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El Niño-Southern Oscillation, rainfall variability and sustainable agricultural development in the Ho Municipality, Ghana

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Abstract

El Niño-Southern Oscillation (ENSO), which occurs in the Equatorial Pacific Ocean, has been identified to have significant influence on rainfall variability throughout the world, especially in the tropics. Such variability in rainfall has implications for agrarian economies, such as that in Ghana. This study therefore sought to demonstrate the effect of ENSO-induced variability in annual and seasonal rainfall on the development of sustainable agriculture in the Ho Municipality of Ghana. Using 61 years of monthly rainfall data (1955–2015) for the Ho Municipality and ENSO indices, this study showed that 15% of the variability in total annual rainfall is explained by the ENSO phenomena. Mean annual rainfall and rainfall in the major rainy season decreased for El Niño years, in addition to a more variable rainfall compared to that received in La Niña years. The major growing season was observed to be longer in La Niña years and shorter in El Niño years. This means that the potential for crop cultivation will be severely hampered in an El Niño year. Farmers within the municipality are therefore encouraged to harness other complementary water sources for farming activities and also employ water management strategies during El Niño years.

Keywords: El Niño; La Niña; Ho Municipality; rainfall variability; sustainable agriculture.

1. Introduction

Rainfall and its variability are very significant to agricultural activities in countries across the West African subregion since the sector is rainfall-dependent (Sultan and Gaetani, 2016). Agriculture, the most prevalent economic activity in the sub-region, depends on rainfall regimes, which are mostly unpredictable, highly variable and seasonal in nature (Owusu *et al*., 2008). Rainfall in West Africa is noted to go through seasonal, inter-annual and a cycle of decadal variability (Giannini *et al*., 2003; Rodríguez-Fonseca *et al*., 2011; Lacombe *et al*., 2012). The main source of this variability in rainfall in the subregion and the tropics in general is El Niño-Southern Oscillation (ENSO), a natural phenomenon associated with sea surface temperatures in the Tropical Pacific (Collins *et al*., 2010). Other sources of variability in tropical rainfall include the influence of Atlantic sea surface temperatures (SSTs) (Opoku-Ankomah and Cordery, 1994; Adler *et al*., 2000), and the influence of the upper level winds such as the African Easterly Jet and the Tropical Easterly Jet (Price *et al*., 2007; Nicholson, 2008). The sea surface temperature anomaly associated with ENSO is known to affect the zonal distribution of wind due to the impact it exerts on sea surface pressure (Kushnir, 1994). The resultant zonal pattern of wind movement influences the distribution of rainfall across the world. For instance, drought conditions are prevalent over Australia, Indonesia and other neighboring countries during El Niño periods. According to McPhaden (2003), this condition is as a result of an eastward shift in rainfall along the equator during El Niño periods. On the contrary, heavy rainfall is recorded by the Island states of Central Pacific as well as the west coast of Central America during El Niño episodes (McPhaden, 2003). According to Huda *et al*. (2004), ENSO-related drought in 1991 caused farmers to abandon large hectares of rice farms in East Java at a significant cost due to insufficient water for irrigation. In West Africa, ENSO is associated with above normal rainfall during the cold phase and below normal rainfall during the warm phase (Adiku and Stone, 1995; Owusu *et al*., 2008; Boadi and Owusu, 2017).

The socio-economic implications of ENSO vary in magnitude across the globe. For instance, an impact assessment by the United States Office of Global Programs of the

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National Oceanic and Atmospheric Administration (NOAA) cited by the World Meteorological Organization (WMO) (2014) found the direct economic losses from the 1997/1998 El Niño events to be US$ 34 billion, accompanied with the loss of 24,000 lives. Similarly, the western Pacific islands, the Philippines and Indonesia were hit by drought, which affected agricultural output, water supply and hydroelectricity generation (WMO, 2014). The 1982/1983 El Niño event caused a devastating drought in West and Southern Africa, India and Australia and, led to rampant forest fires in Indonesia (Huda *et al*., 2004). The severe El Niño of the early 1980s caused severe drought conditions over West Africa and a corresponding decrease in precipitation in the whole monsoon system (Mohino *et al*., 2011), induced by ENSO teleconnections (Joly and Voldoire, 2009; Rodríguez-Fonseca *et al*., 2011).

Consistent with other studies in West Africa, Owusu *et al*. (2008) reiterate the dwindling trend in annual rainfall totals in the sub-region, and that ENSO teleconnections have exacerbated reductions in rainfall inputs for the Volta Basin of West Africa. It has been revealed that El Niño phases are associated with reduced rainfall in the Volta Basin (Waylen and Owusu, 2014) and in some parts of Southern Ghana (Adiku and Stone, 1995), while increased rainfall totals in the Volta Basin (Owusu *et al*., 2008) and in Southern Ghana (Adiku and Stone, 1995) are associated with cold phases of ENSO. Similarly, Adiku and Stone (1995) established that the onset of rainfall in the south of Ghana is delayed with the occurrence of El Niño, while the rains start early in a La Niña year. However, they emphasized that ENSO's teleconnection with rainfall patterns in Southern Ghana is not static since it displays temporal variations. Farmers in Ghana thus require a good understanding of the relationship between rainfall and the ENSO phases (Mawunya *et al*., 2011) in order to develop a sustainable agricultural system that ensures income stability and food security. This will help farmers manage and maximize their seasonal crop output according to the variabilities inherent in rainfall regimes observed in Ghana and the West African sub-region.

