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Assessing Climate and Weather Patterns on Cocoa Yield Trends in Oyo State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate variables like temperature and rainfall are crucial direct inputs to the agricultural industry; therefore, any changes or fluctuations in these variables will inevitably have a big impact on crop production. Climate change and extreme weather events are already leading to low yields of crops in developing countries like Nigeria. Data were collected at the meteorological station located at International Institute of Tropical Agriculture (IITA) and Oyo State Cocoa Development Unit, Ibadan for Thirty years (1985-2014). Non-parametric Mann-Kendall trend analysis and standard parametric methods of linear and quadratic regression analysis were performed on the variables in order to determine the trend direction and magnitude of change over time together with the Sen.'s slope. Annual trend statistics for cocoa yield and climatic variables were analyzed in Oyo State, South Western Nigeria, using the Mann-Kendall test for trend and Sen's slope estimate using the meteorological and cocoa yield data. The annual cocoa yield showed a significant increase at the rate of 468.02 tons/year (P<0.001) in Oyo State while there was an insignificant increasing trend in

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the rainfall pattern at the rate of 0.32 mm/yr. We observed a significant increase in annual Tmax, Tmin, and Tmean at a rate of 0.02/yr. it was also observed that rainfall has the most grievous impact on cocoa yield among all climatic variables. However, the objective of the study is to assess climate and weather patterns effects on cocoa yield trends in Oyo state, Nigeria. Farmers should take measures for effective adaptation strategies to mitigate the impact of future change in climate variable on cocoa yield in the study area.

Keywords: Trend analysis; rainfall; temperature; cocoa yield; Oyo state.

1. INTRODUCTION

One of the most important environmental problems facing the planet today is climate change brought on by human and natural activity [1]. Evidence of variations in temperature, precipitation, and extreme weather occurrences has been substantiated in a more methodical and scientific manner [2,3]. Global socioeconomic, biophysical, and ecological systems are harmed by extreme weather events, such as heat waves, cyclones, droughts, floods, and climate change [2]. In particular, it is thought that the agricultural industry is particularly susceptible to the effects of climate change [4,5].

Climate variables like temperature and rainfall are crucial direct inputs to the agricultural industry, therefore any changes or fluctuation in these variables will inevitably have a big impact on crop production [6]. Climate change brought on by human and natural action is one of the most significant environmental issues the world is currently experiencing [1]. More rigorous and scientific evidence of fluctuations in temperature, precipitation, and extreme weather events has been verified [7,2]. Extreme weather events, including heat waves, cyclones, droughts, floods, and climate change, have a negative impact on global socioeconomic, biophysical, and ecological systems [3]. It is believed that the agriculture sector is more vulnerable to the consequences of climate change [5].

Crop productivity will inevitably be greatly impacted by changes or fluctuations in climate variables like temperature and rainfall because the agricultural sector is highly dependent on these variables [8]. The issue in India is particularly concerning because, in addition to having less arable land than other countries, its population is more dependent on the agriculture sector [9], and it has made less technological progress and has less adaptive capacity to deal with climate change [6]. Similar to this, Nigeria's agriculture sector is expected to suffer greatly from climate factors due to the country's enormous rain-fed territory, with just roughly 48% of the cultivated area having guaranteed access to water. Lower crop yields in Nigeria are mostly thought to be caused by unpredictable rainfall and a lack of irrigation facilities [10]. Because of their greater sensitivity to climate change, Nigeria's food production and agricultural systems are therefore more vulnerable to it [11].

Extreme weather as reported by [12] is a weather phenomenon that is at the extreme of the historical distribution and observed that the main factors having much impact on the optimum yield are temperature and rainfall. This usually happens as results of changes in weather element that alter the rate and stages of development of cocoa. This consequently leads to a decrease in cocoa yield and losses of crops which have its concomitant effects on the wellbeing and socio-economic status such as farmer's income, livelihood and decision making.

