Characterisation of Seasonal Rainfall for Cropping Schedules

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Abstract

El Nino-South Oscillation (ENSO) phenomenon occurs in the Equatorial Eastern Pacific Ocean and has been noted to account significantly for rainfall variability in many parts of the world, particularly tropical regions. This variability is very important in rainfed crop production and needs to be well understood. Thirty years of daily rainfall data (1976–2006 excluding 1991) from the Akatsi District in the Volta Region of Ghana were analysed to observe the variation of rainfall characteristics such as onset and cessation dates, seasonal rainfall amount and their temporal distribution with ENSO phase, namely El Nino, La Nina and Neutral. Using rainfall-reference evapotranspiration relationships, the onset of rainfall during La Nina and Neutral seasons occurred within the same period, March 11–20, but about a month late (April 11–20) during El Nino. Without regards to ENSO phase, the long-term mean onset date of the rainy season occurred from March 11–20. Annual and major season (March–July) rainfall amounts decreased in the order of these ENSO phases; La Nina, Neutral and El Nino but showed an opposite decreasing order of El Nino, Neutral and La Nina during the minor seasons (September-November). The trend of variability of rainfall distribution during the major season was observed to be highest during El Nino years and least during Neutral years. The study also showed that the optimum planting periods on 10-day time scales during La Nina, Neutral and El Nino years were found to be March 13–22; March, 17–26 and April 20–29, with March 16–25 for the long-term situation. These observations seem to reveal that long-term or climatological observations alone are no longer sufficient for seasonal rainfall prediction to aid cropping schedules.

Introduction

Rainfall is a major determinant of agricultural production in any agro-ecological zone anywhere in the world. Its seasonal and annual characteristics such as the onset and intra-seasonal rainfall distribution that promote good crop yields are, however, characterized by marked fluctuations. These fluctuations are not easy to forecast, yet a fore-knowledge will help the farmer to plan his farming activities strategically. The onset of rainfall is very crucial to farmers as it answers the vital question "when to plant?". Adiku & Kuatsinu (1992) and Adiku *et al.* (2007ab) observed that the most variable component of rainfall in Ghana is the onset date, and that rainfall variability is higher at the onset than at the end of the rainy seasons. The onset period of the rainy season and the beginning of the cropping season are often generally considered synonymous.

Using rainfall amount and reference evapotranspiration (ET_o) relationship, the Food and Agricultural Organisation [(FAO), 1986] defined the onset of the rainy season as the date after which mean rainfall amount over any given period of time interval is consistently greater than half of the mean ET_o over the same period under consideration. The agronomic importance here is that more than 50% of field moisture lost through evapotranspiration can be replenished by rainfall for successful crop growth and development. Closely linked with the onset of seasonal rainfall is the issue of optimum planting periods in Ghana's various agro-ecological zones. FAO (1986) again defined an optimum planting period as (i) any week, in the initial period of a rainy season, within which rainfall amounts total at least 25 mm, or (ii) any 10-day period (dekad), in the initial period of a rainy season, with a total rainfall amount of at least 30 mm, and followed by continuity of rain for good emergence and vegetative growth of crops. There is need for more research attention on the onset of rainfall and optimum planting periods in Ghana.

Rainfall distribution throughout the cropping season is another important characteristic of rainfall that affects crop yields. A season with high total rainfall amount but poorly distributed cannot promote high crop yields. On the other hand, fairly good yields can be obtained with well distributed seasonal rainfall that may not be high in terms of total amount. In perhaps all rainfall prediction efforts, however, only forecasts of the seasonal total rainfall amounts are given with some probabilities. Forecasts on seasonal rainfall distribution are rare. Given this situation, farmers' desire for knowledge in this regard remains unsatisfied. A clearer insight into rainfall distribution and levels of variability associated with either the seasonal amounts or seasonal distribution may be obtained only through analysis of historical rainfall data. Undoubtedly, rainfall distribution trends over a given season can be useful in the interpretation of observed crop performance. The challenge to successful rainfed crop production is the timely and precise prediction of the rainfall characteristics of a coming cropping season. These challenges need to be sufficiently addressed through scientific research in order to reduce high fluctuations of crop yields in rainfed ecologies on both seasonal and annual time scales.

