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Impact of Climate Variability on Maize Yields in Southern Togo (Tabligbo)

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Abstract: ***Climate variability continues to threaten agricultural productivity worldwide, especially in Togo where crop production is mostly rainfed-based. This study aims to investigate the impact of climate variables on maize yields in the Maritim region of Togo. Climatic data from 1980 to 2022 and maize yield data from 1990 to 2021 were collected. The Mann-Kendall test and Sen's slope estimator were applied to analyze the trends of climatic variables such as minimum and maximum temperatures and precipitation. Multiple linear regression analysis was used to test maize yields against historical climatic variables. The results of the study showed increasing trends in annual temperatures. The minimum temperature increased by 0.05°C per year in Tabligbo and 0.03°C in Lomé; whereas the maximum temperature showed an increasing trend of 0.03°C per year in both locations. The rainfall significantly increased ($p<0.05$) in Lomé and Tabligbo by 2.29 and 1.6 mm per year, respectively. Any significant impact of climate variables on maize yields was not observed at all locations. A non-significant positive relationship was observed between rainfall and maize yields in Tabligbo. Likewise, a non-significant positive relationship between minimum temperature and maize yields in Tabligbo was noticed. The results of our study indicate that policymakers should actively endorse sustainable agricultural practices. This support would enhance the resilience of maize production in the face of climate variability and change, simultaneously boosting farmers' adaptive abilities and their income prospects.***

Keywords: climate variability, Trend analysis, Mann-Kendall test, crop yields, Multiple regression

1. Introduction

Agricultural production in countries worldwide has been significantly affected by climate change [1,2]. The agricultural sector experiences significant effects on food security due to many factors, including both human-induced and natural influences [3, 4, 5]. Togo's agricultural sector contributes around 40% to the country's GDP and employs about 58% of the active population. However, the effects of climate change are likely to exacerbate food insecurity in Togo, where subsistence farming is primarily focused on food crops, especially cereal production, which accounts for about 68.5% of agricultural GDP [6].Around 70% of Togo's agricultural output is comprised of food crops, which are mainly intended for domestic consumption rather than exportation. These crops consist of grains and tubers, with grains accounting for 56% of the calorie supply of plant-based foods consumed in Togo. Among grains, maize constituted 51%, with rice at 20%, sorghum at 17%, and wheat at 9% from 2014 to 2017. The majority of tubers were cassava at 61.8% and yam at 37.8% [7].

Climate variability is defined as the natural oscillation of climatic variables and can be observed across various spatial and temporal scales [8]. It is also defined similarly by Malpeli et al. (2020) as: ''interannual or interdecadal fluctuations in temperature and precipitation''. Its impacts result in alterations to plant phenology, drought patterns, flooding occurrences, the prevalence of invasive species, and more [9].

The influence of climate change has been observed on both natural and human systems worldwide, with a notable emphasis on developing countries. Smallholder farmers in these regions are acutely experiencing the adverse consequences of these impacts[10,11]. Based on assessments from multiple studies across different regions there is growing evidence that climate change has increasingly and adversely affected crop yields [12, 13, 14]. Global temperatures have likely caused a reduction in cold days and nights while increasing warm days and nights [15].

Agricultural production and yield are strongly influenced by the climate [16,17]. Climate variables such as rainfall and