However, basic skills in cocoa production, coupled with optimum motivation, are necessary requirements for best practices that can lead to a high-quality yield of cocoa [7]. Also, the growth and yield of cocoa are determined by the amount of sunlight falling on the tree. Humidity as a variable has a remarkable effect on the leaf area, while other effects of humidity are connected with difficulties of drying and storage of the products and the spread of fungal diseases [13]

Generally, the accumulated effect of climatic variables likes rainfall, temperature, humidity, sunshine hour and limits of altitude have effects on the cocoa yield [14]. [15] Reported that the yield of crops in Africa may fall by 10-20% by 2050 or even up to 50% due to climate change particularly because most of the African agriculture relies solely on rainfall. Most of the agricultural research on climate change has only been carried out on the assessment of relationship of various attributes of agricultural systems (e.g. crop/livestock yields, pest, diseases, weeds etc) the biophysical aspects of food production, with little or no study on the socioeconomic impact of climate change [16]. These partial assessments in most cases regarded climate change impacts in isolation, providing little insight into the measures the farmers could adopt to mitigate the climate change impact.

2. METHODOLOGY

2.1 Study Area

Oyo State is situated in Nigeria's South-West geopolitical zone, and was formed in 1976 as one of three states by splitting off the previous Western State of Nigeria. The state has a total land area of 28,454 square kilometers. Its borders are as follows: Ogun State to the south, Kwara State to the north, Ogun State and the Republic of Benin to the west, and Osun State to the east. The terrain comprises of dome-shaped hills and old, hard rocks that climb gradually from 500 meters in the southern region to 1,219 meters in the northern region above sea level (oyostate.gov.ng).

The topography of the State is of gentle rolling low land in the south, rising to a plateau of about 40metres. The State is well drained with rivers flowing from the upland in the north-south direction. Oyo State is situated within latitudes 6.5˚ and 9˚ north of the Equator and between longitudes 3˚ and 5˚ east of the Greenwich Meridian [17].

The climate of Oyo State is tropical, having dry and wet seasons as well as a comparatively high humidity level. The wet season begins in April and finishes in October, whereas the dry season runs from November to March. Nearly all year long, the average daily temperature fluctuates between 25 °C (77.0 °F) and 35 °C (95.0 °F). Oyo State's vegetation is composed of guinea savannah in the north and rain forest in the south. In the north, grassland with scattered trees replaces thick forest in the south. Crops including maize, yam, cassava, millet, rice, plantains, cocoa trees, palm trees, and cashew can be grown in the state due to its favorable environment.

2.2 Data Source

The climatic data used for this study (rainfall, maximum temperature, minimum temperature and mean temperature) were extracted between 1985 and 2014 from the archive of

