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Climate Variability and its Implications for the Sustainability and Resilience of Maize Production in the Northern Region of Ghana

Benjamin B. Suolo[1], Bizoola Z. Gandaa[1], Isaka Balma Yakubu[2], Precious K. Blege[1]

[1]*Department of Agricultural Mechanization and Irrigation Technology, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana*

[2]*Department of Agribusiness, University for Development Studies, P. O. Box TL 1882, Tamale, Ghana*

**Corresponding Author's Email: naa.bizoola1970@gmail.com*

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ABSTRACT

Climate variability remains one of the most significant shocks undermining agricultural productivity, particularly in rain-fed systems dominated by smallholder farmers. This study evaluates the impact of rainfall and temperature variability on maize yield, examines the relationship between these climatic variables, and explores adaptive practices aimed at mitigating the effects of dry spells and temperature fluctuations in the Tolon District. Secondary data were employed to assess the time-series trends in maize yield and climatic variables. The Mann–Kendall trend test, Sen's Slope estimator, and Pearson correlation analysis were applied to identify monotonic trends and relationships among climate parameters and maize yield. The results revealed no statistically significant trends in annual rainfall (p = 0.0798), maximum temperature (p = 0.4691), or maize yield (p = 0.0679) over the study period. However, the minimum temperature exhibited a statistically significant increasing trend (p = 0.00017), rising by approximately +0.083°C per year. A positive correlation was observed between annual rainfall and maize yield (r = 0.425). Although no significant yield trend was detected, maize production showed a slight annual increase of about +0.039 t/ha, likely attributable to improved agronomic practices and the adoption of enhanced seed varieties.

INTRODUCTION

Climate variability presents the biggest risk to the world`s current agriculture production system (Rahman et al. 2018; Wiebe et al. 2019; Shafqat et al, 2019). In the semi-arid region, crop production is expected to decrease due to climate variability, at some period poses a challenge to food security (Zhang, *et al.,* 2007; Ahmad *et al.,* 2015). Crop development, growth, and yield are adversely affected by high temperatures and unreliable rainfall amounts, these effects are already more noticeable in arid regions (Ullah *et al.,* 2019; Chattha *et al.,* 2021; Yasin *et al.,* 2022).

Almost all households in Northern Ghana and other parts of country depend heavily on agriculture for their survival. Small-scale farmers generate about 80% of domestic production. Studies show that Ghana`s climate has changed over the last years. The average annual temperature has been rising by 1˚C every ten years since 1960. During this time frame, monthly rainfall has been falling by 2.4% however the rainfall totals were extremely high. Studies show that deviations in climate variability, such as rainfall and temperature, can greatly affect crop production in Ghana (Cudjoe *et al.,* 2021).

Like much of the Ghanaian nation, the maize production in Tolon District is sensitive to climate variability. Studies reveal that rising temperatures, erratic rainfall patterns, and prolonged dry seasons are the three critical climate variability manifestations that negatively impact crop growth, productivity, and food security, and ironically, all three are happening. Despite agriculture being the mainstay of the nation - accounting for 19.2% of the Gross Domestic Product (GDP) climate variability endangers the sustainability of rain-fed agriculture, which is the primary practice of small-scale holder farmers.

Due to the detected climate signals based on validated historical climate data, agricultural productivity has been inconsistent due to rising temperatures and rainfall patterns, rain-fed maize production is expected to decline precipitously up to 25%, by 2050 creating food insecurity and economic instability for already vulnerable rural communities. Unfortunately, there is nothing farmers can do to remedy the situation, complicating their issues with rising input costs, ineffective land tenure systems, and inaccessibility to climate adaptation options.

Agriculture still remain one of the best sectors in the country, which contributes to about 80% of all the agricultural food staffs or produce that we have in Ghana by small scale farmers that depend mostly only on rain fall agriculture for their survival as well as their families. Climate variability raises such conditions as increasing temperatures, irregular rainfall patterns and drought threaten. Long-term viability about sustaining the production of maize in most areas on rainfall such as Tolon. Maize is an extremely staple food crop in Ghana and most importantly the North which is used in the preparation of beautiful and delicious meals like TZ. Research conducted by researchers show and illustrate that climate variation can reduce the yield of maize by 25 % if strategic measures are not adopted.

The study assesses the role of climate variability plays in influencing maize growth and yield. Appraisal of farmers adaption methods and plans, and sharing the findings with policymakers and stake holders in agriculture (Cudjoe *et al.,* 2021). The study broadly assessed the effect of climate variability of rainfall, humidity and temperature on maize yield of small-scale farmers in Tolon District, specifically evaluating; the impact of rainfall and temperature variability, relationship between rainfall and temperature, and the practices that reduce the effect of dry spells and temperature fluctuations.

