

Inter Annual Variability of Onset and Cessation of the Long Rains in Kenya

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ABSTRACT

This study examined the spatial and temporal variability of the onset and cessation of long rains (MAM). The daily rainfall data used in the study was obtained from the Kenya Meteorological Department (KMD). Both graphical and statistical methods were applied in the analyses. Most of the stations indicated the onset month to be March. However, a few stations indicated February as their onset month while a few others had April as the onset month. Further analysis indicated a link between performance of the seasonal rainfall and the onset date. Thus positive (negative) rainfall anomaly was associated with early (late) onset. The results from the analysis showed that over most stations, the mean onset is the 74th day (14th march) with an average standard deviation of 24 days. The mean cessation day was day 150 (29th of May) with an average standard deviation of 21 days. The highest variability was observed in dry areas.

The study showed that over most parts of the country there is very high likelihood of below normal rainfall when the onset is late. However, over the north western part of the country (region 1) which receive it seasonal rainfall over a short period, the rainfall performance may not be affected by the late the onset. It was also noted that over most regions there is high chances of near normal rainfall occurring when the onset is normal. The chances of below normal rainfall occurring when the onset is normal are low. It was noted that whereas the chances of below normal rainfall occurring when there is an early onset were minimal, The western region (region 12) represented by Elgon had substantive chance of having below normal rainfall even with early onset. The onset over this region is associated with the low level westerlies from Congo, while the performance of the seasonal rainfall over this region is largely linked with the characteristics of the ITCZ.

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1. INTRODUCTION

Among the climatic elements, rainfall has the highest spatial and temporal variability in the tropical countries including East Africa (Basalirwa, 1991; Ogallo, 1980). Due to this high rainfall variability, early/late onset and cessation of rainfall is not uncommon. Large deviations of the onset and cessation of rainfall from the mean may sometimes lead to poor crop yields even when the rainfall amount was above normal.

There are two major rainfall seasons over much of Equatorial East Africa. The first occurs from March to May and is referred to as the 'long rainfall' season. The second rainfall season occurs between October and December and is usually referred to as 'short' rains because of its slightly shorter duration and lower average rainfall amount (Ininda, 1994). There is also, a third rainfall peak in parts of Kenya and Uganda, which occurs between July and August (Davies and Vincent, 1985). The rainfall during 'short' rains is spatially coherent and more predictable while the 'long rainfall season' is spatially variable and its prediction elusive. However, the long rainfall season is very important as it may accounts for a higher proportion of the annual rainfall and also these rains generally occur for a longer duration.

Over the years, the space-time distribution and duration of rainfall, coupled with its interruptions within the season have been noticed to vary a lot. Prolonged dry spells within the season often impact negatively on the crop yields and related water uses. Also anomalous high intensity down pour resulting in flooding may affect the yields even though the total amount of rainfall within the seasons is close to normal. Other factors affected by onset and cessation of rains include food security. Kenya, being an agricultural country on agricultural production for its economic growth. Early/late onset coupled with early/late cessation determines about food production and enhances food security and preparedness.

Studies, which have been carried out, indicate that there is a larger intraseasonal variability during the March, April and May (MAM) rainfall seasons (Ininda, 1994).

While high variation has been observed in the onset and cessation dates during MAM rainfall (Chamberlain and Okoola 2003), few studies have been carried out to understand the nature of this variability. Fluctuations in the onset and cessation of long rainfall have led to disruption and poor performance of agricultural activities.

The onset/cessation of rainfall is often associated with abrupt changes in atmospheric conditions which lead to the outbreak of weather related diseases and ailments.. An example is the malaria incidences due to changes in air humidity which may increase after the onset of rains. The onset of rainfall especially after a long spell of drought has been associated with incidences of cholera outbreaks as a result of contamination of domestic water reservoir due to accumulated aerosols in the atmosphere that are washed down by rain.

Thus the onset of rains has both positive and negative impacts. The benefits of onset of rains can be optimized and negative impacts mitigated if the spatial and temporal characteristics of the onset and cessation of rainfall is well understood. There is therefore urgent need to research more on factors associated with these rainfall variations. Forecasts of both the onset, rainfall amount and the expected intraseasonal variation with sufficient lead-time are vital for proper planning of rainfall dependent activities.

The aim of this study was to determine the interannual variability of onset and cessation dates of the long rainfall season in Kenya. Specifically, the study determined interannual variability of the onset and cessation dates of long rainfall season (MAM) and link between the performance of seasonal rainfall in relation to early, normal and late onsets.

Close to 60% of Kenya's economy is largely dependent on rain-fed agriculture. However, the country is vulnerable to rainfall anomalies, which often impact negatively on this key economic activity.

The overall performance of rainfall season is largely dependent on the onset/cessation of rainfall. There are times when the rains come early and also cease early and sometimes the rains and also extend beyond the normal cessation date. Similarly there are incidents when the rains come late and retreat early or extend beyond the normal cessation time. It is however noted that the duration of rainfall is not necessarily directly proportional to the amount of rainfall received within the long rainfall season. However, few studies have concentrated on the intraseasonal variability of rainfall with reference to onset and cessation. It is with these observations in mind that this study was carried out to determine the interannual variability of rainfall during the long rainfall season in Kenya. This study seeks to fill in the gap on the knowledge of the interannual variability of onsets and cessation and their relationship to seasonal rainfall performance.. This will be of great importance since it can be used to maximize the agricultural yield/output.

1.1. THE CLIMATOLOGY OF THE STUDY AREA

The area of study is Kenya and is located between (latitude 5°N and 5° S and between longitude 33°E and 42°E). Kenya has varied topography (Figure 1). The highest point in the area is Mount Kenya (5199 metres), while the coastal area is near mean sea level.

The regional inland lake system includes Lake Victoria (68,400 km²), which is a source of moisture and energy (Mukabana, 1992; Okeyo, 1987). The Indian Ocean lies to the south east boundary of the country.

These physical features significantly modify the space-time variations of the climate over the country(Asnani and Kinuthia, 1979).

Kenya has a variety of climates ranging from Equatorial rain forest to arid/ semi arid climate.

Most locations experience relatively cold temperatures during the month of July, which often spreads to August (Griffith, 1972). Cool and cloudy weather experienced over Eastern Highlands in Kenya has been attributed to the surge of cool and shallow south-easterly monsoons coupled with subsiding easterly winds aloft.

Rainfall in this region exhibits large spatial and temporal variability. The spatial variation has been attributed to the complex topography, the existence of large inland lakes, the Indian Ocean that borders the south eastern side and many other regional factors. The regional features interact with both the synoptic and the large-scale system to produce the observed rainfall distribution (Mukabana, 1992; Asnani, 1993). The wet areas are concentrated in the highlands and near the large water bodies like Lake Victoria, while dry areas include eastern and north eastern Kenya. The temporal variation over this region occurs on various time scales, which include diurnal (Johnson, 1962; Asnani, 1993; Barring, 1997; 1998), seasonal (Ogallo, 1988) and annual (Ogallo, 1980) quasi-biweekly (Okoola, 1989). The quasi-periodic fluctuation of time scales greater than a year has also been observed.