Crop production in Ghana is largely rainfed with only 0.08% of the country's agricultural land under irrigation (MOFA, 2003). Agriculture accounts for 35% of the Gross Domestic Product of Ghana (Ministry of Finance, 2007), therefore, research on rainfall patterns in all of the country's agro-ecological zones becomes imperative for successful economic planning. Globally, some progress has been made in rainfall prediction based on signals from some natural modes, such as the El Niño-Southern Oscillation (ENSO). ENSO refers to shifts in the sea surface temperatures (SST) in the Eastern and Western Equatorial Pacific, coupled with shifts in barometric pressure gradients and wind patterns in the tropical Pacific (the Southern Oscillation) (TOGA, 1996; Hansen, 2001; Hansen *et al.,* 2001; NOAA, 2004). Although the ENSO phenomenon occurs within the tropical Pacific, its effects have been felt through much of the globe and accounts for a substantial portion of the seasonal and interannual variability of weather in many regions (Ropelewski & Halpert, 1996).

The impact of ENSO phenomenon on agriculture becomes evident through its influence on rainfall. El Niño-Southern

Oscillation and precipitation relationships have been documented in several regions of the world including east and southern Africa (Ogallo, 1988; Wang, 1993; Mason, 1997). Similar studies have been carried out in Ghana by Opoku-Ankomah & Cordery (1994), Adiku & Stone (1995), Adiku (2003ab), Adiku *et al*. (2007a). Global impact and predictability are two important characteristics of ENSO that have led to public and research interest (Hansen, 2001). ENSO information, available on internet monthly, have made it possible to predict climate fluctuations globally with lead times of about 1 year (Barnston *et al.,* 1994; Chen *et al.,* 1995; TOGA, 1996; Latif *et al.,* 1998). Hansen (2001) emphasized that where the influence of ENSO on agricultural production can be demonstrated, ENSO prediction may be used either to mitigate the impacts of adverse weather conditions or take advantage of favourable conditions. ENSO predictions by the International Research Institute for Climate and Society (IRI), Columbia University, New York, and others are available on monthly basis *via* internet.

The study sought to use ENSO information to (i) categorise seasonal rainfall amounts at Akatsi, (ii) assess variations of the rainfall parameters (i.e. onset and cessation dates, seasonal rainfall amount and their temporal distribution), and (iii) explore opportunities for using ENSO information to predict the characteristics of a coming season rainfall in the Akatsi District.

Materials and methods

Location and climate of project site

Akatsi (Fig. 1) is a very active farming and marketing district in the south-eastern corner of Ghana. It has a bi-modal seasonal rainfall distribution pattern within a year with a mean annual rainfall amount of 800 mm. The major rainy season spans over March-July with

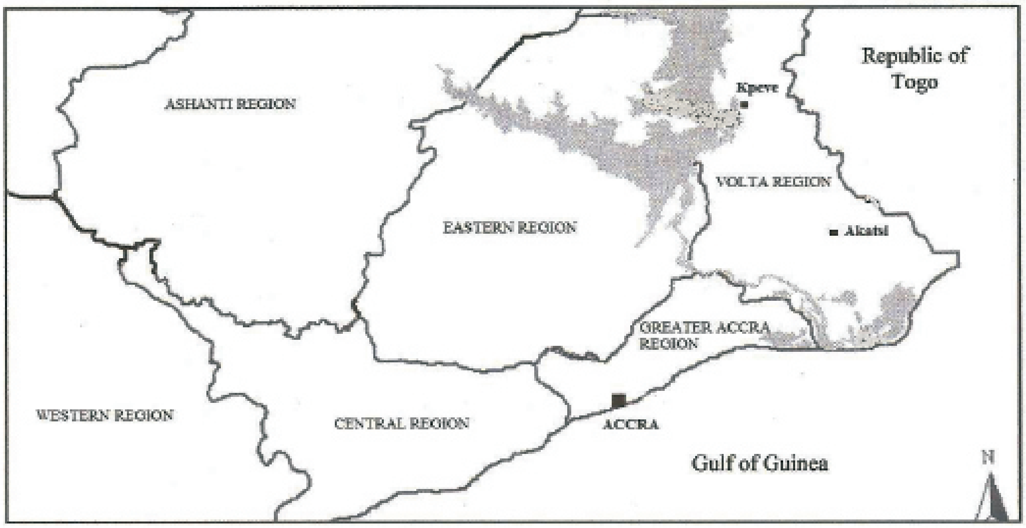

Fig. 1. Partial map of Ghana showing Akatsi (arrowed) [not drawn to scale]

June as the peak month and accounts for about two-thirds of the mean annual rainfall (Adiku *et al.,* 2001). The minor rainy season, which makes up the remaining one third, begins in September, after a short lull in August, and ends in November with a peak in October. This is followed by a 3-month dry season, often referred to as harmattan.