In many nations within African, a percentage of the workforce are small scale farmers, contributing minor percentage to the national Gross Domestic Product (GDP). Farmers live in poverty and struggle for their daily livelihood (Müller-Kuckelberg, 2012). About 70 % of Africans derive their livelihoods from rain-fed agriculture, an activity that is characterized by small, subsistence farms vulnerable to many stresses inclusive of those associated with climate change (Connolly-Boutin and Smit, 2016).

In Sub-Saharan African (SSA), the main engine of economic growth is through agriculture and thus, food security is primarily based farming since majority of the people cultivate their own food. Likewise in West Africa more than 60 percent of the total labor force are engaged in farming that provide about 35% of the regional GDP (Dube *et al.,* 2016).

The SSA is cited as the largest vulnerable pockets of climate change hotspot. This is due to an almost nonexistent adaptive capacity for low levels of prior investment, poverty and inadequate infrastructure to stabilize and/or adapt to climate change. SSA depends upon precipitation for many needs water, food, energy. For instance, the region has much rain-fed agriculture, which renders food systems vulnerable as precipitation patterns change (Ofori *et al.,* 2021).

Occurrences of rainfall and temperature variation is predicted to be a detrimental impacted by crop production (Gezie, 2019). It is clear that climate change will bring about substantial welfare losses especially for smallholders whose main source of livelihood derives from agriculture. Changes in climate extremes are already having impacts on social, economic and natural systems, and future changes associated with continued warming will present additional challenges (Gezie, 2019).

The global production of maize has taken a leap in recent decades, demand pull and yield plus area growth work together made maize the leading cereal in production and will be the most widely grown and traded crop. The SSA has the largest vulnerable pockets of climate change hotspot as a result of an almost nonexistent adaptive capacity for low levels of prior investment, poverty and inadequate infrastructure to stabilize and/or adapt to climate change. SSA depends on precipitation for many needs water, food, energy. For instance, the region has much rain-fed agriculture, which renders food systems vulnerable as precipitation patterns change (Ofori *et al.,* 2021). Occurrences of rainfall and temperature variations are predicted to be a detrimental impacted on crop production (Gezie, 2019). In SSA, maize is the most critical food staple in the region and production by smallholders with less than two hectares per household and climate variation makes them very vulnerable to poverty and food insecurity (Hall *et al.,* 2024). The maize production in Ghana is mainly done under rain-fed conditions by smallholder farmers who are poorly resourced. Maize contributes 50% of the total cereal production in Ghana. The average 1.5 million metric tons (MT) yearly maize production was reported between 2007 and 2010 about 1.7 t/ha average yield. Annual yields have been pegged to grow at about 1.1%. Maize is cultivated in almost every region of Ghana. Maize cultivating agro-ecological zones are broken down into four zones with varying cultivating characteristics (Darfour and Rosentrater, 2018).

In Northern Ghana, annual rainfall of 1,100 mm and a single rainy season is experienced. Maize, sorghum and millet are cultivated and intercropped with legumes. More than 70% of maize production in Ghana occurs in three of these zones - the guinea savanna, the forest savanna, and transitional zones. The five areas where maize is cultivated exist in the Northern Region, Brong-Ahafo, Ashanti Region, Central, and Eastern Regions (Darfour and Rosentrater, 2018). In Ghana, there is high consumption of maize compared to millet and sorghum by households (Wongnaa *et al.,* 2019). It functions as the staple crop for most households in the SSA region, its function as food and a non-food commodity and plays a vital role household food security and income, contributing to at least one-fourth of calories eaten and being cultivated in all agro-ecological zones (Yaro, 2013b). It is also a vital component for livestock and poultry feed and also as a raw material for brewing alcoholic beverages in Ghana, industrial processing and other uses. Fermented maize meals like "koko" (porridge), "banku," "tuo zaafi," "akple," and "kenkey" are common in most homes (Darfour and Rosentrater, 2018).

Maize in spite of its high significance to the economic development in Ghana, the returns in maize yield over is significantly low as compared to other countries globally (Wongnaa *et al.,* 2019). Climatic variation such as maximum temperature and relative humidity is a major factor considered in the production of low maize yield due to their harmful effect on grain yield (PGA *et al.,* 2021). Low yields are realized when planting and plant growth overlap concurring with adverse climatic conditions, especially at growth stages such as tussling and grain filling (Oke, 2016). The spawns of the low yields in maize in Ghana have been linked to inadequate farm inputs, poor soils conditions, low fertilizer utilizations, substandard farming practices, and the infestations of maize plants by insects such as fall armyworms (Li et *al.,* 2019b). However, these are not the only limiting factors facing maize production in Northern Ghana. Maize production depends on climatic factors including rainfall and temperature. For example, maize is cultivated mostly in regions having annual rainfall between 500 mm to 1000 mm (Li *et al.,* 2019). Despite this, excessive rainfall can have either a beneficial or non-beneficial impact on maize yield and this effect varies regionally (Li *et al.,* 2019).