Since the area of study lies within the equatorial region, it experiences bimodal seasonal rainfall (MAM and SON/D) due to the migratory nature of Inter Tropical Convergence Zone (ITCZ). The western areas of the region experience a third rainfall peak in January and August, which is attributed to the convergence of moist air-masses in the location of the meridional component of the ITCZ (Ininda, 1995). The rainfall over coastal strip during JJA season is attributed to the shears in the East African Low Level Jet, EALLJ (Anyamba and Kiangi, 1985; Farmer, 1988; Okoola, 1989). The distribution of the annual rainfall range from monomodal in the North-eastern /Eastern province to bimodal in Central province and parts of the Rift valley. Trimodal rainfall is observed in Western Kenya. Some areas close to the equator and located to the west of the Eastern Rift Valley have a third rainfall peak between July and August. During the December to February season, most of the Kenyan region is generally dry. However, in some years, excessive rainfall is observed over a large portion.



Figure 1. Area of the study region showing the main physical features.

For example, January and February of 1962 and 1993 were generally wet over most parts of Kenya (Ininda, 1994).

2. DATA AND METHODOLOGY USED IN THE STUDY

The data used in this study included, daily and monthly rainfall for the period from 1961 to 2001. The data were obtained from the Kenya Meteorological Department (KMD), Nairobi. Forty one rainfall stations were selected based on completeness of the data set and distribution over the country as shown in Figure 2. While most stations had complete record, those with less than 10% missing were included and the missing data estimated using the mean ratio method.

The representative stations given in table 1 for each of the homogeneous zones shown in Figure 2 were selected for further analysis. For each zone the station with the highest communality was se-

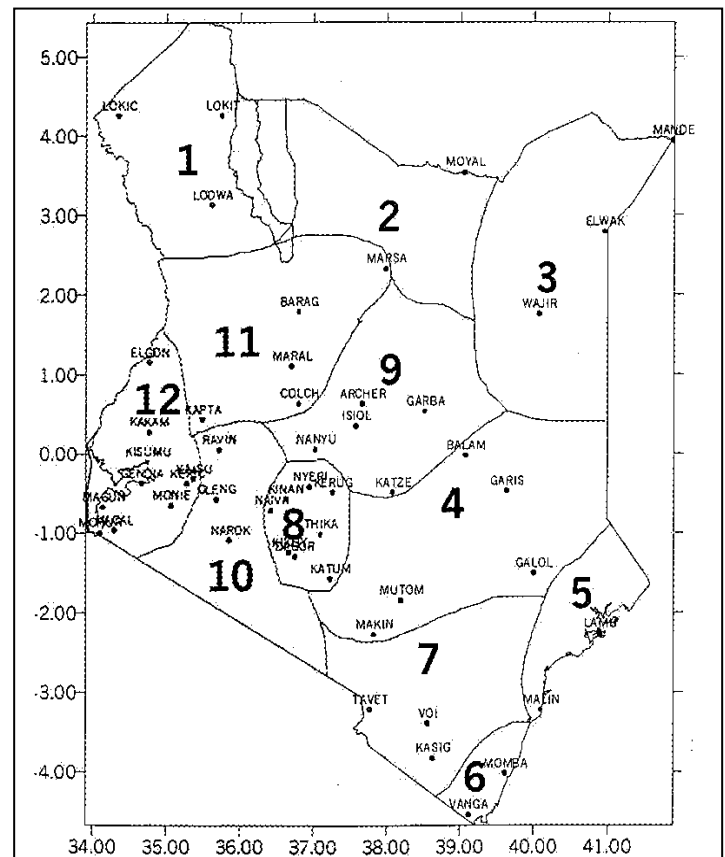


Figure 2: Homogeneous climate zones over Kenya for March-April-May (MAM), showing the rainfall stations (Source: Drought Monitoring Centre, (DMC), Nairobi 2000)

Table 1. List of stations used in the study

Zone	Station	Longitude	Latitude	Altitude (m)
1	Lodwar	35°37' E	03°07' N	506
2	Moyale	39°03' E	03°32' N	1113
3	Mandera	41°52' E	03°56' N	230
4	Garissa	39°38' E	01°29' S	128
5	Malindi	40°06' E	01°04' S	20
6	Mtwapa	39°44' E	03°56' S	23
7	Voi	38°34' E	03°24' S	560
8	Kerugoya	37°16' E	00°30' S	1699
9	Nanyuki	37°04' E	00°01' N	1948
10	Narok	35°50' E	01°08' S	1585
11	Baragoi	36°48' E	01°47' N	1476
12	Elgon	34°52' E	01°04' N	2066

2.2. METHODOLOGY

Both qualitative and quantitative methods were used to determine the onset and cessation of rainfall. The qualitative method involved drawing of the cumulative pentads and determining the point of sharp increase to represent the onset while at the point where the graph becomes flat represent the cessation. The quantitative method involves choosing a criteria upon which the rainfall occurrence must satisfy in order to state whether the rains have set in. The pre-determined values are input into the INSTAT soft ware which is run to give the onset.

The use of pentads (Five-day total) rainfall has been used by many researchers. Asnani (1993) points out the usefulness of dealing with meteorological phenomena in the tropics and applied this method to determine the dates of the onset/withdrawal of monsoon rains in India.

Pentad rainfall data has also been used to determine the normal dates of onset/cessation of seasonal rainfall over East Africa (Okoola, 1996). Jolliffe et al (1994) used a period of 5 days with at least 25mm of rainfall and with 3 days of wetness to determine the start of the rainy season in tropical climates.

Since the onset of rainfall is dependent on rainfall characteristics of a given region, it is therefore necessary to define a criteria that can be used to determine the onset. In this method the season is defined the starting from the first day of the season we search for the onset. Table 1 gives the various criteria that were used in the present study. The onset and cessation were determined with using INSTAT soft ware. The duration of study was first taken to be between March to May. In some cases where the onset occur before March, February is included. Also June was included whenever there was late cessation. The results were compared in order to determine the appropriate criteria for a given station.

Once the onset and cessation dates for each year were determined the time series of the onset and cessation were analyzed to reveal the interannual variability and the mean onset. The relationship between the onset and seasonal rainfall performance was also investigated.

