

Climate-Smart Agriculture on Sustainable Cowpea Beans Production in Katsina State, Nigeria

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ABSTRACT

Climate variability has become a critical concern in agricultural systems globally, particularly in regions reliant on rain-fed agriculture. This paper investigates the multifaceted implications of climatic variability on sustainable cowpea bean production in Katsina State, Nigeria. The daily data of the rainfall and the maximum and minimum temperature were acquired from the Nigerian Meteorological Agency (NIMET). Additionally, satellite imagery from the Global Land Cover Facility (GLCF) was utilized. Data homogeneity was assessed using Pandas Profiling. Descriptive statistics was used for variability and Mann kendall test was used for the trend analysis. Other Python libraries used for the study were NumPy, Pandas, Matplotlib, and Seaborn. The result showed that the mean rainfall value of 814.67 units suggests that, on average, the area experiences a relatively moderate amount of rainfall. The mean minimum temperature of 28.20 units indicates a generally warm climate and the mean maximum temperature of 44.36 units implies a hot climate. The high coefficient of variation (CV) of 61 indicates that the variation in rainfall is considerable compared to the mean. The CV of 41 for minimum temperature suggests a moderate level of variation. During MAM high amount of maximum temperature was observed followed by the DJF, though there is a spread of the maximum temperature during the DJF season. The result of rainfall variability shows that the rainfall is absent during the DJF and it is higher during JJA. The result of the spatiotemporal variation of crop coefficient of the monthly cowpea beans production in the study area shows that in February, March, April and May there is a very low crop coefficient in the study area. The result also revealed that, in January, there is higher amount of Crop coefficient which was observed in the northern part of the study area, similarly in February, March, April and May. The soil moisture is more visible in July, August, September, and October being the cessation period. The result shows that there is a positive trend in water requirement but the northern part of Katsina requires more amount water for cowpea production. It is recommended that policymakers, agricultural extension services, and local communities collaborate in promoting awareness and providing necessary support for the widespread adoption of climate-smart practices.

Keywords: Climate Change, Soil Moisture, Cowpea Varieties, Climate Smart Agriculture.

1. INTRODUCTION

Climate change is a global phenomenon with various implications for different sectors, including agriculture. Cowpea beans (*Vigna unguiculata*) are an essential crop in Nigeria and play a critical role in the livelihoods of farmers in the area, serving as a

crucial source of protein and income. However, the impacts of climate change pose a significant danger to cowpea bean production in Katsina. This state, situated in the semi-arid region of Nigeria, is particularly susceptible to the consequences of climate change. The Intergovernmental Panel on

Climate Change (IPCC) has emphasized that climate change is likely to lead to higher temperatures, modified precipitation patterns, and more frequent extreme weather events in sub-Saharan Africa (IPCC, 2014). These alterations can have broad-ranging implications for agriculture, influencing crop growth, yield, and overall food security.

Katsina state is considered to be one of the state most vulnerable to climate change and its effects on environmental degradation because of its geographic location in Nigeria. These impacts on average temperature and precipitation have a baseline impact on the productive capacity of agricultural activity, altering the underlying yield expectations and risk regimes faced by farmers (Sani & Chalchisa, 2016). In Africa some works have been carried out in a global way on farmers perceptions of climate change, in particular those of simelton *et al.* In Malawi and Botswana, those of comoe` in the Ivory Coast, those of Assoumana *et al.* in Niger and those of Gebreyesus in Kenya (shongwe & manyatsi, 2019). These studies revealed that all respondents have observed a number of changes in the overall climate pattern. The main perceptions are related to the duration of the rainy season, the variability of onset and rainfall amount. In Benin, some studies have also been conducted on farmers perceptions of climate change. These include the work of Houssou-Goe in the Couffo department, Gnangle` *et al.*, in the center of Benin, Gnangle` and Loko *et al.* in the north of Benin (Ragasa & Akirso, 2019). Ubisi *et al.*, (2017) used secondary sources of data including weather events that occurred recently to appraise climate change and agriculture in Nigeria. The results have shown that climate change has already had a negative impact on agriculture in Nigeria and human activities have led to increased concentration of greenhouse gases into the atmosphere which is associated with the industrialize d countries and some emerging nations.

Antle (2018) derived data for 30 years (1981 - 2010) from recent studies by various authors such as the onset and cessation of rains in Kaduna, Kano and sokoto and reasons for the shift in crops production in the semi - arid region of Nigeria to examine the implication of climate change on agricultural activities in Nigeria. The result shows that the various implication of climate change on agriculture according to the study include: changes in rainfall characteristics, erosion / floods, incidence of pests and diseases, dry spells, drought and desertification; shortage of cultivable land, increased water requirement by crops and shift in agro - ecological zone.

