Theor Appl Climatol (2012) 108:479–494
DOI 10.1007/s00704-011-0544-3

ORIGINAL PAPER

Determination of seasonal rainfall variability, onset and cessation in semi-arid Tharaka district, Kenya

**C. W. Recha · G. L. Makokha · P. S. Traore ·
C. Shisanya · T. Lodoun · A. Sako**

Received: 17 February 2011 / Accepted: 18 October 2011 / Published online: 4 November 2011

Abstract The study quantified rainfall variability for March–May (MAM) and October–December (OND) seasons in Tharaka district, Kenya. The parameters analysed were inter-annual variability of seasonal rainfall, onset and cessation using daily rainfall data in three agro-ecological zones' stations. Percentage mean cumulative method was used to determine onset and cessation, and seasonal variability was estimated using rainfall variability indices. Although both seasons are highly variable, OND has been persistently below mean over time while MAM shows high within-season variability. Despite the near uniformity in the mean onset and cessation dates, the former is highly variable on an inter-annual scale. The two rainfall seasons are inherently dissimilar and therefore require specific cropping in agro-ecological zone LM4 and LM4-5. It is possible that farmers in IL5 are missing an opportunity by under-utilising MAM rainfall. The results should be incorporated in implications of climate variability and vulnerability assessment in semi-arid Tharaka district.

C. W. Recha (✉)
Department of Geography, Egerton University,
P.O. Box 536-20115, Egerton, Kenya
e-mail: cshika@yahoo.co.uk

G. L. Makokha · C. Shisanya
Department of Geography, Kenyatta University,
P.O. Box 43844-00100, Nairobi, Kenya

P. S. Traore · A. Sako
International Crop Research Institute for the Semi-arid Tropics
(ICRISAT)-Mali,
P.O. Box 320, Bamako, Mali

T. Lodoun
Institut de l'Environnement et de Recherches Agronomiques
(INERA),
P.O. Box 476, Ouagadougou, Burkina Faso

1 Introduction

At the United Nations Millennium Summit in the year 2000, world leaders agreed to set time-bound and measurable Millennium Development Goals (UN 2005). These included combating poverty, hunger, disease and environmental degradation. Rainfall and climate in general, were implicated directly in the first goal, i.e. to eradicate extreme poverty and hunger. Of all the climate parameters, rainfall is a major input which significantly impacts on socio-economic well-being of the population who depend on rain-fed agriculture. This is particularly important in Sub-Saharan Africa (SSA) where human activity and agricultural production in particular is closely linked to inter-annual rainfall variability (Jury 2002). There are concerted efforts in Africa to address climate-related challenges (African Partnership Forum 2008, Cooper et al. 2008; Few et al. 2006). In part, this has been through the establishment of institutions (Sivakumar 1987; Washington et al. 2006; Vogel et al. 2007) which provide climate services, including early warning systems. To empower these institutions and enable them to formulate evidence-based policy, there is a need for reliable, long-term and well-distributed rainfall stations network. Institutions will also need quantified information on the magnitude of rainfall variability at local level. There are examples of published studies that have analysed the magnitude of rainfall variability in SSA which include Tadross et al. (2009) Camberlin and Okoola (2003), Nicholson et al. (2000), Gommes and Petrassi (1996), Mamoudou et al. (1995) and Nicholson (1993). More often than not, rainfall evaluation has in the past focused on annual averages and less on characteristics of variations (Barron et al. 2003).

Variations in rainfall amount are associated with El Niño/Southern Oscillation Index (ENSO) and related sea surface temperatures. Studies that have analysed rainfall variability with ENSO as the determinant include Yasunaka and Hanawa (2005), Chambers (2003), Goddard et al. (2001), Nicholson et al. (2000), Mamoudou et al. (1995), Nicholls and Wong (1990), Hutchison (1990), Farmer (1988) and Ogallo (1988). The link between rainfall and ENSO contributed to the understanding of the interaction between the atmosphere, land and sea: this has significantly contributed to the improvement of seasonal forecasts (Phillips 2003; Hansen 2005). Nonetheless, such studies do not provide information on the much-needed character of within-season variability as it has implication on the distribution of water which finally affect crop yields. Additionally, there has been (and continues to date) interest in understanding seasonal patterns of rainfall by investigating variables such as amount of rainfall, rainy days, length of growing season and frequency of dry spells. For instance, Tilahun (2006), Seleshi and Zanke (2004) and Sivakumar (1987, 1991) characterised annual and seasonal rainfall totals and rainy days in Ethiopia and the Sudano-Sahelian region, respectively, and all the cases have exhibited high variability. Camberlin and Okoola (2003) and Mugalavai et al. (2008) analysed onset and cessation of rainfall in Kenya and linked their variation to atmospheric, oceanic and local conditions (winds, water body, vegetation cover and topography). Previous studies have also investigated within-season dry spell and their impact on planting dates and crop yield (Kasei and Afuakwa 1991; Tumwesigye and Musiitwa 2001; Barron et al. 2003; Mzezewa et al. 2010). The main findings of these studies include variations in dates of onset, small proportion of rainy days supplying high proportion of rainfall and occurrence of dry spells that disrupt crop development and lower yield in SSA. Similar results have been found in the Czech Republic where standardised precipitation index, percentage of long-term precipitation index (*r*) and *Ped* drought index (S_i) were used as tools in identification of the severity, frequency and extent of drought episodes (Potop et al. 2010).

Taking these findings into consideration, there is a need to quantify rainfall variability at a local level as a first step for on-farm management as suggested by Barron et al. (2003). Since climate (and rainfall in particular) is the most critical factor determining agriculture and that it is not homogeneous, knowledge of its statistical properties derived from long-term observation can be applied to contribute to development of drought mitigation strategies in semi-arid zones. The objective of this study is to determine seasonal rainfall variability for the March–May (MAM) and October–December (OND) seasons in semi-arid Tharaka district, Kenya. The study seeks to characterise seasonal rainfall in Tharaka district by agro-ecological units as an important step for designing appropriate strategies for vulnerability assessment related to climate variability. It is considered here that this is a part of the needed synthesis of climate not only in Eastern Kenya but also in SSA where recurrent droughts and associated famine have continued to ravage (Sivakumar 1991; Washington et al. 2006).

2 Study area

Tharaka district refer to a part of Eastern Kenya that was established in 1999 together with Meru South as administrative districts. The two districts were curved out of the erstwhile Tharaka Nithi district (Republic of Kenya 2001) and today constitute Tharaka Nithi County (Constitution of Kenya). The district covers an area of 1,569.5 km^2 with 175,905 people as per the 2009 population census of Kenya (Republic of Kenya 2010). The district has agro-ecological zones (AEZs) Lower Midland (LM)4, Lower Midland (LM)5, Intermediate Lowland Zone (IL)5 and Intermediate Lowland Zone (IL)6 (Jaetzold et al. 2007, Smucker and Wisner 2008). AEZ LM4 covers the north-eastern part of the district while IL5 covers the central, eastern and northern parts of Tharaka. The southern part of Tharaka is a transition between LM4 and LM5 (for details, refer to Smucker and Wisner 2008). IL5 and LM4 are the main AEZs given their expansiveness in the district, making quantification of rainfall in these zones vital in the assessment of vulnerability to climate.

Tharaka district is located on the Eastern side of Mount Kenya, a feature that combines with latitude, inter-tropical convergence zone, ENSO and sea surface temperatures among others (Odingo et al. 2002) to influence rainfall variability. Tharaka has a bi-modal rainfall, namely: MAM ‘long rains’ and OND ‘short rains’. A large segment of the population in Eastern Kenya depends on OND rains which are considered reliable and can be predicted with a reasonable degree of accuracy (Cooper et al. 2008; Hansen and Indeje 2004). Rainfall is unevenly distributed within these rainy seasons and shows significant variability from year-to-year and season-to-season. The very pronounced long dry season lasts from May to October, with each month receiving less than 2% of the annual rainfall (Shisanya 1996). The study analysed and characterised rainfall variability for MAM and OND seasons in three of the four AEZs (IL5, LM4 and LM5).

3 Materials and methods

3.1 Rainfall data

The study first identified available rainfall stations in and around Tharaka district. Following an inquiry at the Kenya Meteorological Department, a total of seven rainfall stations were found in Tharaka district and six in the neighbouring districts. The stations selected were Marimanti, Tunyai and Chiakariga representing agro-ecological zones IL5, LM4 and LM5, respectively (Fig. 1). The selected three stations had a data set of over 20 years and missing data of less than 10%. Although there was a station in the neighbouring district to represent IL6, the station had inadequate data for a climatological analysis (data available—period, 1974–1988 and 24% of it was missing). Thus, the choice of rainfall stations for this study was informed by agro-ecological zones, percentage of missing data (less than 10% for any given year as required by the World Meteorological Organisation) and length of data available. Most of the rainfall stations in Tharaka district and its environs are not updated at Kenya Meteorological Department (the lead agency in meteorological data) for a period of over 10 years. As Washington et al. (2006) observed, if climate science was to fulfil its potential in formulating evidence-based policy, then there is need to invest and support observing station networks and continuously collect data.

