

Research Article

Impact of Rainfall Variability on Crop Production within the Worobong Ecological Area of Fanteakwa District, Ghana

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Crop production in the Fanteakwa District is predominantly rainfed, exposing this major livelihood activity to the variability or change in rainfall pattern. The net potential effect of severe changes in rainfall pattern is the disruption in crop production leading to food insecurity, joblessness, and poverty. As a major concern to food production in Ghana, this study seeks to show the relationship between the production of major crops and rainfall distribution pattern in the Worobong Agroecological Area (WAA) relative to food security in the face of climate change. The study analysed the variability in local rainfall data, examining the interseasonal (main and minor) rainfall distribution using the precipitation concentration index (PCI), and determined the pattern, availability of water, and the strength of correlation with crop production in the WAA. Data from the Ghana Meteorological Agency (GMet) spanning a 30-year period and grouped into 3 decades of 10 years each was used. Selected crop data for 1993-2014 was also obtained from the Ministry of Food and Agriculture's District office and analyzed for trends in crop yield over the period and established relationship between the crop data and the rainfall data. Part of the result revealed that rainfall variability within the major seasons in the 3 groups was lower than the minor seasons. It further showed that yields of three crops have declined over the period. Among the strategies to sustain crop production is to make the findings serve as useful reference to inform discussions and policy on adaptive agricultural production methodologies for the area in the face of changing climate.

1. Introduction

Poor communities in developing economies mainly depend on climate-sensitive activities such as agriculture for their livelihood and are particularly vulnerable to climate change [1-5]. It has been reported that nearly three in four people living in rural Africa and other developing countries are dependent on agriculture in one way or another [6]. Also, it is estimated that climate change will cause a direct reduction in real household consumption by 5-10% in 2050 and a reduction in real gross domestic production of 1.9-7.2% in Ghana [7, 8]. For instance, it has been reported that rainfall variability affects the production of traditional crops, increases crop diseases incidents, and causes drastic reductions in soil fertility [9-12]. Additionally, analysis of recent rainfall conditions in West Africa suggests long-term

change in rainfall pattern within the semiarid and subhumid zones [13, 14]. Also, the mean number of rainy days has significantly reduced throughout the different seasons in West Africa [15].

The impact of rainfall on crop production has been assessed differently by various authors in the subhumid areas. Among these methods are intraseasonal, interseasonal, and annual rainfall variability [16]. Owusu and Waylen [17] employed intraseasonal and interannual variability methods to monitor rainfall patterns in rainy seasons in the subhumid areas of Africa to assess the potential threat of rainfall variability to food security, although the number of years of rainfall record that is necessary to detect any significant trends in rainfall in arid and semiarid regions is quite debatable [10, 11, 18]. However, there is a substantial evidence of adverse impact of change in seasonal or annual rainfall

patterns on the production of some major cereals [19–22]. Also, it has been reported in other parts of the world that climate variability and/or change have been attributed to changes in production or will be responsible for future change in production dynamics [23–26]. Bewket [19] reported short rainy seasons (March-May) and much more variable rainfall periods between June and September.

A major natural occurrence which is also indispensable in food production especially in the developing world is rainfall. More than 60 percent of staple foods are produced from rainfed agriculture which is practiced by more than 80% and 90% of global and African communities, respectively [27–29]. Rainfed agriculture accounts for a large percentage of the total crop production especially rural areas in Ghana [6]. For instance, cocoa production which contributes a substantial amount to the Gross Domestic Product (GDP) of Ghana is almost entirely dependent on rainfall [6, 30]. Also, most of the major food crops are produced through rainfed agriculture. Rainfed agriculture thus became the main water supply system for the majority of food or crop production in Ghana [4, 6].