For cowpea bean production in Katsina State, rising temperatures and changing precipitation patterns can disrupt the traditional agricultural calendar. The crop is known for its sensitivity to temperature and water availability during key growth stages.

Extreme temperatures can adversely impact germination, flowering, and pod development, ultimately leading to reduced yields (Ehlers and Hall, 1997). Additionally, irregular rainfall patterns may result in water stress during critical growth phases, further compromising the productivity of the crop (Singh *et al.*, 2017). Furthermore, climate change can exacerbate the incidence of pests and diseases that affect cowpea beans. The altered climatic conditions may create a more favourable environment for the proliferation of pests like aphids and thrips, and diseases like Fusarium wilt and bacterial blight (Karungi *et al.*, 2019). These biotic stressors can pose a dual challenge to farmers in Katsina state, who must contend not only with the direct impacts of climate change but also with the indirect consequences of increased pest and disease pressure.

Agricultural productivity is intricately linked to water availability, making the assessment of water requirements a critical aspect of sustainable crop production. In the context of Katsina State, Nigeria, where agriculture plays a pivotal role in the economy, understanding the water needs of key crops like cowpea beans is imperative for ensuring food security and optimizing resource use. Cowpea beans (*Vigna unguiculata*), commonly known as black-eyed peas, are a staple legume in the region, contributing significantly to both nutrition and income generation for local farmers. Several studies have emphasized the importance of water management in enhancing the productivity of cowpea beans. Research by Aliyu *et al.* (2019) highlighted the significant impact of water stress on cowpea beans, emphasizing the need for precise irrigation scheduling to mitigate adverse effects on yield. Additionally, the work of Mohammed and Abubakar (2020) underscored the role of soil moisture conservation techniques in improving water-use efficiency for cowpea beans in similar agro-ecological zones.

This study seeks to build upon existing knowledge by providing region-specific insights into the water requirements of cowpea beans in Katsina State. By employing advanced hydrological modelling, soil moisture monitoring, and climate data analysis, the research aims to develop tailored recommendations for optimizing water use in cowpea bean production. The findings of this study are expected to contribute not only to scientific knowledge but also to the development of sustainable agricultural practices that align with the unique agro-ecological conditions of Katsina State.

2. STUDY AREA

Katsina state is lies between latitudes 11°07'49''E and 13 ° 05'22''N and longitude 6° 52'30''E and 9°20'40''E. The state is bounded by Niger republic to the north, Jigawa and Kano state to the east, Kaduna state to the south and Zamfara state to the

west. (see Figure 1). It has an area of 23,938²km and a population of 5,801,584 (as at 2006 national census) with its 2022 estimated population of 10,750,335. Katsina state was formed in 1987 when it was split from Kaduna state. The inhabitant of the state are predominantly Hausa and Fulani by tribe. Their main occupation of the people of Katsina are farming, animal rearing and trading (NPC, 2018).

3.3 Data homogeneity and Quality Test

Data homogeneity was assessed using Pandas Profiling, it is a Python library that generates a comprehensive exploratory data analysis (EDA) report for Data. It was used to identify the missing values, duplicated rows, and outliers in the data and quickly understanding the distribution and characteristics of each variable in the Data. Pandas Profiling was used to streamline the initial stages of