To fill in the missing daily data, the study used multiple imputations which created several copies of the data sets and imputed each copy with different plausible estimates of the missing values. The multiple imputation method was preferred to single imputation and regression imputation methods. According to Enders (2010), multiple imputations do not suffer from the problem of underestimating the sampling error because it appropriately adjusts the standard error for missing data. This is in addition to the fact that it yields complete data set for analysis. Although many other studies have recommended regression imputation, its requirement to use complete variables to fill incomplete variables (Enders 2010) made it difficult, given the scant nature of data in the neighbouring stations.

3.2 Methods

To quantify seasonal rainfall variability in Tharaka, the amount of rainfall, the number of rainy days, and dates of

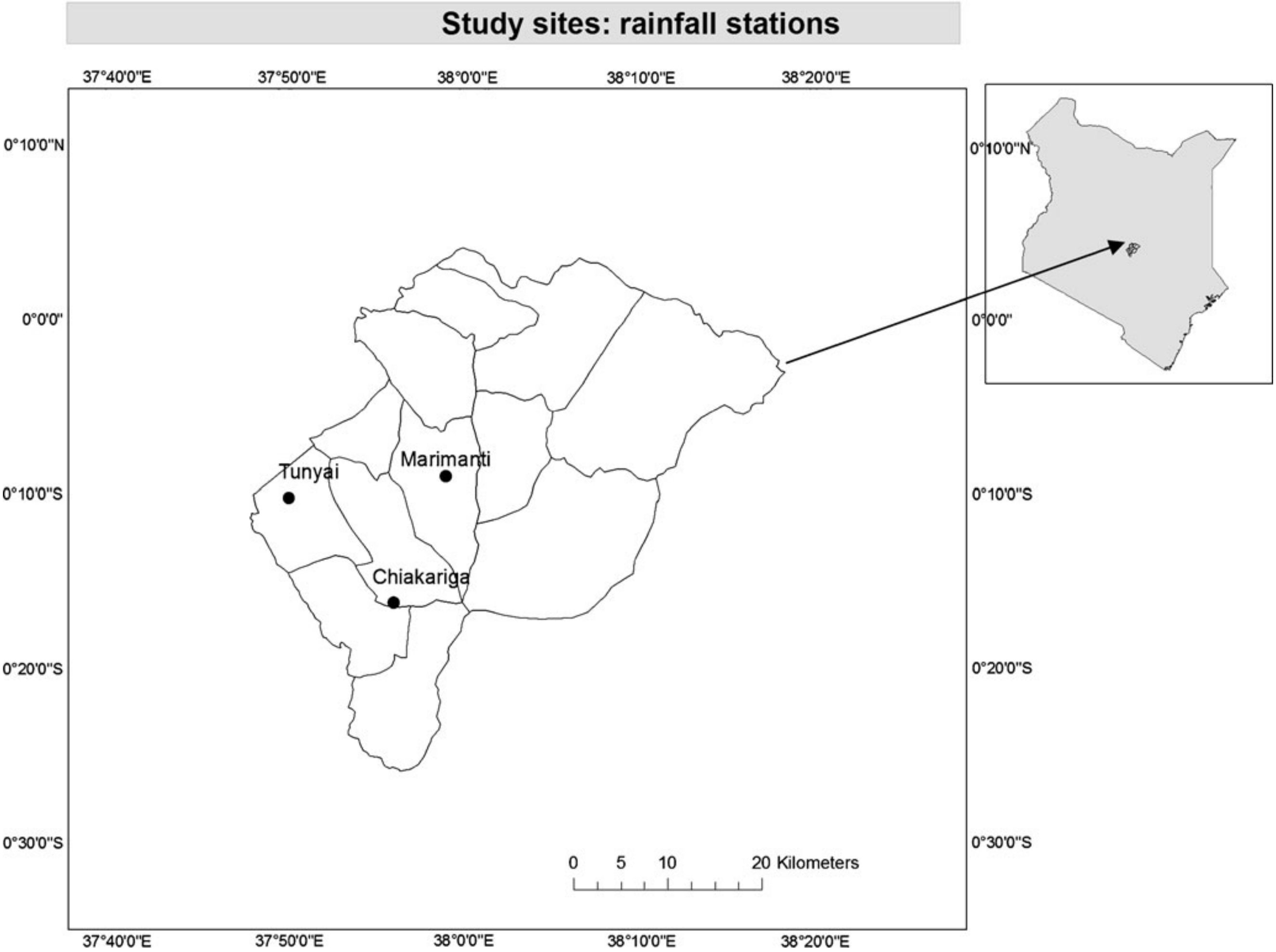


Fig. 1 Rainfall stations in the study sites: the study utilised data for Tunyai (1973–2006), Chiakariga (1974–1999) and Marimanti (1969–1997) representing agro-ecological zones LM 4, LM 4–5 and IL 5, respectively

onset and cessation were analysed for both MAM and OND growing seasons. Cumulative departure index and rainfall anomaly index (RAI) were used to analyse long-term trends of annual and seasonal variability (Tilahun 2006). Cumulative departure index was derived from the arithmetic mean of seasonal and annual rainfall for the period of record. Thus, the arithmetic means of seasonal and annual rainfall were normalised as follows:

$$(r - R)/S \tag{1}$$

Where r represents actual rainfall (seasonal or annual) of a given years, R the mean rainfall of the total length of period and S the standard deviation of the total length of period. Results of the values were cumulatively added to each other for the period of record and plotted to achieve long-term trends for annual and seasonal rainfall. RAI was plotted to illustrate inter-seasonal rainfall variations and calculated as follows for positive anomalies:

$$\mathrm{RAI} = +3\left(\frac{\mathrm{RF} - M_{\mathrm{RF}}}{M_{\mathrm{H10}} - M_{\mathrm{RF}}}\right) \tag{2}$$

and for negative anomalies

$$\mathrm{RAI} = -3\left(\frac{\mathrm{RF} - M_{\mathrm{RF}}}{M_{\mathrm{L10}} - M_{\mathrm{RF}}}\right) \tag{3}$$

Where RAI represents the seasonal rainfall anomaly index, RF the actual rainfall for a given year, M_{RF} mean of the total length of record, M_{H10} mean of the ten highest values of rainfall on record, and M_{L10} the lowest values of rainfall on record. According to Van Rooy (in Tilahun 2006), RAI is a very effective index for detecting persistence of drought periods. Whereas Tilahun (2006) used RAI to analyse annual rainfall variability, the present study analysed seasonal rainfall variability. *INSTAT* software designed to support analysis of climatic data (www.ssc.rdg.ac.uk/software/instat/climatic.pdf) was used to calculate mean rainfall for every 5 days (pentads) starting from the first to the last day of the two seasons. This helped in detecting the distribution of rainfall amount within seasons. A coefficient of variation (CV), defined as the ratio of standard deviation to the mean, is calculated for rainfall amount and rainy days for each station. CV for annual rainfall has been applied by Sivakumar (1987), Shisanya (1990) and Mzezewa et al. (2010) while Barron et al. (2003) and Seleshi and Zanke (2004) used it for seasonal rainfall.

Mean onset and cessation dates of seasonal rainfall was estimated using percentage cumulative mean rainfall approach as used by Odekunle (2006). In using the percentage mean cumulative rainfall approach, the first step was to derive the seasonal rainfall amount and rainy days that occur during each 5-day interval (pentad) of the year using *INSTAT*. This was followed by computing the percentage of the mean seasonal rainfall amount and rain days for each of the pentads. The third step involved cumulating the percentages of the pentad rainfall amount and rain days. The cumulative percentages (of pentads rainfall amount and rain days) were plotted against time for each season. When the cumulative percentage is plotted against time through the season, first point of maximum positive curvature of the graph corresponds to the time of rainfall onset while the last point of maximum negative curvature corresponds to the rainfall cessation. Percentage cumulative means for rainfall amount and rain days are expected to converge to give the same mean dates of onset and cessation. *INSTAT* was used to determine inter-annual variability of onset and cessation for comparison with mean. A significant departure in the use of percentage cumulative mean rainfall is that while Odekunle (2006) plotted the percentage cumulative mean against time through the year, the present study plotted it against time of the two seasons. In this case, the first days of MAM and OND season are considered 1st March and 1st October, respectively. The last day of MAM season is 31st May while the last day of October–January (ONDJ) season is considered 31 January. Even though most of the rain is received during the OND season, there is usually a spill over effect into January (Shisanya 1996), meriting the inclusion of January in the determination of cessation.