The values of the mean monthly air temperature minimum temperature and maximum temperature are, respectively, 27.4 °C, 23.0 °C and 31.8 °C. Relative humidity in the morning ranges between 60 and 100% for most of the year with mean maximum of 95.7%. The afternoon relative humidity ranges between 20 and 80% with mean minimum of 65.5%. The District has only one Meteorological Station at the District capital, Akatsi, where historical data for this study were collected.

ENSO episodes and their associated rainfall characteristics

Rainfall years (1976–2006) were classified into three ENSO episodes, namely El Nino, La Nina and Neutral, based on the widely used October-November-December (OND) sea surface temperature (SST) anomalies of the Japan Meteorological Agency (JMA, 2007). The monthly SST anomaly is the difference between the mean SST value for a given month and the climatology (i.e. the long term mean). The JMA monthly SST anomalies are means of spatially averaged SSTs over the tropical Pacific region of 4° S–4° N and 150° W–90° W. Index values for six consecutive months are considered. If the index values are 0.5 °C or greater, between -0.5 °C and 0.5 °C, and -0.5 °C or less, the ENSO phase is categorized as El Nino, Neutral and La Nina, respectively. Supplementary ENSO forecasts from the International Research Institute (IRI) for Climate and Society website: *(http://iri.columbia.edu/climate/ENSO/currentinfo)* were also used to complement those of JMA. ENSO forecasts are given together with the probabilities of occurrence such that the phase with the highest probability of occurrence over the OND period exerts the greatest influence on rainfall in the succeeding year.

The rainfall characteristics studied with respect to ENSO episodes included the onset and cessation dates for the major season, temporal distribution for the major season, seasonal amounts for the major and minor seasons, as well as the annual and their variability. Typically, climatologists recommend at least 50 years of data to study ENSO developments. However, because of unavailability of sufficient and reliable historical weather data for the District, only 30 years (1976-2006 excluding 1991 due to missing data) of daily weather data obtained from the Ghana Meteorological Agency were used. In practice, long-term average climate parameters are used as points of reference. The available 30 years weather data represented the long-term period in the study, thus, the 30-year average parameters were considered as the points of reference for Akatsi. Pair-wise t-tests were used to determine statistical difference in rainfall amounts for any two ENSO phases.

Determination of onset and cessation periods of rains and planting periods

Based on the FAO (1986), the onset and cessation of rains for each rainfall category were determined from graphical representations of rainfall amount and reference evapotranspiration (ET_o) relationship. Mean 10-day (Table 1) rainfall amounts were determined and plotted against their corresponding 0.5 ET_o values for each ENSO event and for the 30-year average. The ET_o values were estimated using the FAO Penman-Monteith equation (FAO, 1998) as follows:

$$ET_o = \frac{0.408\,(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad 1$$

where ET_o = reference evapotranspiration (mm day^{-1}); ? = slope of vapour pressure curve (kPa $^oC^{-1}$); R_n = net radiation at the crop surface (MJ m^{-2} day^{-1}); G = soil heat flux density (MJ m^{-2} day^{-1}); γ = psychrometric constant (kPa $^oC^{-1}$); T = mean daily air temperature at 2 m height (^oC); u_2 = wind speed at 2 m height (ms^{-1}); e_s = saturation vapour pressure (kPa); e_a = actual vapour pressure (kPa); e_s-e_a = saturation vapour pressure deficit (kPa).

The first point of intersection of the rainfall-0.5 ET_o graphs indicates the onset date and the second point of intersection gives the cessation date. It is considered unpractical to state a single date for onset or end of rains for any season. Hence, onset periods or cessation periods are considered in this study such that the 10-day time interval (Table 1) within which an onset or cessation date falls is taken as the onset or cessation period of rain for the season in question.