Maize production in the Tolon District of Ghana faces significant challenges due to climate variability, which manifests in various ways impacting crop growth, quality, and overall environmental health (Antwi *et al.,* 2022). Northern Region of Ghana experiences a unimodal rainfall pattern. The rainy season starts in May and ends in mid-October. The mean annual rainfall ranges between 950mm to 1,200mm. The rainfall pattern restricts staple crop production to one cropping season. The region experiences dry season from November to April (Ahmed and Anang, 2019). Some challenges faced by farmers are; unreliable rainfall pattern which makes it quite difficult and confusing in timing when actually to sow (Ahmed and Tetteh-Anang, 2019). Due to the indecisiveness when the need demand, maize yield is adversely low in quality and quantity, the incidence of occasional severe high down pour constraint that have detrimental effects on both harvesting and post-harvest processes, and the severity of dry spells localized areas depends on the location farmers' field (Ahmed and Anang, 2019). Farmers in Ghana are conscious of climate parameters over the years but have not been able to manage the variations in rainfall and temperature patterns (Baffour-Ata *et al.,* 2023b). However, the extremeness of these weather parameters has made farmers to take precautions in the onset of rainy season (Yaro, 2013). Farmers are conscious of climate variability in terms of erratic rainfall distribution, reduction in rainfall amounts, and increasing temperatures (Cudjoe *et al.,* 2021).

Observed climate pattern from metrological data depict that increase in temperature trend is tremendously surging during planting season amongst agro-ecological zones of northern Ghana. These trends are depicted by variability in nature and magnitude, with a positive (warming) trend in the average temperature during the growing season (Yeleliere *et al.,* 2023). The effects of climate change are likely to aggravate vulnerabilities associated with maize production, Downpours in rainfall over the years have been relatively inconsistent over the past decades. On analysis of rainfall trends within the Upper-West and North-East Regions have indicated decline in rainfall by 85 mm during the years of 1990 to 2010 rainy seasons (Yeleliere *et al.,* 2023). This prediction has proven to be evident in the study area for the past 5 years and has resulted in a decline in rainfall. The optimum growth of maize needs varied temperatures during the day and night and over the entire planting season (Waqas *et al.,* 2021). Maize strife and grow well at a temperature between 25 and 28. However, studies show that maize faces significant threat at temperatures above 30˚C and there tends to be a rapid decline in maize yield as it challenged by incidences of heat stress for extended durations of time (Waqas *et al.,* 2021).

The Mann-Kendall test for determining statistically significant trends, either monotonic upward or downward to any variable over time. An increasing monotonic trend means that the value of the variable increases consistently with time; conversely, decreasing monotonic trend implies that the value decreases consistently with time. It may not be a linear trend. The M-K test can be used instead of parametric linear regression analysis for testing whether the slope of an estimated linear regression line is different from zero. The major constraint regarding regression analysis is residuals have to fall from a fitted regression line to be normally distributed, which again is not required here as this particular method happens to be nonparametric (distribution-free), p-values are less than 0.05, indicates a positive and significant trend. The test has 95% confidence limit has a monotonic trend test. The null hypothesis (H0) depicts there is no monotonic trend in the tested subjects, while the alternative hypothesis (H1) means a monotonic trend. The null hypothesis (H0) is rejected if $p \leq 0.05$ (Nzali *et al.,* 2024).

MATERIALS AND METHODS

Study Area

The study was conducted in the Northern Region of Ghana, which is characterized by a unimodal rainfall pattern and a predominantly agrarian economy. The region experiences a single rainy season from May to October, followed by a prolonged dry season from November to April. Annual rainfall ranges between 900 and 1,200 mm, while mean annual temperatures vary from 25°C to 35°C. The area is dominated by smallholder farmers who rely mainly on rain-fed agriculture, with maize being one of the principal staple and cash crops cultivated. The research specifically focused on five (5) districts within the region namely; Tolon, Kumbungu, Savelugu, Sangnarigu, and Gushegu-Karaga. These districts were selected due to their significant maize production and vulnerability to climatic variability such as erratic rainfall, high temperature fluctuations, and extended dry spells.