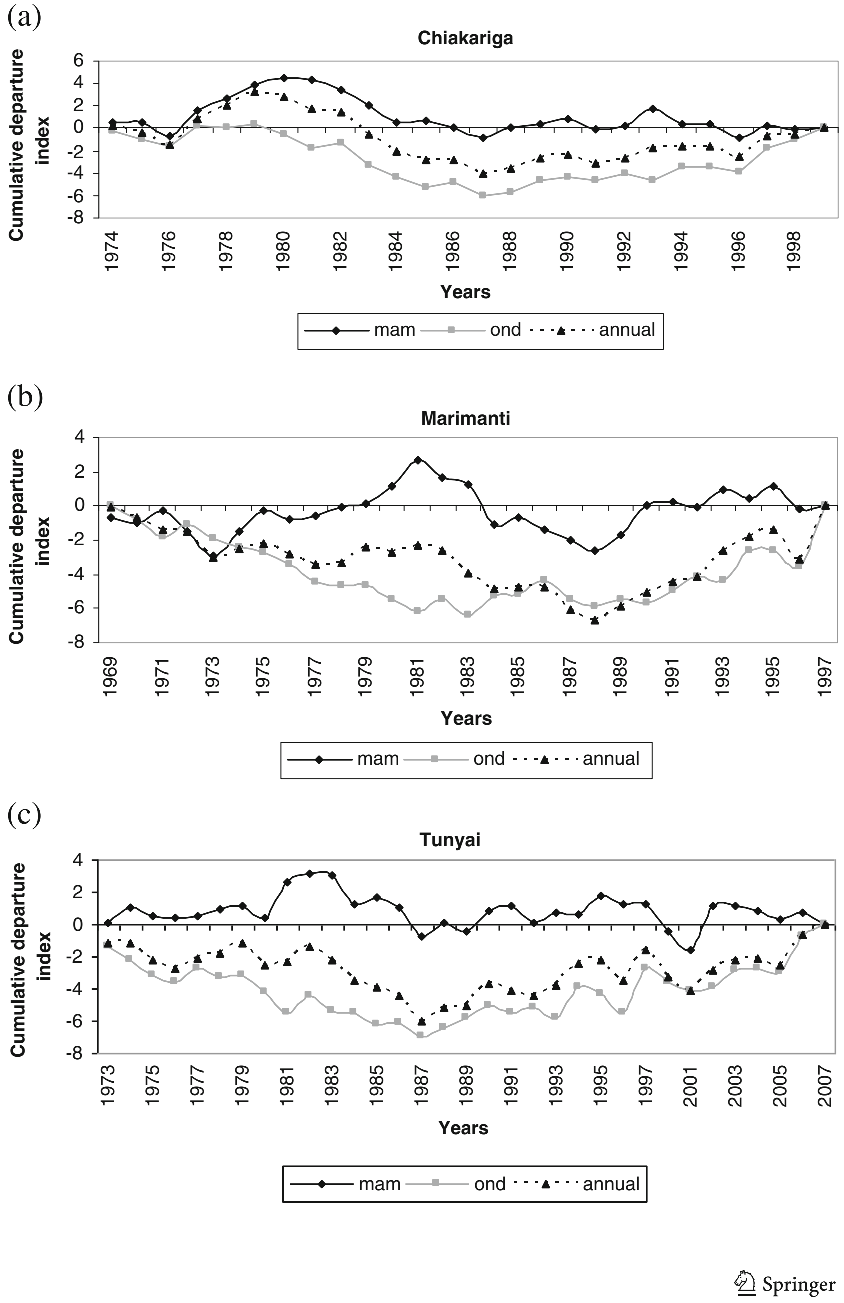
The threshold for a rainy day was put at 0.85 mm as defined by the Kenya Meteorological Department (Shisanya 1996). This threshold was also adopted by Odekunle (2006) in a study of rainy season onset and retreat in Nigeria. Onset of growing period has been defined differently in such studies as Marteau et al. (2011), Dodd and Jolliffe (2001), Omotosho et al. (2000) and Sivakumar (1988). The present study adopted and modified the onset criteria by Sivakumar (1988). Thus, onset was defined as the day after 1 March and 1 October that received at least 20 mm of rainfall totalled over 2 days with a dry spell not exceeding 7 in 30 days. The considered date of onset is informed by the general understanding that MAM and OND rains start in March and October respectively and that seeds for cereals take approximately 7 days to germinate. In addition, sowing by most farmers in arid areas mostly take place during and just after a 2-day wet spell receiving at least 10 mm (Marteau et al. 2011). Similarly, cessation has been defined differently (Tadross et al. 2009; Kasei and Afuakwa 1991). In this paper, cessation is defined as the date after 1st May and 1st December for MAM and OND when the soil water supply becomes null and after which no rain falls for the next 10 days. The soil water holding capacity was fixed at 60 mm.

4 Results and discussion

4.1 Trend analysis of annual and seasonal rainfall

The upward and downward movement of the cumulative departure index graphs correspond respectively to above and below average rainfall (Fig. 2). At Chiakariga, the period 1974–1976 experienced near average rainfall (for annual, MAM and OND) while the period 1977–1983 had above average MAM and annual rainfall but with a decreasing trend. The 1980s and 1990s experienced near average MAM rainfall and below average OND and annual rainfall. During the 1970s, Marimanti received below average rainfall in both seasons. At Tunyai during the same period, MAM rainfall was nearly average but OND and annual rainfall assumed a trend of below average—just like Marimanti. The findings illustrate that the 1970s desiccation of annual rainfall established by Dai et al. (2004), Hulme (2001) and Nicholson (1993) in Sahelian region also affected parts of the Great Horn of Africa. The desiccation could be attributed to a decrease in OND rainfall since MAM rainfall varied minimally from the mean during the 1970s. At Chiakariga and Tunyai, MAM rainfall ranged from average to above average over the period of study. This was unlike the MAM pattern at Marimanti which had periods of above average (1980–1983), average (1990–1997) and below average (1969–1977, 1984–1989). On the other hand, the periods 1970s and 1980s show OND rainfall with a declining trend

Fig. 2 Cumulative departure index time-series plot for annual, MAM and OND from the mean rainfall at **a** Chiakariga, **b** Marimanti and **c** Tunyai



across the three stations, an almost similar pattern as annual rainfall. But the 1990s show OND and annual rainfall with an increasing trend towards normal rainfall.

The rainfall trend established in Tharaka district is similar to the findings of Tilahun (2006), Anyamba and Tucker (2005) and Ovuka and Lindqvist (2000). For instance, Ovuka and Lindqvist (2000) observed a decreasing annual rainfall trend for the period 1963–1976 in Murang'a, district, Central Kenya. Using cumulative departure index, Tilahun (2006) illustrated that parts of Central and Northern Ethiopia persistently received below average rainfall for the period 1970–1995 and 1975–1990, respectively. In the analysis of Sahelian vegetation dynamics using normalised difference vegetation index (NDVI), Anyamba and Tucker (2005) established that 1982–1993 was characterised by below average NDVI and persistent drought; and the period 1994–2003 was marked by a trend towards wetter conditions. Dai et al. (2004) echoed similar sentiment in which they observe that Sahel rainfall recovered by 2003. Based on Anyamba and Tucker (2005) and Dai et al. (2004), the study concludes that OND and annual rainfall in Tharaka is recovering. A clearer picture however can be given if data up to the most recent period is analysed. The pattern observed between OND and annual rainfall suggests that OND rainfall is a significant determinant of annual rainfall variability in Tharaka district. The below normal rainfall trend of OND rainfall is a cause for concern as it signals a reduction in rainfall amount over the years. Hansen and Indeje (2004) and Amissah-Arthur et al. (2002) allude that OND rainfall constitute the main growing season in Eastern Kenya on which annual crops such as maize, sorghum, green grams and finger millet are dependent on. Thus, its decline has implications on agricultural production (cropping systems) and related livelihoods. Smucker and Wisner (2008) have noted a substantial decline in crop productivity in Tharaka district and have attributed this to land degradation and erratic rainfall among other factors. Trends of below normal rainfall for OND, the main growing season, call for an evaluation of the current cropping system (crop cultivars) to determine their viability in the current rainfall pattern.

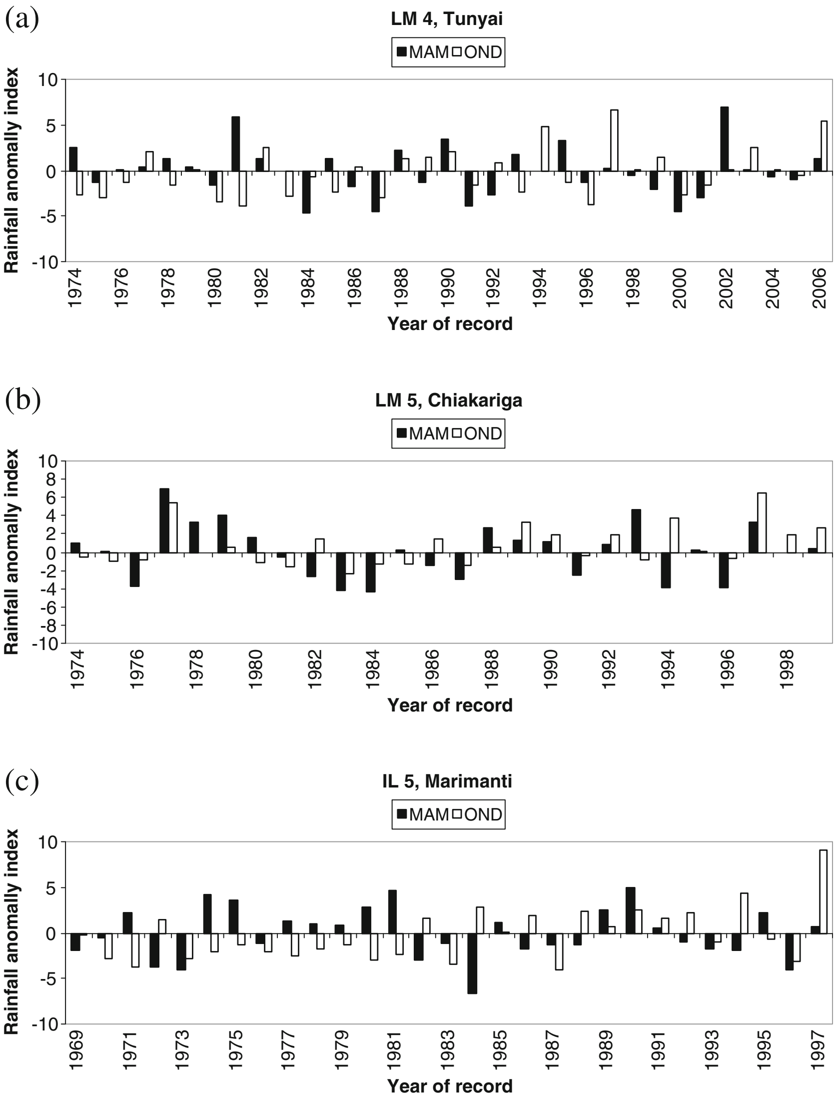
Figure 3 shows patterns of inter-seasonal rainfall variability in the three stations. During the MAM season, the highest positive anomalies were recorded at Tunyai (+7.0) in the year 2000 and Chiakariga (+7.0) in 1977. At Marimanti, 1990 was the wettest year with a positive anomaly of +5.0. On the other hand, 1984 recorded the highest negative anomaly during the MAM season across the three stations: Marimanti, −6.6; Tunyai, −4.6; and Chiakariga, −4.3. For the study period, 1997 recorded the highest positive anomalies at all stations: Marimanti, +9.1; Tunyai, +6.7; and Chiakariga, +6.4. The three stations have a commonality in 1984 and 1997. The year 1984 recorded the driest MAM season and 1997 as the wettest OND season.