The optimum planting period was determined according to the FAO (1986) definition as any 10-day period, starting from the onset date determined from the graph of the rainfall-0.5 ET_o relationship, that has a total rainfall amount of at least 30 mm followed by continuous rain for good emergence of seedlings and vegetative growth of crops. Thus, a mean daily rainfall data was composed for each rainfall episode. Ten-day moving totals were then estimated starting from the onset date determined in the graph. For example, total rainfall for days 1–10, 2–11, 3–12, etc. were estimated. The first "10-day set" after the onset date that satisfied the FAO conditions for a planting period is noted as the mean optimum 10-day planting period.

Rainfall distribution and variability

The temporal distribution of rainfall during the major season at Akatsi was

TABLE 1
Calendar time intervals of 10-day periods

10-day period	*Month*	*Time interval*	*10-day period*	*Month*	*Time interval*
1	March	1–10	10	June	1–10
2		11–20	11		11–20
3		21–31	12		21–30
4	April	1–10	13	July	1–10
5		11–20	14		11–20
6		21–30	15		21–31
7	May	1–10	16	August	1–10
8		11–20	17		11–20
9		21–31	18		21–31

determined for each ENSO phase and the climatological condition. Ten-day period (Table 1) mean rainfall amounts were plotted against 10-Julian day time periods starting from March. Coefficients of variation of the 10-day period rainfall amounts were also plotted in order to observe the levels of variability associated with the rainfall distribution.

Results and discussion

Classification of rainfall years

Table 2 shows the El Nino, La Nina and Neutral years from 1976 to 2006 (1991 is excluded due to missing data). In all, there were nine El Nino years, eight La Nina years and 13 Neutral years.

TABLE 2
Categories of years according to ENSO based on lagged ENSO years*

La Nina	*Neutral*	*El Nino*
1976	1978 – 1982	1977
1985	1984	1983
1989	1986	1987
1996	1990	1988
1997	1993	1992
1999	1994	1995
2000	2001	1998
2006	2002	2003
	2004	2005

* ENSO condition, indicated by Ocotober-November-December (OND) Sea Surface Temperature (SST) anomaly index is experienced in the following year. Source: JMA (2007) and IRI (2007).

Onset and cessation dates of the rainy season and optimum planting periods

In Fig. 2, onset and cessation dates of rainfall are indicated by intersection points A and B, respectively, for the El Nino, La Nina, and Neutral years, as well as the long-term mean for the major rainy season (March-July) at Akatsi. A summary of the onset and cessation dates obtained from Fig. 2 for easy interpretation for all phases is presented in Table 3.

The onset dates for La Nina and Neutral phases, as well as the long-term mean occurred around Julian day (JD) 72, 70 and 75 corresponding to March 13, March 11 and March 16. Thus, the observed 10-day period within which the rainfall onset occurred for the two ENSO episodes and the long-term was March 11–20. For El Nino years, the onset date delayed by about 30 days, thereby, pushing the onset period to between April 11 and 20, which agrees with Adiku *et al.* (2007b). Ussher (1993) estimated a time range of March 1–10 for the climatological onset date for some areas of southern Ghana including Akatsi while Tanu & Mohr (2005) gave a 2-week period of March 1–15. Thus, in a La Nina or Neutral year, onset of the major rainy season is expected to occur between March 11 and 20 whilst in an El Nino year, the onset will occur between April 11 and 20. The results of the FAO procedure for onset date determination show that major season rainfall onset dates can fall within March contrary to that of Adiku *et al.* (2007b) where, based on their assumptions, onset dates occurred only after April 1.

Average cessation date of the major rainy season appears to vary little among the three ENSO phases. For La Nina and the long-term mean, the end date occurred around JD 205 or July 25 in the period between July 21 and 30; for Neutral, JD 215 or August 3, between the period August 1–10; for El Nino JD 200 or July 19, between the period July 11–20.