The changing and irregular patterns of rainfall in the Ho Municipality, coupled with the seasonality of important water bodies (Ghana Statistical Service (GSS), 2014), pose severe threats to rainfall-dependent primary economic activities, especially agriculture. The sustainability of the agrarian economy of the municipality depends on prevailing rainfall regimes. This research therefore seeks to use empirical data to explore the relationship between ENSO and rainfall inputs in the Ho Municipality. The objectives of the study are to: (i) assess the relationship between seasonal and annual rainfall inputs in the Ho Municipality and ENSO events from 1955 to 2015 and; (ii) examine the extent to which ENSO conditions and episodes affect rainfall in the peak crop-water demand months in the municipality. It is hoped that this will help improve farmers' knowledge of rainfall variability and aid them in planning and adjusting their agricultural activities during El Niño and La Niña events.

2. Data and methods

2.1. Study area

The Ho Municipality is located in the southern part of the Volta Basin of West Africa. Its administrative capital, Ho, is also the administrative and commercial capital of the Volta region of Ghana. The municipality lies between latitudes 6° 20′N and 6° 55′N and longitudes 0° 12′E and 0° 53′E, and covers an area of about 11.65 square kilometers (GSS, 2014). According to the 2010 Population and Housing Census, it has a population of about 177,281 (GSS, 2014). The Ho Municipal Assembly is bounded by the Ho West Municipality to the West and North, by the Adaklu-Anyigbe and Agortime Ziope districts to the south and by the Republic of Togo to the east.

The municipality has a tropical monsoon climate. The rainfall pattern is characterized by two rainy seasons, a major and a minor rainy season. The major season begins from March to June, while the minor season starts from August to November. The remaining 4 months of the year constitute the dry season. The highest rainfall inputs occur in June, with a mean value of 192 mm, while the lowest rainfall of 20.1 mm is received in December (Abankwa *et al*., 2009; www.ghanadistricts.com). The double maxima rainfall pattern and high soil fertility support the predominantly agrarian economy of the municipality (Abankwa *et al*., 2009). The northern parts of the municipality are mountainous, comprising parts of the Akwapim-Togo ranges. Rainfall amounts are higher for the areas around the mountains in the north, which have developed moist-semi deciduous forests. The southern part is low-lying (GSS, 2014), has lower rainfall amounts and is characterized by savannah woodland vegetation. Some mountainous settlements like Amedzofe, Biakpa, Vane, and Ashanti Kpoeta experience relatively low temperatures during some parts of the year, attracting the nickname 'local winter' of the Volta Region (www.ghanadistricts.com).

The overdependence of the agrarian economy of the municipality on rainfall renders the economy and livelihoods of most people highly vulnerable to rainfall variability, especially to variability associated with ENSO. Perennial crops such as oil palm, cocoa and avocado are cultivated in the Municipality, whilst food crops such as maize, cassava, yam and banana, legumes and vegetables, as well as non-traditional crops like mangoes and pineapples are also produced (Ho Municipal Assembly, 2013, 2014).

2.2. Data

The study employed a quantitative research approach using historical rainfall amounts from the Ho Municipality and Pacific SSTs. Two different historical rainfall datasets: daily rainfall totals (1960 to 2015) from the national office of the Ghana Meteorological Agency (GMet) and monthly rainfall totals (1955 to 2015) from the GMet regional office at Ho were used for the study. For the detailed daily analysis we depended on the National data set. The ENSO data for the study period (1955 to 2015) were obtained from the Centre for Ocean-Atmospheric Prediction Studies (COAPS) hosted by the Florida State University. The index used for the ENSO signal is the Japan Meteorological Agency (JMA) Index. The JMA was used because it has been used in many ENSO studies globally due to its high quality and the fact that it selects well-known ENSO events. The SST indices used represented a 5 month running mean of spatially averaged sea surface temperature anomalies (SSTA) over the tropical Pacific (4°S – 4°N, 150°W– 90°W) relative to the base climatological period from 1955 to 2015. Values exceeding a threshold of +0.5°C for six consecutive months including October–November–December depict El Niño phases, while values below −0.5°C represent La Niña events. Values between +0.5 and −0.5°C represent neutral phases (http://coaps.fsu.edu/jma).

