Bureau of Statistics (NBS), Nigerian Meteorological Agency (NIMET), and Zonal Coordinating Research Institutes.

Method of Data Analysis

To determine the trend of agroclimatic elements (precipitation, maximum temperature, minimum temperature, relative humidity, solar radiation and wind speed) and the yield pattern for major food crops (maize, millet, rice and sorghum), sequential plots using the trend analysis was employed, which is mathematically denoted using the functional relationship ($Y = b_1t$). Moving average approach was also employed to forecast future trends on the data sets. Linear models (equations) were obtained from the observed trends, alongside R^2 value which describe the reliability of the equation in forecasting a given variable.

Results and Discussion of Findings

This research aims to examine the trends of climate parameters and the yield of major food crop in Sokoto State. This aim is achieved through the following objective: Determine the trend of agroclimatic parameters and yield for key food crops in the Sokoto State during the period 2008–2022.

Trends Analyses of Agroclimatic Parameters

Trend Analysis of Maximum Temperatures

The trend of the mean annual maximum temperature is represented in Figure 2a below. Using the time series analysis, the following forecasting model, $Maximum\ Temperature = 0.0184T$, was developed with an R^2 value of 99.98%. The data set obtained using the moving average approach equally followed the same trend as can be seen in Figure 2a.

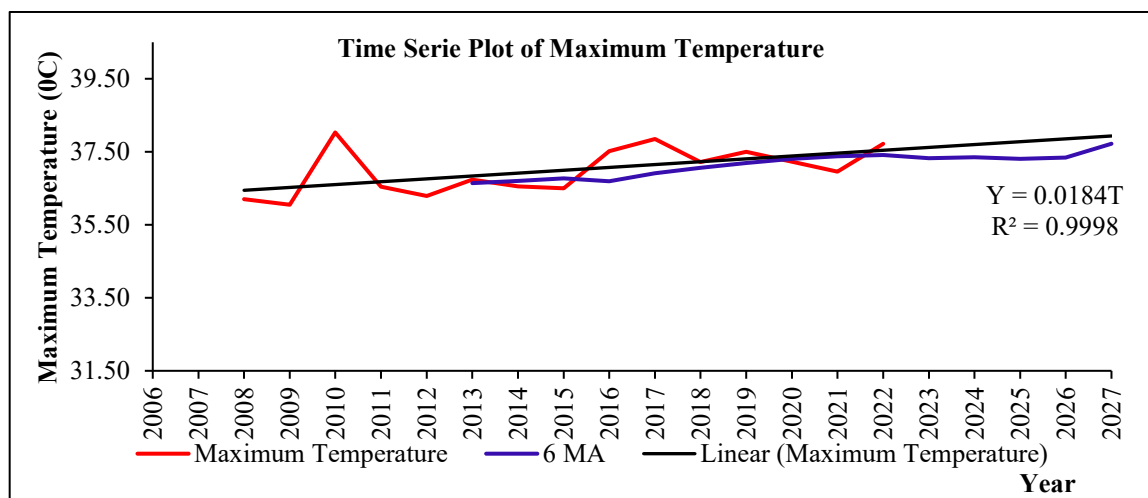


Figure 2a: Time Series Plot of Maximum Temperature in the Study Area Over the Period (2008-2027)

It is evident from the results of the time series that, maximum temperature in Sokoto state over the period of study had experienced fluctuations with a general positive (upward) trend increasing by 0.0184°C per unit time as revealed by the linear model. (99.98%) of behavior in maximum temperature over the study period is attributed to the time factor as given by R^2 .

Hence, the model is reliable for forecasting maximum temperature in Sokoto state. The analysis revealed highest extreme of 38.03°C in 2010 and a lowest extreme of 36.05°C in 2009. The result of a 6-year moving average present a data set that followed the same trend as the main data.

Trend Analysis of Minimum Temperatures

The trend of the mean annual minimum temperature is represented in Figure 2b. Using the time series analysis, the following forecasting model, $MinimumTemperature = 0.0113Time$ as developed with an R^2 value of 99.98%. Using moving average approach, a data set was obtained and presented as can be seen in Figure 2b.