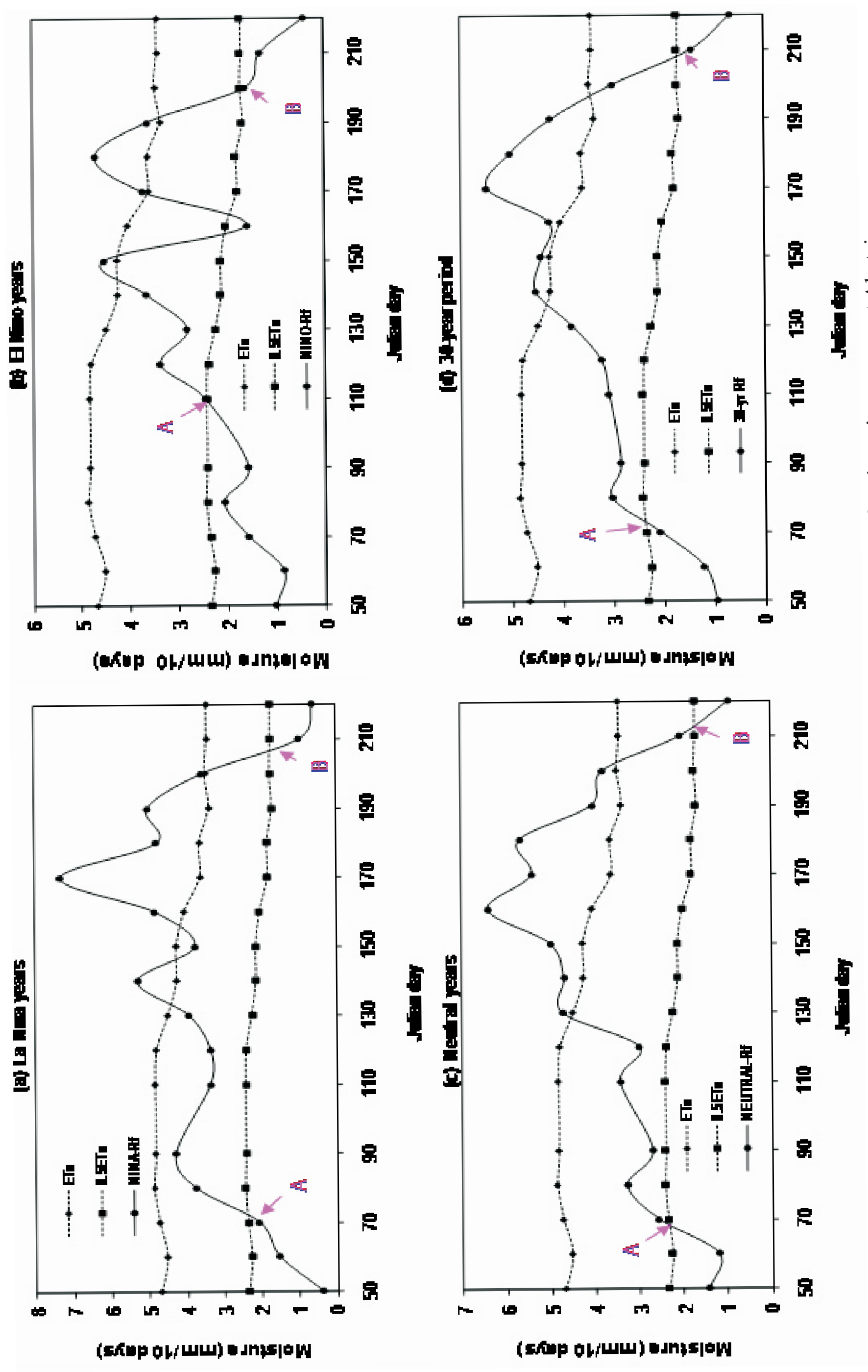

Fig. 2. Mean onset (points A) and cessation (points B) dates of major rainy season at Akatsi

TABLE 3
Summary of onset and cessation dates for the major rainy at Akatsi during La Nina, Neutral and El Nino phases as well as the long-term

ENSO phase	*Onset date Julian day*	*Cessation date Roman*	*10-day period*	*Julian day*	*Roman*	*10-day period*
La Nina	72	March 13	March 11–20	205	July 25	July 21–30
Neutral	70	March 11	March 11–20	215	August 3	August 1–10
El Nino	110	April 20	April 11–20	200	July 19	July 11–20
Long-term	75	March 16	March 11–20	205	July 25	July 21–30

Ussher (1993) estimated July 1–10 while Tanu & Mohr (2005) found July 15–30 as the long-term end period of the major season rains for some areas in southern Ghana including Akatsi. The closeness of the end dates for all the ENSO phases and the 30-year period seem to affirm earlier observations by Adiku & Kuatsinu (1992) and Adiku *et al.* (2007b) of higher variation in onset than the cessation dates.