2.3. Methodology

The data were analyzed using the Statistical Package for Social Sciences (SPSS), Microsoft Excel and Instat+ (used for the analysis of the start, cessation and length of the rainy seasons for the different ENSO phases). Data quality checks were performed by first comparing the two historical rainfall datasets against each other. Additional data quality checks were performed using neighborhood checks after Instat+ codes for missing values were implemented and daily summaries were generated for each month of the year. The mean monthly rainfall as well as the mean annual rainfall for the study period (1955 to 2015) were computed. Since ENSO is known to be the largest determinant of variability in tropical rainfall (Mude *et al.*, 2007), the relationship between the ENSO phenomenon and rainfall variability in the Ho Municipality of Ghana was analyzed. As indicated earlier, the ENSO data for the study period (1955 to 2015) obtained from COAPS was used to demonstrate the effect of ENSO on annual and monthly rainfall in the municipality. The Centre for Ocean-Atmospheric Prediction Studies (COAPS) puts ENSO into three phases: warm (El Niño), neutral and cold (La Niña) phases. Using this as a grouping variable, a one-way analysis of variance (ANOVA) was used to test for differences in rainfall to assess if variability in total annual rainfall in the Ho Municipality has a statistically significant relationship with ENSO. The assumption of normality was evaluated using normal Q-Q plots and Shapiro-Wilk's test (Table 1), and found to be tenable. The Shapiro-Wilk's test and a visual inspection of normal Q-Q plots showed that the total annual rainfall amounts were normally distributed for both El Nino (p = 0.145) and La Nina years (p = 0.083), but not for neutral years (p = 0.004).

An F-statistic, F, is defined as:

$$F = \frac{MS_{between}}{MS_{within}},$$

Where:

$$MS_{between} = \frac{SS_{between}}{df_{between}} \; and \; MS_{within} = \frac{SS_{within}}{df_{within}},$$

$$SS_{total} = \sum\left[\sum(x^2)\right] - \frac{[\sum(\sum X)]^2}{N},$$

$$SS_{between} = \sum \frac{(\sum X)2}{n} - \frac{[\sum(\sum X)]^2}{N},$$

$$\mathrm{SS_{within}} = \mathrm{SS_{total}} - \mathrm{SS_{between}},$$

Where x is the individual observation, n is the number of observations in a group, N is the total number of observations in all groups (total sample size), $\mathrm{df_{between}}$ = (k-1), $\mathrm{df_{within}}$ = (N-k) and k is the number of groups.

In this application, *x* is the total annual rainfall inputs from 1955–2015, the total number of years falling under the El Niño (15), neutral (31) and La Niña (15) phases determine *n.* The total number of observations in all groups (61) determine *N*, and the number of groups (3) constitute *k.* Partial Eta Square is used to measure the percentage of the variability in rainfall attributable to the ENSO phenomena. Finally, bar graphs were employed to depict and display the observed relationship between the ENSO phases and the seasonal and annual rainfall distribution in the Ho Municipality.

In order to analyze the onset and cessation of rainfall for the different ENSO phases, the calculated mean monthly rainfall was plotted using the ENSO phases as the data series to illustrate start and cessation months for both major and minor rainfall seasons. This was then complemented by an analysis of daily rainfall in order determine the start and cessation dates (based on days of the year) for both rainfall seasons. Different studies have employed

Table 1. Test of normality

		Shapiro–Wilk		
	ENSO phase	**Statistic**	**Df**	**Sig.**
Total rainfall	El Niño	0.912	15	0.145
	Neutral	0.891	31	0.004
	La Niña	0.896	15	0.083

varied definitions in studying the onset and cessation of the rainy season in tropical Africa. In this study, the onset date of the rainy season is defined as the first day from 1st March (major season) or 1st August (minor season) of one or two consecutive days receiving at least 20 mm of rainfall without any seven-day dry spell of less than 5 mm during the following 20 days. March is when the major rainfall is known to start for the municipality, with the minor rainfall season also beginning in August (GSS, 2014; www.ghanadistricts.com). The selection of these 2 months as the earliest months when the rainfall season can begin is both climatological and agricultural. According to Omotosho *et al.* (2000), dry spells within the initial 20 to 28 days of the rainfall season hinder crop germination and growth. This definition of the start of the rainfall season was adopted for this study to help identify the true start days for the rainfall season as opposed to false starts days, which are mostly characterized by dry spells after the initial days of rainfall. The cessation date of rainfall is also defined as any day from 1st June (major season) and 1st November (minor season), after which there are 21 or more consecutive days of rainfall that provide less than 50% of the crop-water requirement (5 mm). Both definitions were adapted from Omotosho *et al.* (2000) and Marteau *et al.* (2009).

3. Results and discussion

3.1. ENSO effect on annual rainfall

Several studies have found significant associations between ENSO events and annual rainfall totals across the Volta Basin (Owusu *et al.*, 2008; Waylen and Owusu, 2014; Boadi and Owusu, 2017). Previous studies have looked at the influence of ENSO on the prospects for water-sharing in the Volta Basin (Owusu *et al.*, 2008), the implications of ENSO for rainfall changes in Accra (Waylen and Owusu, 2014), and the implications of ENSO-induced rainfall changes in the south Volta Basin for hydropower generation (Boadi and Owusu, 2017). The point of departure of this study is that it looks at the implications of ENSO for sustainable agricultural development in the Ho Municipality. In this study, a one-way analysis of variance was conducted to evaluate the null hypothesis that there are no differences in total annual rainfall received in the Ho Municipality based on the three phases of ENSO: El Niño years (M = 1,203.86, SD = 213.65, N = 15), neutral phase (M = 1,311, SD = 204.59 N = 31) and La Niña years (M = 1,451.2, SD = 228.7, N = 15).