The threat of food insecurity has increased as a result of the phenomenon of climate change and variability among many farming communities [13, 31, 32]. Climate change and variability is arguably the most debated scientific phenomenon in recent literature [33, 34]. Although these debates are highly controversial, there is a broad consensus that climate change has happened and still ongoing process although there are disagreements over the major cause as natural or anthropogenic [33–36]. An empirical evidence that there is an ongoing climate change especially in sub-Saharan Africa is the receding ice on Mount Kilimanjaro [37]. Among the most vulnerable ventures that can also have major food security implications is the impact of climate change or variability of agricultural production [10, 11]. For instance, it has been reported that maize yield in Ghana is expected to reduce by about 20 percent by 2050 due to climate change [6].

Agriculture is reported to be a major source of livelihood to a large number of Ghanaians where small-scale farming accounts for 80% of domestic production [38]. The sector employs close to 60% of the formal and informal labour force. On the average, agriculture contributes about 30% of the Gross Domestic Product (GDP) of Ghana [6]. In terms of production practices in Ghana, the main method used is rainfed, with only 0.2% of practiced irrigation [39]. As a result, seasonal rainfall variability has a profound effect on soil water availability especially for crop production. In recent times, changes in rainfall distribution, interseasonal fluctuations, and erratic rainfall patterns have been reported to have resulted in reductions in crop production which has become a major issue to farmers and policy-makers as threats to food security as reported elsewhere [11, 13, 24–26]. This is especially so for the major crops produced in Ghana, namely, cassava, cocoyam, plantain, and tomatoes [39]. Although current cassava production outputs show increasing trends, climate change scenarios in the future predict yield reductions of cassava and cocoyam by 3%, 11%, and 13.5% and 29.6%, 53%, and 68% by 2020, 2050, and 2080, respectively [40, 41]. Also, more recent statistical

evidences show that interannual variability has increased within the major and minor rainy seasons, while the minor rainy seasons have become much drier and shorter (GMet) even though the report provides very little details on specific localities where these trends were observed including major crop producing areas which includes the WAA of the semideciduous areas of Ghana. WAA constitutes a unit in developing a national map for agricultural performance in climate variability or change and for decision-making in resolving challenges within the agricultural sector of the semideciduous areas which have rarely been studied relative to climatic variability. This study analysed the variability in local rainfall data, examined the interseasonal (main and minor) rainfall distribution for trends, and determined the pattern and strength of correlation with crop production in WAA to serve as future reference as well as engender policy discussions on agriculture production strategies for the area in the face of changing climate.

2. Method

2.1. Study Area. Fanteakwa District is in the Eastern Region of Ghana, with Begoro as its capital. The district lies within longitude $0^{\circ} 32.5$ west and $0^{\circ} 10$ east and latitude $6^{\circ} 15$ north and $6^{\circ} 40$ north (Figure 1). It is bordered to the north by the Volta Lake, north-west by Kwahu South District, south-west by East Akim District, east by Manya Krobo, and south-east by Yilo Krobo District. The district has a total land area of 1,150 km² with cultivable land area of 76,133 Ha. The district is endowed with large tracks of arable land suitable for cultivating cocoa, cereals, root crops, vegetables, plantain, banana, and yam. Land in the forest belt is fertile for cultivation of crops [41].

2.2. Data Collection and Analysis. We studied rainfall records from the Ghana Meteorological Agency (GMet), spanning a thirty-year period, from 1985 to 2014. Additionally, time series data on cocoyam, plantain, cassava, and tomato production and yield from MoFA for a 12-year period (2003–2014) was used. This data was used to establish trends in interannual rainfall distribution and interseasonal one (i.e., major and minor seasons) for the above-mentioned 30-year period, while assessing the pattern in annual rainfall distribution and crop yield over the already mentioned 12-year period. Our analysis was due to limited data from MoFA in the Fanteakwa district.