Data Collection

Both secondary and primary data sources were used in this study. Secondary climatic data, including annual rainfall, temperature (maximum and minimum), and relative humidity, were obtained from the Ghana Meteorological Agency (GMet) for a period covering multiple years (specify years if available). Corresponding maize yield data were sourced from the Ministry of Food and Agriculture (MoFA). Primary data were collected through field surveys to capture farmers' perceptions of the effects of climate variability on maize production. A structured questionnaire was administered to a total of 150 farmers, comprising 30 respondents from each of the five (5) districts. Farmers were randomly selected to ensure a representative sample of smallholder maize producers in the study area. The survey gathered information on farmers' awareness of climate change, perceived impacts of rainfall and temperature variations on maize yield, and adaptation measures adopted to mitigate adverse effects.

Data Analysis

Quantitative data were analyzed using Statistical Package for the Social Sciences (SPSS) and Microsoft Excel. Descriptive statistics, including means, standard deviations, and frequency distributions, were used to summarize the perception survey results. Trends in climatic variables (rainfall, temperature, and humidity) and maize yield were analyzed using the Mann–Kendall trend test and Sen's Slope estimator to identify the direction and magnitude of monotonic trends. The Mann–Kendall test is a non-parametric method widely applied in hydrological and climatic studies for detecting long-term trends in time-series data. The Pearson correlation coefficient was also computed to assess the strength and direction of relationships between climatic parameters and maize yield. All statistical tests were conducted at a 5% significance level ($p < 0.05$). Results were presented in tables and figures to illustrate spatial and temporal variations in climatic variables and maize productivity across the selected districts.

RESULTS AND DISCUSSION

Trends of Climatic Parameters and Maize Yield in Northern Region

The non-parametric Mann-Kendall trend test was used to identify monotonic trends in the Climatic parameters (rainfall, temperature and humidity), against the yield of maize. To measure the difference in trends in Mann-Kendall trend slope, an estimator by Sen was applied. Mann Kendall long-term trend analysis is important to give us the information about climatic patterns over time and the possibilities that this has on agricultural productivity in Tolon District. The data indicate that two of the variables analyzed presented statistically significant trends with a $p < 0.05$ (i.e. level = 0.05 of significance).

Average minimum temperature showed strong increasing trend ($p = 0.000839$, and 0.4800), with a Sen`s slop of + 0.0591 C/year. This shows a clear trend of an increase in the temperatures during the night, and that increase shows a large growth of the night temperatures during the study period. The observation is in agreement with larger-scale regional and global trends of asymmetric warming, in which minimized temperatures warm much more rapidly than maximized temperatures.

Table 1. Mann-Kendall Trend Test and Sen's Slope Results (2000–2024)

Variable	Trend	p-value	Sen's Slope	Kendall Tau (τ)
Rainfall (yearly totals, mm)	No trend	0.079839	6.65mm/year	0.2533
Avg Max Temperature (T_{max})	No trend	0.743623	0.0066°C/year	0.05
Avg Min Temperature (T_{min})	Increasing	0.000839	0.0591°C/year	0.4800
Avg Day Humidity (%)	decreasing	0.010633	-0.1250%/year	-0.3667
Avg Night Humidity (%)	No trend	0.943835	0.0000%/year	-0.0133
Maize Yield (ton/ha)	No trend	0.067874	+0.0392 ton/ha/year	0.2633

Average daytime humidity showed a substantial downward trend was observed (p = 0.010633, 07 = -0.3667), with Sen`s slope -0.1250 percent each year. The implication of this is that there is a gradual drying in the day-time that will contribute to a reduction in the crops evaporative demand and lead to changes in the water relation of plants. This finding is within the outcomes made by Baffour *et al.* (2021) during the study in the Asante Akim North District in Ghana, where tropically high increasing warming trends were reported, especially in the minimum temperatures, with p-values lower than 0.05. Initially such trend has become to be frequent in West Africa and this is raising concerns in relation to climate change effects on food security.

Maize yield (p = 0.0679) exhibited an almost significant upward trend, with a Sen's slope of +0.0392 t/ha/year and a correlation coefficient of r = 0.2633. This suggests a modest annual increase in maize productivity over the study period. The gradual improvement in yield may be attributed to the adoption of better agronomic practices, increased access to farm inputs such as fertilizers and improved seed varieties, and the use of drought-tolerant maize cultivars. However, the observed trend was not statistically significant, indicating that although productivity is improving, the rate of increase is not yet strong enough to be confirmed through statistical testing. These non-significant results are close enough to provide rationale of close supervision in the future since longer time series can validate the trend, particularly on agricultural production whereby management interventions can moderate the effects of climate changes.