As shown in Table 2, the assumption of homogeneity of variances was tested and found to be tenable using Levene's Test, F (2, 58) = 0.515, p = 0.600. The ANOVA was statistically significant, F (2, 58) = 5.11, p = 0.009 (Table 2). Thus, there is enough evidence to reject the null hypothesis and conclude that there is a statistically significant difference in total annual rainfall for the different phases of ENSO for the study period. A Scheffe Post-Hoc test was used to evaluate pairwise differences among group means for the three ENSO phases. At the 95% confidence interval, there appears to be no statistically significant difference in total annual rainfall between El Niño and neutral phase years. There also appears to be no statistically significant difference in total annual rainfall between La Niña and neutral phase years. However, there is a statistically significant difference in total annual rainfall between the El Niño and La Niña phases (mean difference = −247.33, p = 0.009). The effect size as estimated by partial eta squared is large, 0.150 (15%). This means that 15% of the variability in total annual rainfall received in the municipality is attributable to the ENSO phenomenon. This is quite a significant effect as Cabrera *et al.* (2010) found ENSO to be just one of the many factors that affect rainfall inputs in any given locality. The finding also means that, although the variability exerted by ENSO on rainfall in the municipality is significant, a greater proportion of the variance in annual rainfall is accounted for by local factors other than ENSO. Such localized factors most likely include the orographic effect of the mountains on the northern parts of the municipality as well as the Togo ranges (GSS, 2014), which have significant influence on the rainfall amounts received in the area. Consistent with Owusu *et al.* (2008), the warm phases of ENSO were associated with a reduction in mean annual rainfall totals in the municipality from a long-term average of 1,319 to 1,203.86 mm (Figure 1).

Table 2. Summary ANOVA results for ENSO influence on total annual rainfall

Parameters	El Niño	Neutral phase	La Niña
N	15	31	15
Mean	1203.86	1311	1451.2
Standard deviation	213.65	204.59	228.7
Levene's Test	F (2, 58) = 0.515, p = 0.600		
ANOVA	F (2, 58) = 5.11, p = 0.009		
Partial eta squared	0.150		

Note: *N in years; mean and standard deviation in mm.

In general, lower mean annual rainfall inputs in the Ho Municipality are associated with warm ENSO phases. This means that as tropical Pacific SSTs increase, rainfall amounts in the municipality decrease, as depicted in Figure 1 by the lower rainfall inputs for El Niño years. Also, La Niña episodes in the tropical Pacific correspond to increases in the mean annual rainfall amounts for the municipality (Figure 1). This finding is consistent with that

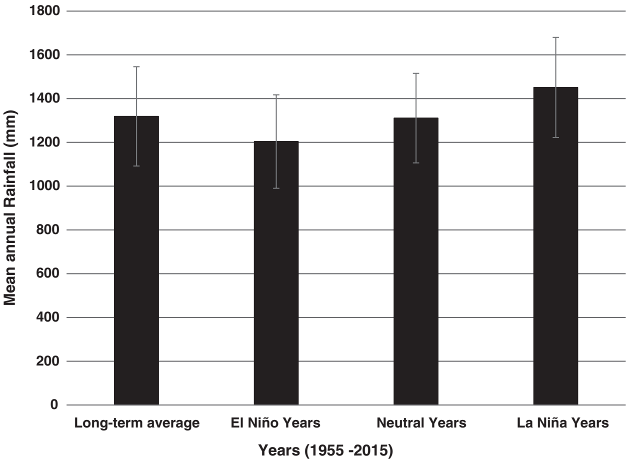

Figure 1. Mean annual rainfall distribution at Ho for the various ENSO phases. Standard deviations are shown using error bars. *Source:* Based on data from GMet.

of Mason and Goddard (2001), who found that La Niña events resulted in increased annual rainfall totals for regions in the Guinea Coast of West Africa. Mean annual rainfall for the municipality as can be seen in Figure 1 increased from a long-term average of 1,319 mm to about 1,451.2 mm in La Niña years for the period under study. The year-to-year rainfall amounts were therefore analyzed for trends to complement the mean annual rainfall analysis for the different ENSO phases. This is presented in Figure 2, which shows the annual rainfall amounts for the Ho Municipality from 1955 to 2015. Annual rainfall was relatively higher for the 1950s and 1960s compared to the 1980s and 1990s (Figure 2). For instance, from 1970 to 1997 annual rainfall amounts were constantly below 1,500 mm compared to the 1950s and 1960s, where 1955, 1962, 1963, 1965 and 1968 recorded rainfall amounts above 1,500 mm. The lowest rainfall inputs (about 1,000 mm and below) were recorded in 1977, 1992, 1994, 1982 and 1983.