2.3. Models for Rainfall and Crop Assessment. In earlier assessment and rainfall impact studies on crop production, predictive models and forecasts have dominated literature. Ecophysiological model provides the aggregation of diverse components such as rainfall data and agronomic information to forecast how a particular plant will respond to different environments [42]. Ricardian or cross-sectional approach [43, 44] is a similar model which is linked closely to a correlation between how potentially viable a particular land is and the existing agroclimatic conditions. To understand the current relationships of rainfall and crop production, the

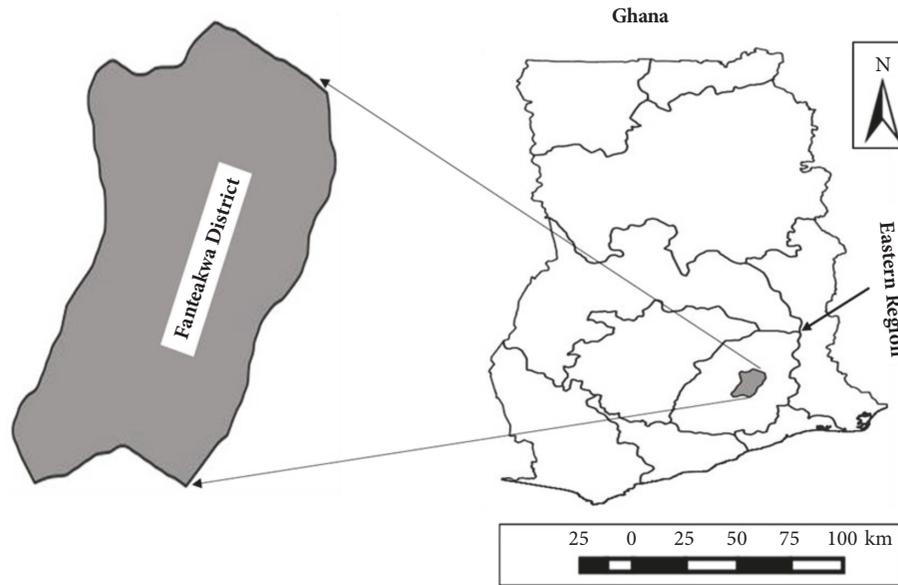


FIGURE 1: A map of Ghana showing Fantekwa district in the Eastern Region of Ghana.

Pearson product moment correlation coefficient was used to generate statistical indices, while analysis of the interannual and interseasonal rainfall variability was done using coefficient of variation (CV) and precipitation concentration index (PCI) [45]. The PCI was used for this study because it has been the choice of model in recently published works on analysing rainfall variability and also due to its high ability to measure temporal variations in rainfall [46–50]. Most importantly, the PCI has the ability to describe how rainfall is distributed yearly (i.e., whether it is evenly distributed or concentrated in a single month), an attribute considered for this study. Beside PCI, there are other rainfall variability measures such as the precipitation concentration period (PCP), fulcrum (centre of gravity), and precipitation concentration degree (PCD) that can equally perform well [51–53]. Other methods such as Fournier Index for year (FI), Modified Fournier Index for year (MFI), and the Modified Fournier–Maule Index for year measure rainfall aggressiveness, which was not an attribute considered in this study [47].

2.4. Crops Output and Rainfall Relationship. We assessed annual crop yield for cassava, cocoyam, plantain, and tomatoes for the period 2003–2015 and rainfall data for 2003–2014. The discrepancy of applying a standardized period between the two data sets is attributed to gaps in the production crop data. To this extent, the period between 2003 and 2014, spanning eleven years of rainfall and crop production relationship and trends, was cautiously used. The two data sets were subjected to bivariate correlation and cross tabulation analysis to determine the impact of rainfall variability on change in crop production. For a minimal effect, the study analysed an annual average temperature over a period of 35 years (1980–2015) in some instances and 27 years (1980–2007) in the Worobong area that showed two outputs of minimum and maximum levels. Results from questionnaires that were

administered and information from MoFA in the Fantekwa district show that cropping systems and agronomic practices remained basically the same or constant in the period that the data was taken (i.e., number of planted seeds per stand, quantity and type of fertilizer applied, weed and pest control measures, etc.) in those farms used for data collection.