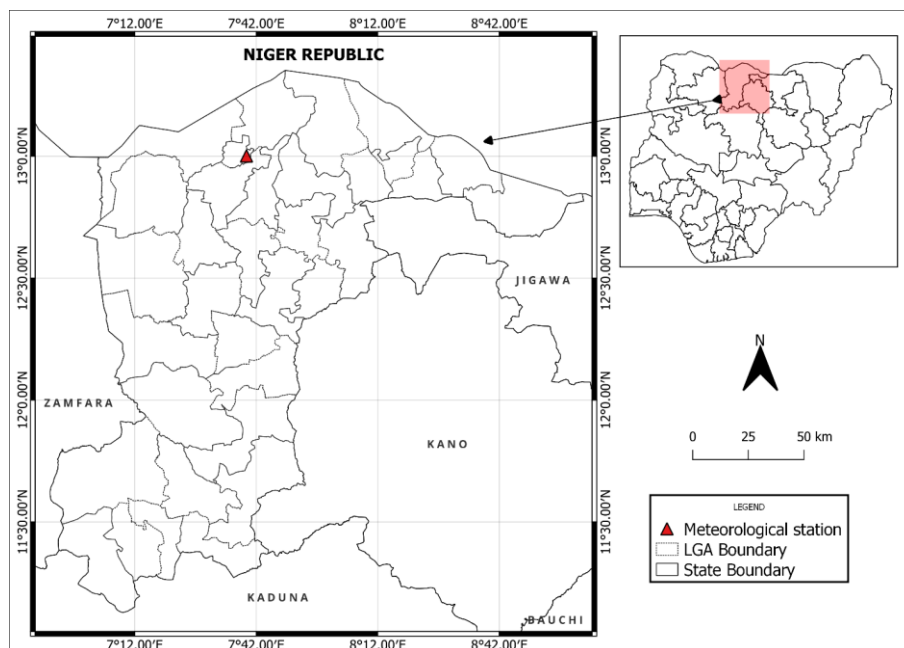


Figure 1: Map of Katsina state showing the State Meteorological Station

3. MATERIALS AND METHODS

The materials and methods of data analysis, that were applied to analyzing the data obtained for the study are discussed here.

3.1 Materials

The daily data of the maximum and minimum temperatures as well as the daily precipitation were acquired from the Nigerian Meteorological Agency (NIMET). Additionally, satellite imagery from the Global Land Cover Facility (GLCF), which is affiliated with the University of Maryland in the United States, -acquired from www.earthexplore.usgs.org, was utilized in this study.

Table 1: Katsina state Meteorological Station and its Location

STATION NAME	WMO ID	STATION ELEVATION (m)	LAT	LONG.
65028	427	13°01'N	13°01'N	07°41'E

3.2 Analytical Methods

The digital data of the station was analysed and the threshold was defined by the user as the mean of the value for the day plus or minus four times the standard deviation.

data exploration and gain insights into the structure and quality of the datasets. The inter-annual variability of temperature and rainfall in the Katsina state of Nigeria was determined using statistical measures such as mean, standard deviation, variance, and the coefficient of variance. The analysis was conducted using the Addin Soft XlStat Excel tool software. The findings of the inter-annual variability of the selected elements were presented through the use of tables and graphs.

3.4 Inter-annual variability of temperature and rainfall

Simple statistical techniques such as the mean, standard deviation, variance, skewness, kurtosis and the Coefficient of variance was used to determine the inter-annual variability of temperature and rainfall of the savanna region in Nigeria. Addin Soft XlStat Excel tool software was used for the analysis. The result of Inter-annual variability of selected element was presented using Charts, Tables and graphs. To calculate the mean, the formula is;

$$\text{Mean, } \bar{X} = \frac{\sum x}{n}$$

The standard deviation is; we have to calculate the variance first and the formula for the variance is;

$$\text{Variance, } \sigma^2 = \frac{\sum (X - \bar{X})^2}{n-1}$$

The STD is the Square root of Variance

$$\text{i.e STD, } \sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{n-1}}$$

The Coefficient of Variance is the Standard deviation divide by the mean times 100,

$$\text{i.e CV} = \frac{\sigma}{\bar{X}} \times 100$$

3.5 Trends in temperature and rainfall of the study area

To investigate the Trends in minimum and maximum temperature and daily rainfall, Mann Kendall test was used, it is a statistical test widely used for the analysis of trend in climatologic (Mavromatis and Stathis, 2011) and in hydrologic time series (Yue and Wang, 2004). There are two advantages of using this test. First, it is a non parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari, *et al.*, 2011). Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1 , which assumes that there is a trend (Onoz and Bayazit, 2012).

The study also adopted Mavromatis and Stathis (2011) method in using Man kendall to determine the trend of annual temperature and rainfall because it is a non parametric test and does not require the data to be normally distributed and the test has low sensitivity to abrupt breaks due to inhomogeneous time series as adopted by Muhammed, Abdussalam and Isah (2019).

The computational procedure for the Mann Kendall test considers the time series of n data points and T_i and T_j as two subsets of data where $i = 1, 2, 3, \dots, n-1$ and $j = i+1, i+2, i+3, \dots, n$. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S (Drapela and Drapelova, 2011).

The Mann-Kendall S Statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{Sign}(T_j - T_i)$$

$$\text{Sign}(T_j - T_i) = \begin{cases} 1 & \text{if } T_j - T_i > 0 \\ 0 & \text{if } T_j - T_i = 0 \\ -1 & \text{if } T_j - T_i < 0 \end{cases}$$

where T_j and T_i are the annual values in years j and i , $j > i$, respectively (Motiee and McBean, 2009).

If $n < 10$, the value of $|S|$ is compared directly to the theoretical variability of S derived by Mann and Kendall.

