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Climate Variability and Change Impact on Crop Production: Evidence from Ghana

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Abstract
This paper explores the impact of climate variability and/or change on two major crop yields (cassava and maize) and cash crop (cocoa) in two districts in different agroecological zones - Atwima Mponua (Semi-Deciduous Forest Zone) and Ejura-Sekyeredumase (Transition Zone) of the Ashanti Region of Ghana. A comparative-case mixed-methods research design was adopted for the study, involving household survey questionnaires, focus group discussions (FGDs) and in-depth interviews with key informants to discuss farmers' perceptions about changes in climate and impact on crop yields. Three hundred participants were involved in the study - 150 from each district. The study also used time series panel data approach to analyse the impact of climate variables (mean annual maximum and minimum temperatures; and total rainfall) on the three crops over the period 1992 - 2014.Farmers perceived changes in the weather patterns - mainly increasing temperature and erratic and low rainfall. Besides, farmers had observed invasion of weeds; and dryness of aquatic habitats (especially, during dry periods); and loss of major staples. The findings from the analysis of secondary data corroborate farmers' perceptions about changes in climate and its negative impacts on cassava and maize yields for the past 20-30 years. However, qualitative feedback about impact of climate variables on cocoa yield conflicted with the findings of analysis of secondary data. The findings from this study can form a basis for policy makers to develop region specific adaptation policies to address climate change impacts on crops studied and extend it to other crops.
Keywords: Climate variability and change; Vulnerability; Food crop; Cash crop.
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1. Introduction

There is growing evidence to suggest that the global temperature has risen over the last century, which has resulted in unpredictable and unprecedented variations in the climate and its adverse impacts on human lives across the world (IPCC (IPCC (Intergovernmental Panel on climate change), 2022). Climate change has slowed down agricultural growth globally and is expected to impact significantly on crop production because of the high dependence of agricultural activities on weather (IPCC, 2022). The harsh impacts of global climate on crop production are evidenced by the many reported cases of continuous decline in crop yields around the globe (Bednar-Friedl et al., 2022, Trisos et al., 2022). Although positive impacts are expected in some cases (e.g., increases in yields of maize and sugar beet in higher latitudes) (Bednar-Friedl et al., 2022), overall, it is projected that most climate change impacts are likely to be negative, with the severity of impacts from extreme weather events, changes in precipitation patterns and reduction in yields of most crops (Field et al., 2015).

In Africa, mean annual and seasonal temperatures have increased between 1°C and 3°C since the mid-1970s with the highest increases experienced in the Sahara and Sahel (Trisos et al., 2022). It is projected that sub-African region will experience a gradient of precipitation decrease in the west and increase in the east (Trisos et al., 2022). Sub-Saharan Africa has already experienced reduction in major crop yields, example an average of 5.8% and 2.3% reductions in maize and wheat yields respectively due to climate change (Trisos et al., 2022). Climate change is projected to worsen food insecurity due to likely reduction in the yields of major crops such as maize and wheat in the tropical regions (Trisos et al., 2022; Porter et al., 2014) due to the expected increased vulnerability of the agricultural sector, particularly among poor farmers (World Bank Group, 2016; Dasgupta et al., 2014) including Ghana.

Ghana has experienced about 1^0C rise in temperature since 1960, rising from 26.5^0C to the current mean temperature of 27.5 ^{0}C (Ghana Environmental Protection Agency (GEPA), 2012). Asante and Amuakwa-Mensah (2014) observed that the temperatures in all the ecological zones of Ghana are rising while rainfall patterns are increasingly becoming erratic, with an overall reduction in the amounts of rainfall. It is projected that annual rainfall totals will decrease by 1.35 – 2.25% between the year 2060-2079 due to rising temperatures (World Bank Group, 2021).

Crop production contributes approximately 19.2% of Ghana's Gross Domestic Product (GDP) and constitutes 60% of the labour force (GSS (Ghana Statistical Services), 2018). The agricultural sector in Ghana is believed to have the potential to grow at rates as high as 6% per annum (World Bank Group, 2017). However, the present level of crop production fails to meet the food demands mainly because of challenges posed by climate variability and change (MoFA (Ministry of Food and Agriculture), 2015). De Pinto et al. (2012) report that farmers in different parts of Ghana recognise reduction in yields of major staples, disappearance of forest and wildlife, high incidence of pests and diseases due to proliferation of insects, and changes in growing season due to the impact of changes in climate. Low yields for both staple and cash crops have been observed in Ghana due to the negative impact of climate variability and change, with cereal yields estimated at 1.7 t/ha compared to the regional average of 2.0 t/ha; and average cocoa yield estimated at 400 – 450 kg/ha, comparatively lowest in the world (Ghana COCOBOD, 2015). It is projected that in aggregate, it is highly likely that there will be a continual decrease in the yields of major crops (e.g., maize, cassava and groundnut) if effective adaptation strategies are not implemented to support farming activities (Chemura et al., 2020; Ndamani and Watanabe, 2017; de Pinto et al., 2012). This is because agricultural activities in Ghana have been vulnerable to seasonal climatic variability, particularly over the last 30 years (Asante and Amuakwa-Mensah, 2014).

Studies by Stanturf et al. (2011) and Kemausuor et al. (2011) on climate variability and change in Atwima Mponua and Ejura-Sekyeredumase districts respectively indicated that dry spells in critical periods where many crops such as maize wither instead of flower contribute significantly to crop failure. The outcomes of the studies point to climate variability and change as a major contributing factor to food insecurity and poor livelihoods of farmers and the population. In the wet season, it is projected that the Deciduous Forest Zone (Atwima Mponua District) will experience a decrease in precipitation ranging from 48-45%, whilst the Transition Zone (Ejura-Sekyeredumase) will experience a precipitation decrease in a range of 46-36% by 2080 due to rising temperature with corresponding decreasing rainfall across the region (Stunturf et al., 2011).

Maize and cassava are one of the major staple crops grown in both study areas, additionally, cocoa is grown in Atwima Mponua District (MoFA, 2015). Crop simulation models for root and tuber crops showed a reduction in yields with rising temperatures of 1-2 ^{0}C (Sagoe, 2006). It is projected that the current annual national yields of cassava, 15t/ha (MoFA, 2015) will reduce by 3%, 13.5% and 53% in 2020, 2050 and 2080 respectively (UNFCCC, 2011).

Cocoa is the primary cash crop, accounting for 70-100% of household incomes of cocoa farmers in Ghana (World Bank, 2017). It is projected that by 2050, a rise in temperature of 2.1°C, without change in total rainfall will cause significant reduction in cocoa production if effective adaptation measures are not taken (Dasgupta et al., 2014).