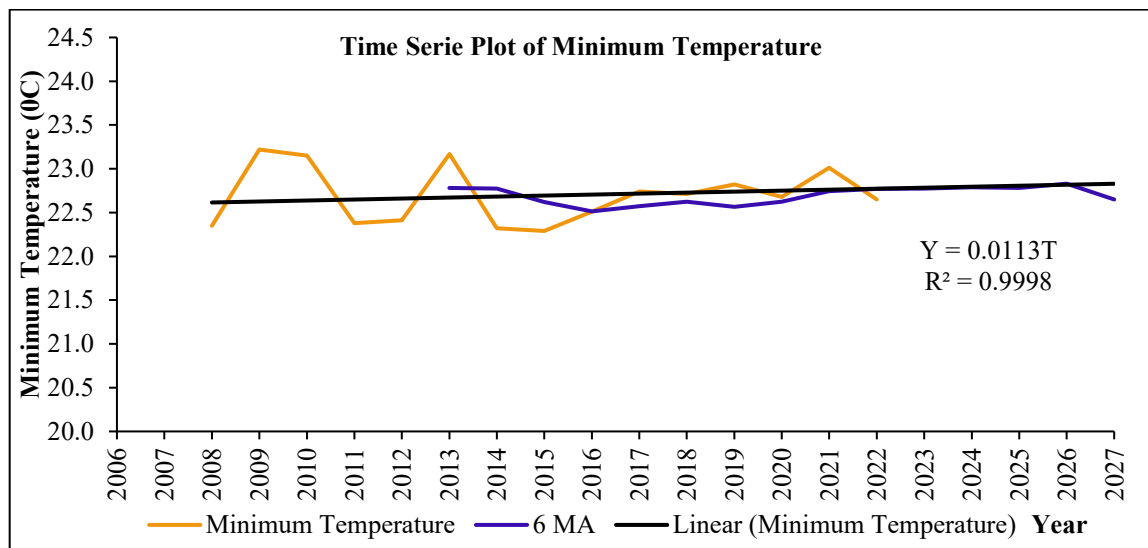


Figure 2b: Time Series Plot of Minimum Temperature in the Study Area Over the Period (2008-2027)

The results revealed that the minimum temperature experienced a cycle between 2009 and 2014 during which it recorded the highest extreme of 23.2°C recorded in 2009, 2010, and 2013, after which it drops steadily until a lowest extreme of 22.3°C was recorded in 2014 and 2015. It witnessed a relatively upward trend. The forecasting model revealed that minimum temperature in the study area over period of study increased by 0.0113°C per unit time. The model is reliable in forecasting the value of minimum temperature because 99.98% variability in record can be explained by the time factor as indicated by the value of R^2 . The data set obtained using the moving average approach equally followed the same trend as the main data set.

The result of this research supports the findings of Adedapo (2020), that there is an increase in the values of temperature (minimum and maximum). He added however that, no definite break in the trend of temperature is observed, although the values fluctuate. The rate of increase in trend is very small. This clearly revealed that, more efforts by government such as tree plantings and education against deforestation as well as reduction in emissions are highly needed. The findings of this work equally align with the report of Wisconsin Department of Natural Resources that, the global temperature is projected to increase by about 1.5 degrees Celsius (2.7 degrees Fahrenheit) by the year 2050 and 2-4 degrees Celsius (3.6-7.2 degrees Fahrenheit) by 2100 which if left unchecked could have serious consequences on weather and climate across the globe. Accordingly, variability in average temperature during the past 20 years has been reported from 9.07 °C to 24.7 °C, while over the past 10 years, it has varied from 10.5 °C to 25.56 °C (Bedair, Alghariani, Omar, Anibaba, Remon, Bornman, & Alzain, 2023). This demonstrates unequivocally an upward trend in the mean temperature over Africa.

Trend Analysis of Rainfall

The trend of the mean annual precipitation totals is graphically represented in Figure 3 below. Using the time series analysis, the following forecasting model, $Precipitation = 0.4009Time$, was developed with an R^2 value of 94.32%. Using moving average approach, a data set was obtained and presented as can be seen in Figure 3.