temperature have a direct impact on cultivation, and even small changes can affect crop yield and production [5,18,19]. The effect of climate variability on agriculture [20]is a growing concern worldwide, with multiple studies showing the significant impact of climate parameters variation on average crop yield [21, 22, 23, 24]. A study conducted in South Asia [8]shows that climate variables, such as temperature and precipitation, have a significant impact on crop development and growth. The strength of the relationship between crop yield and climate variables varies greatly depending on the season and location. A study conducted in Sudan examined the effects of long-term climate variables (temperature and rainfall) on the yield of five major crops. Results indicated that between 1984 and 2018, the annual maximum temperature (Tmax) increased by 0.03 °C per year, and the minimum temperature (Tmin) increased by 0.05 °C per year [25]. The yield for all five crops analyzed in the study exhibited a negative correlation with both Tmin and Tmax. However, the study found a strong positive correlation between annual rainfall and sorghum yield [25]. Koudahe et al. (2018) found in southern Togo the increase in temperature has a significant positive effect on maize and bean in Kouma-Konda while non-significant effects on crop yields were observed in Atakpamé and Tabligbo. The period of crop data collected for their study covers 24 years which was probably due to the long period of data available at the time of the study. Our study focused on 31 years maize yield data to investigate the change occurred due to the climate to meet the minimum time (thirty-year period) required by the World Meteorological Organization for climate change studies.
Hence, this study aims to (1) investigate the trends in precipitation, maximum and minimum temperature, and maize yields in Maritime region (Tabligbo) and (2) analyze the impact of climate variables (temperature and precipitation) on maize yields of the area.

2. Material and methods

Study area: Located between the meridians 0° 40' and 1° 50' of East longitude and the parallels 6° and 6° 50 of North latitude, the Maritime Region covers an area of 6,600 km² or about 11.66% of the national territory [27].It borders the Plateaux Region to the north (130 km), the Atlantic Ocean to the south (50 km), the Republic of Benin to the east (100 km) via the Mono River, and the Republic of Ghana to the west (80 km).The main crops cultivated in this region are maize, cassava, yams, cowpeas, and rice. The climate is subtropical hot and humid [28].The precipitation regime is marked by two dry seasons and two rainy seasons: a long rainy season (April to July), a short dry season (August), a short rainy season (September to October), and a long dry season (November to March) [29]. The annual rainfall of the region is between 800 and 1200 mm [30].

Figure 1: Map of the study area

Daily minimum and maximum temperatures, as well as daily rainfall for Lomé and Tabligboweather stations, were obtained from the National Meteorological Agency of Togo covering the period 1980 – 2022 (43 years of data). Data on the yield of maizewas obtained from the Statistics Department of the Ministry of Agriculture for the period 1990 to 2021. The selection of maize was based on the fact that it is the largest staple crop grown in the region.

The average annual minimum and maximum temperature, and rainfall, were computed based on daily data records from the Meteorological Office of Togo. Subsequently, the Mann-Kendall [31,32]trend analysis was employed by using R software (version R 4.1.2) to these variables to determine any positive or negative trends in temperature and rainfall between 1980 and 2022 [5,33]. The Mann-Kendall test is a non-parametric test that is commonly used for analyzing historical time series data [25]. This test does not require data to be normally distributed. During the testing process, the null hypothesis (H0) assumes that there is no trend present in the population from which the dataset is sampled. The alternative hypothesis (H1), on the other hand, suggests that there is a trend in the population. The null hypothesis (H0) will be rejected if the p-value is less than 0.1 [34]. The Mann-Kendall test was calculated as follows:

$$\sum_{j=1}^{n-1} \sum_{i=j+1}^{n} Sign(xi - xj) \quad (1)$$

Where:

- xi is the data value at the time i
- xj is the data value at time j
- n is the length of the time-series data
- Sign(xi – xj) is the sign function which can be calculated as follow:

$$\text{Sign}\ (xi - xj) = \begin{cases} 1 \text{ if } (xi - xj) > 0 \\ 0 \text{ if } (xi - xj) = 0 \\ -1 \text{ if } (xi - xj) < 0 \end{cases} \quad (2)$$

Sen's slope method was applied to quantify the trend [35]. The slope Q was computed as follows:

$$Qi = \frac{xi - xj}{i - j} \ ; I = 1, 2, 3, \ldots N \quad (3)$$

Where xi is the data value in the time series at time *i* and xj is the data value at time *j* (*j=i-1*). Sen's estimator of the slope is calculated as the median of N values of Qi. Qi is calculated differently depending on whether N is even or odd:

- $Qi = Q(\frac{N+1}{2})$ if N isodd (4)
- $Qi = \frac{1}{2}\ (Q\frac{N}{2} + Q\frac{N+2}{2})$ if N is even (5)

The sign of the slope's value indicates whether there is an increasing trend or not. Positive values indicate an increasing trend and negative values entail a decreasing trend.