Considering that maize and cassava make major contribution to food security and cocoa to the Ghanaian economy, some studies have been conducted to explore the impact of climate variability and or change on crop yields (e.g., Cudjoe et al. (2021); Chemura et al. (2020); Fosu-Mensah et al. 2012). Chemura et al. (2020) and Fosu-Mensah et al. (2012) adopted crop stimulating models to assess the impact of climate variables on crop yields. Crop simulation models explain the physiological effects of high temperature on crop yield but not the effects of small increase in temperature associated with global warming. Therefore, the simulation model is not reliable method of assessing the impact of environmental changes on crop yields (Maharjan and Joshi, 2013; Sarker, 2012). Cudjoe et al. (2021) used climatic data (mean annual temperature and mean annual total rainfall) to assess the impact of climate variability on maize yield. Although mean temperature is the widely used variable used to assess the effects of climate variability or change on crop yield, the use of mean temperature assumes no difference in the influence of day versus night temperature (Maharjan and Joshi, 2013; Peng et al., 2004). Peng et al. (2004) suggest that the inclusion of minimum and maximum temperature in the assessment will capture differential effects of day and night temperature in addition to climate extremities to some extent. This study therefore assesses the impact of environmental changes on crop yields using the mean annual minimum and maximum temperatures, and the mean annual total rainfall.

Whereas food crops (maize and/or cassava) are common for all the studies, this study extends the existing knowledge to cash crop-cocoa, as well as making comparative study between the two study areas - Atwima Mponua and Ejura-Sekyeredumase districts. There is no empirical study on the impact of climate variables on crop yield in Atwima Mponua District; hence, this study seeks to fill the knowledge gap.

2. Theoretical Framework for Estimating the Impact of Climate Variables on Crop Yields

Although food production depends on biophysical factors such as temperature, light, humidity, soil nutrients and non-biophysical factors such as irrigation, inputs and market, the scope of the study is limited to the impact of biophysical aspects (climate variability) on crop productivity (yield per unit area). To establish the relationship between climate variables and crop yield, researchers have used descriptive and regression models - Ordinary least squares (OLS) (Acquah and Kyei, 2012; Trivedi and Cameron, 2010). The OLS regression method was chosen for the analysis of impacts of climate variables on crop yields. The model is shown below:

$$Yt = \alpha + \beta_1 maxtt + \varepsilon t \quad (1)$$

$$Yt = \alpha + \beta_2 mintt + \varepsilon t \quad (2)$$

$$Y\mathrm{r} = \alpha + \beta_3 traint + \varepsilon t \quad (3)$$

where, $Y =$ yield of crop (in tonnes/ha)
$maxt$ = average maximum temperature (^{0}C) from March - July (major season) and September - November (minor season)
$mint$ = average minimum temperature (^{0}C) from March - July (major season) and September - November (minor season)
$train$ = total rainfall (mm) from March - July (major season) and September - November (minor season)
εt = error term
t = time (year)
All variables under each model were log transformed before estimation.

The correlation co-efficient, r and r^2 - values are used to determine the relationship between a climatic factor and crop yield. The value of the intercept is the expected mean value of y when all x = 0. Thus, if x = 0, the intercept is simply the expected mean value of y at that value. If x is never = 0, then the intercept has no intrinsic meaning. The r is a measure of linear relationship, and the r^2 is the percentage of variability in crop yield loss caused by a climate variable.

3. Materials and methods

3.1 Study areas

Atwima Mponua and Ejura-Sekyeredumase districts of Ashanti Region of Ghana were selected as the study locales (Figure 1).

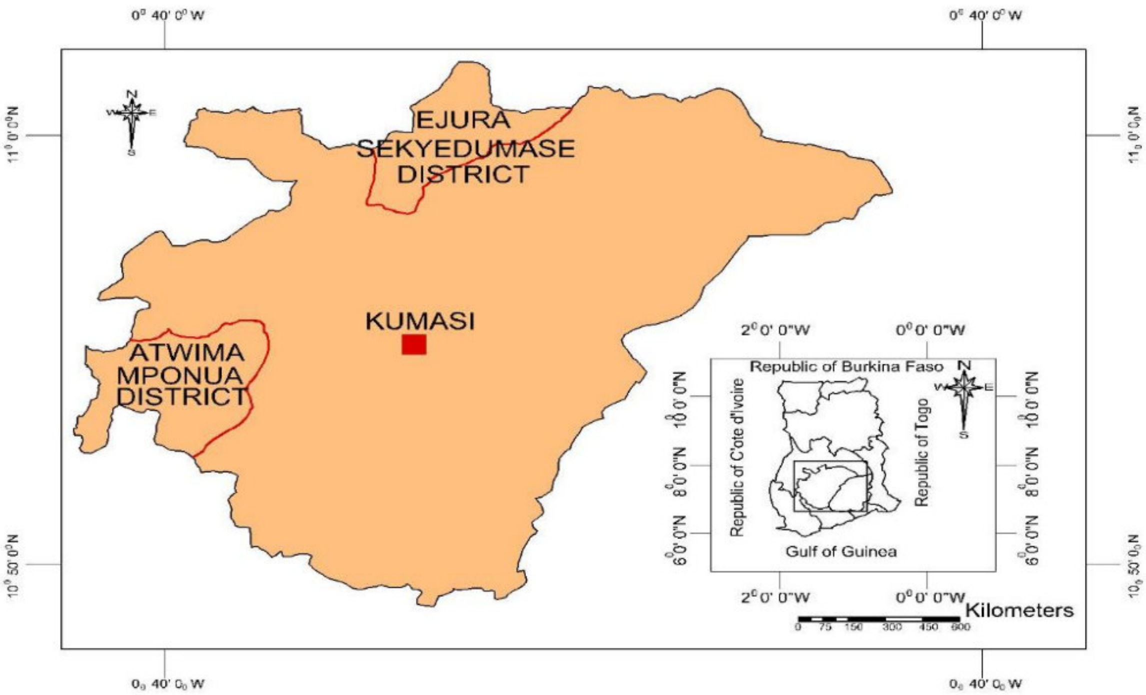

Figure 1. Case study districts in Ashanti Region of Ghana.
Source: Author's construct.

Atwima Mponua District is located in the western part of Ashanti Region, with Nyinahin as its capital town (Figure 2).