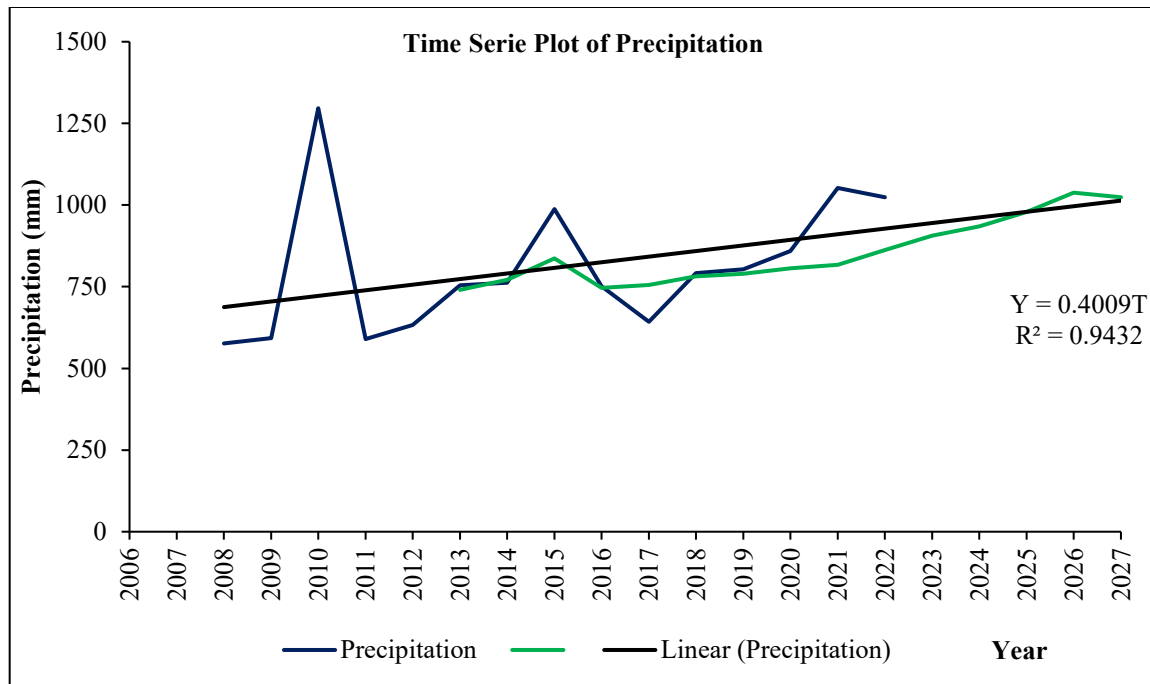


Figure 3: Time Series Plot of Precipitation (Rainfall) in the Study Area Over the Period (2008-2027)

Though with a cyclic fluctuation, the behavior of the precipitation data set maintained a general upward (positive) trend with extreme values 576.43mm (lowest) and 1296.35mm (highest) recorded in 2008 and 2010 respectively. The linear model clearly revealed that for every unit change in the time factor, precipitation experienced an increase of 0.40mm. 94.32% variability in trend of precipitation is attributed to the time factor, hence, the reliability of the model in forecasting precipitation in study area. The data set obtained using the moving average approach equally followed the same trend as the main data set. This result support the report of Zhang *et al.* (2000) small global trend in precipitation has shown about 1% increase over land. However, more evident has been the increase in precipitation over the 20th century during the cold months in the northern Hemisphere. This result is also in agreement with the observation of Sallau (2017), who reported precipitations increase during which the ITCZ is in the northern-most position.

Trend Analysis of Relative Humidity

The trend of the mean annual relative humidity is graphically represented in figure 4 below. Using the time series analysis, the following forecasting model, $RelativeHumidity = 0.0223Time$ was developed with an R^2 value of 99.14%. Using moving average approach, a data set was obtained and presented as can be seen in Figure 4.

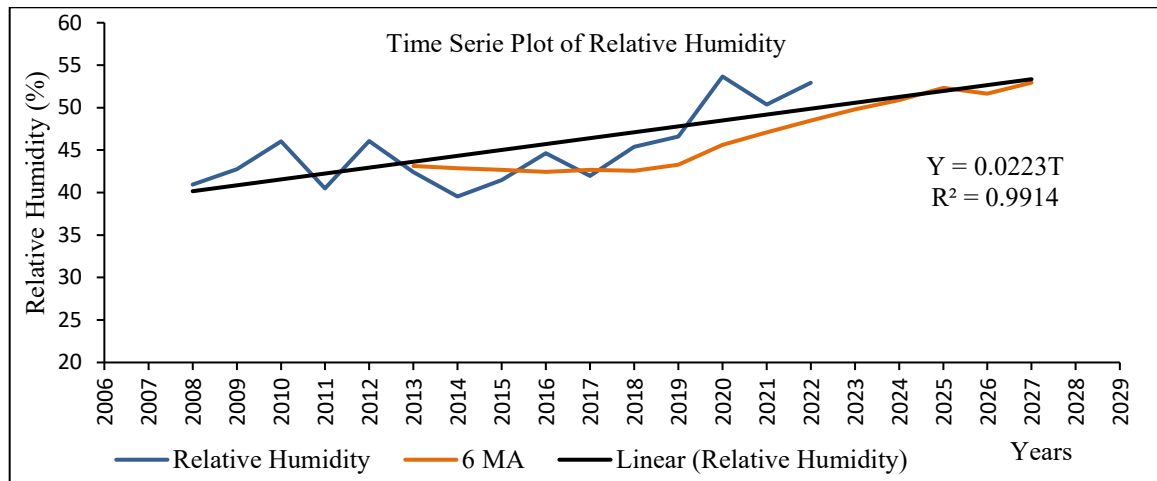


Figure 4: Time Series Plot of Relative Humidity in the Study Area Over the Period (2008-2027)