The 1984 national drought, caused by widespread failure of the MAM rains is documented (Hutchinson 1996; Shisanya 1990; Cohen and Lewis 1987). During this period, several provinces in Kenya recorded low production of staple cereals prompting the then President of Kenya to launch a National Food Relief Fund among other responses (Shisanya 1990). In fact, at Tunyai and Chiakariga, the year 1984 experienced failure of both the MAM and OND rains. Shisanya (1990) argues that the La Niña event of 1982–1984 might have contributed significantly to the drought which affected the entire Kenya. The high positive anomalies of 1997 OND rainfall could be attributed to the 1997/98 El Niño rains that characterised the OND season in Eastern Africa (Amissah-Arthur et al. 2002; Anyamba et al. 2001). Observation of MAM and OND inter-annual rainfall variability show that the latter's deviation from mean is greater. Results of cumulative departure index and rainfall anomaly index highlight the inter-annual and inter-decadal rainfall variability that characterises Sub-Saharan climatology. Inter-annual variability of seasonal rains results from complex interactions of forced and free atmospheric variations. Mutai et al. (1998) observed that OND variability is stronger than MAM while Phillips and McIntyre (2000) observed that the low inter-annual variability of MAM rainfall can be attributed to its insignificant relationship with ENSO. The ENSO is the most dominant perturbation responsible for inter-annual climate variability, especially OND over eastern and southern Africa. Studies by Ogallo (1988), Farmer (1988), Phillips and McIntyre (2000) and Hutchison (1990) have found OND rainfall to be in phase with ENSO. In general, seasonal rainfall in Tharaka district varies a lot around the mean, with occasions of subsequent below average rainfall. Persistence of below normal rainfall risk peoples livelihood and majority in Tharaka are left vulnerable to hunger and famine. Crops fail and livestock die, prompting shipment of food relief in the district. But besides relief food, farmers have learnt to farm in ways that partially adjusts to such variations by making adjustments in labour requirements, dig ridges to trap water and plant and replant due to 'false' start of season with a view of reducing their risk (Wisner (1977).

4.2 Variation in seasonal rainfall amount and rainy days

Tharaka district is largely semi-arid and with the exception of agro-ecological zone LM4, receives less than 1,000 mm of annual rainfall. Chiakariga, Marimanti and Tunyai stations receive 950, 805 and 1,138 mm of annual rainfall, respectively. Seasonal rainfall accounts for over 90% of the annual rainfall and OND season receives more rain than MAM season except at Marimanti (Table 1). In a related study, Mzezewa et al. (2010) found that in Ecotope—South Africa, 80% of annual rainfall is usually received between October and March. The emerging point in Mzezewa et al.

Fig. 3 A time series of rainfall anomaly index at **a** Tunyai, **b** Chiakariga and **c** Marimanti stations in Tharaka district, Kenya



(2010) and the current study is that a comparatively small proportion of rainy days supplies most of the annual rainfall. Since rainfall in SSA is largely seasonal, it is therefore important that a meaningful analysis of the impact of rainfall on crop yield be based on seasonal and not annual rainfall. In Tharaka therefore, analysis of rainfall impact on such crops as maize, millets, green grams and sorghum (Smucker and Wisner 2008) should be based on MAM and OND growing seasons and not annual rainfall to avoid the high covariance arising from the dry spell periods during the year.

Agro-ecological zone LM4 (Tunyai) is the wettest with an average of 503 and 606 mm of rainfall, and 28 and 36 rainy days during MAM and OND rainfall, respectively. During MAM, Chiakariga (LM5) and Marimanti (IL5) receive nearly the same amount of rainfall. But during the OND, Chiakariga receives 527 mm and Marimanti receives 386 mm. Despite the remarkable difference in rainfall amount during OND, the difference in the number of rainy days is 1 day, suggesting that the distribution at Chiakariga is better than at Marimanti. The relatively higher rainfall amount and rainy days at Tunyai suggest that the agro-ecological zone can support crop varieties with relatively long growing period than at Marimanti and Chiakariga. Nonetheless, support for crop development is subject to within-season rainfall characteristics and soil's water retention capacity. Compared with other seasons such as the ones in Sahelian and Guinean region (Sivakumar 1987; Kasei and Afuakwa 1991), Southern Africa (Tadross et al. 2009) or even Eastern Africa for March–September (Shisanya 1996; Phillips and McIntyre 2000), the two rainfall seasons in Tharaka district have a short growing period. In the neighbouring Ethiopia, Araya and Stroosnijder (2011) established that short growing periods were among the causes of crop failure. This makes breeding of short season crops and development of drought mitigation

Table 1 Rainfall amount (in mm) and coefficient of variation (CV; %) for MAM and OND seasons in the selected stations

Station	MAM				OND			
	Rain (mm)	CV	Rainy days	CV	Rain (mm)	CV	Rainy days	CV
Chiakariga	409	0.34	19	0.39	527	0.41	27	0.48
Marimanti	408	0.33	22	0.35	386	0.43	26	0.33
Tunyai	503	0.34	28	0.27	606	0.44	36	0.31

strategies such as supplementary irrigation and rainwater harvesting a viable venture in Tharaka. Results of CV for seasonal rainfall amount show that both OND and MAM have a CV exceeding 0.30. According to Araya and Stroosnijder (2011), a CV > 30% is an indicator of large rainfall variability. When the CV of rainfall amount is compared with that of rainy days, it is observed that rainy days have higher CV values than rainfall amount. Analysis of seasonal rainfall shows that Chiakariga (LM5) and Tunyai (LM4) receive more rainfall during OND than MAM. Marimanti on the other hand receives slightly more rainfall during MAM than OND season. A paired sample *t* test was used to test the significant difference of means (at the probability level of 0.05) of OND and MAM seasons for each station. *t* Test results show that the difference between MAM and OND at Chiakariga and Tunyai to be significant, implying the two seasons are markedly different and farmers need to adopt different cropping system and farm management strategies. At Marimanti (IL5) however, it would appear that variations in rainfall amount of the two seasons is not significant. These findings corroborate those of Barron et al. (2003) and Amissah-Arthur et al. (2002) which demonstrate that parts of Eastern Kenya receive more OND than MAM rainfall. With the perception that OND is the main season, it is possible that farmers in Tharaka reduce area under farming and number of cultivars during MAM. Such a decision implies a missed opportunity for farmers in agro-ecological zone IL5 (Marimanti) who may benefit from MAM just as much as they would for OND. This calls for a need to determine how much of each of these seasons contributes to yield in each of the agro-ecological zones.

Table 2 shows the distribution of monthly rainfall amount and rainy days in the three sites of study. Nearly one fourth of the total rainfall in the three stations is received during the onset months (May and October). Although April and November are the wettest months of the two seasons, their contribution to the seasonal rainfall varies. Thus, rainfall received in April accounts for nearly 60% of the total MAM rainfall while November rainfall accounts for about 50% of the total OND rainfall at the three stations. May, the cessation month of MAM rainfall, accounts for less than 20% of the total rainfall while December, the cessation month of OND rainfall, accounts for about 25% of the total rainfall. The results imply that OND rainfall amount and rainy days are fairly spread through the season, potentially reducing the impact of within-season variability. The rainfall received in May is little and might not be sufficient to buffer crops from agricultural drought, especially in Tharaka where soils are predominantly sandy loam and shallow (Jaetzold et al. 2007). A planting date is important, especially during the MAM season. It is important that sowing takes place prior to or upon onset, failure to which a significant amount of rainfall will be missed and therefore affect crop performance.