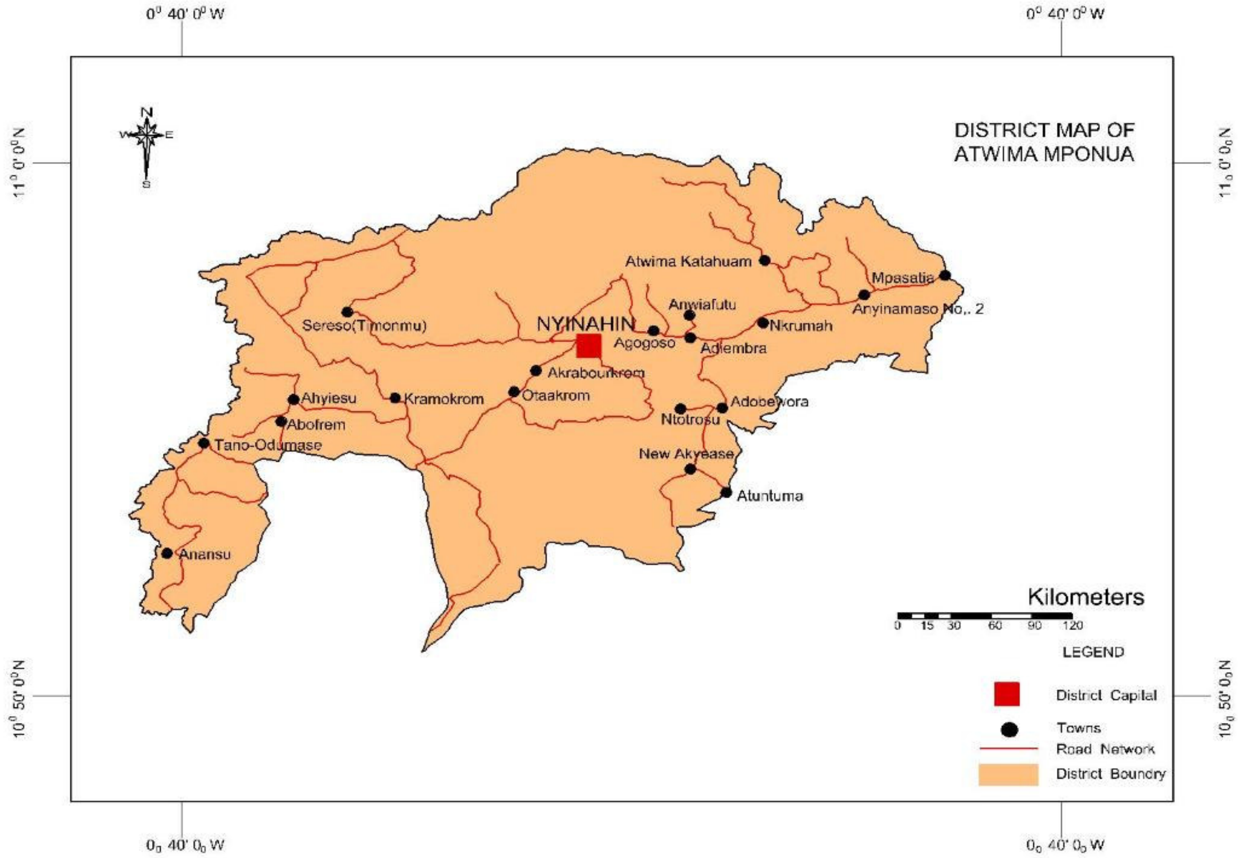

Figure. 2. Study communities in Atwima Mponua District in Ashanti Region of Ghana.
Source: Author's construct.

Ejura-Sekyeredumase is in the northern part of Ashanti Region, with Ejura as its capital town. (Figure 3).

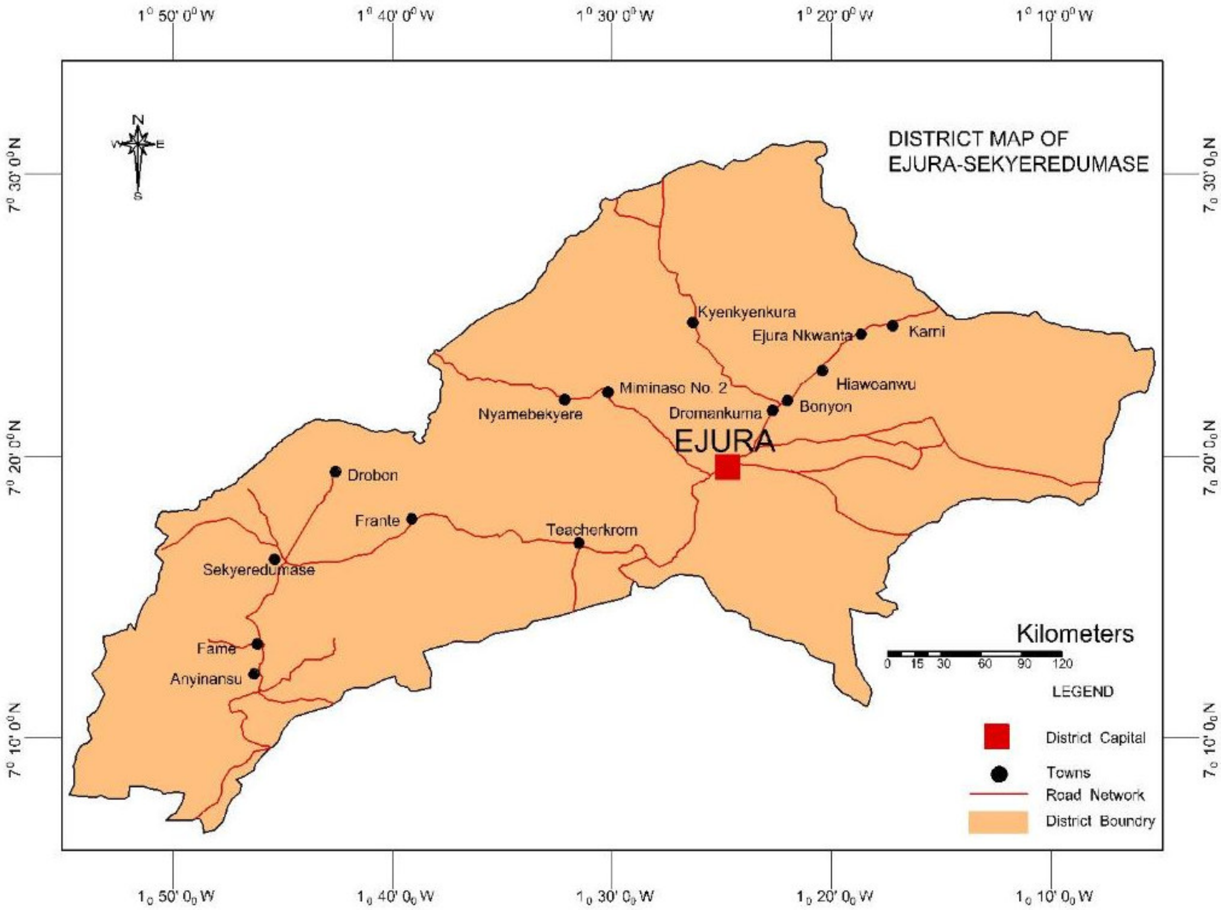

Figure. 3. Study communities in Ejura-Sekyeredumase District in Ashanti Region of Ghana.
Source: Author's construct.