Relative humidity clearly depicted a relatively uniform upward (positive) trend with extreme values 53.67% (highest) and 39.54% (lowest) recorded in 2020 and 2014 respectively. The linear model showed that for every unit change in the time factor, relative humidity increases by 0.02%. 99.14% variability in trend of relative humidity is attributed to the time factor, hence, the reliability of the model in forecasting relative humidity in study area. The data set obtained using the moving average approach also followed the same trend as the main data set. The discovery made from this research follows the reports of Oyewale, Thompson, Akinpelu, and Jegede (2014) that, both precipitation and relative humidity experience an upward trend in Nigeria. Adedapo (2020) also reported that, there is an increase in the values of relative humidity. However, no definite break in the trend of humidity is observed, although the values fluctuate. The rate of increase in trend is very small.

Trend Analysis of Solar Radiation

The trend of the mean annual solar radiation is graphically represented in Figure 5 below. The forecast model *Solar Radiation* = 0.0545Time with an R² value of 99.98% was obtained from the time series analysis. Using moving average approach, a data set was obtained and presented as can be seen in Figure 5.

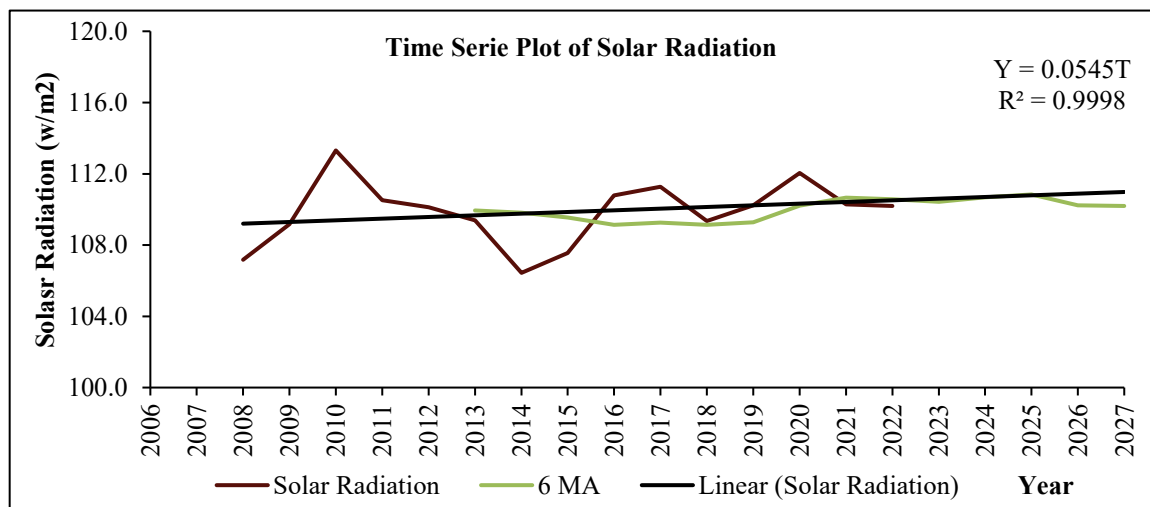


Figure 5: Time Series Plot of Solar Radiation in the Study Area Over the Period (2008-2027)

The Solar radiation data set revealed progressive cyclic fluctuations with a relatively uniform positive trend. Maximum (113.30W/m^2) and minimum (106.40W/m^2) records were observed in 2010 and 2014 respectively. From the linear model, it is revealed that solar radiation increased by 0.05W/m^2 per unit change in the time factor. The time factor account for 99.98 variability in trend of solar radiation; hence, the model is reliable in forecasting solar radiation in study area. The data set obtained using the moving average approach also followed the same trend as the main data set. This finding showing relatively uniform positive trend contradicts the reports of Ohunakin *et al.* (2015) who predicted a decrease in solar radiation towards the end of the century with more reduction found in the South zone and the least in the North region. Furthermore, future changes in global solar radiation across the country in all the periods are however found to be insignificant.

Trend Analysis of Wind Speed

The trend of the mean annual wind speed is graphically represented in Figure 6 below. The forecast model $Wind\ Speed = 0.0012Time$ with an R^2 value of 99.85% was obtained from the time series analysis. Using moving average approach, a data set was obtained and presented as can be seen in Figure 6.