Based on the FAO (1986) procedure, the period between the onset and the cessation dates defines the length of the rainy season (LRS) and inherently the growing season. Earlier onset and late cessation periods for La Nina and Neutral phases suggest (i) LRS for La Nina ranging from 123 days (March 20–July 21) to 141 days (March 11–July 30), which gives an average of 132 days, (ii) for Neutral seasons, a range of 134 days (March 20–August 1) to 152 days (March 11-August 10), with an average of 143 days. A shorter growing period, ranging from 82 days (April 20–July 11) to 100 days (April 11–July 20), with an average of 90 days, was observed for the El Nino seasons. Thus, the mean LRS for El Nino is at least 30 days shorter than those of the other two ENSO phases. The observed LRS for the long-term was similar to that of La Nina. It may be deduced, therefore, that the LRS and possibly the total seasonal rainfall amount are determined more by the onset date than the cessation date. These observations confirm the earlier findings of Stewart & Hash (1982), Sivakumar (1988) and Adiku & Kuatsinu (1992) that for tropical rainfall, in general, good seasons have early onset and poor seasons have late onset.

The mean optimum 10-day planting periods were March 13-22 during La Nina years, March 17–26 for Neutral, and April 20-29 for El Nino. For the long-term, March 16–25 was the observed optimum planting period.

Seasonal and annual rainfall amounts

Seasonal and annual rainfall amounts for ENSO phases and the mean of the 30-year period are presented in Table 4. Generally, La Nina resulted in high rainfall amounts in the major seasons followed by Neutral and El

TABLE 4

Seasonal and annual total rainfall amounts† (mm) and their coefficients of variation (%), in parenthesis] for Akatsi with respect to ENSO phases

		Total rainfall amount	
Phase	*Major season*	*Minor season*	*Annual*
El Nino	428.6 (22.2)	357.0 (31.7)	836.9 (14.3)
La Nina	655.1 (21.6)	278.9 (38.8)	1005.2 (13.0)
Neutral	556.6 (16.5)	310.2 (26.2)	983.0 (13.1)
30 years	544.5 (24.9)	315.9 (31.7)	945.1 (15.0)

† Means represented

Nino in that order. A similar trend was observed for the annual rainfall amounts. In the minor seasons, El Nino produced higher rainfall amounts (no significant difference) followed by Neutral and La Nina in that order. On seasonal scale, rainfall variation was greatest in the minor season, followed by the major and least on the annual time scale.

Pair-wise t-test showed that during El Nino years, the mean rainfall amount was less than those of La Nina and Neutral years by over 200 mm and 100 mm, respectively. T-test for La Nina and Neutral years did not show any significant difference. Table 4 also shows that both La Nina and El Nino, which could be described as extreme ENSO events, have high rainfall variability during the major season. Variability is also high during the minor season, which shows that there is a fairly high level of uncertainty associated with rainfall prediction during La Nina and El Nino years. The fairly high coefficients of variation observed for the long-term mean also portray the difficulties in predicting the rainfall amounts on year to year scale.

Major season rainfall distribution and variability

The intra-seasonal rainfall distribution at Akatsi, and the associated variability are shown in Fig. 3. All the rainfall events show similar distribution trends. Low rainfall amounts are observed during the early part of the season and gradually peak over 10-day periods 9 and 10 (i.e. between May 21 and June 10), and then decrease to a minimum from 10-day period 14 (i.e. July 11–20). Generally, La Nina years are associated with high rainfall amounts followed by Neutral and El Nino. While rainfall amounts during La Nina years tended to decrease in April (10-day periods 4–6) and increased to the peak, thereafter, those of El Nino and Neutral increase gradually to their peaks. For all rainfall events, the peak generally occurred over 10-day periods 9 and 10 (i.e. between May 21 and June 10). Steady increase in rainfall amount, started from 10-day period 6 (April 21–30), reaching the peak as discussed already and declining to dramatic low amounts from 10-day period 14 (i.e. July 11–20).