The choice of the study areas is based on being one of the major food producing centres, which is rainfed, making agriculture susceptible to the impact of climate variability and change. Meanwhile, studies have concluded that climate variability and / or change is evident in the study areas and its effect on crop yield is severe (Cudjoe et al., 2021; Fosu-Mensah et al., 2012; Fosu-Mensah, 2011; Stunturf et al., 2011).

3.2 Profile of the Study Areas

According to GSS (2014), Atwima Mponua District lies within latitude 6^0 35'59.99'N and longitude 2^0 06'60.00′W. The district is characterized by bi-modal annual rainfall pattern - (March to July: 1700 – 1850 mm) and (August to November: 1000 - 1250 mm), with mean annual temperature range between 27 ^{0}C in August and 31 ^{0}C in March (GSS, 2014).

Ejura-Sekyeredumase District lies within latitudes $7^0$9' N and $7^0$36'N and longitudes $1^0$5'W and $1^0$39' W. The district experiences bi-modal annual rainfall pattern in the south and a unimodal pattern in the north with mean annual rainfall of 1430 mm, with temperature range of 21 ^{0}C in August and 35 ^{0}C in March (GSS, 2014).

3.3 Research Design

A comparative-case mixed-methods research design (qualitative and quantitative tools) was used to explore the impacts of climate variability and change on crop yields for the period 1992 - 2014.

3.3.1. Sampling Participants

The communities selected in Atwima Mponua District (referred to onwards as the Forest Zone) were Nyinahin, Adiembra, Otaakroom, Anansu and Kramokrom. In Ejura-Sekyeredumase District (referred to onwards as the Transition Zone), the communities were Ejura, Sekyeredumase, Frante, Anyinasu and Drobon.

Stratified random sampling was adopted to select farmers based on age, gender, and years of experience. A simple random sampling using a computer - generated random number table was applied to select 150 household heads from each district.

3.3.2. Sample Size

The binomial sampling size calculator (http://www.surveysystem.com/sscalc.htm) was used to calculate the sample size using the formula:

$$Cl^1 = \sqrt{\frac{\hat{p} + z \times p\ (1 - p) \times (N - n')}{N-1}}$$

where:
Cl^1 = sample size
z = z score
p̂ = the population proportion
n, n' = sample size (Atwima Mponua District = 18,281; Ejura-Sekyeredumase District = 15,761 (GSS, 2014)
N = population size (Atwima Mponua District = 108,235; Ejura-Sekyeredumase District = 88,753) (GSS, 2014)
Confidence interval = 8%
Confidence level = 95%

3.3.3. Sampling of Key and Additional Informants

A snowballing method (a non-probability sampling method where existing participants recruit future participants from among their acquaintances **(**Robert et al., 2010) was adopted to select the key informants (traditional leaders, Agricultural Extension Officers (AEOs) and District Meteorological staff).

3.4 Data collection

3.4.1. Primary Data Collection

Data collection started with a reconnaissance visit to the study locales to identify prospective participants, see the topography, and learn about the weather patterns and agricultural activities. A pilot study was carried out to test the research questionnaires with small groups of participants, followed by the main data collection.

A structured questionnaire was used for data collection through a household survey. Sequentially, semi-structured questions were used to collect qualitative data, through one-to-one interviews and FGDs held with the key informants. Four FGDs were held at each location. The size of focus groups ranged from 8 to 12 participants with gender differentiated. The main objective of the data collection was to explore farmers' perception about changes in climate and impact on crop yield over the past 20-30 years.

3.4.2. Secondary Data Collection

Secondary data on the climate (rainfall and temperature) for the period 1992 - 2014 were collected from the Statistical Division of the Ghana Meteorological Agency and crop yield data for maize and cassava from the Ministry of Food and Agriculture, and cocoa yield data from the Ghana Cocoa Board for the period (1992 - 2014). The validity of the data was checked through interviews with the heads of the statistical departments of the institutions. The Head of the Statistical Department of the MoFA indicated that the collation of crop yield data was introduced in 1992. Hence, although there were data available for climate variables and cocoa yield beyond 1992, however, to ensure uniformity of the years to reflect the real representation of how climate variables have impacted on crop yields, the data used for the study was selected from the period (1992-2014). The data were analysed and compared with the feedback from farmers' perception about changes in climate and crop yields.

3.5. Data Analysis

The Statistical Package for Social Sciences (version 18) software was used to analyse the field data. Quantitative data were analysed using descriptive statistics. Qualitative data from interviews and focus groups were first categorized into themes before being entered into the computer.

The OLS regression analysis was used to assess the impact of climate variables (mean annual minimum and maximum temperatures; and the mean total annual rainfall) on crop yields (cassava, maize and cocoa) over a period of (1992-2014). The crop yield data (measured in tonnes per hectare [ton/ha] for cocoa, and mega tonnes per hectare (Mt/ha for cassava and maize) include the time series average crop yields for maize, cassava and cocoa. Crop yields are reported for the production year, which does not correspond to the calendar year, but for simplicity of analysis, the years were merged. For example, maize yield data in 1992–1993 is considered as the yield for the year 1993. Feedback from household survey, key informant interviews and FGDs were used to triangulate any ambiguities observed in the data.

4. Results

The results of the findings from the study are in two categories – field study and the quantitative analysis of the secondary data.

Three hundred household heads were interviewed, out of which 86.3% were male and 13.7% were female. Specifically, 82.7% male, 17.3% female were from the Forest Zone; and 78.6% male, 21.3% female were from the Transition Zone.