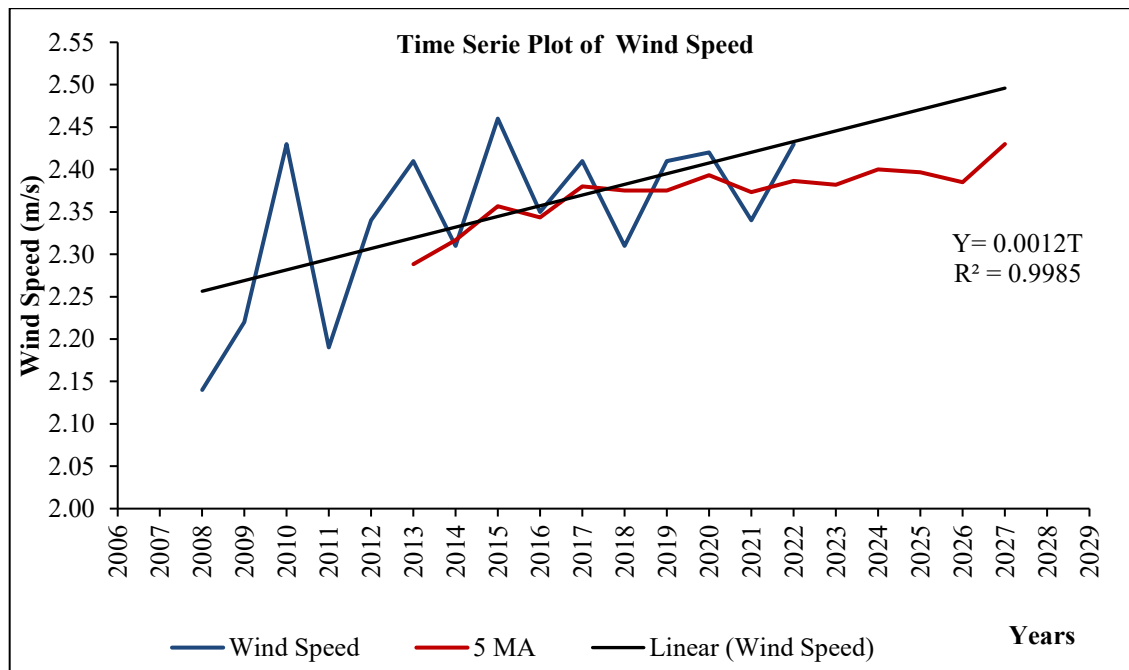


Figure 6: Time Series Plot of Wind Speed in the Study Area Over the Period (2008-2027)

Wind speed data set revealed fluctuations with a steadily positive (upward) trend. Maximum (2.46m/s) and minimum (2.14m/s) records were observed in 2015 and 2008 respectively. From the linear model, it is revealed wind speed increased by 0.001m/s per unit change in the time factor. The time factor accounted for 99.85% variability in trend of wind speed; hence, the model is reliable in forecasting wind speed in Sokoto state. The data set obtained using the moving average approach also followed the same trend as the main data set. This result is in agreement with the report of Danlami (2017) during his study on the Spatio-Temporal Variations of Harmattan Season in Northeastern Nigeria, which 99% of the measured wind speeds at the stations, revealed an upward trend and fell within the range 0 to 4.40 m/s . Danlami, *et al.* (2019) also affirmed that, the speed of the wind varied both temporally and spatially with latitude and some geographical factors playing significant role in bringing about the patterns of variations and their trends over the years i.e. it is higher in the North particularly.

Table 1a: Salient Features of Climatic Parameters in Trends (Years with Extreme Records)

Parameters	Maximum		Minimum	
	Value	Year(s)	Value	Year(s)
Rainfall	1296.35	2010	576.43	2008
Maximum Temperature	38.03	2010	36.05	2009
Minimum Temperature	23.22	2009	22.29	2015
Relative Humidity	53.67	2020	39.54	2014
Solar Radiation	113.31	2010	106.44	2014
Wind	2.46	2015	2.14	2008

Source: Field Work, 2023

Table 1b: Summary of Climatic Parameters Trend Models

Variables	Model				Conclusion
Independent (Time) Years	Dependent	($Y = \beta_i T$)	β_i	R^2 (%)	
	Tmax	$Tmax = 0.018T$	0.018	99.98	Reliable
	Tmin	$Tmin = 0.011 T$	0.011	99.98	Reliable
	P	$P = 0.401T$	0.401	94.32	Reliable
2008	- SR	$SR = 0.055T$	0.055	99.98	Reliable
2022	RH	$RH = 0.022T$	0.022	99.14	Reliable
	WS	$WS = 0.001T$	0.001	99.85	Reliable

NOTE: **Tmax** = Maximum Temperature, **Tmin** = Minimum Temperature, **P** = Precipitation, SR =Solar Radiation, **RH** = Relative Humidity, **WS** = Wind Speed.