Simple linear regression was first applied by using R software version 4.1.2 to analyze the trend of crop yields over time because crop yield is influenced by various factors besides climatic variables [25]. To assess the strength of the relationship between crop yields and climate parameters, Pearson's correlation coefficient *r* was used. A multiple regression analysis was performed to assess the impact of climate variation and crop yields by considering climate data (temperature and precipitation) that cover the period 1990 – 2021. The linear equation that explains the change in the yield as a function of minimum, maximum temperature, and precipitation is given as follows:

$$Y = c + b1 * Tmin + b2 * Tmax + b3 * P$$

Where Y is the yield (kg ha^{-1}), c is the intercept of the regression equation, and b1, b2 and b3 are the coefficients of Tmin (minimum temperature), Tmax (maximum temperature) and P (mm) is the precipitation.

3. Results

3.1 Maximum and minimum temperatures trends analysis

The Figure 2 presents minimum and maximum temperatures from 1980 to 2022 in Lomé, Tabligbo, and Kara. The Mann-Kendall and Sen's slope tests showed significant ($p<0.0001$) increasing trends in maximum and minimum temperatures at all locations. The magnitude differs from one location to another. Minimum temperatures increased by 0.05°C per year in Lomé, and 0.03°C in Tabligbo. Likewise, maximum temperatures increased by 0.03°C per year in Lomé and Tabligbo(Table 1). The annual average minimum temperature in Lomé ranged from 22.43°C to 25.61°C, from 22.08°C to 25°C in Tabligbo. The average maximum temperature varied from 30.53 to 32.63°C in Lomé and 32.17 to 34.47°C in Tabligbo. Lomé experienced the highest minimum and maximum temperature variability (3.01% and 1.67% respectively) followed by Tabligbo (2.51% and 1.51% respectively). By considering the maize growing period (April – July) in Tabligbo by 0.03°C per year (Table 2).

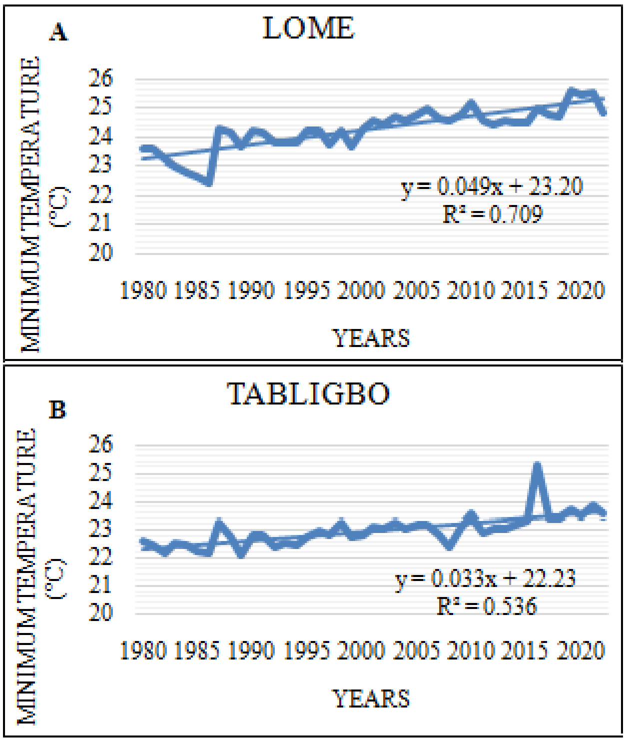


Figure 2: Minimum temperature in Lomé (A) and Tabligbo (B) from 1980 to 2022. (R^2 = Coefficient of determination)