Table 2: Criteria used in determination of onset using the INSTAT programme

CRITERION	CRITERION
1	Onset dates for rainfall totalled for 5 days rainfall period (pentad) with at least 25 mm of rainfall and with 3 days of wetness.
2	Onset dates for rainfall totalled over 5 days with total rainfall amount exceeding 10 mm with 3 rainy days.
3	Onset dates for rainfall totalled for 5 days with total rainfall amount exceeding station's pentad mean during MAM with 3 rainy days.
4	Onset dates for rainfall totalled over 10 days with total rainfall amount exceeding station's pentad mean for MAM season with 3 rainy days.

2.2.1. Determination of the relationship between onset, cessation and rainfall performance

The correlation between the seasonal rainfall and the onset was computed using the following equation;

$$r_{xy} = \frac{\frac{1}{n} \sum_{i=1}^n [(x_i - \bar{x})(y_i - \bar{y})]}{\left[\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \cdot \frac{1}{n} \sum_{i=1}^n (y_i - \bar{y})^2 \right]^{\frac{1}{2}}} \dots\dots\dots (1)$$

Where x_i is data values of onset date and y_i are the corresponding rainfall value. The statistical significance of computed correlation (r) was tested for using the t-test.

Table 3. Key conditions used to classify early, normal and late onset/cessation for composite analysis

ONSET/ CESSATION		RAINFALL	
CATEGORY	RANGE	CATEGORY	RANGE
Early onset/ cessation	$-1 < Z$	BELOW NORMAL	$-1 < Z$
Normal onset/cessation	$-1 \leq Z \leq 1$	NORMAL	$-1 \leq Z \leq 1$
Late onset/cessation	$Z > 1$	ABOVE NORMAL	$Z > 1$

3. RESULTS AND DISCUSSIONS

The results obtained by applying the methods described in the preceding sections are presented and discussed below. These results include; selection of representative stations, onset and cessation months, the mean onset and cessation dates, the interannual variability of onset and cessation and the relationship between onset and seasonal rainfall performance.

2.2.2. DETERMINATION OF RAINFALL ANOMALY INDICES

The standardized anomaly indices for rainfall, onset and cessation dates were derived subtracting the mean from the value and dividing by standard deviation, thus

$$Z_i = \frac{X_i - \bar{X}}{\sigma} \dots\dots\dots (2)$$

Where X_i is value of the variable, σ is Standard deviation, Z_i is Standardized anomaly index and \bar{X} is Mean.

Once the standardized anomaly were computed the categories of early, normal and late onset/cessation were determined using table 3. The rainfall categories for below normal, normal and above normal were similarly determined.

3.1. Representative stations for homogenous Regions

Table 4 shows the communality of the stations in each zone. The station with the highest communality was chosen as a representative station. The stations with the highest communality are put in bold.

Table 4: Communality analyses table showing communality of various stations in particular zones, with the station with highest communality in bold.

ZONE	STATION	COMMUNALITY		ZONE	STATION	COMMUNALITY
1	LODWAR	0.911		1	LOKITAUNG	0.789
2	MOYALE	0.933		2	NORTHHOR	0.704
3	ELWAK	0.867		3	WAJIR	0.819
3	MANDERA	0.873		4	MAKINDU	0.829
4	GALOLE	0.786		4	MUTOMO	0.820
4	GARISSA	0.832		5	LAMU	0.770
5	MSABAHA	0.819		5	MALINDI	0.867
6	MOMBASA	0.858		6	MTWAPA	0.862
7	VOI	0.736		8	DAGORETTI	0.867
8	WILSON	0.810		8	KATUMANI	0.706
8	NAIVASHA	0.842		8	KERUGOYA	0.892
8	NYERI	0.871		8	NKINANGOP	0.801
9	ARCHERS	0.720		9	NANYUKI	0.878
9	KATZE	0.738		10	NAROK	0.827
11	BAROGOI	0.892		11	MARALAL	0.662
11	CLAIKIPIA	0.739		11	MARSABIT	0.807
11	KAPTAGAT	0.801		11	TAMBACH	0.599
12	KAISUGU	0.773		12	MAGUNGA	0.795
12	KAKAMEGA	0.849		12	MOHURU	0.768
12	KISII	0.721		12	ELGON	0.906
12	KISUMU	0.782				

3.2. The mean Onset and Cessation Months

In order to identify the evolution of the wet season, the wet month is defined as one having at least 50mm of total rainfall. The 50mm threshold value has been used in many studies including Jackson (1986), and Jackson et al (1994). This is the rainfall received in much of the savannah lands of Kenya with approximately 600 mm per annum (Okoola, 1998). Figure 3a to 3f. show the monthly mean rainfall at selected locations.

From these histograms, the summary of the onset months and cessation months is displayed in Table 3 below.

It can be seen from diagram that most regions receive two rainfall seasons, March to May (MAM) and October to December (OND). Thus March and October are the onset month for the two seasons respectively while May and December are the cessation months for the two seasons respectively. However, there are regions that do not conform to this pattern. Narok has an onset in November and rainfall continues until May of the following year.. This rainfall characteristic result from the interaction between the local feature and the synoptic systems.

This region seem to benefit from wind incursions from the Lake Victoria region. These moisture laden winds condense as they move over Mau Narok hills.

Parts of Western Kenya which are close to the lake receive substantial rainfall throughout the year. This is attributed to the strong mesoscale circulation systems induced by lake Victoria and the western Kenya high ground areas which interact favourably with the monsoon air to give rise to active weather conditions.

There are other zones such as the one represented by Elgon that have three rainfall peaks within the year. The third rainfall peak which occur in July to August is associated with the westerly influx of moisture from the Atlantic Ocean and the moist Congo air mass (Bazira, 1997). It was noted that not all regions close to Lake Victoria receive abundance rainfall, for example Kisumu area receives less rainfall as it is located in a channel with hills on both sides. The air undergoes horizontal divergence as it flows through the channel (Asnani, 1992).