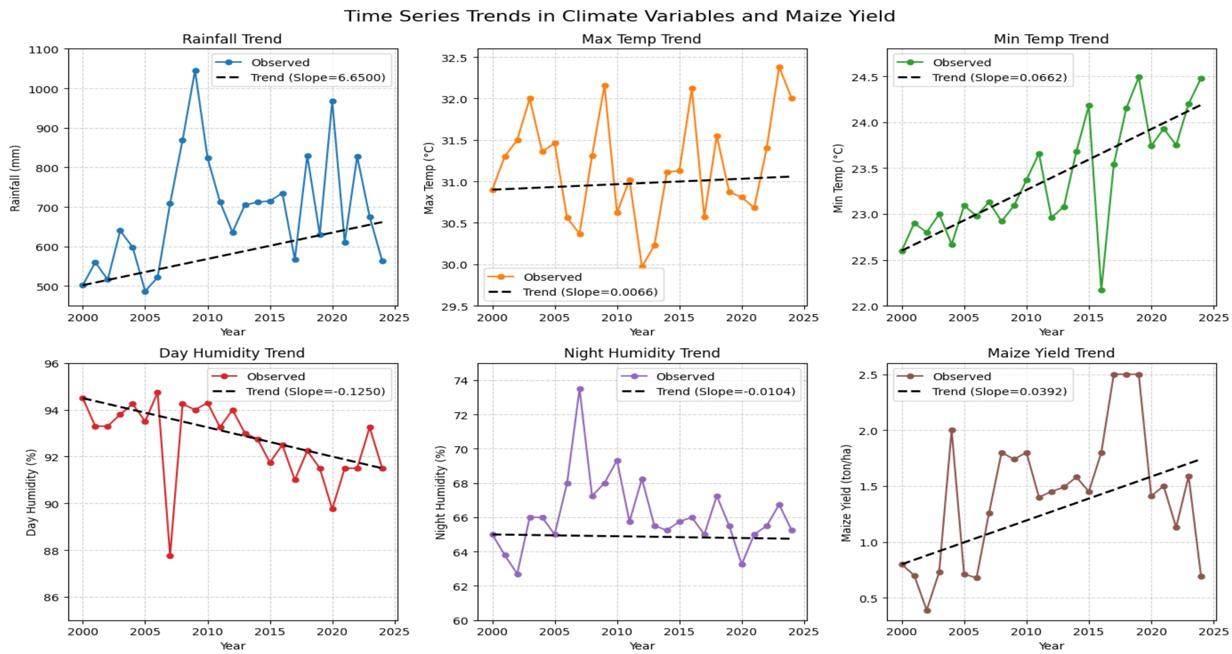

Figure 1. Trends of climate parameters with the Mann-Kendall Test

The slope in Sen's figures shows that the yield of maize is increased over the year by 0.0392 ton/ha/year and a rainfall rate of 6.65 mm per annum. The increase of maize yield by a factor of 0.0392 is highly insignificant. This implies that over a period of 25 years will result in (0.0392 x 25) tons/ha. When the Sen's slope is multiplied against the 25 years period, it is revealed that, on average minimum temperature has changed by a percentage of about 2.075. A study revealed that an increase in total average annual temperature by a degree result in maize yield decline (Cudjoe *et al.,* 2021). This repetitive increase over the years led to low crop yield when the right conditions necessary for growth is exceeded (Limantol *et al.,* 2016).

Time-series analysis indicates specific patterns on the climatic variables and maize yield throughout the 25-year period (2000-2024) in the study area. There is a weak and irregular trending pattern caused by the rainfall displaying an increase, with Sen Slope of +6.65 mm/year, which states a slow and steady rise in annual rainfall amounts. Nevertheless, such a tendency is covered with large inter-annual variability, as the following sharp changes (over 1000 mm in 2009 and less than 500 mm in 2005 and 2024) show. This indicates that although there might be a continual trend to wetting, there still is great unpredictability in terms of rainfall, thus making planning of agricultural activities difficult.

Maize yield at T_{max} and humidity does not show a clear directional trend, but it is slightly positive (0.0392 ton/ha/year). The trend noted is drastically uneven between annual years, with both high production (~2.5 ton/ha in 2017-2019) and dramatic decreases (e.g,. <0.5 ton/ha in 2002 and 2024). It means that maize productivity is very responsive to short-term climate distortions (e.g., drought, heat waves) and family management as opposed to being determined by long-run climate tendencies.

The increased warming at night is an obvious and troubling observation, but the absence of more regular patterns in other variables and yield shows that farming systems are resilient or have a buffering effect, perhaps through adaptive measures including the use of superior inputs, planting dates, or variety choice. But warming and uncertain rainfall in the future can potentially outweigh the current adaptive actions requiring climate-smart agriculture actions. All these findings indicate that agricultural systems in Tolon are complex as well as dynamic. The increased warming at night is an obvious and troubling observation, but the absence of more regular patterns in other variables and yield shows that farming systems are resilient or have a buffering effect, perhaps through adaptive measures including the use of superior inputs, planting dates, or variety choice. But warming and uncertain rainfall in the future can potentially outweigh the current adaptive actions requiring climate-smart agriculture actions.