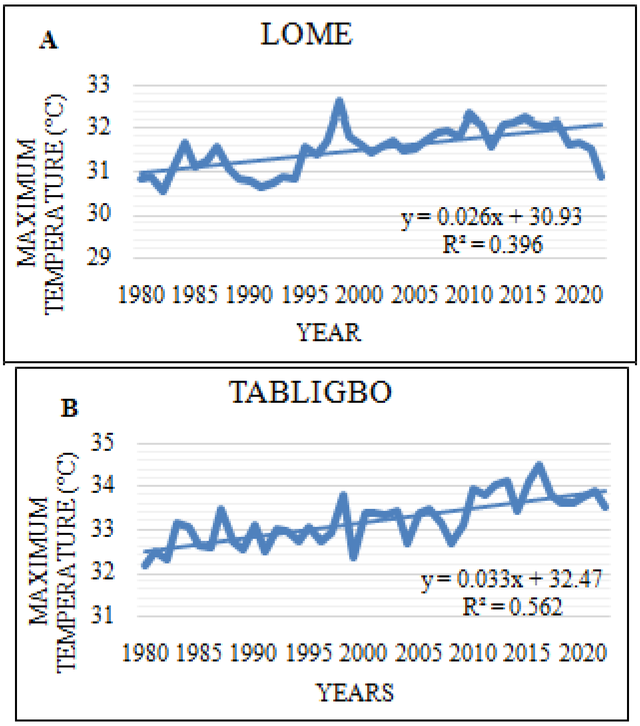
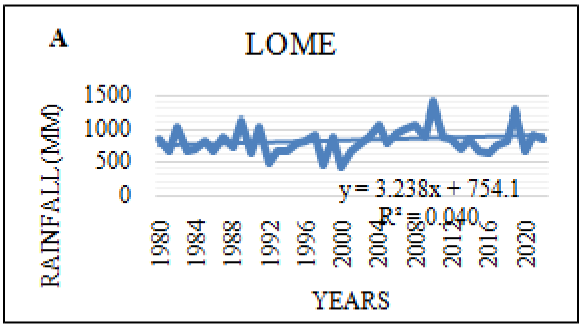


Figure 3: Maximum temperature in Lomé (A) and Tabligbo (B) from 1980 to 2022. (R^2 = Coefficient of determination)

3.2 Rainfall trends analysis

The average rainfall of the three locations is presented in Figure 4. In Lomé, the annual rainfall values were between 423.9 and 1416.7 mm with a coefficient of variation of 24.45% and an average of 825.36 mm from 1980 to 2022, in Tabligbo between 706.1 and 1428.2 mm with an average of 1041.58 mm and a coefficient of variation of 16.19%. The number of rainy days varies at different stations. In Lomé, the number of rainy days varies from 52 to 120 rainy days with an average of 79 days and in Tabligbo it varies from 68 to 110 rainy days with an average of 91 days. The Mann-Kendall and Sen's Slope tests revealed slight increases at all locations. The rainfall significantly increases ($p<0.05$) in Lomé and Tabligbo by 2.29 and 1.6 mm per year respectively (Table 1). By considering the growing season of maize (April – July), the rainfall significantly increased ($p<0.01$) in Tabligbo by 2.4 mm per year (Table 2).