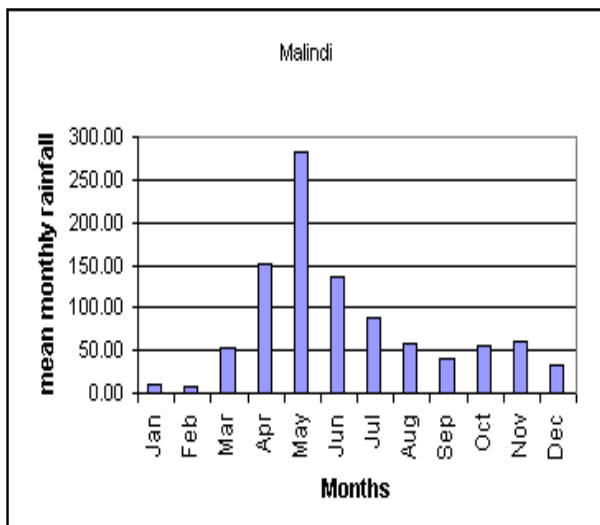


Figure 3a: Monthly mean rainfall histogram for Malindi

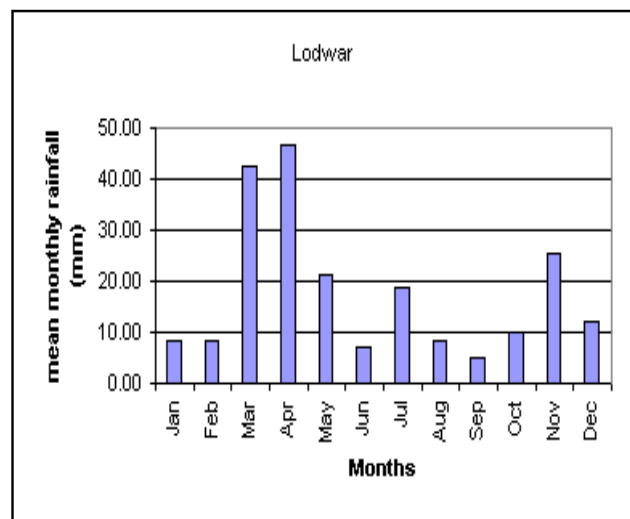


Figure 3b: Monthly mean rainfall histogram for Lodwar

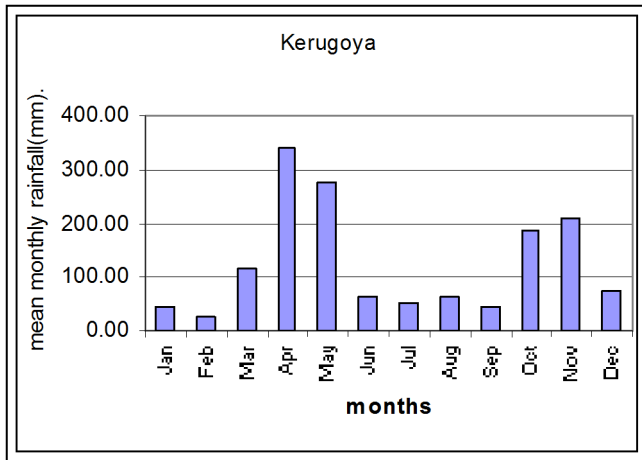


Figure 3c: Monthly mean rainfall histogram for Kerugoya

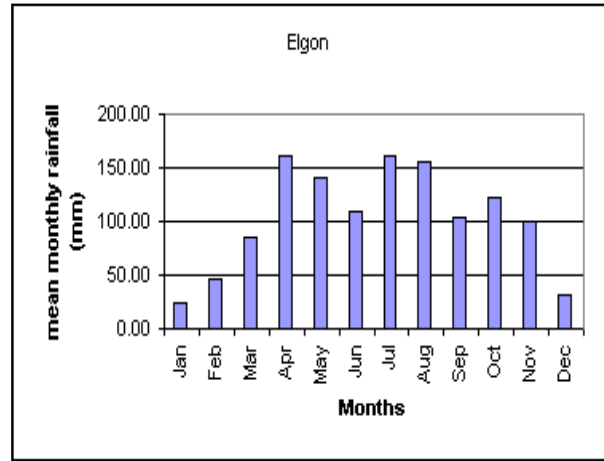


Figure 3d: Monthly mean rainfall histogram for Elgon

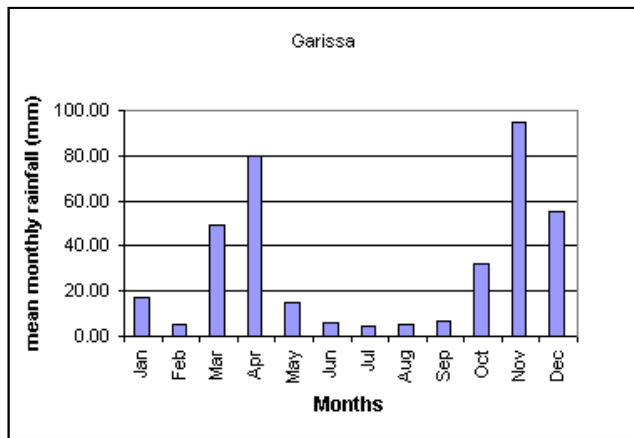


Figure 3e: Monthly mean rainfall histogram for Garissa

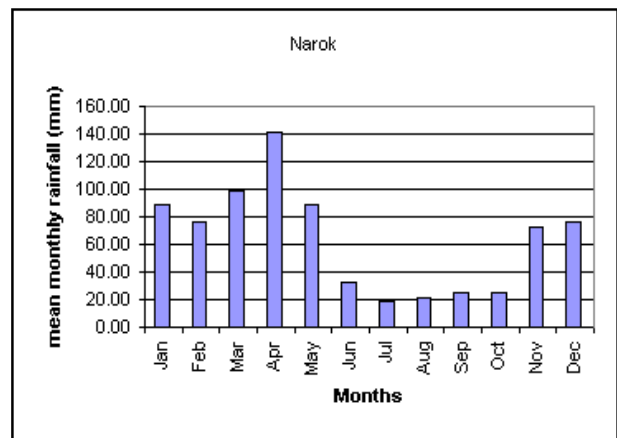


Figure 3f: Monthly mean rainfall histogram for Narok

Table 5: Onset months for the various stations during the long rains season

ZONE	STATION	ONSET MONTHS	CESSATION MONTHS
1	LODWAR	MARCH	MAY
2	MOYALE	MARCH	JUNE
3	MANDERA	APRIL	MAY
4	GARISSA	MARCH	MAY
5	MALINDI	APRIL	JUNE
6	MTWAPA	APRIL	JUNE
7	VOI	MARCH	MAY
8	KERUGOYA	MARCH	JUNE
9	NANYUKI	MARCH	JUNE
10	NAROK	MARCH	JUNE
11	BARAGOI	MARCH	MAY
12	ELGON	FEBRUARY	MAY

3.3. Mean Onset and Cessation Dates and Pentads

In order to identify the criteria that is suitable for determining the onset of rainfall over Kenya, several criteria listed in table 2 were used and the results compared. First the onsets were obtained using the cumulative pentad.

3.3.1. Onset and Cessation Dates using Mass Curves.

Figure 4 shows examples of the curves of cumulative mean pentad rainfall. The onset/withdrawal is at the point when there is a sudden increase in rainfall values while the cessation occur at the point when there is substantial decrease in the slope or the curve becomes flat.

3.3.2. Results from Criteria One

Using criteria one, onset of the rainfall is said to occur when the total rainfall for 5 days is at least 25 mm and within the five days there are at least 3 wet days. This method was recommended by Joliffe and Siarria-Dodd (1994). This criteria was found to be stringent and it failed to detect the onset of some years whose total seasonal rainfall exceeded the mean. For example it failed to capture the onset in Elgon in 2001 even though the total seasonal rainfall exceeded the long term mean. Moreover, it cannot be used for areas, such as Lodwar where 25mm of rainfall within a pentad is rare.