Analysis of rainfall by months shows that the first and last months (of both seasons) are characterised by high CV for rainfall amount and rainy days. Similar findings are reported in Sivakumar (1987) in which onset (May) and cessation (October) months in Sudano-Sahelian zone are characterised by variations of over 100%. When the month of January is added to OND, the average number of rainy days change to 29, 29 and 40 while average seasonal rainfall amount change to 563, 420 and 653 mm at Chiakariga, Marimanti and Tunyai, respectively. This indicates a slight increase in mean number of rainy days and rainfall amount. This also had a minimal increase on CV for both rainy days and rainfall amount in the three stations when compared with OND. For instance, ONDJ recorded a CV for rainfall amount of 0.42, 0.42 and 0.44 and rainy days of 0.51, 0.33 and 0.32 for Chiakariga, Marimanti and Tunyai, respectively. The results suggest that the contribution of January to the increase in variability of ONDJ season is less. The minimum influence of January on the coefficient of variance especially on rainy days, suggest that January rainfall is critical to the overall seasonal performance and may be vital to the maturation of crops. Mzezewa et al. (2010) also reported high coefficient of variation for annual (315%) and monthly (50–114%) rainfall in semi-arid Ecotope, north-east of South Africa. Findings of Seleshi and Zanke (2004) show that annual and seasonal rainfall (*Kiremt* and *Belg*) in Ethiopia are also highly variable (with CV values ranging between 0.1 and 0.5). Sivakumar (1987) found that annual rainfall in the Sudano-Sahelian zone of West Africa is less variable than monthly rainfall. In Tharaka district in East Africa, seasonal rainfall is less variable than monthly rainfall

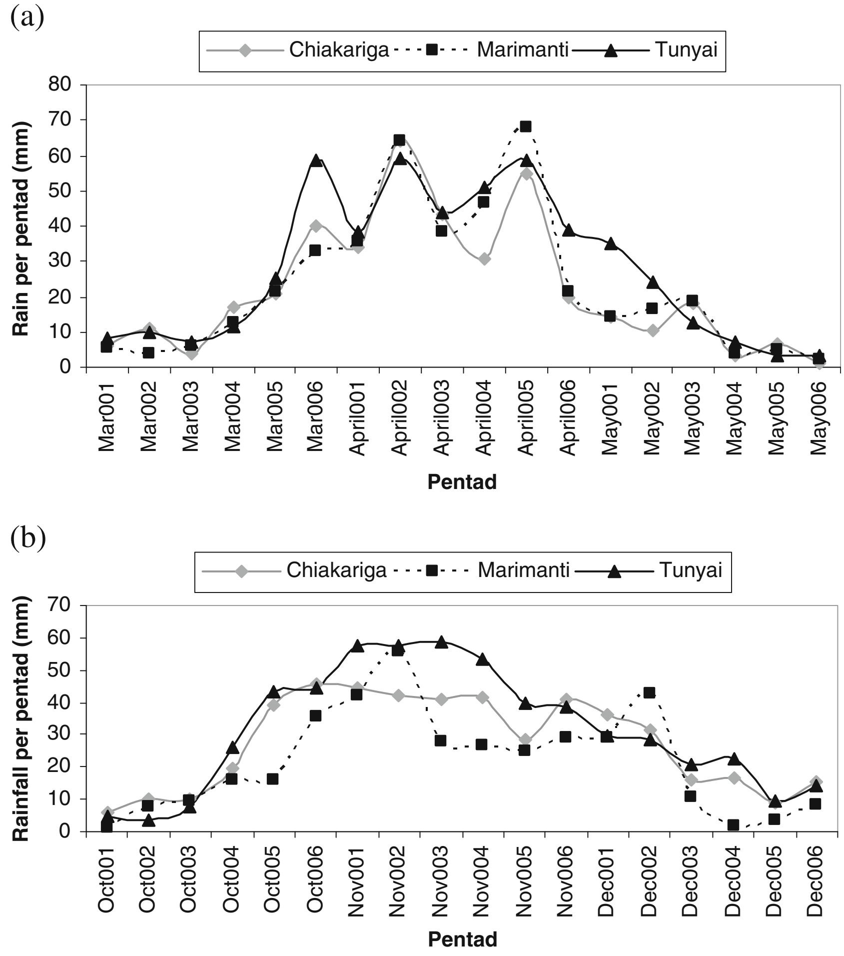
Figure 4a shows that April rainfall amount is characterised by within-season variation. This is unlike in March and May rainfall which shows increasing and decreasing

Table 2 Monthly rainfall amount (RA) and rainy days (RD) and their respective coefficient of variations (CV) by station

Station	March	April	May	October	November	December
Chiakariga						
RA (mm)	101	255	52	127	260	134
RA-CV	0.76	0.40	1.18	0.73	0.55	0.69
RD	5	11	3	7	13	7
RD-CV	0.81	0.42	0.65	0.72	0.45	0.81
Marimanti						
RA (mm)	80	262	66	78	217	106
RA-CV	0.83	0.42	0.76	0.83	0.39	0.73
RD	5	11	6	6	13	7
RD-CV	0.94	0.43	0.70	0.83	0.40	0.45
Tunyai						
RA (mm)	126	293	83	148	324	134
RA-CV	0.74	0.38	0.70	0.73	0.45	0.63
RD	7	14	7	9	17	10
RD-CV	0.68	0.30	0.57	0.47	0.28	0.55

trends respectively. During the month of March, all stations receive less than 20 mm/pentad with an average of one rainy day per pentad. Rainfall amount increases in April, with an average of two rainy days per pentad but the months is characterised by suppressed rainfall. Over 80% of the May rainfall amount is received between the 1st and 3rd

Fig. 4 Mean rainfall amount received during the MAM (**a**) and OND (**b**) seasons by pentads



pentads. The last rainy days for the season are in the 3rd pentad (Chiakariga) and 4th pentad (Marimati and Tunyai).

Figure 4b illustrates that all stations have an increasing trend in rainfall amount in October up to the 1st pentad of November before assuming a declining trend thereafter. Although November is the peak month in rainfall amount, there are significant differences in the distribution pattern. At Tunyai, rainfall peaks between the 1st and the 4th pentads of November with an average of over 55 mm/pentad before assuming a declining trend. At Chiakariga, rainfall peaks between the 6th pentad of October and the 4th pentad of November, with a pentad average of slightly above 40 mm. However, Marimanti presents a different pattern from the two other stations. OND rainfall assumes an increasing trend from onset up to the 2nd pentad of November when the peak is reached—56 mm. The rains then decline in the 3rd pentad of November to less than 30 mm—a pattern maintained until the 2nd pentad of December. A notable feature of OND rainfall is that its distribution from onset to retreat dates is fairly constant in the three stations when compared with MAM rainfall. With rainfall peaking in early November, it is important for farmers to plant early in the three agro-ecological zones if crops have to optimise rainfall received at the early stages of the season. As stated by Hansen and Indeje (2004), the findings are particularly useful in crop production and management decisions which depend more on distribution of rainfall within the season than the seasonal average.

The results compliment previous studies (Kasei and Afuakwa 1991; Sivakumar 1987) which have tied the length of a rainy season to rainfall amount. For instance, Tunyai records the highest number of rainy days and also receives the highest amount of rainfall. A combination of these results would therefore lead to the conclusion that optimum planting time for seasonal crops to meet crop water requirements could start in the 4th pentads of March and October. However, this should be done in consideration of the existing agro-meteorological advisories. Kasei and Afuakwa (1991) recommend early planting in areas with relatively longer growing seasons (such as Tunyai) to allow for maximum crop production.

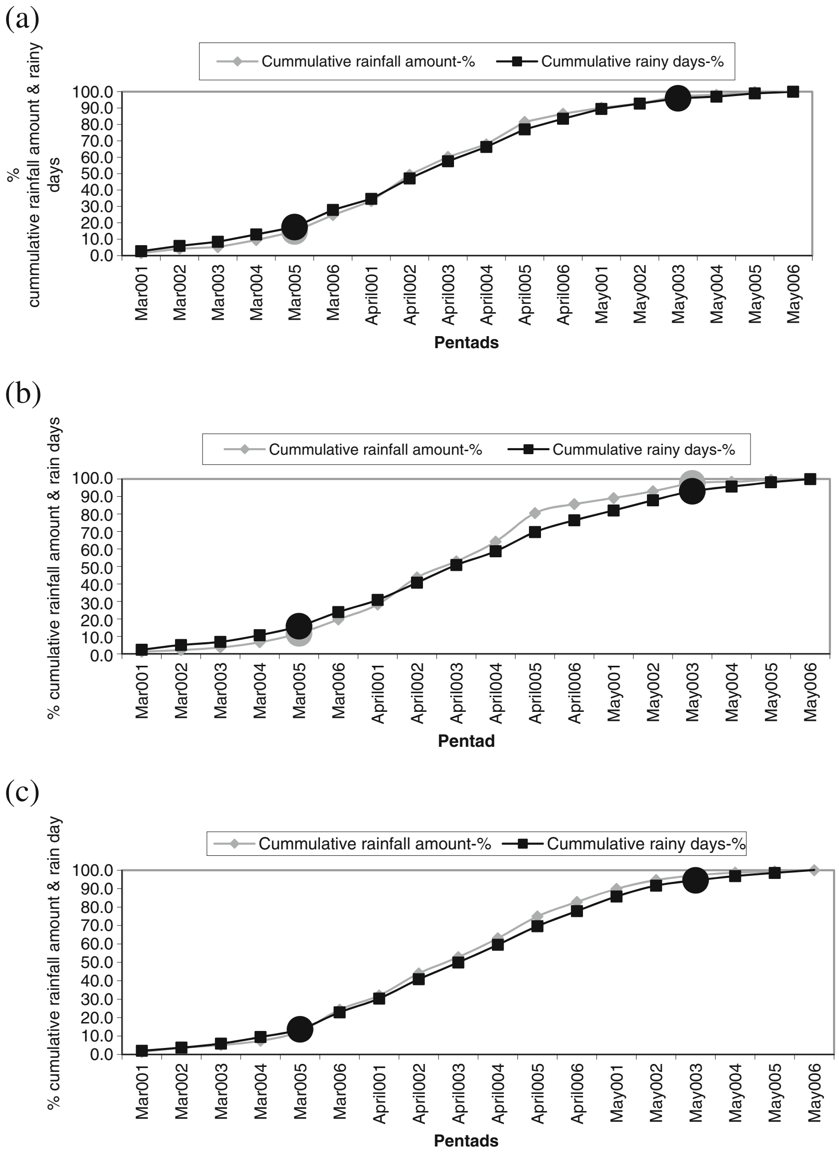
4.3 Onset and cessation of seasonal rainfall