3. Results

3.1. Seasonal Rainfall Variability. Analysis of monthly rainfall data from GMet between 1985 and 2014 established a pattern of variability. Three data sets, described as Climate Assessment Decade (CAD), of 10 years, ranging from 1985 to 1994, 1995 to 2004, and 2005 to 2014, were categorised to allow comparison of variation in rainfall distribution in the area. As the area experiences a bimodal rainfall regime, the CAD for each data set is further grouped into the major season, between March and July, and minor season, between September and November. This grouping was intended to examine the comparative basis for the extent of variability. The result shows a trend in seasonal (major and minor) variability in rainfall distribution (Figure 2). The major season for the first decade under consideration (1985–1994) recorded an average rainfall of 1449.94 mm compared to the third decade (1995–2004) which recorded a significantly lower rainfall (1278.58 mm) and 1098.94 mm between 2005 and 2014. In other words, there was a decrease in rainfall distribution in the major seasons over the 30-year period. Similarly, the minor season for each CAD recorded increased variability (Figures 2 and 3), 1374.98 mm, 967.50 mm, and 1117.82 mm for 1985–1994, 1995–2004, and 2005–2014, respectively, with the highest incidence of variability observed in the first and second decades of the period under consideration.

The result from the coefficient of variation (CV) of the major and minor seasons of the three decades showed

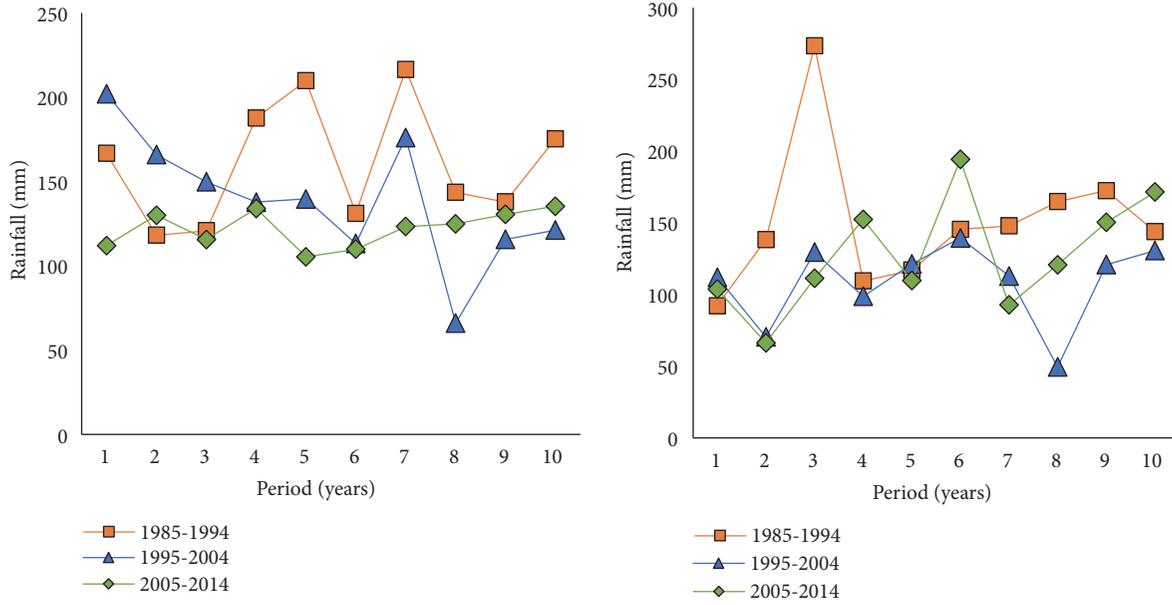


FIGURE 2: Annual average rainfall for major and minor seasons for three separate decades of 1985-1994, 1995-2004, and 2005-2014 within the Fantekwa District, Ghana. Source: GMet, 2017.