3.2. *ENSO effect on seasonal rainfall*

Seasonal rainfall distribution and its variability tends to impact agricultural production more than the annual total and its variability (Feng *et al*., 2013). The impact of the different phases of ENSO on the major and minor seasons at Ho Municipality were therefore investigated. Mean monthly rainfall amounts in the municipality associated with the different ENSO phases throughout the study period are illustrated in Figure 3. The study area, just as for the Guinea Coast in general, experiences a bimodal rainfall with a first peak in June and a second in October.

Crop production in the Ho Municipality, similar to Ghana in general, is largely rain-fed (Ministry of Food and Agriculture, 2003), raising two crops in the year corresponding to the major and minor rainy seasons. As shown in Figure 3, the mean monthly rainfall is strongly affected by the different phases of ENSO. The mean monthly rainfall begins to increase significantly from March, reaching above 200 mm in June in La Niña years. This is the peak of the major rainy season. Also, Figure 3 shows that the minor rainy season peaks in September for El Niño and La Niña years, and has similar means for September and October in neutral years, reaching a mean of 180 mm. The highest mean monthly rainfall in the municipality for the period under study was experienced in June, with the

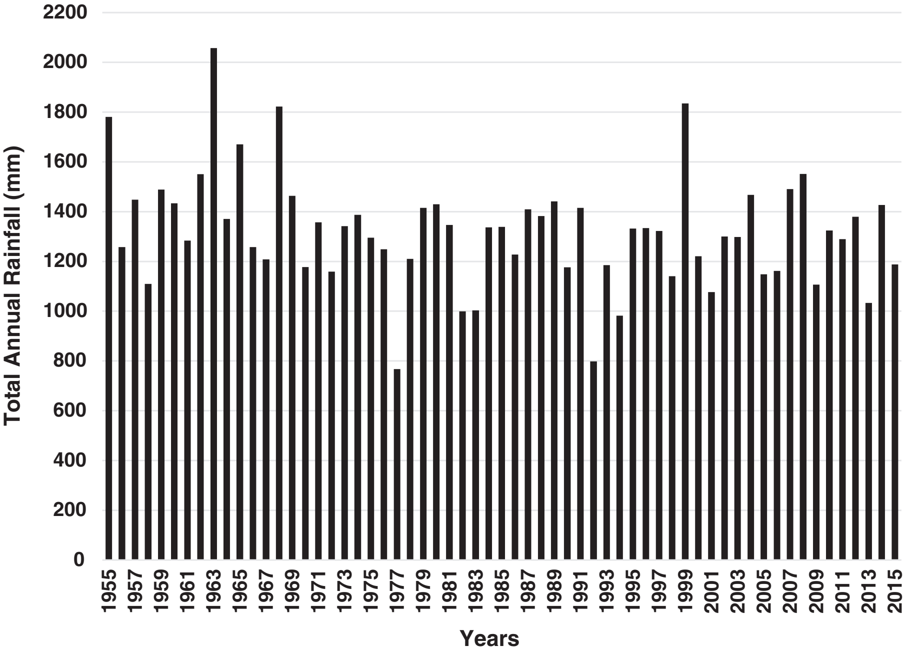

Figure 2. Total annual rainfall from 1955 to 2015. *Source*: Based on data from GMet.

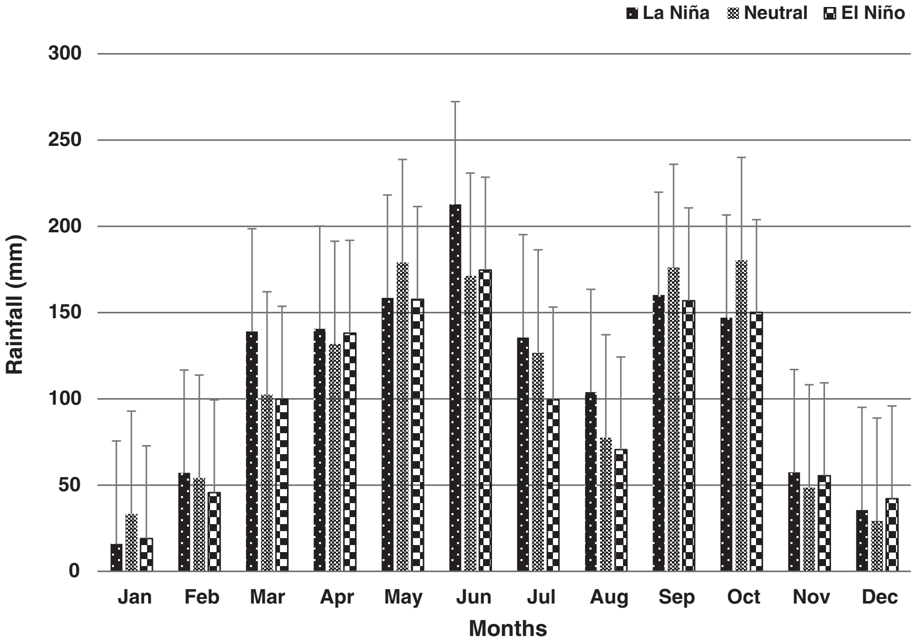

Figure 3. Mean monthly rainfall at Ho in different ENSO phases, 1955–2015. Standard deviations are shown using error bars. *Source*: Based on data from GMet.