Using this criterion indicated late onset for most year over various stations. The earliest onset pentad using this criterion is pentad 11 at Narok and the latest onset pentad is pentad 21 at Mandera. Out of 492 the maximum possible number of onsets that could be captured for the period of study, this criterion was able to capture a total of 372 onsets representing 76%.

3.3.2. Results from Criterion Two:

For criterion two, the onset occurs when the total rainfall over 5 days exceed 10 mm with 3 rainy days within that pentad. This criteria is based on the minimum threshold for a rainy month of 50mm of rainfall. This criteria being less stringent than the one described above it captured the onsets at most station, however, over the drier regions it did not determine the occur during some years that had rainfall

This criteria indicate an early mean onset at the Narok station at pentad 10, while Malindi has an onset at pentad 20. This criterion captures 392 onsets from a possible 492 onsets which constitute about 79.6% of the total available onsets.

3.3.3. Results From Criterion Three

This criteria depends on the rainfall characteristic of the specific station, thus the onset occurs when the rainfall totalled for 5 days amount exceeds station's pentad mean for the MAM season and that pentad having 3 rainy days.

This criterion captured more of the onsets over the drier regions compared to criteria one and two. The earliest pentad of onset is 16 at Narok, and the latest pentad of onset is 20 at Mtwapa. While this criteria capture onsets over the drier regions, it fails to detect onsets at some stations, thus out of a possible 492 onsets, it captured up to 77% of the onsets.

3.3.4. Results from Criteria Four

Onset dates for rainfall totalled over 10 days with total rainfall amount exceeding station's ten days (dekadal) mean with 3 rainy day occurring within in the first five days. The rationale of using ten days is based on the fact that this time period widely used for agricultural practices. Onsets dates for most stations were captured.

Using this criterion, the earliest pentad of onset is pentad 9 in Narok. The latest onset captured is on pentad 13 March for Malindi. Out of a possible 492 onsets, this criterion captured 442 onsets, representing a 90% of the total.

3.3.5. Comparison of the Results from Various Criteria

Table 5 gives the mean onset from the four criteria together the cumulative pentad curve for each of the twelve stations representing the homogeneous climatologically zones. The results from criteria four was found to agree closely with the results from the cumulative pentad and hence the results of onset and cessation obtained from this method were used for further analysis. The results indicate that the onset of rains always starts from the southern and western parts of the country and the progresses to the eastern and then northern.

3.3.6. Cessation Dates

Cessation was said to occur when the amount of rainfall totalled for 10 days was less than the station pentad mean and cessation pentad has 3 dry days. Table 6 shows the mean cessation dates.

The earliest cessation pentad is 24 at Garissa. The latest cessation pentad is 35 at both Elgon and Malindi stations. Thus the cessation does not follow the pattern of the onset. The coastal region continue to receive rainfall after it has ceased at the interior stations as a results of the influence of the East African Low Level Jet. On the other hand the western station continue to receive rainfall after the passage of the ITCZ as a result of the incursion of the Congo Air mass.