Table 2. Bivalent Pearson Correlation between Climate Variables

		yearly total rainfall (mm)	Maize yield (MT/HA)	average maximum temperature(°C)	average minimum temperature (°C)	relative humidity at 0600 HRS_	relative humidity at 01500 HRS
yearly total rainfall (mm)	Pearson Correlation	1	.425*	.149	.141	-.172	.260
	Sig. (2-tailed)		.034	.476	.502	.410	.209
	N	25	25	25	25	25	25
Maize yield (MT/HA)	Pearson Correlation	.425*	1	-.111	.292	-.175	.206
	Sig. (2-tailed)	.034		.597	.157	.402	.323
	N	25	25	25	25	25	25
average maximum temperature(°C)	Pearson Correlation	.149	-.111	1	.053	.190	-.228
	Sig. (2-tailed)	.476	.597		.800	.364	.274
	N	25	25	25	25	25	25
average minimum temperature (°C)	Pearson Correlation	.141	.292	.053	1	-.429*	-.087
	Sig. (2-tailed)	.502	.157	.800		.032	.681
	N	25	25	25	25	25	25
relative humidity at 0600 HRS_	Pearson Correlation	-.172	-.175	.190	-.429*	1	-.155
	Sig. (2-tailed)	.410	.402	.364	.032		.459
	N	25	25	25	25	25	25
relative humidity at 01500 HRS	Pearson Correlation	.260	.206	-.228	-.087	-.155	1
	Sig. (2-tailed)	.209	.323	.274	.681	.459	
	N	25	25	25	25	25	25

*. Correlation is significant at the 0.05 level (2-tailed).

The correlation matrix establishes and studies the type of relationship that exists between maize yield in metric tons per hectare with climatic variables. These comprise annual rainfall totals, measured in mm, average maximum temperature (Tmax), average minimum temperature (Tmin), day humidity, and night humidity. A total of 25 sample sizes were used to establish these relationships. The key findings are interpreted below.

Impact of rainfall on maize yield

There is a considerable positive correlation between the amount of rainfall in a year and maize yield in the Tolon District. The correlation value of Pearson is 0.425 ($p = 0.034$), which is statistically significant at a 5 percent level ($p < 0.05$). This implies that as the amount of rain increases per annum, the yield of maize also increases during the 25 years (2000-2024). Maize is rain-fed and its growth and development rely heavily on the adequate supply of water to fulfil the physiological roles like photosynthesis, uptake of nutrients and transpiration. The positive correlation (Fig. 2) observed is attributed to rainfall as a parameter of climate-related variable affecting maize production (Yaro, 2013; Cudjoe *et al.,* 2021). Although there is moderate correlation, it highlights the need for an appropriate pattern and an adequate amount of rainfall during the growing season to achieve the best productivity of maize.

Nevertheless, it is important to mention that not all the rainfall is desirable, as large amounts or when unevenly distributed, have an adverse effect, such as causing waterlogged conditions, soil erosion, or diseases that reduce the potential yields. Therefore, the total annual rainfall trend is significant with yield, but the other factors that could be considered just as significant is the timing and distribution and intensity of rainfall, which is not reflected in the total annual rainfall.