Figures 5a–c and 6a–c show the percentage cumulative mean rainfall amount and rainy days for MAM and OND seasons. Based on both cumulative rainfall amount and rainy days, onset for MAM and OND is in the fifth pentads of March and October respectively which translates to between 21st and 25th of March and October. By the 5th pentad of March and October, all stations record between 11% and 16% of the total rainfall amount and 14% and 17% of the total rain days. For an area with a highly variable rainfall, it would therefore imply that in a normal season, seeds are sown prior or on onset. Planting later than the 5th pentad of March and October is likely to hamper crop development and potentially lower yields or lead to crop failure, depending on the maturity length of the cultivar.

Cumulative percentage mean shows that MAM rains retreat 3rd pentad of May (16th–20th May) and ONDJ rains retreat in the 2nd pentad of January. There is also relative uniformity in the amount of rainfall received by the date of cessation. By the date of MAM retreat, Chiakariga, Marimanti and Tunyai received 97%, 98% and 97% of the rainfall amount and 96%, 93% and 95% of the rainy days, respectively. Marimanti and Tunyai had received 97% of the rainfall amount and 95% of the rain days by the date of cessation for ONDJ rainfall season. At Chiakariga the mean retreat date is reached after 96% of rainfall amount and 95% of rainy days. From these results, it is observed that although mean rainfall amount and rainy days converge to give mean onset and cessation; there are differences in the cumulative values. For instance, in all the three stations, the amount of rainfall received is less than the number of rainy days by the date of onset for both OND and MAM season; though the difference is bigger for the later. It therefore implies that determination of onset based on rainfall alone signal an early onset while rainy dates a late onset. There is lack of concurrence for cumulative rainfall amount and cumulative rainy days at the maximum positive curvature for MAM when compared with ONDJ. This suggests that onset and cessation are steadier in terms of rainfall amount and rainy days for ONDJ than for MAM. By the dates of cessation, all the stations had recorded more rainfall amount than rainy days. The case at Marimanti is of particular interest where the difference between rainfall amount and rainy day cumulative percentage is the largest. Thus, use of rainy days would signal an early cessation.

Although mean dates of onset and cessation appear to be uniform for the period on record, results of individual years show high inter-annual variability for both MAM and OND season (Fig. 7). For instance, onset for 1983 was as late the 8th pentad (5–10 April) at Chiakariga and Tunyai and 11th pentad (15–20 April) at Marimanti during the MAM season. Other years of late onset for MAM are 1979, 1987, 1992 and 1993. Early onsets for the same season were realised in 1977, 1981 and 1990. The latest onset (after November) during OND for the period under study was in 1981, 1987 1nd 1996. While 1982, 1991 and 1994 recorded early OND onsets for the period on record. Figure 7 also shows the general trend of onset dates for MAM and OND for the period of study. During MAM, onsets at Marimanti show a constant trend with onset occurring within the first week of April (pentad 7). Chiakariga and Tunyai record mixed fortunes of increasing

Fig. 5 Mean rainfall onset and cessation using cumulative percentage mean for **a** Chiakariga, **b** Marimanti and **c** Tunyai for MAM season

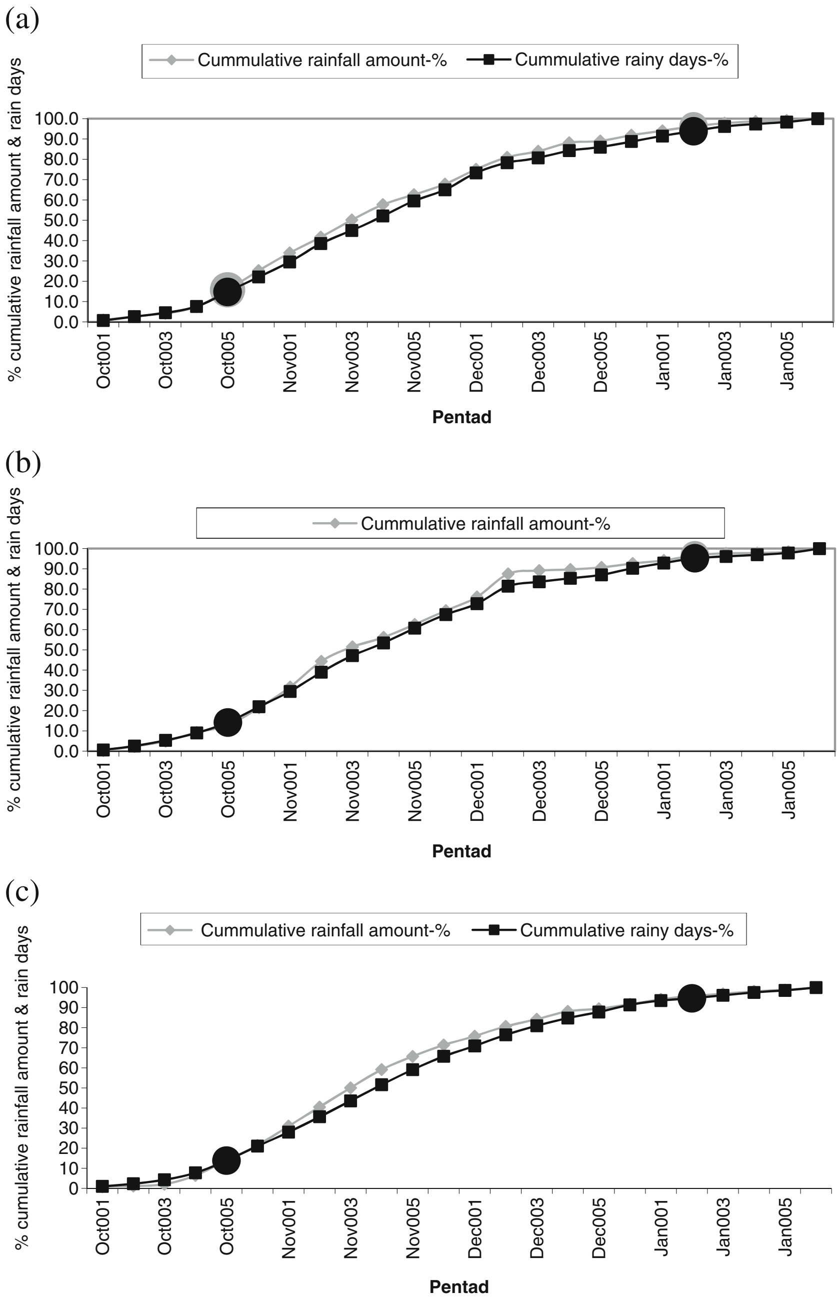


and decreasing trends respectively for MAM. Onset for OND seasons depicts a declining trend at Marimanti and Tunyai and a constant trend at Chiakariga. What emerges from these results is that whereas there is uniformity on pentads of onset using the percentage cumulative mean across the three stations—there are several instances when onset varied from station to station. Trend lines show that onset for OND season is moving towards the mean dates of onset (21–25 October). Onset dates for MAM at Chiakariga appear to be progressing towards the 1st pentad of April from the 6th pentad of March.

Dates of rainfall cessation are less variable when compared with onset (Fig. 8). During MAM season, cessation is expected between the 14 pentad (6–10 May) and 16th pentad (16th–20th May). Although cessation can start as early as the 14th pentad (6–10 December) during OND, it stretches to the 1st week of January (pentads 19 and 20). A notable feature of this that although dates of cessation vary from year-to-year just like onset, the amplitude of variation is not as high compared with onset.