lowest received in January (Figure 3). As can be seen from Figure 3, more rainfall is experienced in the major rainy season (March-June) in the Ho Municipality for the cold phases of ENSO than in both neutral and El Niño years. This implies that the potential for agricultural activities in the municipality is enhanced during La Niña episodes, especially in the months of March-April-May-June. Temperature and sunshine hours are important factors for assessing agricultural potential and crop adaptability but in the tropics, the dominant factor is rainfall, which also controls temperature and sunshine hours. Rainfall in the minor season for the municipality is also affected by ENSO events. Analysis from this study shows that the mean monthly rainfall during the minor rainy season (August-November) is higher in neutral episodes than in either El Niño or La Niña episodes. Out of the 31 neutral years that occurred from 1955 to 2015, 18 of them were associated with higher minor season rainfall (analysis not shown). The explanation for the higher rainfall observed during the minor rainy season could lie in the seasonal migration of the Intertropical Convergence Zone. However, unlike for the entire Volta Basin (Owusu *et al*., 2008), La Niña episodes do not bring significantly higher rainfall than El Niño episodes in the minor rainy season as the mean monthly rainfall inputs for the minor season are similar for both El Niño and La Niña episodes.

There are also visible trends in the peak rainfall month for both the major and minor rainy seasons, as shown in Figure 3. Peak rainfall in the major rainy season still occurred in June, except for the neutral phases, when the rainfall peaked in May. In the minor rainy season, the peak rainfall month shifted from October in neutral years to September in El Niño and La Niña years, albeit a 20 mm decrease over the neutral rainfall input (Figure 3). This observation is quite significant as the cessation of the rainfall season is influenced by the peak month. As Figure 3 illustrates, rainfall amounts start to decline significantly after peak months. An early peak will therefore mean an early cessation of the rainy season. One major problem with rainfall inputs in Ghana and West Africa usually relates to the distribution of monthly rainfall in the major and minor rainy seasons, which corresponds with the major and minor cropping seasons. This is because the best measure of variability in rainfall for Ghana and West Africa has often been in the form of a shift or delay in rainfall onset, and a reduction in the length of rainfall period (Lacombe *et al*., 2012). The rainfall start days associated with the different ENSO phases from 1960 to 2015 were thus analyzed in detail. The major season rainfall onset days are shown in Figure 4.

As seen from Figure 4, most La Niña years have early start dates (shown in triangles) compared with El Niño years (shown in diamonds), which have later start dates. A line of best fit is used to show the mean start dates associated with all three phases (El Niño and La Niña compared to neutral years [normal years]). As shown by the lines, both El Niño and La Niña years are associated with onset dates above the start dates of the neutral years (Figure 4). El Niño years have later mean start dates, followed by La Niña years. This indicates an early start of the major season rainfall during La Niña events compared to El Niño events. The lines also indicate that the onset dates for El Niño years have been starting later and later over the timespan of the study period. For example, with the exception of the

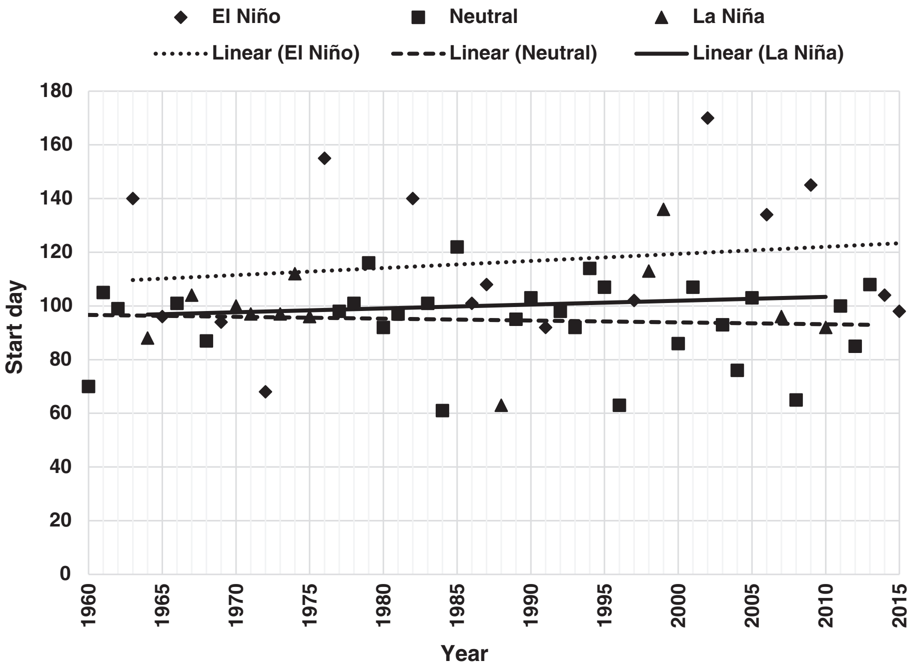

Figure 4. Major season rainfall start day for ENSO phases, 1960 to 2015. *Source*: Based on data from GMet.