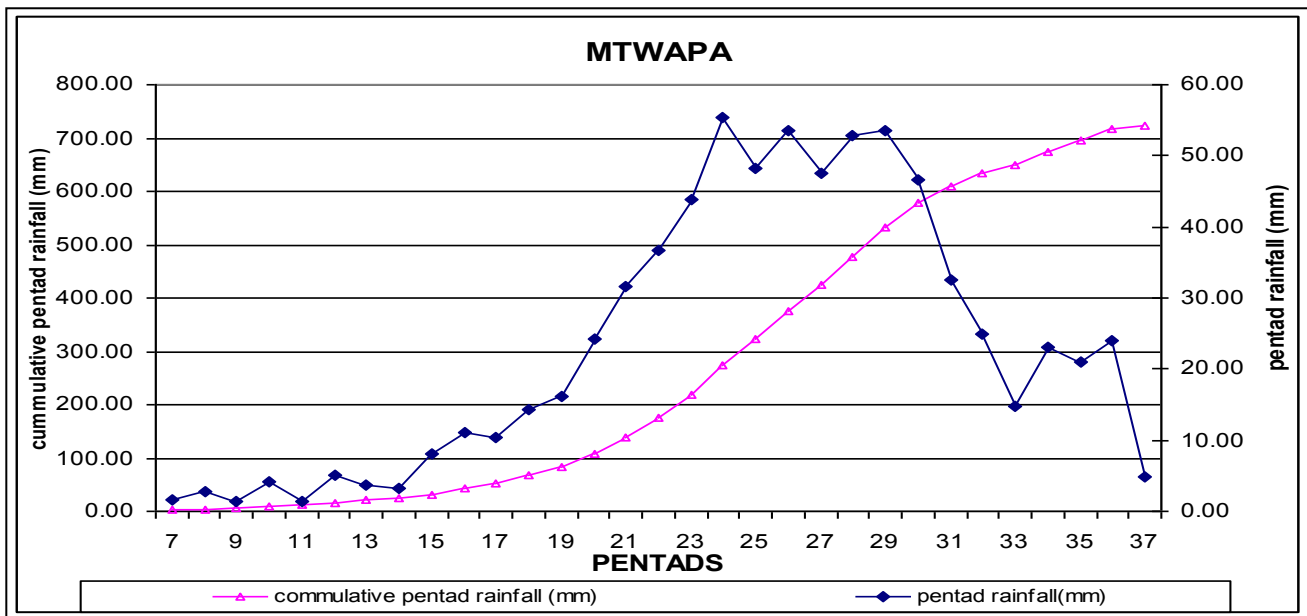


Figure 4a: Mtwapa mass curve and pentad rainfall for pentads 7 to 37

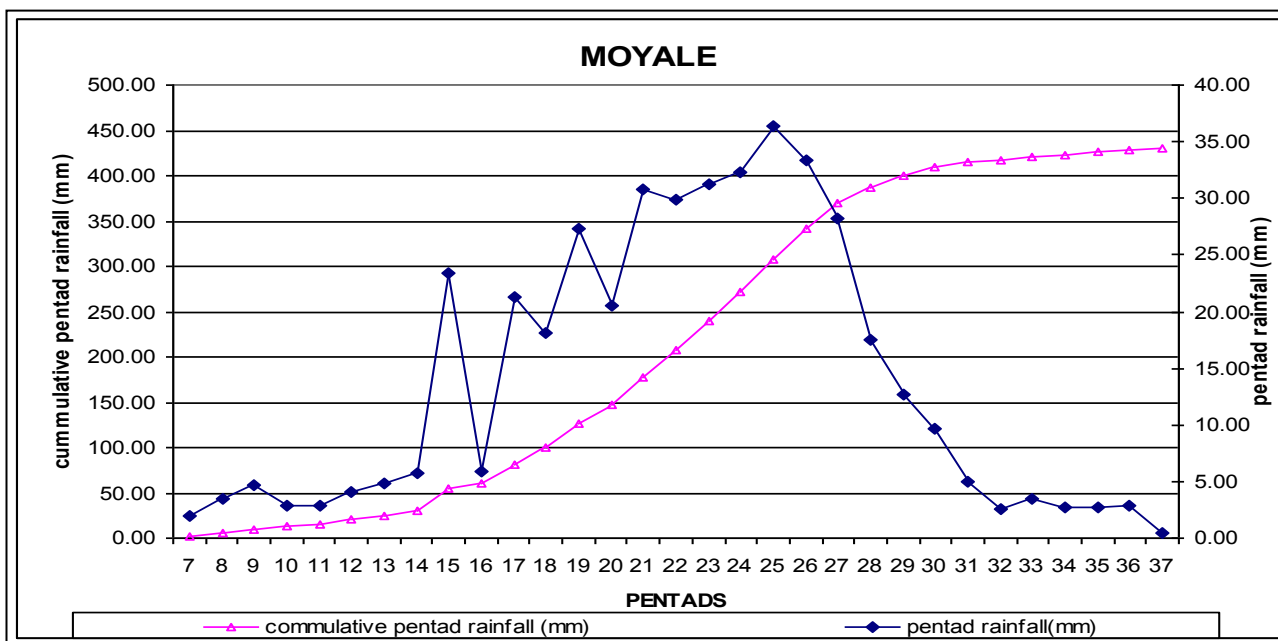


Figure 4b: Moyale mass curve and pentad rainfall for pentads 7 to 37

Table 6: The Onset Pentads based on various Methods

ZONE	STATION	PENTADS OF ONSET				USE OF MASS CURVES
		USE OF INSTAT PROGRAMME				
		CRITERIA 1	CRITERA 2	CRITERIA 3	CRITERA 4	
1	LODWAR	20	13	19	17	16
2	MOYALE	19	15	18	15	17
3	MANDERA	21	18	20	20	19
4	GARISSA	19	19	19	18	17
5	MALINDI	21	20	20	19	21
6	MTWAPA	18	16	20	17	19
7	VOI	19	12	18	12	16
8	KERUGOYA	17	15	18	15	17
9	NANYUKI	19	16	18	14	17
10	NAROK	17	10	16	9	13
11	BARAGOI	19	16	19	15	16
12	ELGON	18	14	18	13	14

3.4. Interannual Variation of Onset and cessation

The time series of the onset and cessation dates were analyzed in order to determine their temporal characteristics. The years with early/ late onset and cessation were identified. Figure 5a shows the cumulative pentad a case of Lodwar when there was an early onset while figure 5b shows the case when there was a late onset.

The station with the highest interannual variability of cessation is Lodwar with 37 days while the station with the lowest interannual variability of cessation is Elgon with 7 days (see table 7)

Table 7: Mean Onset and Cessation Day and Standard Deviation Based on Criteria Four.

STATION	ONSET DAY		CESSATION DAY	
	ONSET	STD	CESSATION	STD
NAROK	42	15	160	20
NANYUKI	67	24	161	20
BARAGOI	76	28	141	27
KERUGOYA	74	22	153	19
ELGON	63	24	175	7
GARISSA	90	23	120	27
MTWAPA	84	24	170	10
LODWAR	64	33	134	37
MALINDI	93	22	171	11
MANDERA	97	21	126	19
MOYALE	73	27	151	20
VOI	58	24	135	28
AVERAGE	73	24	150	20

Figure 6 shows example of the time series for onset and cessation. The years with early onset for the period of study were 1962, 1978, 1979, 1985 and 1998 while the years with late onset were 1980, 1983, 1984 and 2000. In particular the year earliest onset occur on February 11th in 1962 while the latest onset occur on 13th April in 1983. On the other hand, it the years with the early cessation were, 1984, 1995, 1999 and 2000 while those with late cessation include 1974, 1979, 1990 and 1993. The earliest termination was found in May 3rd in 1974. For the onset and the latest on June 9th 1990. The season for 1984 was particularly short in that it had late onset which occurred on April 9th and also an early cessation which occurred on 10th of May.

Years with early cessation had their rainfall as below normal across the country. Examples of these years are 1999, 1984, and 2000.

Years with late cessation had their rainfall above normal. Examples of these years are 1979 and 1998.

Observational studies, for example Komutunga, 2006 show that most El-Nino (La-Nina) years tend to have early (late) onset. An example of El-Nino (La-Nina) is 1998 (1980)

In order to evaluate the variability of the onset and cessation the standard deviation was evaluated. From table 6, it can be seen that Narok (Lodwar) has the lowest (highest) standard deviation of the onset days. With respect to cessation Elgon (Lodwar) has the lowest (highest) standard deviation of the cessation onset days.

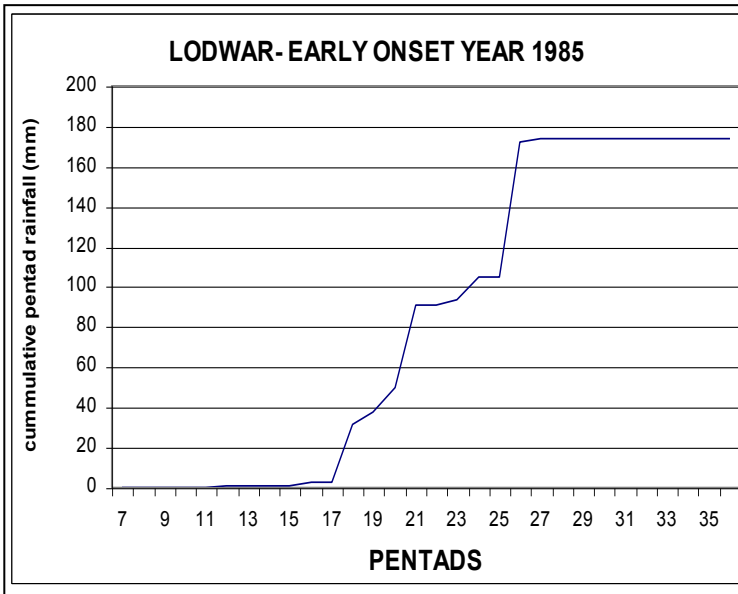


Figure 5a: Mass curve for Lodwar during the early onset year 1985 with 'O' for onset and 'C' for cessation.