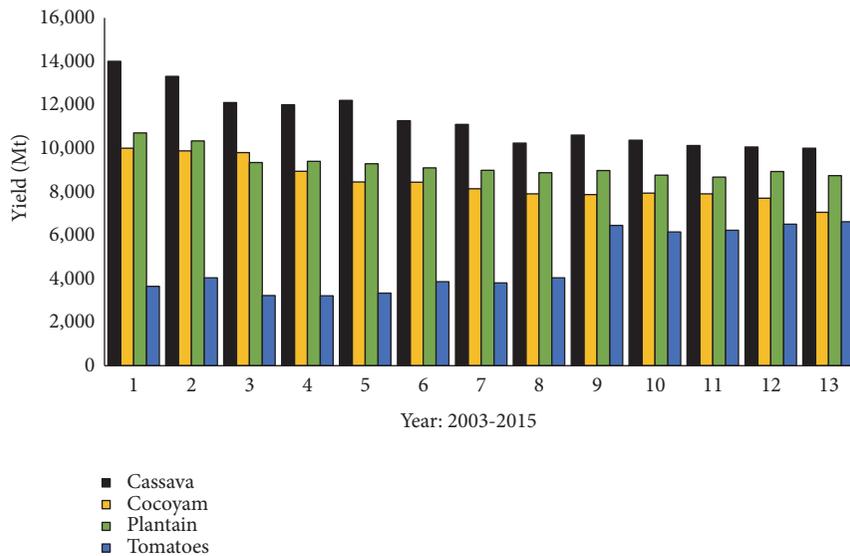


FIGURE 3: Selected crops yield between 2003 and 2015 within the Fantekwa District of Ghana. Source: MoFA-Begoro, 2016.

significant variation in both seasons with the highest in the minor season (CV, 5.7%) compared to the major (CV, 7.6%). In effect, for the 30-year period (1984-2014), the total average rainfall amount reduced by 351 mm consistently for the major season and 267.16 mm in the minor season.

According to Oliver [45], PCI values for determining rainfall concentration are computed as $PCI = 100 \times \frac{\sum P_1^2}{(\sum P_1)^2}$ where P_1 is the rainfall amount of the X^{th} (for each decade of both seasons) and Σ is the summation of the three decades (30 years). He further evaluated the outcomes of PCI using the following indicators: values less than 10 suggest a uniform concentration; values between 11 and 20 indicate high concentration, while those above

21 are considered very high rainfall amounts. A value for both seasons at 33 indicates a high concentration of rainfall, thereby showing enough rainfall for crop production in the 3 decades although there was significant variability over the period.

The findings of the yearly crop output within the Fantekwa agroecological zone showed a downward trend for all major crops considered except tomato (Figure 2). Cassava production in 2003 was about 14,000 mt/ha compared to cocoyam and plantain which recorded 10,000 mt/ha and 10,700 mt/ha, respectively, over the same year. Just like cassava which has recorded some steady reduction from 2003 to 2015 with percentage declines of 16.7%, cocoyam and

plantain also recorded 17.3% and 10.1% over the same period, respectively. Tomatoes on the other hand recorded rather a steady increase of 3,650 mt/ha in 2003 to 6,620 mt/ha in 2015 and increase of 28.9 % within the same period.

The Pearson product moment correlation coefficient analysis carried out for the major cultivated crops considered (cassava, cocoyam, plantain, and tomatoes) and two climatic variables (rainfall and temperature) revealed that rainfall negatively correlates with all crops, i.e., cassava (-0.466), cocoyam (-0.431), plantain (-0.274), except tomatoes (0.417) within the Fanteakwa District. Again, except tomatoes, none of the crop outcomes showed positive significance with the major and minor rainfall seasons; $P < -0.283$, $P < -0.41$ for cassava between 2003 and 2014.