Patterns of Crops Yield

Trend Analysis of Maize Yield

The trend of maize yield in Sokoto State over the period of study is presented in Figure 6 below. The forecast model $Maize\ Yield = 0.1906Time$ with an R^2 value of 93.02% was obtained from the time series analysis. Using moving average approach, a data set was obtained and presented as can be seen in Figure 7.

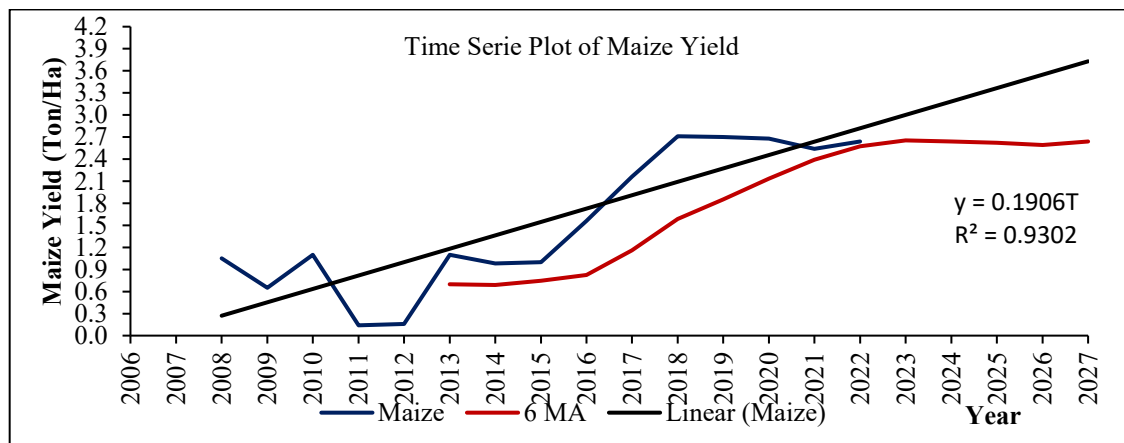


Figure 7: Time Series Plot of Maize Yield in the Study Area Over the Period (2008-2027)

The mean annual yield of maize crop has experienced tremendous sharp increase over the study period with only a drastic decline in 2011 during which the minimum record of 0.14ton/ha was observed, after which a continuous increase was observed until it recorded a maximum value of 2.71ton/ha in 2018. Thus, maize yield generally displayed a positive (upward) trend as can be seen in figure 6. The forecasting model showed that, maize yield increased by 0.191ton/ha for every unit change in time. 93.02% variability in the trend of maize yield can be explained or determined by the time factor. Plotting of the data set obtained using the moving average approach also followed the same trend. This finding supports the report of FAOSTAT, (2022) that, Nigeria recorded impressive growth in maize production over the last 60 years. It concluded that, holding input and land use constant, Nigeria now produces ten times more maize per year than it did in 1960. Accordingly, Affoh (2023) shows that maize yields have increased at a higher or similar rate relative to cultivated area, suggesting that maize production growth was driven by both yield improvements and expansion of area under cultivation.

3.2.2 Trend Analysis of Millet Yield

The trend of maize yield in Sokoto State over the period of study is presented in Figure 8. The forecast model $Millet\ Yield = 0.1598Time$ with an R^2 value of 91.76% was obtained from the trend analysis. Using moving average approach, a data set was obtained and presented as can be seen in Figure 8.