4.1. Farmers' Observation of Changes in the Climate and Environment

Feedback from FGD indicate that most farmers in both study areas perceived an increase in temperature over the past 20-30 years. Observed changes include high intensity of sunshine, increased severe hot days and nights although the temperatures are relatively low during rainy seasons. There have been delays in the onset of rainfall and shorter duration. Aside from the observed changes common in both Zones, in the Transition Zone, the number of dry spells was also perceived to have increased from one period to at least 2 episodes.

Farmers in both Zones indicated that the changes in weather patterns had caused significant negative impact on the environment and crop yields. Feedback from the participants suggests that there had been observed changes in the natural resources in the districts. The observed changes were frequent dryness of streams and waterlogged lands, and loss of staple crops. In the Forest Zone, Key informant A described her experience as below:

> *Reduction in rainfall has led to loss of one of our major staples-* ***Taro*** *yam (Colocasia esculentum) which grows in water-logged areas. Traditionally, no farmer cultivated the crop, as its habitat provides suitable conditions for germination and growth. Currently, all the water-logged areas are drying up and the crop is gradually becoming scarce* - Key Informant A – key informant interview, Kramokrom (Forest Zone).

Feedback from the interview suggests that in the Transition Zone, water bodies are drying up, especially in the dry seasons and that is increasing the distance households had to travel in search of an alternative source to fetch water. The participants also shared their observations in changes in biodiversity of plant species and how this adversely affects food security.

There had been invasion of new plant species such as *Cyperus rotundus*, *Euphorbia heterophylla, Centrosema pubescens, Commelina spp.* and *Chromolaena odorata, which* are progressively leading to reduction of some useful local plants and crops.

In the Transition Zone, Key informant B noted that:

> *Traditionally, we never planted cocoyam (Xanthosoma sagittifolium) because the cocoyam corms which are already in the soil sprout after the first rains in Easter (March-April) when we had prepared our lands for the next faming season. Now, cocoyam does not sprout but "Akyeampong" weeds (Siam weed or Chromolaena odorata) sprout out and dominate crops. As the years go by, we have seen gradual reduction of cocoyam production and yield, and now we have started planting it as we do for any other staple crop* – Key informant B – key informant interview, Anyinansu, (Transition Zone).

Another farmer in the Transition Zone - Farmer D claimed that:

> *We have lost count of the rainfall calendar; we don't know when to expect the rains and now "esre" (Spear grass or Imperata cylindrica L. Beauv) has gradually taken over our farmlands* - Farmer D – key informant interview, Ejura (Transition Zone).

The narrations above indicate that climate variability and / or change had had a negative impact on food security. In both Zones, the participants emphasized that due to the unreliable onset and cessation of rains, there have been unpredictable flowering and fruiting times of crops over the past 20-30 years.

4.2. Farmers' Perceived Changes in Crop Yield due to Climate Variability and Change

Since crop farming is rainfall and temperature dependent, farmers can identify the impacts of changes in climate variables on their livelihoods. Participants were asked to express their views about changes in crop yields observed over the past 20-30 years as shown in Figure 1.

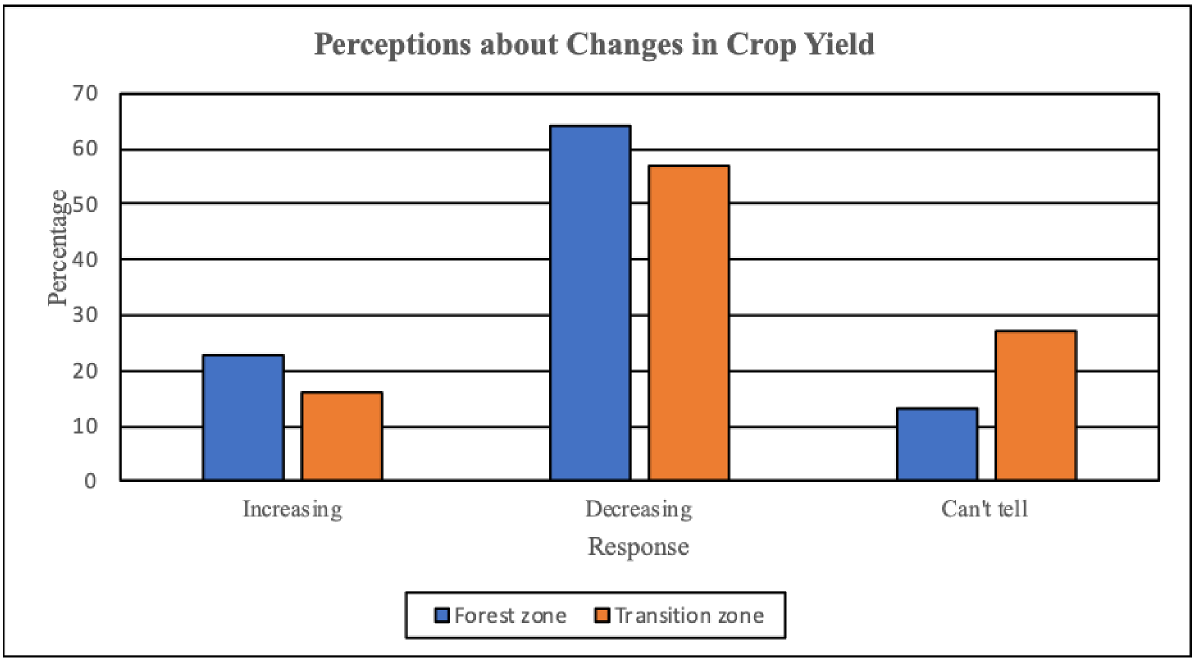

Figure 1. Perceptions of Farmers about Changes in Crop Yields, as Reported, n=150 in each Zone.

In the Forest Zone, 64.0% of household heads indicated that they have observed a reduction in crop yields (cassava, maize and cocoa) over the past 20-30 years. On the contrary, 23.0% were of the view that there had been a rise in yields of the crops, whilst 13.0% could not detect any changes in the yields. Similarly, most (57.0%) of household heads in the Transition Zone recognized a reduction in crop yields; 16.0% had observed increase in yields whereas 27.0% could not tell any changes in crop yield.

4.3. Results of Analysis of Impact of Climate Variables on Crop Yields

The crop data received from the MoFA for the period 1992-2014 provided the basis for making comparisons between farmers' perceptions and how the changes in climate variables have affected crop yields. The yield data for all three crops - cassava, maize and cocoa were regressed on the climate variables to estimate their effects on the crop yields. See Table 1.

Table 1. Results of Analysis of Trends in Variability of Crop Yield in the Forest and Transition Zones (1992–2014) due to Climate Variables.