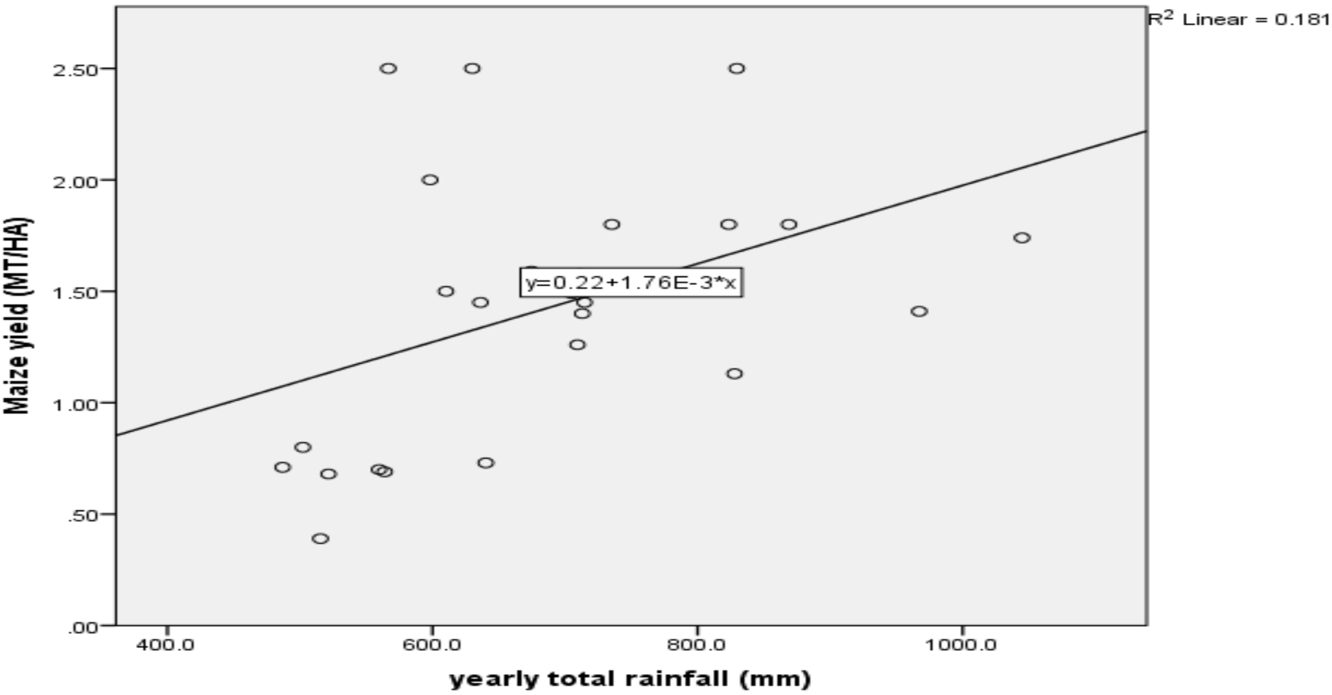

Figure 2. Correlation between maize yield and rainfall

Impact of temperatures on maize yield

Correlation analysis showed a weak and insignificant attitudes between maximum and minimum temperature with maize yields. Maximum temperature (T_{max}) averaged over the growing season had no significant relationship with the maize yield (r = -0.111, p = 0.597). This implies an increase in day temperatures does not have a significant negative effect on maize yields. Mean average minimum temperature (T_{min}) is positively related correlated but weak (r = 0.292, On the other side, farmers have adjusted early planting and growing heat-tolerant varieties, and irrigation mitigates the impact of temperature increase. However, though correlation does not mean causation, the insignificance of the association between temperature and yield does not imply that temperature has no biological effect. Rather, it means that other conditions may stand out in yield determinants in this region, p = 0.157) and not significant. Even though T_{min} has recorded a high trend of increase over years (Mann-Kendall test: $p < 0.001$) its effect on maize yield showed weak effects.

These findings imply that the extremes in temperature, especially high T_{max} above 30^0C, which have been shown to impose heat stress and lower pollen viability in maize (Waqas *et al.,* 2021) may not have been sufficiently severe, or frequent enough to be reflected as negative effect on yield during the period of study.

notably including rain variability, soil fertility or management.

Humidity and Maize Yield

Visual reports and findings from the maize yield and humidity analysis show there is no significant correlation. However, studies southern Ghana indicate that relative humidity have positive impacts on yield when p-values fall within specified range of less than or equal to 0.05

(Dwamena *et al.,* 2022). However, based on the p-values of 0.241 and 0.172, respectively, for humidity during the day and night, it supersedes the benchmark of 0.05 (Figures 5 and 6).

Impact of Climate Variability on Maize Yield

Yield has a significant positive correlation with rainfall, clearly indicating that water availability is an important factor in supporting healthy crop growth. Since maize is classified among the group of crops considered as water-loving or water-requiring for optimum development, adequate rainfall, particularly during the critical growth stages of flowering and grain filling, among others.

On the other hand, the weak correlation with temperature and maize yield means that implying that temperature fluctuations within this range have been detrimental to maize production is not a safe assumption, however. One caveat to these results not generalizing perfectly elsewhere, however, is that this was a somewhat smaller sample and specific climate trends. For instance, very high and very low temperatures would be expected to decrease yield, but such results were not found in this particular data set.

Humidity, while positively correlated to rainfall, exerted no statistically significant impact on maize yield; perhaps because the levels of humidity measured are not conducive to stressful growth. However, in times of drought or extreme humidity, this factor may impact more as it stresses plants for water and transpiration needs.