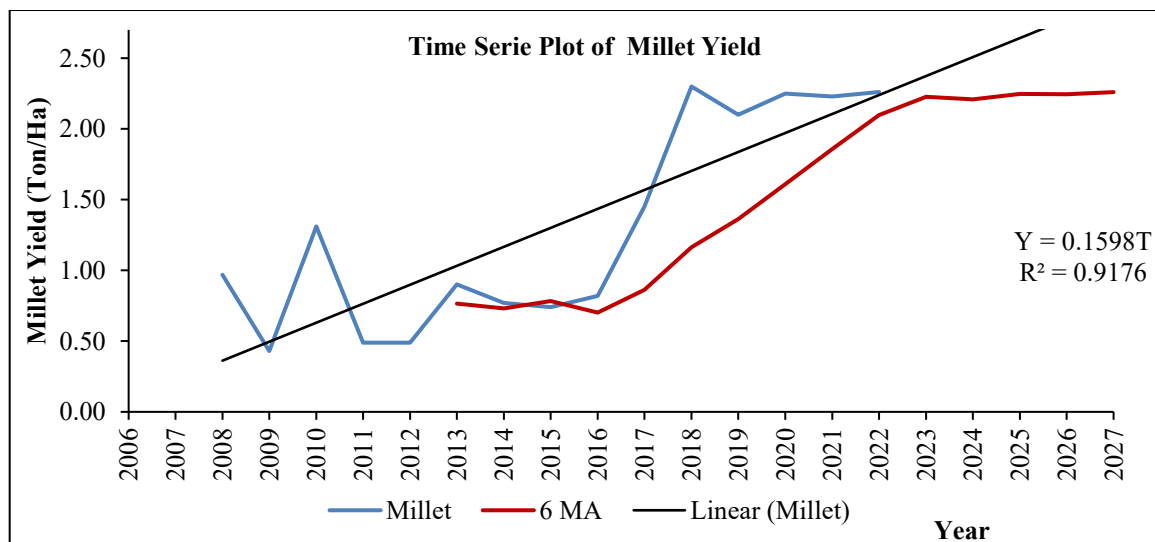


Figure 8: Time Series Plot of Millet Yield in the Study Area Over the Period (2008-2027)

The mean annual yield of millet crop has experienced generally displayed a positive (upward) trend as can be seen in figure 7. Plotting of the data set obtained using the moving average approach also followed the same trend. Extreme records of 2.30ton/ha (maximum) and 0.43ton/ha (minimum) were observed in 2018/2019 and 2009 respectively. From the linear model, it is revealed that, millet yield increased by 0.160ton/ha for every unit change in time. 91.76% variability in the trend of millet yield can be accounted for, or determined by the time factor. Thus, the model can be said to be reliable in forecasting the yield of millet in Sokoto State. The result of this work agreed with the findings of Abah, *et al.* (2021) who revealed that the trend of millet production has fluctuated considerably over the years but has experienced a fairly constant trend in the last few years. It equally follows the report of FAOSTAT of United Nation, (2016), that, global production of millet was 28.4 million tones, led by India with 36% of the world total. Niger also had significant production of 3.9m annually. Nigeria is the fifth producer of millet in the world as at 2016 with an annual tonnage of 1.5million tones.

Trend Analysis of Rice Yield

The trend of rice yield in Sokoto State over the period of study is presented in Figure 9 below. The forecast model $Rice\ Yield = 0.1797Time$ with an R^2 value of 72.73% was obtained from the time series analysis. Using moving average approach, a data set was obtained and presented as can be seen in Figure 9.



Figure 9: Time Series Plot of Rice Yield in the Study Area Over the Period (2008-2027)

The mean annual yield of rice crop has experienced a relatively negative (downward) trend over the study period with cycle between 2009 and 2015 within which the extreme records 2.60ton/ha (highest) and 1.05ton/ha were observed in 2009 and 2014 respectively. Immediately after that, the yield maintained a declining trend as can be seen in figure 8. Plotting of the data set obtained using the moving average approach equally followed the same trend. From the linear model, it is revealed that, rice yield increased by 0.179ton/ha per unit change in time. 72.73% variability in the trend of rice yield can be explained or determined by the time factor. Thus, the model is reliable in forecasting the yield of rice in Sokoto State. This finding is supported by the report of Ikuemonisan, *et al.* (2023) that, rice yield was the most unstable between 1961 and 2020.

Trend Analysis of Sorghum Yield

The trend of sorghum yield in Sokoto State over the period of study is presented in Figure 10 below. The forecast model $Sorghum\ Yield = 0.1237Time$ with an R^2 value of 86.34% was obtained from the time series analysis. Using moving average approach, a data set was obtained and presented as can be seen in Figure 10.