Ecosystem	Crop Yield	Independent Variables	Coefficient	r - value	r^2 - value	Intercept
Forest Zone	Maize	Mean Min Temp	-0.0384	0.17	0.03	2.4496
		Mean Max Temp	-0.0855*	0.45	0.20	4.3539
		Total Rain	8E.05	0.06	0.00	1.3426
	Cassava	Mean Min Temp	0.1876	0.20	0.04	4.8989
		Mean Max Temp	0.0561**	0.51	0.26	3.3092
		Total Rain	-0.004	0.06	0.00	11.812
	Cocoa	Mean Min Temp	-0.0016	0.04	0.00	0.4059
		Mean Max Temp	0.004	0.11	0.01	0.2307
		Total Rain	-2E-05	0.11	0.01	0.3999
Transition Zone	Maize	Mean Min Temp	-0.0563	0.22	0.05	0.9485
		Mean Max Temp	-0.0789	0.17	0.03	4.3864
		Total Rain	0.0002	0.18	0.03	1.1619
	Cassava	Mean Min Temp	0.0497	0.03	0.00	4.8005
		Mean Max Temp	-0.6389**	0.74	0.54	24.232
		Total Rain	-0.0016	0.13	0.02	8.6483

Note: * and** represent levels of significance ≤ 5% and ≤ 1% respectively.

4.3.1. Analysis of Impact of Climate Variables on Maize Yield

Regarding maize yield in the Forest Zone, the correlation coefficient for the mean maximum temperature is -0.0855 and r - value of 0.45 ($p \leq 0.05$) meaning there is a negative moderate correlation between maximum temperature and maize yield. The correlation analysis registers r^2 - value of 0.20 implying that maximum temperature caused 20.0% of variability in maize in the Forest Zone.

In the Transition Zone, the results show that the impact of all the climate variables on maize yield is statistically non-significant. Although the results indicate that there is no significant impact of rainfall on crop yield in both districts, however, the study focuses on the trend on climate variables over time and it is possible that farmers' perceptions are strongly influenced by their experiences on individual years. During the FGDs, all the farmers were resolute in their thinking that:

> *Delays in rainfall, accompanied by rising temperature are scorching our crops, hence we end up getting poor yields. To offset this problem, we have to hand irrigate our crops, which costs a lot in terms of getting labour* – Farmers – FGD, Nkramokrom (Forest Zone).

The farmers in these communities were able to refer to specific years e.g., 2008, 2013 when they experienced delays in rainfall and had very erratic rainfall seasons, which caused reduction in maize yield. The farmers recalled fetching water from wells to water their maize crops. Most of the farmers shared the view of Famer V who was of the opinion that:

> *We have observed a general decline in maize harvest because the frequent rains have reduced. The rainfalls are erratic and the temperature keeps rising. When you expect the rains to come, they do not. When you do not expect the rainfall, then it rains. This makes it hard to know when to plant crops to have enough rain for the crops to grow well and to have a good harvest* – Farmer V – FGD, Nkramokrom (Forest Zone).

The observation is that while there is evidence to support the decline in the amount of rainfall and rising temperature, the other disclosure is that the patterns of rainfall have also changed considerably making it hard for farmers to predict when to start farming to meet with episodes of rainfalls. Farmer E revealed that:

> *Meteorological reports [forecasts] are not always correct and reliable and this makes it very hard to know when to start planting maize* – Farmer E – FGD, Nkramokrom (Forest Zone).

Unreliable weather forecast implies that farmers are unable to devise effective adaptive strategies to meet the harsh impacts of lack of rainfall on maize production due to lack of better irrigation processes.

During the interviews in the Forest Zone, Farmer J was concerned about the livelihood of his family as his only source of living is produce and sales from maize harvest. He stated that:

> *I am struggling to provide enough food, clothing and medical care for my family. In the previous years, maize harvest has been good because the rains were enough and they (rainfalls) came at the time we expected. For the last 10 years, the rainfall patterns have been erratic and they were either heavier than usual or come in like drizzles for a short while and stop. The harvest [of maize] has been poor and I am now struggling to care for my family - Farmer* J - interview, Anansu (Forest Zone).

Such anxieties were echoed by almost all the farmers that participated in the research.

During the FGD, farmers unanimously expressed deep trepidations about the high levels of diurnal temperature, which result in high levels of heat which in turn affect crop planting, growth and productivity. Farmer X summarized the concerns of the rest of the farmers by indicating that:

> *Although, we can see that rainfall patterns have changed what is worse is that the levels of temperature are high and this is what is destroying our crops. Maize is very vulnerable to excessive heat and because of this, maize yield has been very low in the past 5 to 10 years* – Farmer X - FGD, Sekyeredumase (Transition Zone).

During the interviews, another farmer revealed that:

> *These days, the Sun comes out so early and goes out so late. It looks as if the days are longer and what is worse is that we can feel the heat. Our crops and animals are feeling the heat too. There is so much bush fire and the plants have been burnt and there is no vegetation cover. The soils are now hard and infertile and maize farming is a useless effort because you put in so much into farming and get only a little return* – Farmer I - interview, Sekyeredumase (Transition Zone).

Another farmer who commented on both the rainfall and temperature patterns highlighted that:

> *I'm not so much concerned about the rainfall patterns. Rainfall has been regular in the past and we are used to that. It seems that the rainfall patterns are regular and heavier than previously but what is concerning is the high temperature and the associated bush fires which destroy our crops e.g. maize. –* Farmer B - interview, Drobon (Transition Zone).

The farmers' statements highlight that they perceive that the rising temperature has an extremely negative effect on maize production. The farmers reveal the direct effect of biophysical factors on crop production, and the indirect impact of these factors on non-biophysical factors such as bushfires which also affect crop production.

In both study areas, the farmers seem to suggest that rainfall patterns and rising temperature associated with heat and fire outbreaks might have caused reduction in maize yields. The data analysis shown in the Table 1 indicate that total mean annual rainfall has no correlation with maize yield. However, the key observation from the statements is that heightening of the temperature levels in both districts, coupled with erratic and reduced rainfall means maize plants do not thrive well and their production is low. Further studies need to be carried out to investigate whether rainfall has impact on maize yield or not by using more data.