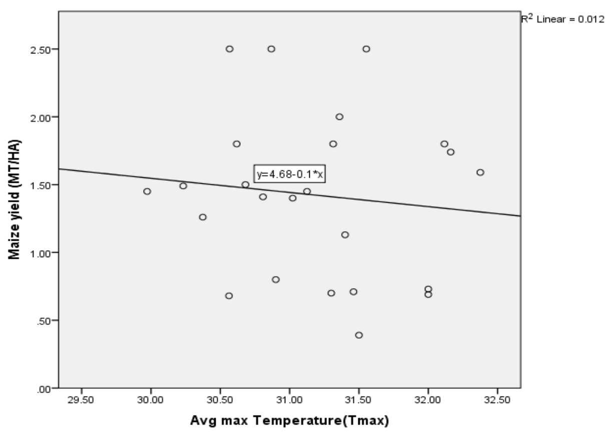

Figure 3. Maize yield versus maximum temperature

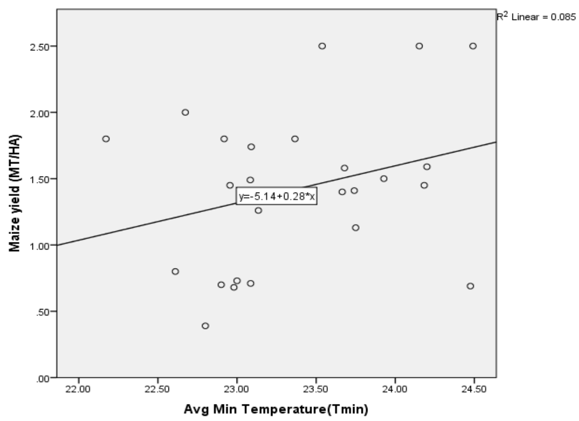

Figure 4. Maize yield versus minimum temperature

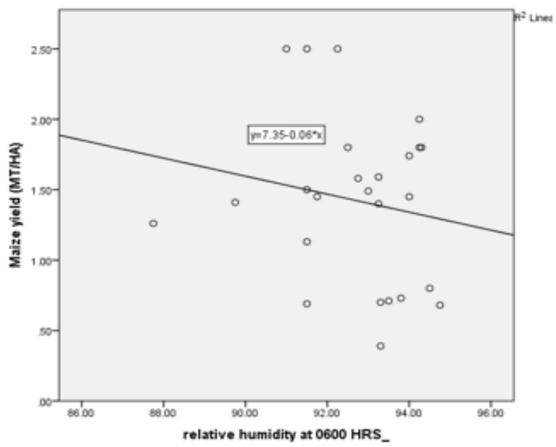

Figure 5. Average Humidity against maize yield

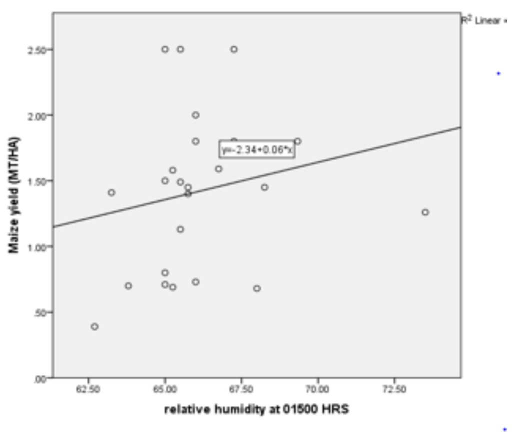

Figure 6. Night humidity against maize yield

CONCLUSION

Mann-Kendall and Sen Slope and Pearson correlation used in analyzing relations between climatic variables and maize yield revealed the positives and negatives effects. The study showed a complicated and dynamic climate condition with great insights on the viability of agriculture. The study identified inter-annual variation, including extreme values. Irregular compromises and less predictability of crop yield, thus making planting choices among smallholder farmers.

Minimum temperature (T_{min}) was observed to a have mean increment of + 0.0591^{0}C per annum (P< 0.001) with the sum addition of almost 1.5°C. The adverse response T_{min} to maize is the elevation of respiration rate, a decrease in net photosynthetic gain, a shortened grain-fill duration, and improved pest and disease survival. Conversely, there was no substantial trend (p = 0.7436) in maximum temperature (T_{max}), which means there was relative stability in daytime heat. Nonetheless, these changes indicate an asymmetric warming trend (most strongly on the nights) which is consistent with overall climate change indicators, through a reduction in the diurnal temperature range.

Humidity patterns are also disturbing: nighttime humidity (0600 HRS), which is very important in dew formation and maintenance of soil moisture, has dropped significantly (-0.125%/year, p = 0.0005), and the daytime humidity has not significantly changed. This nighttime drying trend can also add to crop water stress, and this can be more so during dry periods.

Maize yield showed a positive, insignificant trend (+0.0392 ton/ha/year, p = 0.0679), and large variability of yield between years, scattered between 0.39 and 2.50 ton/ha. Pearson correlation test showed a statistically significant positive correlation between rainfall and maize yield (r = 0.425, p = 0.034), implying the availability of soil moisture improves maize yield. Maize yield showed no significant relationship with maximum temperature (r = -0.111, p = 0.597) or minimum temperature (r = 0.292, p = 0.157), daytime humidity, and nighttime humidity.

CONFLICT OF INTEREST

The authors have declared no conflict of interest regarding the publication of the paper.

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