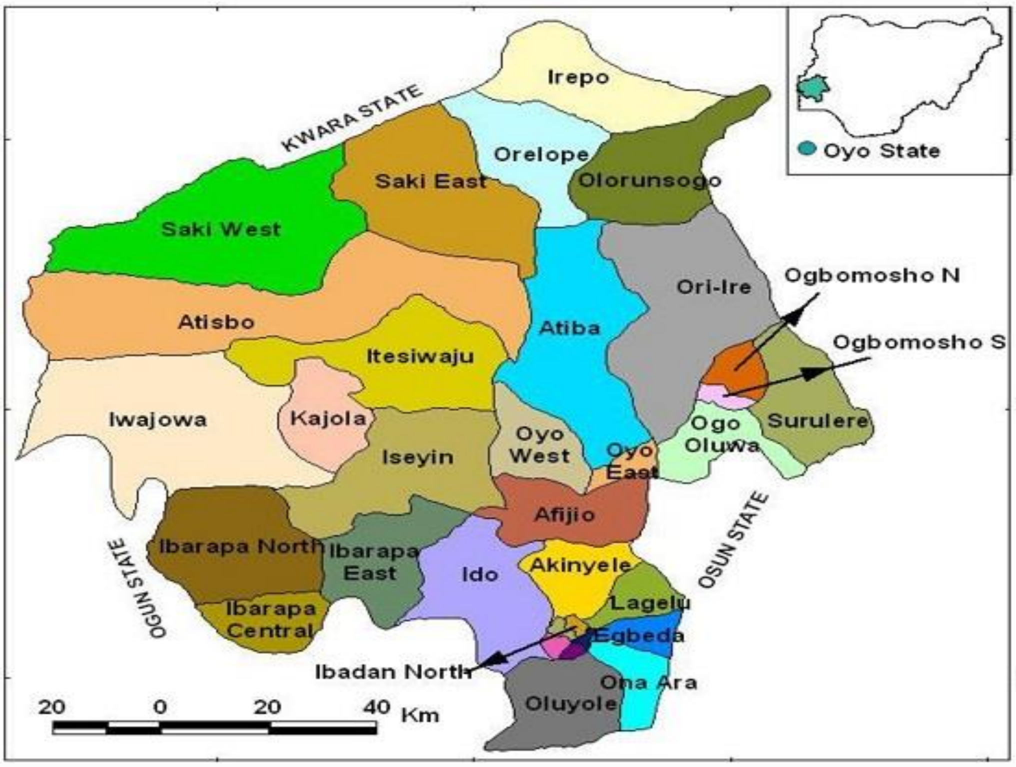

Fig. 1. Map showing the study area

International Institute of Tropical Agriculture (IITA) Ibadan. While the cocoa yield data used for this study was obtained from Oyo State Cocoa Development Unit, Ibadan (between 1985 and 2014).

2.3 Trend Analysis of Yield and Climatic Variables

MAKESENS (the Mann-Kendall test for estimating trend and Sen's slope) is used to assess the trend and variability of cocoa yield and meteorological data in the study area. Using secondary data, An Excel template MAKESENS (Mann-Kendall test for trend and Sen's slope estimates) which was developed for detecting and estimating trends in the time series was used to evaluate the trend in cocoa yield and variability meteorological variables. The Excel template is designed for identifying and estimating patterns in the time series [18]. The Mann-Kendall test statistic S is as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad (1)$$

Where:

n is the length of the time series $x_i \ldots x_n$,
and sgn(.) is a sign function,
x_j and x_k are values in years j and k, respectively.

The expected value of S equals zero for series without trend and the variance is computed as:

$$\sigma^2(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] \quad (2)$$

Where q is the number of tied groups and t_p is the number of data values in p^{th} group. The test statistic Z is then given as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\sigma^2(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{\sigma^2(S)}} & if \quad S < 0 \end{cases} \quad (3)$$

The Z statistic was then used to test the alternative hypothesis, H1, which holds that there is a decreasing or increasing monotonic trend, against the null hypothesis, Ho, which holds that the data are ordered randomly in time. No assumptions regarding the underlying distribution of the data are highly significant as a non-parametric test. A monotonic trend that is increasing or decreasing is indicated by a positive or negative Z value. If the absolute value of Z is bigger than Z1-α/2, which is derived from the conventional normal cumulative distribution tables, then Ho will be rejected at a specific level of significance. According to [19], the Mann-Kendall test is non-dimensional; it simply measures the trend's direction; it doesn't measure its size or intensity. The true slope of the existing trend, the Sen's slope non-parametric method was used for this study [18].

3. RESULTS AND DISCUSSION

The descriptive and statistical trends of annual time series of cocoa yield and climatic variables in the study area are presented in Table 1. The annual cocoa yield showed a significant increase of about 468.02 ton/yr (P<0.001). It was observed that annual Tmax increased significantly at the rate of 0.02^{o}C/yr (P<0.01). Annual Tmin increased significantly at the rate of 0.02^{o}C/yr (P<0.1). The annual Tmean also showed a significant increased at the rate of 0.02^{o}C/yr (P<0.1).