3.6 Python Libraries used for the study

Python as a versatile programming language that is widely used for various types of data analysis was used for the data analysis for this study; NumPy offered extensive support for handling large, multi-dimensional arrays and matrices, and also collected advanced mathematical functions designed to operate on these arrays. Pandas provided an efficient data structures for handling large datasets for the study such as Series and Data Framing. Matplotlib and Seaborn were used for statistical data visualization library, they both were used in this study to create a variety of plots and visualizations. Seaborn was used to generate informative and visually appealing statistical graphics particularly due to the complexity of the datasets and their multiple variables, simplifying the process of creating aesthetically pleasing visualizations through its intuitive functions and high-level customization options.

4. RESULT AND DISCUSSIONS

4.1 Climate Variability

The table 2 below covers three main indices - Rainfall, Minimum Temperature, and Maximum Temperature. These are crucial factors for understanding the climate and its impact on vegetation.

Table 2: Variability of Climate Indices and Normalised Vegetation Index

Indices	Mean	STD	CV
Rainfall	814.67	295.10	61
Minimum Temperature	28.20	0.87	41
Maximum Temperature	44.36	1.26	42

Source: Author's analysis, 2023

The mean rainfall value of 814.67 units suggests that, on average, the area experiences a relatively moderate amount of rainfall. The mean minimum temperature of 28.20 units indicates a generally warm climate. The mean maximum temperature of

44.36 units implies a hot climate. With a relatively high standard deviation of 295.10, it indicates a substantial variation in rainfall, potentially leading to unpredictable weather patterns. The low standard deviation of 0.87 suggests minimal variation in minimum temperatures, implying a relatively stable temperature pattern. The standard deviation of 1.26 is also relatively low, indicating relatively consistent maximum temperatures.

The coefficient of variation, which serves as a metric for quantifying the extent of variability in rainfall, is recorded at 19.1% in the region of Kaduna and 13.7% in Niger. As noted by Durdu (2009), rainfall variability can be classified into three categories based on the coefficient of variation (CV). When CV is less than or equal to 10%, it signifies low variability. CV values between 10% and 40% indicate moderate variability, while CV values exceeding 40% are indicative of high variability. Therefore, the moderate coefficient of variation (CV) of 61 indicates that the variation in rainfall is considerable compared to the mean. This level of variability can have significant consequences for agriculture, water resource management, and ecosystems. The result of the variability of rainfall is inline with the result of Muhammed, Abdussalam and Isah (2019) which showed a moderate variability of rainfall in Katsina state. The CV of 41 for minimum temperature suggests a moderate level of variation, which could still impact agriculture and ecological systems. The CV of 42 for maximum

temperature is similar to the minimum temperature, indicating some variation in temperature, which can affect various aspects of life, such as health, agriculture, and energy consumption.

The result in Figure 2 shows a seasonal variability of temperature and rainfall in the study area. It revealed a variation of maximum temperature across the season. During MAM high amount of maximum temperature was observed follows by the DJF, though there is spread of the maximum temperature during the DJF season. This might be as a result of absences of cloud and other insulation because it is the harmatan season, which allows solar radiation without any disruption. Also, the result revealed that during the JJA the minimum maximum temperature was observed. Both the JJA and SON are season of rainfall in the study area as such cooled the surrounding environment of the study area. The result shows a similar pattern in the minimum temperature in all the seasons. The only difference is that it shows a bid more spread in all the seasons (DJF, MAM, JJA and SON). The result of rainfall variability shows that the rainfall is totally absent during the DJF and it is higher during JJA, this is the period of the peak rainfall followed by SON, the SON is the cessation period of the rainfall, and the result shows a spread during the period, the is because the rainfall stopped gradually in the study area and MAM has a minimum amount of rainfall because the study always usually experienced a fake starting period of the rainfall.