1999 La Niña year when the major rainfall season began on day 136 (15 May), the extremely late start dates observed within the study period were associated with El Niño years. The prominent ones are onsets for 1976 (day 155), 2002 (day 170), and 2009 (day 145). These onset days correspond to 3 June for 1976, 18 June for 2002 and 24 May for 2009. These are quite late onsets of the major rainy season when compared to the mean start dates for normal years (as shown by the line of best fit for neutral years, which is constantly below day 97 [6 April]).

As shown in this study and also by other studies (Waylen and Owusu, 2014; Boadi and Owusu, 2017), El Niño is known to be associated with lower rainfall inputs for the entire Volta Basin, so it is not surprising that such years are mostly characterized by late onset for the major season rainfall. Adiku and Stone (1995) similarly found El Niño events to be associated with late rainfall season onsets. However, it was expected that La Niña events will be associated with starts earlier than for normal years. This is however not the case as shown by Figure 4. The explanation for this could lie in the identical rainfall inputs, which are observed for both neutral years and the long-term rainfall in the municipality (analysis shown in this study). This could mean conditions that produce the normal behavior of rainfall seasons in the municipality are also observed during neutral years, and thus produce identical rainfall means and season onsets.

Figure 5 shows the rainfall start days associated with the different ENSO phases for the minor rainfall season. Similar to that of the major rainfall season, the start dates for both El Niño and La Niña years are later than for neutral years (normal conditions). For both El Niño and La Niña years, the mean onset dates for the first 30 year period under study are identical as shown by their respective lines of best fit. There is a slight difference in the mean onset dates for the latter half of the period under study, with the rainfall starting slightly earlier for El Niño years compared to La Niña years. In addition to expecting a distinct mean onset trend for El Niño and La Niña years compared to neutral years, it was also expected that La Niña years will have earlier onset dates than El Niño years and neutral years. However, this is not the case as shown by the mean onset dates for all three phases (Figure 5). The possible climatological explanation is that if ENSO is not sustained over a year, its influence could have waned by the time of the minor season. This will reduce the ENSO effect on the minor rainfall season.

From Figure 3, the major season experiences the largest reduction in rainfall in El Niño years. This means that in El Niño years, the major rainy season is shorter after starting late and finishing early in June. This finding is consistent with Mawunya *et al.*'s (2011) study in Akatsi, also in the Volta region of Ghana, which established that El Niño years correlate with a late onset and early cessation of rains in the major rainy season, hence resulting in shorter rainy seasons compared to La Niña. In La Niña years however, rainfall in the major rainfall season is distributed over a longer period, starting in March for most years, and ending in July (Figures 3 and 4). The implications of these findings are that major season crop cultivation in the municipality will be severely hampered during El Niño years as the rainfall regime fails for most months and is characterized by a late start and an early cessation. In La Niña years however, major season crop production will be boosted as higher rainfall inputs are observed amidst an early start and a late finish. Farmers in the municipality will thus have

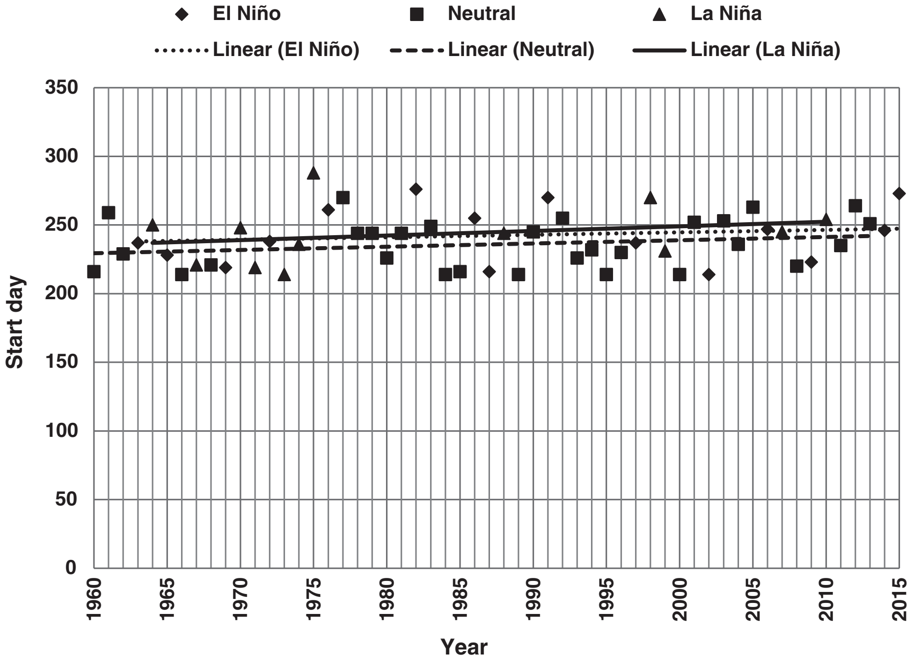

Figure 5. Minor season rainfall start day for ENSO phases, 1960 to 2015. *Source*: Based on data from GMet.

longer farm periods in the major cropping season in La Niña years and a shorter cropping season in El Niño years.