Temporal pattern trends and variability in the cocoa yield and climatic variables are presented in Figs. 2, 3, 4, 5 and 6. Fig. 2 revealed an increasing trend in the cocoa yield while there was an insignificant increasing trend in the rainfall pattern in Fig. 4 at the rate of 0.32 mm/yr. Tmax, Tmin and Tmean in Figs. 4, 5 and 6 increased at the rate of 0.02^{o}C/yr. The increase in the cocoa yield could be ascribed to decrease in the amount of rainfall. This relates to [20] that reported that a decreasing rainfall will engender an increase in cocoa yield. [7,18] Also observed that yearly variations in the yield of cocoa were more affected by rainfall than any other climatic variables. The effects of rainfall as one of the climatic variables affecting cocoa yield was also reported by [21]. According to [22], rainfall has the most grievous impact on agriculture among all climatic variables. This implies that the infestation of cocoa pod by fungi is mainly as a result of excess rainfall which always leads to decrease in cocoa yield [7]. It was also asserted by [7] that yearly variation in cocoa yield was more affected by rainfall as compared to all other climatic variables.

Table 1. Trends Test results of Annual cocoa yield and climatic variables for Oyo State

Time series	Test Z	Significance	Slope
Yield	3.71	***	468.02
Rainfall	0.07		0.32
Tmax	3.18	**	0.02
Tmin	1.75	+	0.02
Tmean	1.91	+	0.02