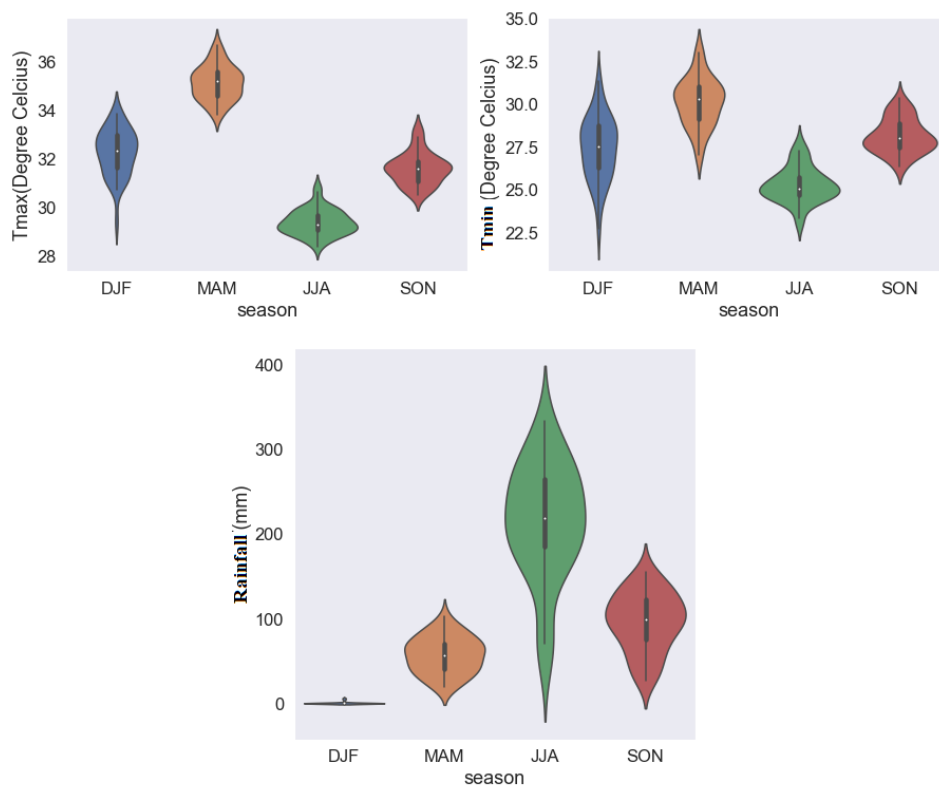


Figure 2: Seasonal Variability of Minimum and Maximum temperature and Rainfall

4.2 Crop Coefficient Variability

The Figure 3 above shows the spatiotemporal variation of crop coefficient of the monthly cowpea beans production in the study area. The result shows

part. This implies that this particular period (June–October) is more suitable period for cowpea production considering the requirement of the crop coefficient.

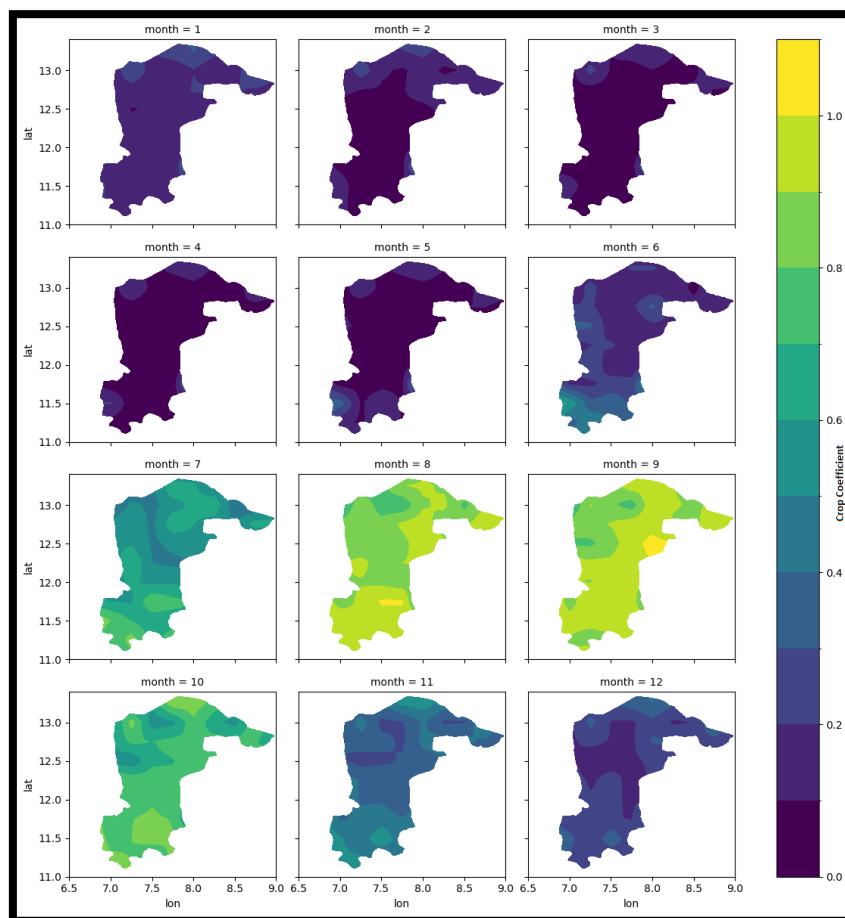


Figure 3: Soil Moisture and Crop Coefficient Variability

that, in the month February, March, April and May there is very low crop coefficient in the study area. Furthermore, the result revealed that there is high amount of crop coefficient in the month of July and October and extremely high in August and September. These months coincide with the period of raining season that is a period when the study area experienced high amount of rainfall.