Mean monthly rainfall in El Niño years does not deviate much from mean monthly La Niña rainfall in the minor rainy season as seen in Figure 3, which shows identical monthly rainfall totals in El Niño and La Niña episodes for September and October. This means that the minor rainy season is not affected by El Niño events. The reason for this may lie in the fact that ENSO events are declared in October-November-December with the strongest influence from December to April, and a weakening effect thereafter until September (http://coaps.fsu.edu/jma). This means that by September-October of the following year, the strong influence exerted by the ENSO event would have weakened, except in the case of sustained ENSO events. This could possibly explain why the influence of El Niño events on rainfall is more severe in southern Ghana than in the northern savannah regions (Adiku and Stone, 1995), which have just one rainy season that occurs closer to when southern Ghana records its minor rainy season, by which time the effects of the El Niño event would have waned.

In total, 12 El Niño events have occurred since 1970 compared to only five El Niño events in the 45-year period prior to 1970 (analysis not shown here). El Niño events have become more frequent, persistent and severe since the mid-1970s, a trend which is predicted to continue into the future as a result of climate change (IPCC, 2001, 2013). The implications of this is that low rainfall inputs with more pronounced variability and late onset are likely to be frequent in the Ho Municipality in a future in which El Niño is predicted to be frequent and severe. Farmers can therefore select crops that are resilient and resistant to dry spells and low rainfall in the major season during El Niño episodes and cultivate their usual crops during the minor rainy season, which records the same monthly rainfall totals in El Niño years as in La Niña years. However, this crop selection technique will be useful only if the El Niño is not a sustained event. Farmers can also cultivate their usual crops in the major rainy season during La Niña episodes as rainfall inputs are more favorable and are characterized by an early start and a late cessation. Also, farmers can select crops and crop varieties that require longer growing periods for cultivation in La Niña years, as these years are associated with longer major rainy seasons as opposed to El Niño years.

4. Conclusions

This study sought to examine the relationship between ENSO and rainfall inputs in the Ho Municipality and its implications for the development of sustainable agriculture in the area. The study therefore analyzed historical rainfall data from the municipality and SST anomalies from the tropical Pacific. The findings of the study showed a significant relationship between ENSO and annual rainfall in the Ho Municipality from 1955 to 2015. The study found that La Niña conditions generally result in higher monthly and annual rainfall inputs for the municipality, while El Niño conditions are associated with reduced rainfall inputs. About 1,451.2 mm of annual rainfall was observed during La Niña years, while El Niño was associated with reduced annual rainfall amounts averaging 1,203.86 mm and a slightly higher year to year variability. Rainfall in the peak crop-water demand month of June was observed to increase during La Niña conditions. On the other hand, El Niño conditions were characterized by reduced rainfall in peak crop-water demand months for the municipality. A key finding of this study is that the minor season rains are less affected by both El Niño and La Niña events.

The implications of these findings for sustainable agricultural development in the Ho Municipality are that major season crop cultivation will be more severely affected by El Niño events due to the associated lower rainfall inputs in addition to a delayed onset and an early cessation. If highly valued by farmers, crops with longer growing periods can be cultivated in La Niña years as the major season rains are distributed over a longer period due to an early onset and a late cessation. The findings of the study support a hypothesis that ENSO has a significant relationship with both annual and seasonal rainfall inputs in the Ho Municipality of Ghana. El Niño years showed the highest rainfall reduction in the municipality across the study period, suggesting an erratic and unreliable pattern of rainfall for El Niño years. The priority of the Ho Municipal Assembly and Ministry of Food and Agriculture should therefore be providing farmers in the municipality with timely and accurate information on the occurrences of ENSO phenomena and how long they are likely to last to assist in crop selection and also inform farmers' planting dates.

Based on the findings of this study, farmers can shift part of their agricultural activities, especially the cultivation of crops with shorter growing periods, to the minor season during El Niño episodes since it is the major rainfall season that is usually characterized by pronounced rainfall failure. Also, it is recommended that farmers within the Ho Municipality be encouraged by agricultural extension officers to look for complementary water sources and implement water management strategies to augment the low rainfall amounts, especially during El Niño episodes. Underground water, which will be recharged during La Niña episodes, can be used to irrigate farms in El Niño years to prevent significant crop failures. Water storage facilities can also be constructed to store excess water in La Niña years to be used to undertake dry season farming. In addition, the municipal management, in collaboration with the local GMet office at Ho, should monitor ENSO events as well as localized drivers of rainfall to be able to sufficiently advise and help farmers adapt their cultivation times and crops to prevailing ENSO phases.

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