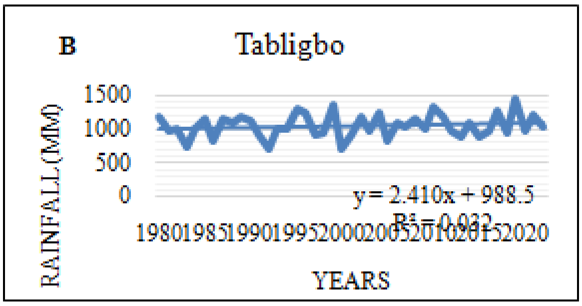


Figure 4: Rainfall in Lomé (A), Tabligbo (B), and Kara (C) from 1980 to 2022. (R^2 = coefficient of determination)

Table 1: Sen's slope values for annual rainfall, minimum and maximum temperature

Location	Sen's slope	p-value	Alpha Value	Significance
Rainfall (mm)				
Lomé	2.29	0.03	0.05	Yes
Tabligbo	1.6	0.005	0.01	Yes
Minimum temperature (°C)				
Lomé	0.05	6E-27	0.01	Yes
Tabligbo	0.03	5E-41	0.01	Yes
Maximum temperature (°C)				
Lomé	0.03	6E-11	0.01	Yes
Tabligbo	0.03	1E-47	0.01	Yes

Table 2: Sen's slope values for rainfall, the minimum and maximum temperature during the growing period of maize in Tabligbo

Variables	Sen's slope	p-value	Alpha Value	Significance
Rainfall (mm)	2.40	3.02E-07	0.01	Yes
Minimum temperature (°C)	0.03	2.66E-37	0.01	Yes
Maximum temperature (°C)	0.03	9.23E-33	0.01	Yes

3.3 Rainy days trends analysis

Figure 5. shows the trends in the number of rainy days from 1980 to 2022 in Lomé and Tabligbo. In Tabligbo, the number of rainy days insignificantly decreased ($p>0.05$) by 0.1days per year. In Lomé, a slightly non-significative increasing trend was observed by 0.03 days per year.

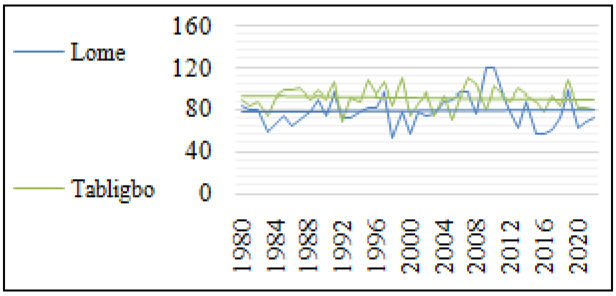


Figure 5: Rain days trends in Lomé and Tabligbo from 1980 to 2022

3.4 Crop yields trends

The crop yield analysis revealed a positive trend from 1990 to 2021 in Tabligbo (Figure 6). Maize yield significantly increased by 4 kg per hectare, per year ($p<0.05$). The average yield was 754.69 kg/ha with a coefficient of variation of 18.2%.

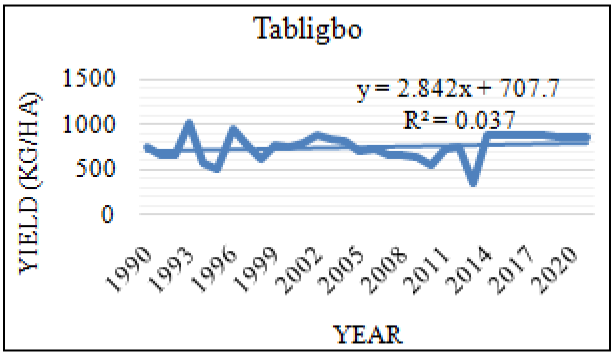


Figure 6: Maize yield trends in Tabligbo from 1990 to 2021. (R^2 = Coefficient of determination)

3.5 Impact of climatic variables on maize yields

Table 3: Multiple regression analysis during growing seasons

Location	Intercept	Tmin (°C)	Tmax (°C)	Rainfall (mm)	R square
Tabligbo					
Coefficient	-3.29901	0.13629	-0.10608	0.000065	0.1748
P-Value	0.607663	0.074773	0.154795	0.738419	

The results of the multiple linear regression analysis estimating maize yields change related to climate variables such as minimum and maximum temperatures, and rainfall during the growing season of maize are shown in Table 3. From these results, no significant impact on climate variables (precipitation, minimum and maximum temperature) was revealed in Tabligbo. A non-significant ($p>0.05$) positive impact of rainfall and minimum temperature on maize yields was observed.