These findings vindicate those of Camberlin and Okoola (2003) who observed that inter-annual variability of the onset is larger than the withdrawal in Eastern Africa. The study further established that in Eastern Kenya, the average onset for MAM occur on 25 March and cessation on 21 May. The results however contradict those of Araya and Stroosnijder (2011) who established that in northern Ethiopia, onset of rain over the study area was less variable than the cessation. Mugalavai et al. (2008) has illustrated the role of atmospheric winds (NE and SE monsoon) and localised effects (escarpments and Lake Victoria) in the determination of onset and cessation for the long rains (March–September) and short rains (October–December) in the humid region of western Kenya. Odekunle (2006)

Fig. 6 Mean rainfall onset and cessation using cumulative percentage mean for **a** Chiakariga, **b** Marimanti and **c** Tunyai for ONDJ season



observed that onset is first realised in the south of Nigeria by end of March and progress northward where northern stations such as Kano realising onset in June. In Nigeria, onset and cessation are associated with south-westerly winds and Harmattan winds, respectively. Inter-annual variations of onset and cessation in Tharaka could be attributed to local factors and position of sites in relation to the amplitude of inter-tropical convergence zone, a critical determinant of onset and cessation. The presence of hills and protected forest cover (Smucker and Wisner 2008) in the south of Tharaka are potential determinants of onset and cessations. The high variations that characterise rainfall onset in Tharaka make agricultural planning difficult for farmers. But farmers can find hope in the improved skill of seasonal climate forecast in Eastern Africa (Recha et al. 2008; Cooper et al. 2008). Effective use of climate forecast information (on date of onset and rainfall amount) can significantly optimise rainfall and lead to improved yields. An early onset of the rains give a longer growing season and a delayed onset may mean a short growing season as documented by Sivakumar (1987) and Kasei and Afuakwa (1991). On the efficiency of the methods in determining mean onset and cessation, results corroborate those of Odekunle (2006) who found that use of rainfall amount and

Fig. 7 Estimated dates of onset by pentads (*x*-axis) using INSTAT software for **a** MAM and **b** OND for the period on record (*y*-axis)

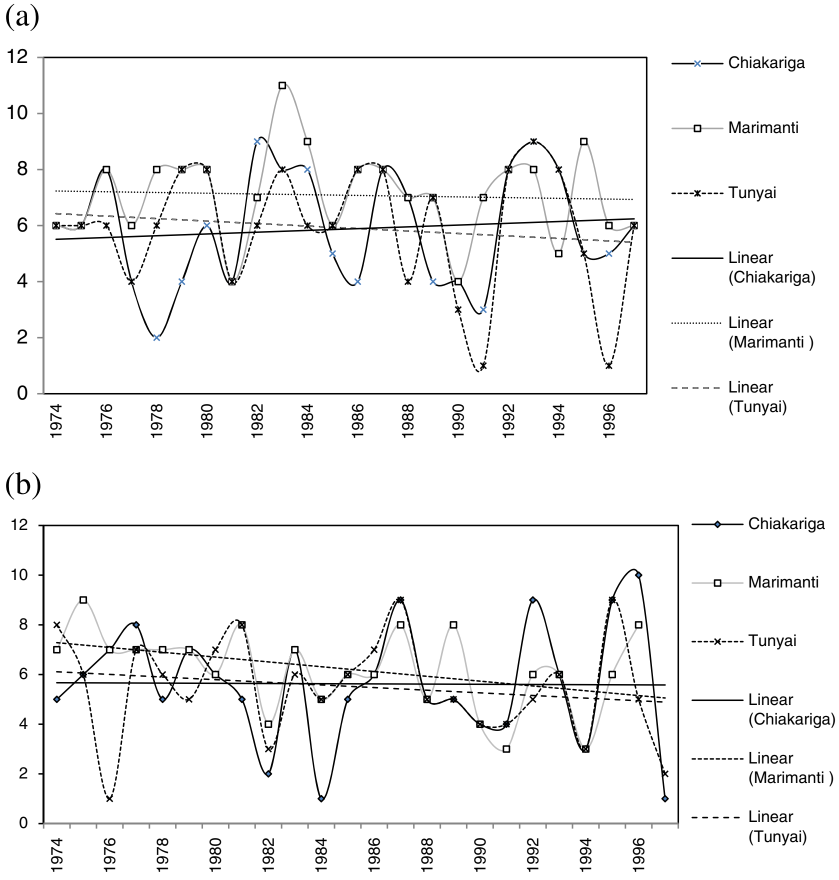
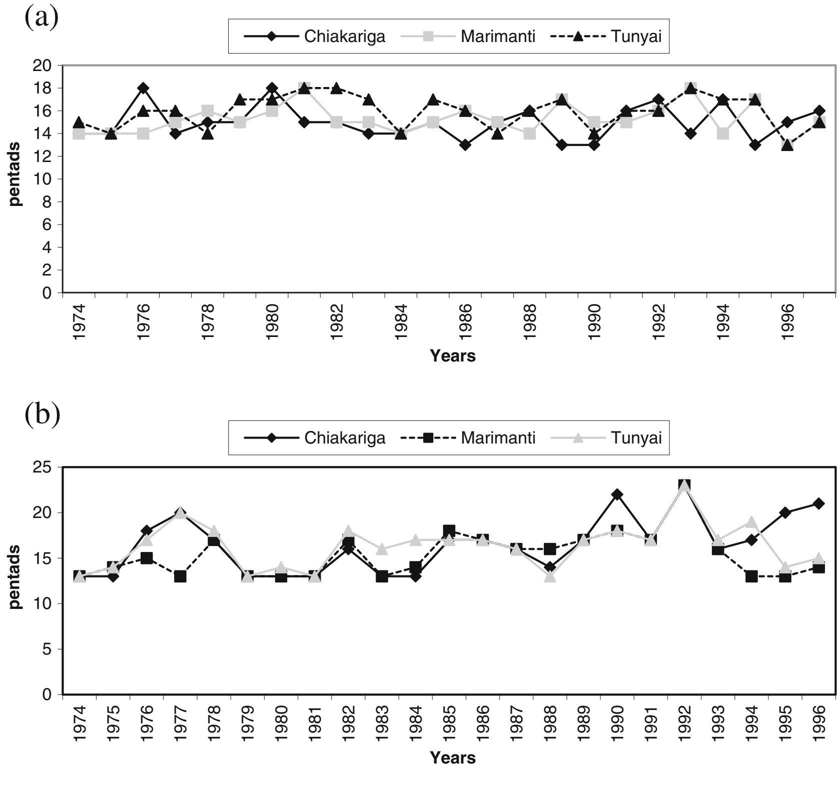


Fig 8 Estimated dates of cessation using INSTAT software for **a** MAM and **b** OND



rainy days do not have major differences in determining mean onset and cessation. The study however recommends that in cases of significant variations, percentage mean cumulative rainfall amount be used. The conclusion is informed by the percentage of rainfall amount received by the dates of onset and cessation.

5 Conclusions

This study sought to quantify rainfall variability for MAM and OND seasons in three agro-ecological zones in Tharaka district and the variables investigated are inter-annual variability, dates of onset, cessation and length of growing season. Rainfall variability was examined using the cumulative departure index and rainfall anomaly index. Mean dates of onset and cessations were determined using the percentage cumulative mean and INSTAT.

The study reveals that OND rainfall has been persistently below mean since the 1970s while MAM rainfall shows low inter-annual variability. The inter-annual variability of OND rainfall, associated with ENSO event, is a major determinant of annual rainfall in the three agro-ecological zones. The two growing seasons, MAM and OND, have average growing seasons of 19–28 and 26–36 days, respectively. MAM and OND receive a seasonal mean rainfall of between 408 and 503 and 386 and 606 mm in the three agro-ecological zones of study, respectively. The *t* test results showed that the difference between MAM and OND rainfall in LM4 (Tunyai) and LM5 (Chiakariga) to be significant, an indication the two seasons have unique characteristics and therefore there is need for specific farm management practices for each season. The perception derived from previous studies that OND is the main season in Eastern Kenya could be leading to a missed opportunity in Marimanti: OND and MAM rainfall seasons are not significantly different. Results of cumulative percentage mean show that the average date of onset for MAM and OND is 21–25 March and 21–25 October. Whereas cessation for MAM occurs by 16–20 May, cessation for OND rainfall spills into 1st pentad of January of the following year. Within-season characteristics such as length of growing season, distribution of rainfall (by pentads and months) show that OND rainfall is more reliable for rain-fed agricultural activities than MAM. The high inter-annual variability (of rainfall amount and date of onset) associated with both MAM and OND seasons can be addressed by scheduling of supplementary irrigation and timely dissemination and use of seasonal climate forecasts that are regularly disseminated by the Kenya Meteorological Department. Results of cumulative rainfall trends and onset dates suggest that rainfall in semi-arid Kenya, which experienced a decline in the 1970s and early 1980s, could be returning to wetter conditions.

For the semi-arid Tharaka district, the findings need to be incorporated in implications of climate variability and vulnerability assessment (Fussel and Klein 2006). However, for on-farm management, rainfall partitioning alone has limited value. Crop growth is also dependant on agro-ecological conditions (e.g. water holding capacity of the soil) and growth stages. Consideration of these variables in future studies would complement the present findings and provide farmers with the needed information on the occurrence of crop water stress within the season.

Acknowledgments The authors acknowledge financial support from the EU Water Facility Project (no. 9 ACP RPR 50/11) in form of field work support and the African Climate Change Fellowship Programme (2009/2010)—a programme of International SysTem for Analysis, Research and Training (START) and partners for a study fellowship award to the first author. Daily rainfall data were provided by the Kenya Meteorological Department and we are indeed grateful. The anonymous reviewer and Victor Makuto (edited) are thanked for helping improve the quality of this work.