4.3.2. Analysis of the Impact of Climate Variables on Cassava Yield

In the Forest Zone, the correlation coefficient for maximum mean temperature is 0.0561 and r - value of 0.51 ($p \leq 0.01\%$) implies there is a strong positive correlation between maximum mean temperature and cassava yield. The r^2 - value of 0.26 implies mean annual maximum temperature accounted for 26.0% variability in cassava. In the Transition Zone, the correlation coefficient for mean annual maximum temperature is - 0.6389 and r - value of 0.74 ($p \leq 0.01\%$) means there is a very strong negative correlation between mean maximum temperature and cassava. The r^2 - value of 0.54 implies mean maximum temperature accounted for 54.0% variability in cassava yield.

Farmer C who participated in the research interview gave a deeper insight in the climatic changes and strategies adopted to improve farming activities and crop production. The farmer revealed that:

> *It seems for the past few years the weather conditions do not support maize production, so I have shifted my attention to cassava farming. I think the lower amounts and erratic patterns of rainfall is not helping maize production but the increase in temperature appears to support cassava production* – Farmer C - interview, Drobon (Transition Zone).

Other farmers who took part in the FGDs revealed that they have already devised strategies to improve farming activities. The various ideas revealed include:

> *We now concentrate on cassava production which gives better yield than maize production. It seems cassava responses better to the current climate than maize* – Farmer K - FGD, Drobon (Transition Zone).
>
> *I rarely focus on maize farming because I have had very poor yield over the last few years. I wait till the second rainy season starts before I plant maize. The second rainy season seems to come at the times that we expect but it comes for a short period only* – Farmer N - FGD, Drobon (Transition Zone).

The narrations above suggest that farmers have observed marked changes in the climate and their impact on crop yields.

The quantitative data suggest that the rainfall patterns in the Transition Zone support cassava production and yield, while the contrary is true for maize production. The farmers in the Transition Zone revealed that:

> *Previously, cassava did not grow well in this area but now it seems it is becoming possible to grow cassava and have a good harvest. The weather has become unpredictable to grow maize. It is rather good hope that we may be able to cultivate cassava and get a good yield.* – Farmer Z - FGD, Ejura (Transition Zone).

This means the climate has changed in both Zones so that the type of crops which appear to thrive in these areas are also changing. As a result, the farmers are already attempting to change the usual crops they grow in these different climatic Zones. This means the farming seasons are also changing in both Zones. However, farmers were not able to tell emphatically that the change in the type of crops they grow has resulted in increased crop yield.

4.3.3. Analysis of the Impact of Climate Variables on Cocoa Yield

Cocoa is cultivated in the Forest Zone only. The quantitative data analysis shows that cocoa yield has very weak correlation with all the climate variables and the impact of climate variables on cocoa yield is statistically non-significant (see Table 1). Yet, during FGD the farmers expressed concerns about the impact of the changing rainfall and temperature patterns on cocoa yield. They indicated that:

> *For the past 10 years or more, cocoa yield has not been consistent. There are years of high yield and other years where the yield is low because of the spread of the Black pod disease which destroyed the pods before they were matured.* – FGD, Otaakroom (Forest Zone).

The observation is that farmers had a good idea of how the changing weather conditions impact negatively on cocoa. The conflicting findings imply that further studies need to be carried out to explore the impact of climate variables - temperature and rainfall on cocoa yield by using additional data. In the Forest and Transition Zones, it appears that the mean maximum temperature influenced the variation in maize and cassava yields. The r^2 - values for all the models are all low, except for cassava yield in the Transition Zone, indicating that the models explain relatively little variability in maize and cassava yields in response to climate variables (mean annual maximum temperature and total rainfall); i.e. other factors such as farm inputs, weed management, soil quality can contribute to variability in maize.

5. Discussion

5.1. Farmers' Perceptions about Changes in Climate

The observation of climatic changes in both study areas confirms the findings of Cudjoe et al. (2021), Klutse et al. (2013) and Fosu-Mensah et al. (2012) and other international studies (e.g., Porter et al., 2019; FAO et al., 2018).

The study observed that relative to the Forest Zone, there was increased occurrences of dry spells observed in the Transition Zone. This could be due to the location of the region in the semi-arid region, characterized by highly variable climatic conditions, therefore a slight change in climatic variables could easily be noticed.

5.2. Observed Changes in Environment due to Climate Variability and Change Impacts

The study finding indicates that farmers in both study areas have observed changes in their community due to the impacts of changes in the weather patterns on the natural resources. The observed changes include dryness of aquatic bodies, natural habitats for local crops (e.g., cocoyams), unpredictable flowering and fruiting times of crops. These observations agree with findings of Choi et al. (2021) study in the Republic of Korea and other international studies [e.g., Trisos et al. (2022)]. It can be suggested that these problems may negatively affect food security and farm income, as the extra time spent in search of water can affect the time farmers spent on farming activities. Additionally, farmers who rely on fetching water to irrigate their crops struggle to get enough water to irrigate all crops and this results in low productivity.

The study found weed invasion as one of the contributory factors to decline in food crop. However, the invasion and fast spread of Siam weed and spear grass cannot necessarily be attributed to changes in climate variables. Keoboualapha et al. (2013) report that bushfires induce flowering, seeding and stimulate rhizome sprouting of the spear grass, thus reducing competition from other plants. Meanwhile, the study revealed that bushfires are very rampant in both districts due to charcoal production and land preparation method in the Transition and Forest Zones respectively. Bolfrey-Arku et al. (2006) suggest that the use of hoe and cutlass for land preparation facilitate the spread of spear grass as these tools usually break rhizomes of weeds into small pieces, which may eliminate apical dominance leading to increased sprouting of buds and shoot growth. Therefore, it is worthy of notice that changes in temperature and rainfall are not the sole factors for weed invasion in the districts. However, the menace of weed infestation cannot be ignored.

5.3. Observed Changes in Crop Yield due to Climate Variability and Change Impacts

The crop data received from the MoFA for the period 1992-2014 provided the basis for making comparisons between farmers' perceptions and how the changes in climate variables have affected crop yields. It was evident from crop yield data analysis (see Table 1) that there has been variability in the mean values of maize and cassava yields in both Zones in the period (1992-2014). Farmers perceived changes in climate variables such as rising temperature and reduced and erratic rainfall patterns have contributed to yields in major staple crops. This finding agrees with Cudjoe et al. (2021), Klutse et al. (2013) and Fosu-Mensah (2011) about impact of climate variability and or change on maize; and Sagoe (2006) on root and tuber productions in the Transition Zone. The finding also confirms international studies (e.g., Porter et al., 2019; Porter et al., 2014). A temperature increases of 3–4^{0}C above the local temperature could cause reduction in day length required by plants to flower and the quality of inflorescence produced, and lead to reduction in crop yields by 15–35% in the Tropical region (Singh et al., 2013). Delayed or early flowering may lead to pollen withering while low temperatures below 15 ^{0}C can cause embryo abortion and pseudo-setting of fruits without normal fertilization (Dixon and Aldous, 2014). Additionally, extreme temperatures have negative impact on insect-pollinators as this can limit the quantity of floral visits by potential insect-pollinators, subsequently limiting pollination (Kumar et al., 2012). Thus, the overall effect of increasing temperatures above expected thresholds is poor crop output, with eventual increase in farmers' vulnerability. The question that needs to be answered is whether variability in crop yields was caused by climatic variables alone or other factors.