4. Discussion

The results of the study revealed an increasing trend in temperatures, 0.05°C per year for minimum temperature in Lomé and 0.03°C in Tabligbo; 0.03°C per year for maximum temperature between 1980-2022 at both locations. These results imply in Lomé that the minimum temperature rose more rapidly than the maximum temperature. [36] in

Nepal obtained similar results of an increase of up to 0.06°C per year for minimum temperature and 0.02°C per year for maximum temperature. Koudahe et al. (2018)reached to a similar conclusion in Togo with an increase of 0.5°C per decade in minimum temperature and 0.4°C per decade for minimum temperature between the period 1971 – 2014, results that are similar to ours.Our results revealed that rainfall significantly increased in Lomé and Tabligbo. These results agreed with some studies [26], but are in contradiction with others [38] who found a slight decrease in rainfall in Lomé and Tabligbo from 1961 to 2011. Globally, the rainfall increases at all locations, this situation could be explained by the increase in temperatures that led to the increase of evapotranspiration.

We found that the number of rainy days slightly decreased in Tabligbo, while rainfall and annual temperatures increased. These results agreed with the synthesis report of IPCC (2014) which revealed that global warming leads to a decrease in rain days and then contributes to more extreme rainfall regimes. Maize yield trends increased in Tabligbo but it varied from year to year. This finding implies that because maize is a solely rainfed crop, there could be a link between the amount of rainfall and the yield of maize in the area[21].Also, for rainfed crops, water could be a limiting factor as well as soil management practices [39].

The results of the multiple regression analysis revealed non-significant effects of climatic variables on maize yields. In Tabligbo, minimum temperature and rainfall were positively correlated with maize yields. But these effects were not significant ($p<0.05$). These results suggest that maize yields depend also on some other environmental factors like soil health or management [25]. Similar results were obtained by Baffour-Ata et al. (2021) in Ghana and Tunde et al. (2011) in Nigeria who suggest that the minimum impact of climatic variables on some selected crop yields could be due to some other parameters known as non-climatic factors like soil fertility, type of soil etc. These non-climatic factors are susceptible to an increase the yield gap which is the difference between the potential yield of a crop cultivar and the actual yield by farmers [41]. Crop yields are known to be influenced by agricultural practices such as conservation agriculture, and field management practices [42]. In the same way, studies confirmed that yields of crops depend not only on climatic factors but also on non-climatic factors [43]. This is a justification for the use of a crop simulation model to minimize the effects of non-climatic factors [44,45] This could be somehow because maize needs much water to grow perfectly in the hotter environment [21] since the temperature in Kara is known to be high. The variation in climate variables constitutes the main threat to agricultural productivity [46], and is expected to substantially affect rainfed-based such as in Togo. Maize growing as many other bowls of cereal is climate-sensitive, its yields could continue to decrease when the environment is not optimal. Maize is most often grown in the southern part of Togo between April and July by using long cycle variety and between September and October by using short cycle variety.

5. Conclusion

This study aimed to investigate the impact of climatic variables on maize yields in southern (Tabligbo) Togo by considering the period 1980-2022. The results of the study revealed that minimum temperatures increased up to 0.05°C per year in Lomé and 0.03°C in Tabligbo, and maximum temperatures increased up to 0.03°C at both locations. A positive trend in annual rainfall was expressed differently as per the locations and did not show a significant correlation on maize yields. It is important to highlight the fact that, crop yields depend not only on climatic variables but also on other environmental conditions like the biochemical state of the soil, biotic stressors, and crop management. The results of the study showed that annual temperatures and rainfall increased at all locations. The results of our study could be used by researchers and all stakeholders involved in agricultural production including government to promote sustainable agricultural production that could enhance maize yields and subsequently increase farmer's incomes.

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