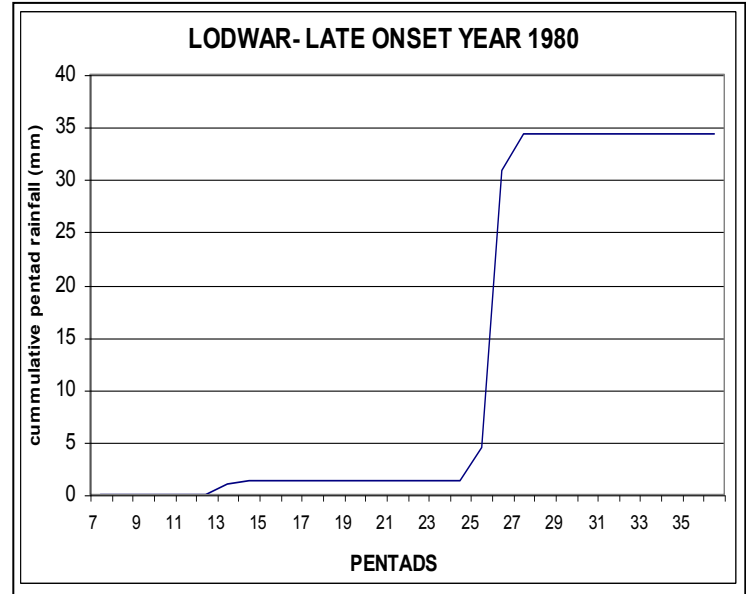


Figure 5b: Mass curve for Lodwar during the late onset year 1980 with 'O' for onset and 'C' for cessation

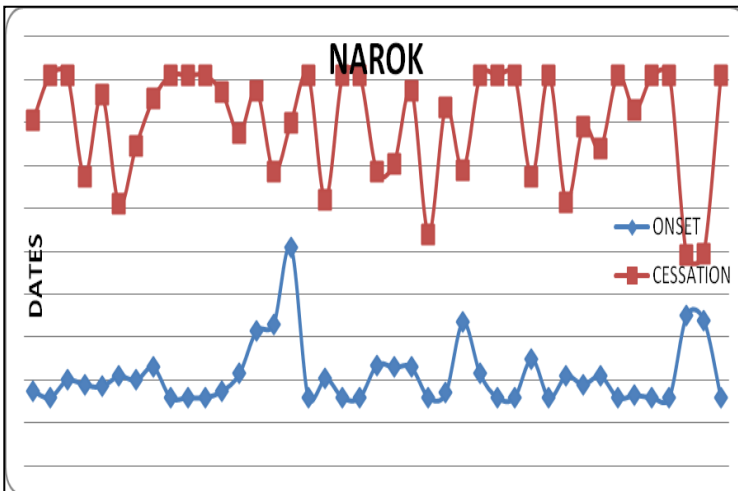


Figure 6a: Time series for the onset and cessation at Narok

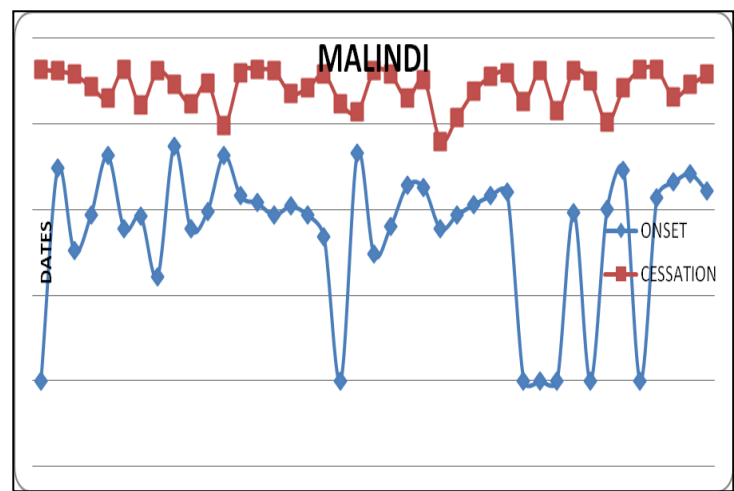


Figure 6b: Time series for the onset and cessation at Malindi

3.5. Relationship Between Onset and Rainfall Performance

The anomaly of onset and the rainfall were analyzed, and example of the time series of the standardized onset and cessation are given in figure 7 below. In general it was noted that early (late) onset coincides with above (below) normal rainfall. However, there are years when early onset (negative onset anomaly) did not necessarily result in above normal rainfall in a particular area.

The correlation values computed between onset and rainfall are shown in column three of table 7. It can be seen that rainfall over most stations was significantly negatively correlated with the onset. The correlation values were not significant at four stations, namely, Lodwar, Moyale, mandera, Baragoi, and Elgon.

As stated earlier, the dry regions receive the seasonal rainfall within a few days so that even with late onset the seasonal totals can still be met. On the other hand, over wet regions like Elgon, there are other systems that may cause early onset, yet the seasonal rainfall may perform poorly due to disorganized ITCZ. Similar results have been observed by Camberlin and Okoola (2003).

Table 7 displays the conditional probability of the category (Below normal, normal and above normal) given; early, normal, or late onset. From the table it can be seen that the chances of below normal rainfall occurring given an early onset is minimal except for Elgon where the chances are as high as 50%.

The probability of receiving near normal rainfall given normal onset is over 50% for most stations except for Lodwar and Mandera where the probability is less than 50%. Over most locations the probability of receiving above normal rainfall when the onset is late is close to zero, except for Lodwar. The chance of above normal rainfall given early onset is over 70% over most regions except Elgon where it is only 50%. On the other hand the probability of below normal rainfall is close to 100% over most locations when the onset is late save for Lodwar where the chance is only 50%.

Alusa and Mush (1974) found, that on average, the onset and cessation dates for Kenya were 17th to 21st March and 5th to 9th June respectively.

Chamberlain and Okoola (2003), using cumulative PC1 scores, found that the mean pentads of onset and cessation over equatorial East Africa occurred on 25th March and 21st May respectively. The interannual variability of onset was larger than that of withdrawal.

Alusa (1978) defined dry spell as a period of dry day(s) between two successive rainy days. He observed that the times of onset of rains progress northwards along the coast.

Oteng'i (1982) observed that the period of onset of long rains vary for the whole country.

Along the coastal strip, the onset of the long rains is the 15th to the 20th pentad. Around the lake basin, the onset varies from the 11th to the 15th pentad. For the rest of the country onset varies from the 12th to the 16th pentad. Cessation of rains was not possible to locate because of the persistence of the southerly monsoons over the country.

Okoola (1999b) observed that rainfall onset and subsequent performance over the equatorial eastern Africa region during MAM associated with the occurrence of mid tropospheric westerlies. The westerlies have been suggested to result from the turning eastwards of meridional southerlies.

Camberlin and Wairoto (1997), showed that low to mid-level westerly/easterly wind events in Equatorial East Africa coincided with wet/dry spells. The mid-level westerlies constitute an incursion of the Congo air mass into East Africa.