4. Discussion

There are visible changing trends in rainfall patterns for minor seasons spanning September to November at a higher rate than the main season in the three decades considered for our analysis in the study area. This corroborates the finding from previous study in Ghana [22]. Such a trend shows there is a relatively less amount of rain water for crop production in the minor season in relation to previous decades and also the major season. This study did not project detailed month-on-month comparison of the data; such an exercise would have provided for each season (major and minor) the actual rainfall amounts relative to the corresponding months in other CAD and their values to show extent of variability. This will further show the direct impact of monthly rainfall on agriculture for instance. In the absence of that, average yearly major and minor rainfall amount will also provide enough basis for assessing the effect of the variability on crop production in each CAD [20]. Temperature also plays a major role in determining the overall relationship between crop production and other factors such as soil, water, and technology [22–24, 53]. This observation formed the basis for recommending that a lot more effort must be done to improve crop production within the major season because of less rainfall variability compared to the minor season. This strategy can help increase crop production, food security, and availability even as production in the minor season reduces. Although the calculated PCI values states a very high rainfall concentration in the two seasons, the variability within the season was also revealed by the coefficient of variation and mean values. There were no statistically tested and proven reasons for an increase in tomato production although all other crops produced in the area suffered production loss due to climate change. The immediate speculated reason for this increase could be the use of irrigation facilities during the off-production season [personal observation], but no study has been conducted to verify this assumption. The use of irrigation facilities in crop production especially vegetable production is known to increase production. For instance, crop yields increased up to 43% in smallholder farms in rural Ethiopia with the use of irrigation facility for production [54]. Other studies in Ghana have all indicated increases in crop yields under irrigation [55–57]. Although there seems to be

a correlation between irrigation and increased production in tomato even under climate change situations even when other major crop yields are reducing, there could be other hidden reason(s) for why tomato production could go up in the study area. There is therefore the need for a thorough study on tomato production and climate variability in the study area and Ghana in general to find out these reasons for proper adaptation measures to be taken.

5. Conclusion

Analysis of rainfall distribution and crop production could be done using several models for a relatively high-humid agroecological area. In this study, variation analysis of major and minor rainfall seasons showed variability in both seasons although it was relatively high in the latter season. Such differences in rainfall variability play a major role in crop production in the WAA where agriculture is generally rainfed. The high variability of rainfall in the minor season correlated with a reduction in crop production output. WAA has also recorded off-season tomatoes production through irrigation practices although the traditional crops; plantain, cocoyam, and cassava have all experienced steady declines. Attributing decline in yield solely to rainfall variability may not be accurate. Bad agricultural practices, nomadic herdsmen activities, and bushfires are analogous variables affecting crop production in the area. Nevertheless, our analysis showed a clear relationship between rainfall variability and crop production in our study area and also because production practices have not changed much over the period of study. To resolve rainfall challenge and sustain crop production in the area, piloting irrigation for selected crops, as some farmers are already doing, is highly recommended.

Data Availability

There was no other data used in this study apart from the one included in the manuscript and the supplementary materials (available here).

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Supplementary Materials

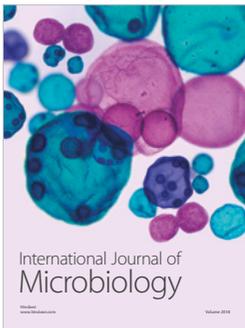
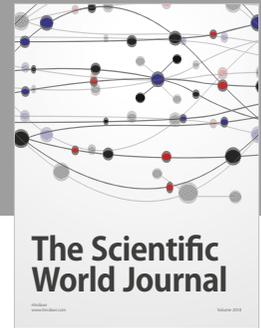
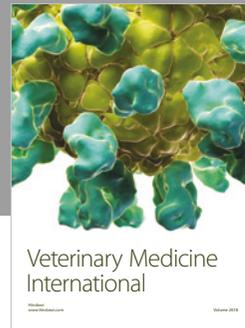
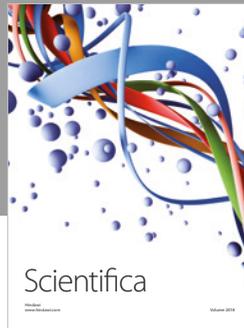
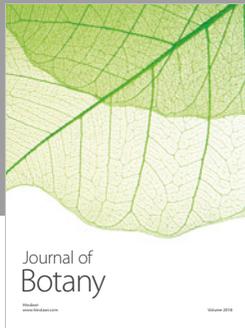
Table S1: mean difference in rainfall between major and minor seasons in three separate decades, namely, 1985-1994, 1995-2004, and 2005-2014, within the Fanteakwa District of Ghana. Table 2: correlation analysis of climatic variability and crop yields between 2003 and 2014 within the Fanteakwa District in Ghana. (*Supplementary Materials*)

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