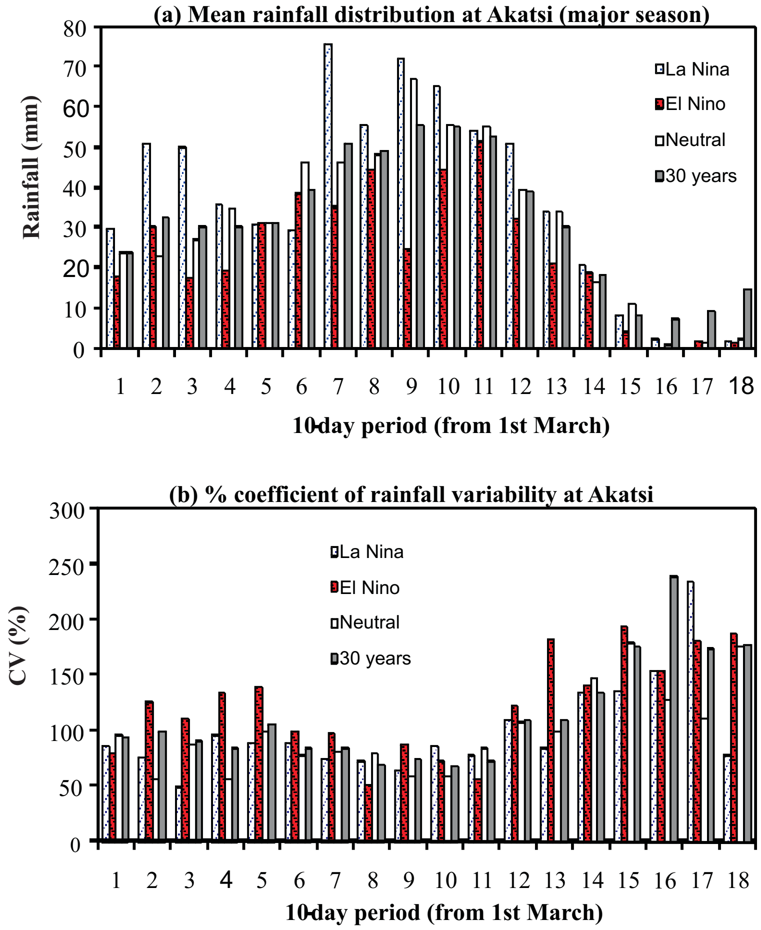

Fig. 3. Major season rainfall amount distribution (a) and dekadal coefficient of variation (b) at Akatsi

Generally, rainfall coefficients of variation on the 10-day time scale (Fig. 3b) were high ranging from about 50–250%. Rainfall variability was relatively low (lower CVs) during the peak rainfall periods occurring between 10-day period 8 and 11, corresponding to the period May 11–June 20, and high during low rainfall periods from 10-day period 14–18 corresponding to the period July 11 to the end of August. El Nino years showed the highest rainfall variability, suggesting the very erratic nature of the El Nino seasonal rainfall. Neutral years showed slightly less variability than La Nina years. The 10-day period coefficients of variation for the 30-year period were also high.

Conclusion

The rainfall patterns during the major and minor rainy seasons, as well as annual totals, showed some variability during different

ENSO phases at Akatsi. Rainfall amounts in the major season were high in La Nina but low in El Nino years. Conversely, in minor rainy seasons, comparatively high rainfall amounts were observed during El Nino but low amounts in La Nina years. Rainfall during Neutral years of ENSO showed characteristics in-between La Nina and El Nino.

Rainfall onset was observed to occur earlier between March 11 and 20 during La Nina and Neutral years whilst in El Nino years the onset delayed by about a month, occurring between April 11 and 20. These observed onset dates are important in the determination of crop planting periods. No significant variability in the cessation dates of the major season rainfall was observed for all the ENSO phases. The late onset and relatively earlier cessation during El Nino years resulted in a significantly shorter length of the rainy season compared with La Nina and Neutral years which had earlier onset and late cessation. Observed optimum 10-day planting periods were found to be about the same for La Nina and Neutral years but about a month late for El Nino seasons.

Temporal rainfall distribution during the major season on 10-day time scales generally varied greatly for all ENSO phases. Variability was high towards the end but low towards the peak of the seasons. The study also showed that El Nino seasons have the highest variability in the temporal rainfall distribution followed by La Nina and Neutral in that order. These observations seem to reveal that climatological (long-term) observations alone are no longer sufficient for seasonal rainfall prediction and agricultural planning. Thus, there appears the possibility of using ENSO OND indices to forecast rainfall characteristics at Akatsi.

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