Camberlin and Philipon (2001) observed that the “long rains” as a whole do not exhibit very strong relationships with any large-scale climate anomalies, a fact that is related to a much weaker internal coherence than e during the October-December “short-rains”.

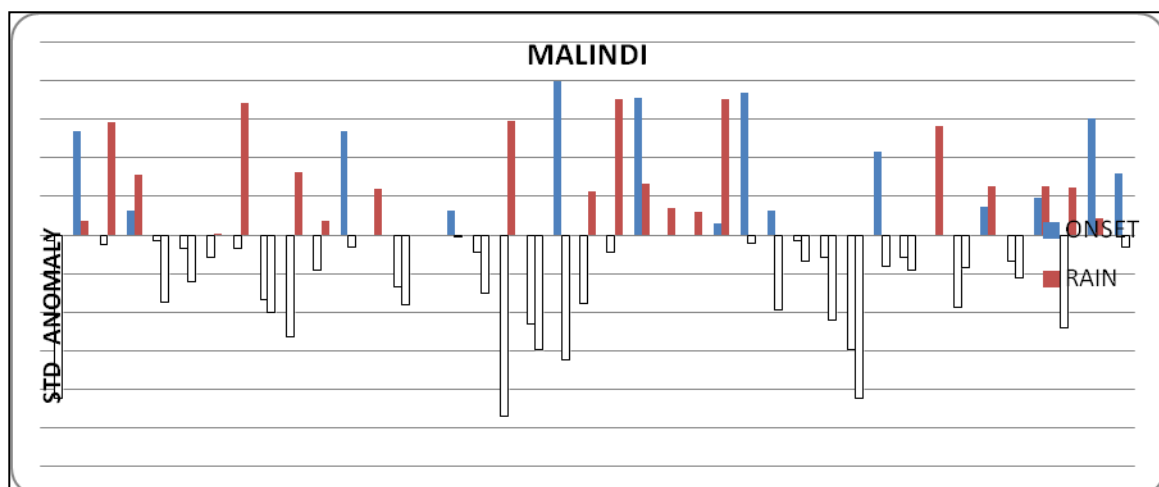


Figure 7a: The time series of standardized anomaly of the onset and rainfall at Malindi

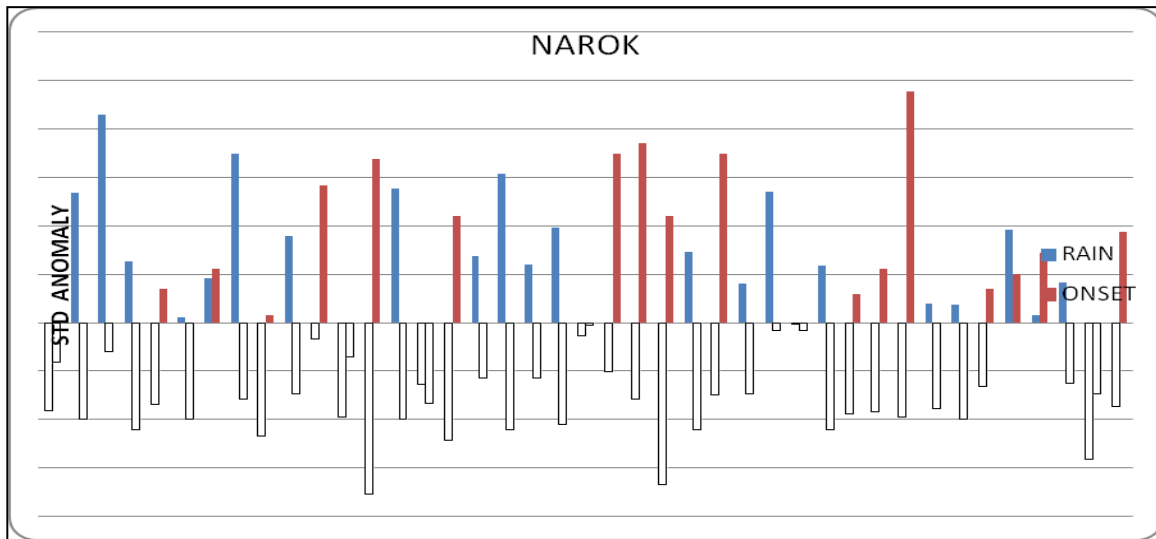


Figure 7b: Time series of standardized rainfall anomaly of onset and cessation at Narok

Table 7. Correlation and conditional probability of rainfall category given Onset Category

Zone	Station	Corre-	BN/Early	N/ Normal	AN/	AN/Early	BN/late OS
1	Lodwar	0.28	0.00	0.67	0.50	1.00	0.50
2	Moyale	-0.30	0.29	0.46	0.00	0.71	1.00
3	Mandera	0.10	0.13	0.23	0.00	0.87	1.00
4	Garissa	-0.61	0.00	0.75	0.00	1.00	1.00
5	Malindi	-0.50	0.00	0.91	0.00	1.00	1.00
6	Mtwapa	-0.26	0.20	0.77	0.00	0.80	1.00
7	Voi	-0.68	0.00	0.69	0.00	1.00	1.00
8	Kerugoya	-0.40	0.17	0.55	0.00	0.83	1.00
9	Nanyuki	-0.58	0.00	0.80	0.00	1.00	1.00
10	Narok	-0.53	0.00	0.73	0.00	1.00	1.00
11	Baragoi	-0.24	0.00	0.82	0.00	1.00	1.00
12	Elgon	-0.11	0.50	0.68	0.00	0.50	1.00

4. CONCLUSION

From the study it was noted that criteria that could successfully determine the onset and cessation at most stations over Kenya is the one that considers the onset to occur when the 10 days rainfall totals from the onset day exceed the station's pentad mean with 3 days any days within the onset pentad.

The results from the analysis showed that while the long rains season is from March to May there are locations that have their mean onset date in February, while there are others whose mean cessation is in June. The earliest onset pentads were observed in stations located to the southern part country represented by Narok and over the western part represented by Elgon. The latest onset pentads were observed along the coast and to the north of the country.

The study further demonstrates that there is large interannual variability of onset, ranging from 11th February to 9th April. The stations in the northern part of the country have the highest onset variability, for example Lodwar which has a standard deviation of 39 days. The lowest variability in the onset was observed in the station located to the south west of the country such as Narok which has a standard deviation of 15 days.

The interannual variability was observed in the cessation dates as well. The earliest cessation pentad is pentad 24 at zone 4 represented by Garissa. The latest cessation pentad is pentad 35 at both zone 5 and zone 12 represented by Malindi and Elgon respectively.

Apart from Lodwar (region 1) there is very high likelihood of below normal rainfall when the onset is late. It was also noted that with the exception of Mandera, the other stations indicated that there is high chances of near normal rainfall occurring when the onset is normal.

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