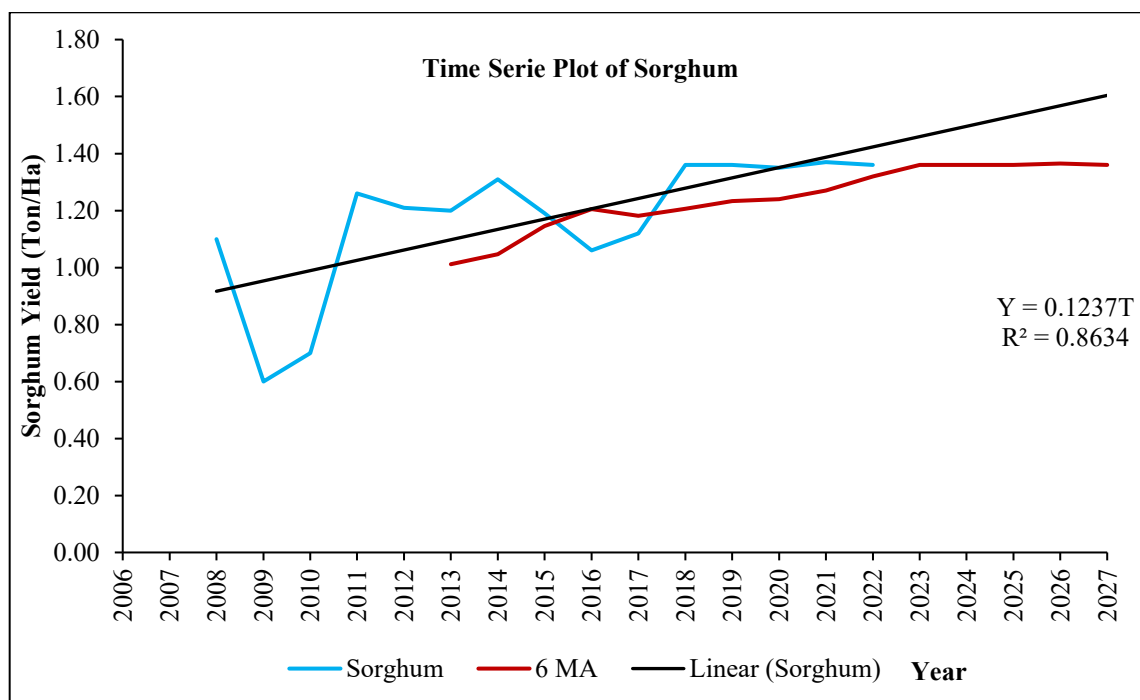


Figure 10: Time Series Plot of Sorghum Yield in the Study Area Over the Period (2008-2027)

The mean annual yield of sorghum crop has experienced a relatively positive (upward) trend over the study period after a sharp decline between 2008 and 2009. Extreme values 0.60ton/ha (lowest) and 1.37ton/ha (highest) were recorded in 2009 and 2021 respectively. Plotting of the data set obtained using the moving average approach equally followed the same trend. See figure 9. The linear model clearly revealed that, sorghum yield increased by 0.124ton/ha per unit change in time. 86.34% variability in the trend of sorghum yield can be explained by the time factor. Thus, the model can be said to be reliable in forecasting the yield rice in Sokoto State. This result is in line with the submission of FAOSTAT (2019) that, sorghum production in the country generally increased and that, productivity in the country is within 1.23 ton/ha, which is relatively low compared with the world average of 1.45 ton/ha and the USA with 4.58 ton/ha. Accordingly, Ahmad, *et al.* (2022), reported that, Nigeria is the leading sorghum producer, followed by Ethiopia in Africa in terms of total production.

Table 2a: Salient Features of Crop Yield in Trends (Years with Extreme Records)

Parameters	Maximum		Minimum	
	Value	Year(s)	Value	Year(s)
Maize (Ton/Ha)	2.71	2018	0.14	2011
Millet (Ton/Ha)	2.30	2018, 2019	0.43	2009
Rice (Ton/Ha)	2.60	2009	1.05	2014
Sorghum (Ton/Ha)	1.37	2021	0.60	2009

Source: Field Work, 2023

Table 2b: Summary of Crop Yield Time Series Models

Variables		Model	Coeff.		Conclusio
Independent (Time) Years	Dependent (Yield) Ton/Ha	$(Y = \beta_i T)$	β_i	R^2 (%)	n
2008 – 2022	Maize Yield	$MY = 0.191T$	0.191	93.02	Reliable
	Millet Yield	$Mil.Y = 0.160T$	0.160	91.76	Reliable
	Rice Yield	$RY = 0.179T$	0.179	72.73	Reliable
	Sorghum Yield	$SY = 0.124T$	0.124	86.34	Reliable

NOTE: MY = Maize Yield, $Mil.Y$ = Millet Yield, RY = Rice Yield, SY = Sorghum Yield, T = Time

Conclusion and Recommendations

Climate parameters have experienced a degree of fluctuations with maximum temperature, minimum temperature, wind speed, precipitation, solar radiation and relative humidity revealing upward trends over the period of study. The fluctuations observed in the yield of major food crops revealed that rice, maize, millet, and sorghum depicted upward trend generally. To address climate irregularities and enhance food security, this study recommends several measures targeting government bodies, agricultural agencies, and farmers. Specifically:

- i. Promote climate-resilient farming practices like tolerant crops and efficient irrigation to boost yields of maize, millet, and sorghum.
- ii. Invest in research to improve rice cultivation and develop climate-adapted rice varieties.

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