The result also revealed that, in the month of January, there is higher amount of Crop coefficient was observed in the northern of the study area, similarly in the month of February, March, April and May. Although, the southern part of the study area also has a high amount of crop coefficient while it is more pronounce in the month of June (higher amount of crop coefficient). This month (June) is the onset period of the rainfall, as such; preparation of cowpea production is advised to begin in the month of June. Furthermore, during the month of august, and September, the higher amount of crop coefficient was observed to be about two-third ($\frac{2}{3}$) of the total study area with dominant in the southern

The Figure 4 above shows the spatiotemporal variation of soil moisture of the monthly cowpea beans production in the study area. The result shows that, in the month of January, February, March, April, May, June, and November, and December has a very low amount of soil moisture, this is because it is the period where rainfall is totally absent in the study area. The result revealed that there is a moderate variability of soil moisture in July and October, it is because, July is the period of the start of the rainfall and October is the period of/after rainfall cessation, so the soil is still moist. The soil moisture is higher during the month of august and September, this is the period of the peak of rainfall.

The result also revealed that, the soil moisture is higher in the down south and it reduces as it spread upward/northward of the study area and also, it shows a high amount of soil moisture in the central part of the study area. The Figure 4, the soil moisture is more visible in the month of July, August, September, and October being the cessation period. This is because it is the rainfall period of the area

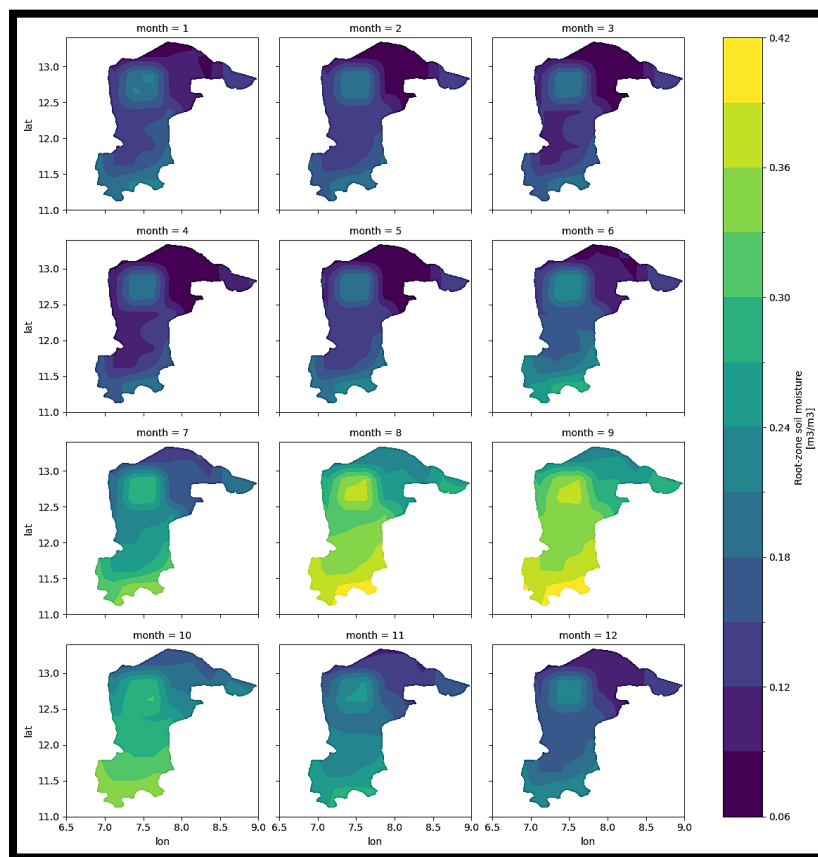


Figure 4: Soil Moisture

from the onset period from the month of June to the cessation period in the month of October in the southern part of the area. It is obvious that the soil moisture is more visible in the southern part of the region which is called Karadua zone/Funtua zone than central or northern part of the region. The region has more rainfall amount and more vegetation. From the result, it shows that the southern part of the region has less water requirement than the central area and the northern part for the production of cowpea beans in the study area.

The Figure 5 above shows the seasonal variability of the soil moisture in the study area. the result revealed that high amount of soil moisture observed was JJA followed by SON. The JJA is the period of rainy season in the study area which favors a high accumulation of soil moisture while SON is the season of rainfall cessation. However, this season (SON) has a less amount of evapotranspiration and the remnant accumulation of water from the raining season is still present in the soil which favours the rise of the level of the soil moisture. In addition, it was observed that the MAM season has the least amount of the soil moisture. This is the period where a warm air favors the evapotranspiration to occur and making the soil dried-up in the study area.