**** Significant at 0.001, **significant at 0.01, + significant at 0.1*

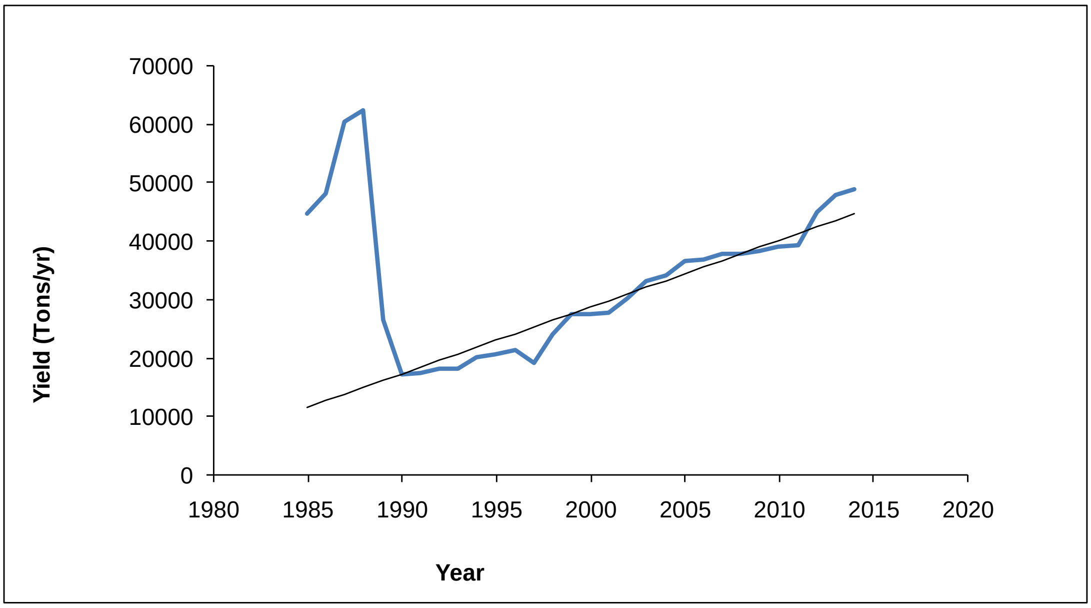

Fig. 2. Annual trend in cocoa yield between 1985 and 2014

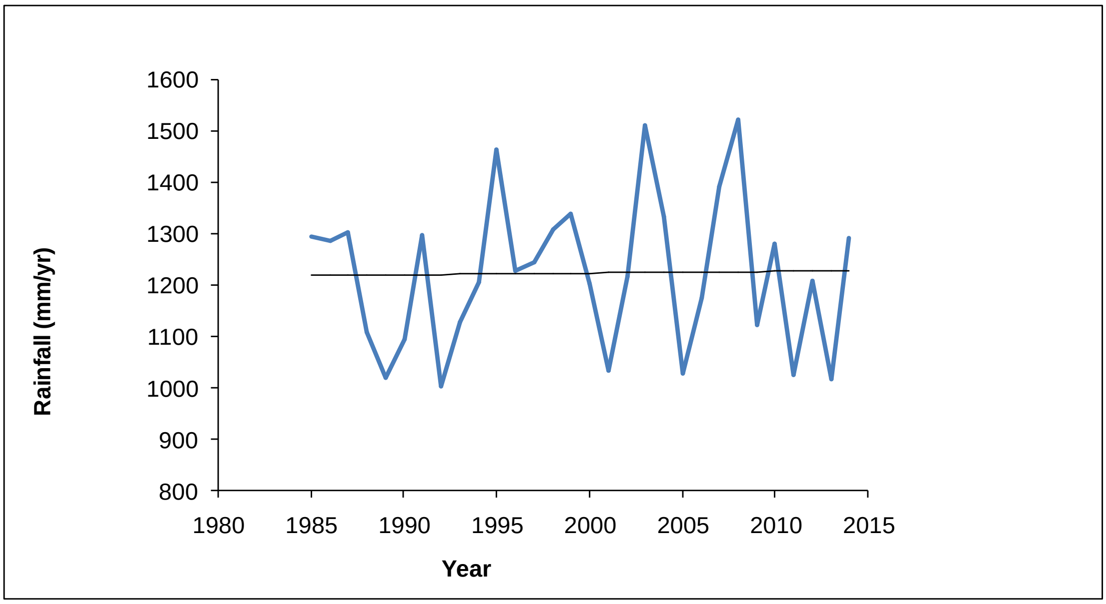

Fig. 3. Annual trends in rainfall between 1985 and 2014

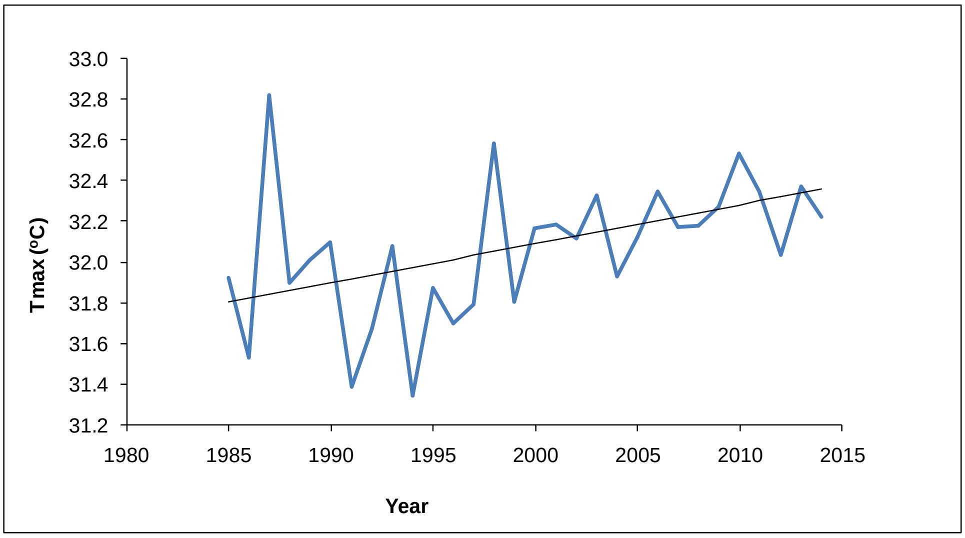

Fig. 4. Annual trends in Tmax between 1985 and 2014

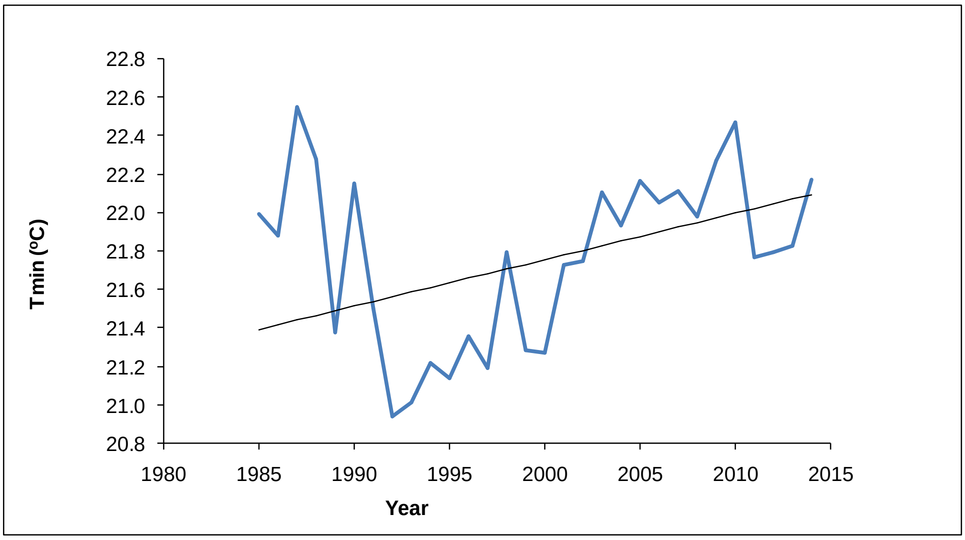

Fig. 5. Annual trends in Tmin between 1985 and 2014

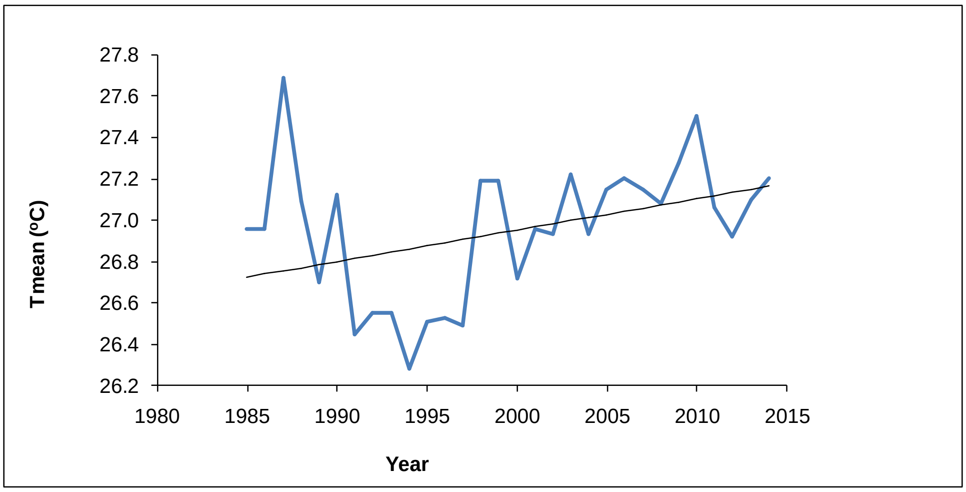

Fig. 6. Annual trends in Tmean between 1985 and 2014

4. CONCLUSION AND RECOMMENDATION

The evaluation of trends in climatic variables and cocoa yield were examined during the course of this study. The annual cocoa yield showed a significant increase study area. Out of the climatic variables considered, only rainfall showed no significant trends. It could be observed that annual maximum temperature increased significantly. Annual minimum temperatures increased significantly while the annual Tmean also showed a significant increase for the period under study. This demonstrated how climate factors have a significant impact on agricultural production and cocoa yield in the study area. In order to boost the state's cocoa production, farmers in the research area need take steps to effectively adjust to the ravaging effects of climate variables. Some of these steps include planting improved breeds and drought-resistant types. Where there is insufficient rainfall to produce cocoa, supplemental irrigation facilities ought to be offered. To lessen the influence of future climate change on cocoa yield, farmers should implement effective adaptation strategies.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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