During interviews and FGDs, it was revealed that there has been frequent pest invasion in the Transition Zone. The most common pests mentioned were grasshoppers and army worms which attack maize leaves and ears. Participants mentioned that the rate of pest invasion recently has been relatively higher than in the past 20-30 years with frequency of invasion reported at least once in 3-4 years. This finding agrees with the observations made by de Pinto et al. (2012). Some of the farmers acknowledged that these pests and diseases have contributed to poor yields. Nevertheless, the yields for some farmers may have increased due to the use of improved farming and crop management practices such as high yielding/drought resistant crop variety, chemicals to control pest and other inputs capable of enhancing crop yields.

Other factors mentioned were poor soil fertility due to either short fallow periods or continuous use of land. Short fallow period and continuous farming limit the soil's ability to regain fertility and subsequently reduce crop yield over the years.

In the Forest Zone, the key informants cited two major reasons for decreasing crop yields as the conversion of farmlands into residential areas, which has caused scarcity of farmlands. Meanwhile, land ownership is held by households and is shared among the members. Therefore, with scarcity of land coupled with increasing population, farm sizes apportioned to household members continue to get smaller, thereby leading to less crop cultivated with less overall crop production.

In view of scarcity of farmlands and the proximity to the urban centres or communities, prospective farmers, especially the youth, migrate into the urban towns and cities in search of jobs other than farming. Farming is left in the hands of the old people and children, thus negatively affecting the labour needed to support productive farming. It was observed that vast acres of farmlands had been converted into residential developments. The informants explained that some landowners prefer to sell their farmlands for estate development to giving the farmlands for farming purposes. Consequently, there is scarcity of farmlands resulting in low crop production. It can be hypothesized from these findings that although scarcity of farmlands and migration may be a contributing factor, yet climate variability and / or change may contribute to the cause of variability in crop yields, as the removal of vegetation affects rainfall pattern experienced in a specific location (Spracklen et al., 2018). Despite the possible factors which could cause poor crop yield, the finding of this study agrees with other studies (Cudjoe et al., 2021; Chemura et al., 2020; de Pinto et al., 2012; Fosu-Mensah et al. 2012) that climate variability and /or change has impacted negatively on crop yield.

6. Conclusions

This study uses a comparative-case mixed-methods research design to explore farmers' perceptions about changes in climate and impacts on crop yields in two study areas: Atwima Mponua and Ejura-Sekyeredumase districts. Feedback from qualitative analysis confirms that most farmers in both districts had observed climate variability from year to year as perceived by the variability in temperature and rainfall patterns over the past 20-30 years.

Common to both districts, observed changes in climate were high intensity of sunshine, increased severe hot days and nights, delays in the onset of rainfall and shorter duration. In contrast to Atwima District, the number of dry spells was also perceived to have increased from one period to at least 2 episodes.

Household heads in both districts had observed changes in natural resources. Reduction / loss of cocoyams and dryness of water bodies were common observation made by farmers in both districts. Also, unpredictable flowering and fruiting times of crops. Additionally, farmers in Ejura-Sekyeredumase District had observed invasion of new plant species (weeds); and relatively increased rate of pest infestation (at least once in 4 years) due to changes in climate patterns over the past 20-30 years.

Most of the participants in both districts have observed a reduction in cassava and maize yields. Additionally, a reduction in cocoa yield was observed by farmers in Atwima-Mponua District. In both study areas, the farmers perceived that rainfall patterns and rising temperature coupled with heat and fire outbreaks might have caused reduction in maize yields. Feedback from participants also indicate that although changes in climate might have resulted in poor crop yield, in Ejura-Sekyeredumase District, other contributory factors to poor crop yield could be pest and weed infestations, and poor soil fertility. In Atwima-Mponua District, a reduction in land availability, and migration of the youth to urban centres have contributed to poor crop yield.

The study found that inaccurate and unreliable weather forecasts hinder implementation of effective adaptation strategies.

Quantitative analysis of the impact of climate variables on crop yields in the study areas suggest that the mean annual maximum temperature correlates with reduction in maize in Atwima-Mponua District and cassava yields in both districts although the total mean annual rainfall has no correlation with maize yield in none of the districts. The perceptions of farmers therefore confirm results of secondary data analysis of cassava and maize. However, the impact of climate variables on cocoa yield is statistically non-significant although this finding contradicts with farmers' observation.

7. Policy Recommendation

The study makes an original contribution to knowledge in the climate change impact studies because there is no known literature in Ghana that explores the impacts of climate variability and / or change on crop production in different agro-ecological locales using unique methodological approaches – comparative-case study mixed-methods approach and econometric tools. A comparative-case mixed-methods approach provides a useful contribution towards reliable and more comprehensive results that may be lacking in a single - scale approach adopted in most of the existing research in the field. The policy implications that aim at improving crop yield amid climate variability and / or change in the study areas and sub-Sahara Africa are outlined.

All agricultural institutions, especially Crop Research Institutes in the regions should focus on the development of crop varieties that can adapt to drought and temporary flooding conditions to overcome increasing climate change vulnerabilities. Capacity building of the Agricultural Extension Officers through training is key in disseminating information on new crop varieties among farmers and encourage them to adopt the improved varieties.

The government should provide financial support to the meteorological stations to get more advanced equipment and increase the technological capacity of the staff through trainings to improve accuracy and reliability of data readings and interpretations.

The efficiency in the delivery of weather forecast can be improved using mobile phone systems, media (radio, television), gong-beater; and delivery by the AEOs through visits.

This study advocates that an interdisciplinary approach should be taken by the Ministry of Food and

Agriculture and the Ministry of Environment, Science and Technology supported by the National Climate Change Committee and the National Development Planning Commission to ensure that these recommendations are embedded into national developmental agenda. The government must demonstrate the political will to increase food production by supporting the ministries with appropriate resources so that these recommendations are implemented.

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