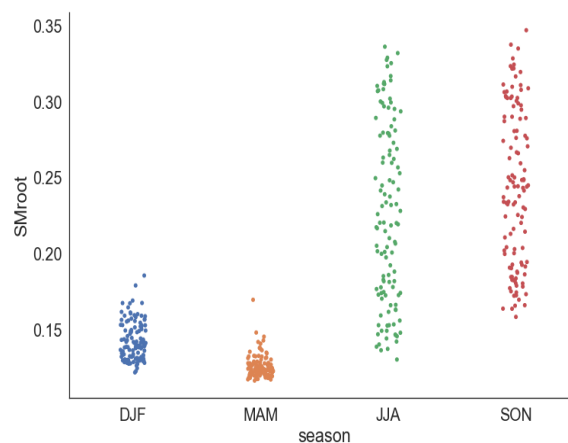


Figure 5: Seasonal Variability of the Soil Moisture in the Study Area

The result of the Figure 6 shows the trend of the availability of the water requirement for cowpea production in the study area. This was achieved by the use of seasonal decomposition to separate between the trend and variability. It revealed that there is positive trend of water requirement in the study area. This implies that as a result of climate variability and the changes in the study area. there is an increasing trend of water requirement for the cowpea beans production in the study area. In addition, the least amount of water requirement was observed in the year 2009, 2011, 2014 and 2020.

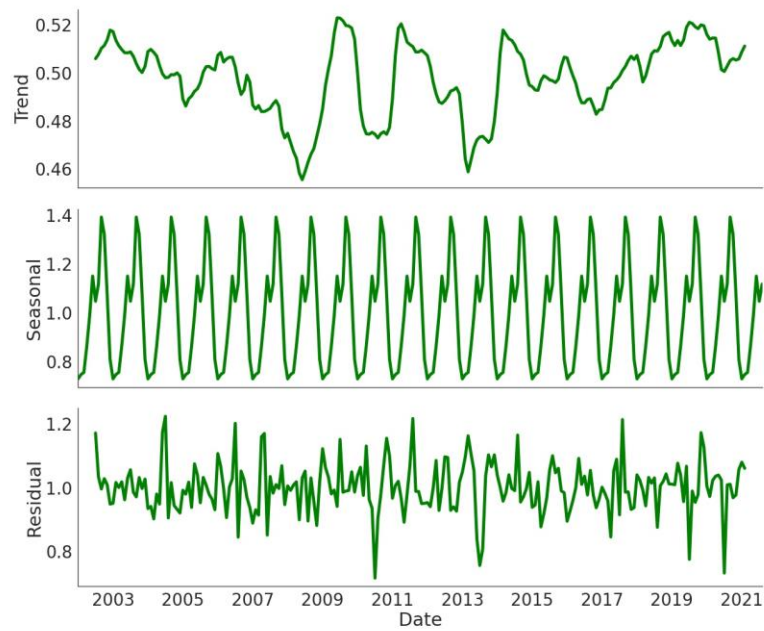


Figure 6: Trend Analysis

The Figure 7 above shows the amount of water requirement in the study area. The result revealed that northern part of the area needs/requires high amount water for cowpea production. The central

part of the study requirement less amount of water compare to the northern part while the southern which is Karadua zone have enough water for cowpea beans production in Katsina state.

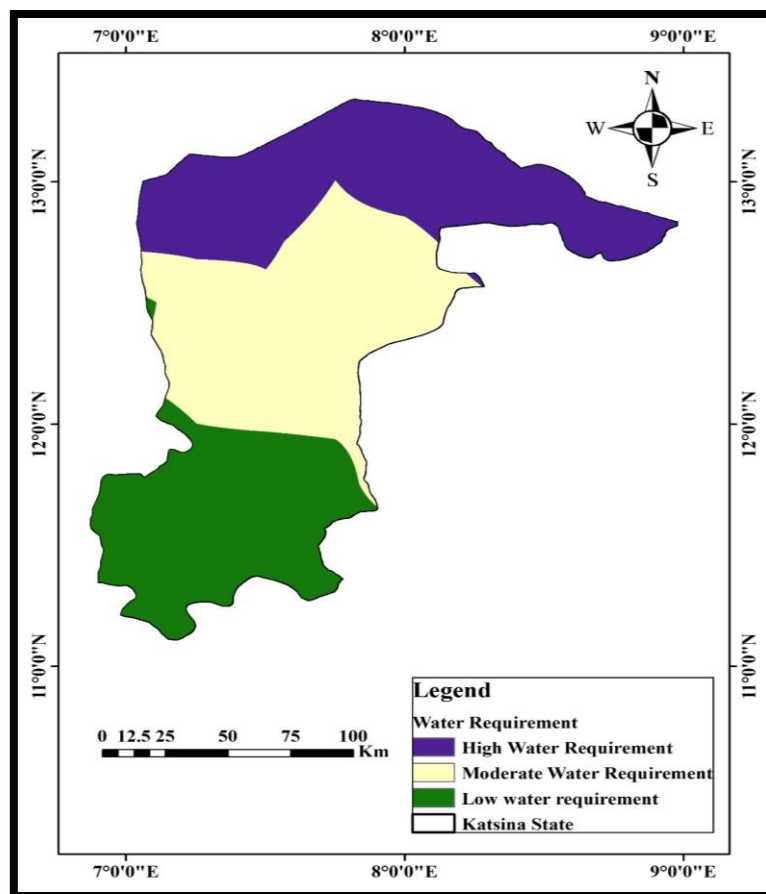


Figure 7: Amount of Water Requirement in the Study Area

5. CONCLUSION

In conclusion, the incorporation and execution of climate-smart agricultural methodologies in the cultivation of cowpea beans in Katsina State present a promising and sustainable approach to tackle the challenges posed by climate change. The findings of this study emphasize the significance of integrating climate-smart strategies to enhance the resilience and productivity of cowpea farming systems in the region. The multidimensional advantages observed in this research, including increased yields, efficient use of resources, and climate adaptability, underscore the potential of climate-smart agriculture to revolutionize the agricultural landscape in Katsina State.

Rainfall exhibits a high level of variability with a substantial coefficient of variation. This signifies that the region encounters considerable fluctuations in rainfall, which can result in droughts or floods and have significant impacts on agriculture and water availability. Temperature, both minimum and maximum, displays lower variability compared to rainfall, but the mean values suggest a consistently warm to hot climate. This can influence various aspects of life, encompassing health concerns and agricultural practices.

There is also spatial and temporal variation in soil moisture during the monthly production of cowpea beans in the study area. Soil moisture is higher during the months of August and September, which coincide with the peak of rainfall. The results reveal that there is a moderate variability of soil moisture in July and October. This is because July marks the beginning of rainfall, while October is the period after rainfall cessation, resulting in the soil retaining moisture.

The results demonstrate that the highest amount of soil moisture is observed during JJA, followed by SON. JJA represents the rainy season in the study area, which facilitates a substantial accumulation of soil moisture, whereas SON signifies the season of rainfall cessation. Soil moisture is more prominent in the Karadua zone/Funtua zone than in the central or northern part of the region. The results indicate an increasing trend in water requirement for cowpea bean production, with the least amount of water requirement observed in the years 2009, 2011, 2014, and 2020. The findings regarding water requirement highlight that the northern part of the area necessitates a higher amount of water for cowpea production compared to the central and southern parts of Katsina State.

6. RECOMMENDATION

Based on the findings, it is recommended that:

1. Encourage farmers to diversify their crops by integrating cowpea beans with other climate-resilient crops suitable for the region. This can

help mitigate risks associated with climate variability and enhance overall farm resilience. Promote the adoption of cowpea bean varieties that exhibit tolerance to drought, heat, and prevalent pests, especially in the northern part of Katsina State. Collaborate with agricultural research institutions to develop and disseminate improved varieties tailored to local conditions.

2. Encourage the adoption of efficient water management practices such as rainwater harvesting, drip irrigation, and the utilization of drought-tolerant irrigation systems. This can help ensure water availability for cowpea bean production, particularly during periods of drought. Strengthen agricultural extension services to provide farmers with training, technical assistance, and access to information on climate-smart agricultural practices. This can empower farmers to make informed decisions and adopt sustainable farming methods.
3. It is crucial for policymakers, agricultural extension services, and local communities to collaborate in promoting awareness and providing necessary support for the widespread adoption of climate-smart practices. Capacity-building initiatives, financial incentives, and research and development efforts should be directed towards empowering farmers with the knowledge and resources needed to implement these sustainable strategies effectively.
4. Enhance the capabilities of agricultural extension services in order to furnish farmers with instructional programs, technical support, and access to knowledge regarding climate-resilient agricultural techniques. This approach has the potential to enable farmers to acquire the necessary knowledge for making well-informed choices and embracing sustainable farming methodologies. Policymakers, agricultural extension services, and local communities must establish a strong collaborative relationship to raise awareness and offer essential assistance for the widespread adoption of climate-smart practices. In order to effectively empower farmers, it is imperative to focus capacity-building programs, financial incentives, and research and development endeavors on equipping them with the necessary knowledge and resources to successfully implement these sustainable strategies.

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