References

African Partnership Forum (2008) Climate Challenges to Africa: A call for action. 10th Meeting of the African Partnership Forum, April 7–8, 2008, Tokyo, Japan. Available at www.africapartnershipforum.org/dataoecd/46/47/40333574.pdf. Accessed 05 Feb 2010

Amissah-Arthur A, Jagtap S, Rosenzweig C (2002) Spatio-temporal effects of El Niño events on rainfall and maize yield in Kenya. Int J Climatol 22:1849–1860

Anyamba A, Tucker CJ (2005) Analysis of Sahelian vegetation dynamics using NOAA-A-AVHRR NDVI data from 1981–2003. J Arid Environ 63:596–614

Anyamba A, Tucker CJ, Eastman JR (2001) NDVI anomaly pattern over Africa during the 1997/98 ENSO Warm Event. Int J Remote Sens 24(10):2055–2067

Araya A, Stroosnijder L (2011) Assessing drought risk and irrigation needs in northern Ethiopia. Agric For Meteorol 151:425–436

Barron J, Rockstrom J, Gichuki F, Hatibu N (2003) Dry spell analysis and maize yields for two semi-arid locations in East Africa. Agric For Meteorol 117:23–37

Camberlin P, Okoola RE (2003) The onset and cessation of the 'long rains' in Eastern Africa and their inter-annual variability. Theor Appl Climatol 75:43–54

Chambers LE (2003) South Australian variability and trends. Bureau of Meteorology Research Centre, Australia, BMRC research report no. 92

Cohen JM, Lewis DB (1987) Role of government in combating food shortages: lessons from Kenya 1984–85. In: Glantz MH (ed) Drought and hunger in Africa: denying famine a future. Cambridge University Press, Cambridge, pp 269–296

Cooper PJM, Dimes J, Rao KPC, Shapiro B, Shiferaw B, Twomlow S (2008) Coping better with current climatic variability in the rain-fed farming systems of the sub-Sahara Africa: an essential first step in adapting to future climate change. Agric Ecosys Environ 126:24–35

Dai A, Lamb PJ, Trenberth KE, Hulme M, Jones PD, Xie P (2004) The recent Sahel drought is real. Int J Climatol 24:1323–1331

Dodd DES, Jolliffe IT (2001) Early detection of the start of the wet season in semiarid tropical climates of western Africa. Int J Climatol 21:1251–1262

Enders CK (2010) Applied missing data analysis. The Guilford Press, New York. ISBN 978-1-60623-639-0. Available at http://books.google.co.ke/. Accessed 30 Jul 2011

Farmer G (1988) Seasonal forecasting of the Kenya coast short rains, 1901–1984. Int J Climatol 8:489–497

Few R, Osbahr H, Bouwer LM, Viner D, Sperling F (2006) Linking climate change adaptation and disaster risk management for sustainable poverty reduction: synthesis report. Ref MWH 475000177.001-6 rev.1

Fussel H, Klein RJT (2006) Climate change vulnerability assessment: an evolution of conceptual thinking. Clim Chang 75:301–329

Goddard L, Mason SJ, Zebiak SE, Ropelewski CF, Basher R, Cane MA (2001) Current approaches to seasonal-to-inter annual climate predictions. Int J Climatol 21:1111–1152

Gommes R, Petrassi FP (1996) Rainfall variability and drought in Sub-Saharan Africa since 1960. FAO Agrometeorology Series, working paper no. 9. Available at http://www.fao.org/waicent/faoinfo/sustdev/EIdirect/EIan0004.htm. Accessed 08 Feb 2010

Hansen JW (2005) Integrating seasonal climate prediction and agricultural models for insights into agricultural practice. Philos Trans R Soc B 360:2037–2047

Hansen JW, Indeje M (2004) Linking dynamic seasonal climate forecasts with crop simulation for maize yield prediction in semi-arid Kenya. Agric For Meteorol 125:143–157

Hulme M (2001) Climate perspectives on Sahelian dessiccation: 1973–1998. Glob Environ Chang 11:19–29

Hutchinson CF (1996) The Sahelian desertification debate: a view from the American south-west. J Arid Environ 33:519–524

Hutchison P (1990) The Southern oscillation and the prediction of 'Der' seasonal rainfall in Somalia. J Clim 5:525–531

Jaetzold R, Schmidt H, Hornetz B, Shisanya C (2007) Farm management handbook of Kenya: part C, East Kenya, vol II, Ministry of Agriculture, Nairobi, Kenya

Jury MR (2002) Economic impacts of climate variability in South Africa and development of resource prediction models. J Appl Meteorol 41:46–55

Kasei CN, Afuakwa, JJ (1991) Determination of optimum planting date and growing season of maize in the northern savanna zone of Ghana. In: Proceedings of the Niamey Workshop, February 1991. IAHS Publ no. 199

Mamoudou B, Frouin R, Nicholson SE (1995) Satellite-derived inter-annual variability of West African rainfall during 1993–1988. J Appl Meteorol 34(2):411–431

Marteau R, Sultan B, Moron V, Alhassane A, Baron C, Traoere SB (2011) The onset of the rainy season and farmers sowing strategy for pearl millet cultivation in southeast Niger. Agric For Meteorol 151:1351–1369

Mugalavai EM, Kipkorir EC, Raes D, Rao MS (2008) Analysis of rainfall onset, cessation and length of growing season for Western Kenya. Agric For Meteorol 148:1123–1135

Mutai CC, Ward MN, Coleman AW (1998) Towards the prediction of the east Africa short rains based on sea surface temperature—atmospheric coupling. Int J Climatol 18:975–997

Mzezewa J, Misi T, Rensburg LD (2010) Characterisation of rainfall at a semi-arid ecotope in the Limpopo Province (South Africa) and its implications for sustainable crop production. Water SA 36(1):19–26

Nicholls N, Wong KK (1990) Dependency of rainfall variability on mean rainfall, latitude and the southern oscillation. J Clim 3(1):163–170

Nicholson SE (1993) An overview of African rainfall fluctuations of the last decade. J Clim 6:1463–1466

Nicholson SE, Some EB, Kone B (2000) An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Niño and 1998 La Niña years. J Clim 13:2628–2640

Odekunle TO (2006) Determining rainy season onset and retreat over Nigeria from precipitation amount and number of rainy days. Theor Appl Climatol 83:193–201

Odingo S, Nyakwada W, Njihia JK (2002) Weather and Climate Sector. In: IGAD and DMCN (eds) Factoring of weather and climate information and products into disaster management policy: a contribution to strategies for disaster management, Nairobi, Kenya. pp 1–33

Ogallo LJ (1988) Relationship between seasonal rainfall in East Africa and the southern oscillation. Int J Climatol 8:31–43

Omotosho JB, Balogun AA, Ogunjobi K (2000) Predicting monthly and seasonal rainfall, onset and cessation of the rainy season in West Africa using only surface data. Int J Climatol 20:8865–8880

Ovuka M, Lindqvist S (2000) Rainfall variability in Murang'a district, Kenya: meteorological data and farmers' perception. Geografiska Annaler Ser A Phys Geogr 82(1):107–119. doi:10.1111/j.0435-3676.2000.00116.x

Phillips G (2003) Determinants of forecast use among communal farmers in Zimbabwe. In: O'Brien K and Vogel (Eds) Coping with climate variability. Ashgate, Burlington, USA. pp 111–127

Phillips J, McIntyre B (2000) ENSO and interannual rainfall variability in Uganda: implications for agricultural management. Int J Climatol 20:171–182

Potop V, Tukkott L, Koznarova V, Mozny M (2010) Drought episodes in the Czech Republic and their potential effects in agriculture. Theor Appl Climatol 99:373–388

Recha CW, Shisanya CA, Makokha GL, Kinuthia RN (2008) Perception and use of climate forecast information amongst small-holder farmers in semi-arid Kenya. Asian J Appl Sci 1 (2):128–135

Republic of Kenya (2001) Tharaka district poverty reduction strategy paper: consultation report for the period 2001–2004.

Republic of Kenya (2010) The 2009 population and housing census. CBS and Ministry of Finance and Planning

Seleshi Y, Zanke U (2004) Recent changes in rainfall and rainy days in Ethiopia. Int J Climatol 24:973–983

Shisanya CA (1990) The 1983–1984 drought in Kenya. J East Afr Res Dev 20:127–148

Shisanya CA (1996) Chances and risks of maize and bean growing in the semi-arid areas of SE Kenya during the expected deficient, normal and above normal rainfall of the short rainy season. Ph.D. thesis (published), Trier, Germany

Sivakumar MVK (1987) Agro-climatic aspects of rain-fed agriculture in the Sudano- Sahelian Zone. In: ICRISAT (ed) Soil, crops and water management systems for rain-fed agriculture in the Sudano-Sahelian zone. Proceedings of an international workshop, Niamey, Niger, 11–16 January 1987, pp 17–38

Sivakumar MVK (1988) Predicting rainy season potential from the onset of rains in southern Sahelian and Sudanian climatic zones of West Africa. Agric For Meteorol 42:295–305

Sivakumar MVK (1991) Drought spells and drought frequencies in West Africa. Research bulletin no. 13. Patancheru, A.P 502 324, India. International Crop Research Institute for Semi-Arid Tropics

Smucker TA, Wisner B (2008) Changing household responses to drought in Tharaka, Kenya: vulnerability, persistence and challenge. In: Overseas Development Institute (doi:10.IIII/j.0361-3666.2007.01035.x). Blackwell, New York

Tadross M, Suarez P, Lotsch A, Hachigonta S, Mdoka M, Unganai L, Lucio F, Kamdonyo D, Muchinda M (2009) Growing season rainfall and scenarios of future change in South-east Africa: implications for cultivating maize. Clim Res 40:147–161

Tilahun K (2006) Analysis of rainfall climate and evapo-transpiration in arid and semi-arid regions of Ethiopia using data over the last half a century. J Arid Environ 64:474–487

Tumwesigye EK, Musiitwa F (2001) Characterizing drought patterns for appropriate development and transfer of drought resistant maize cultivars in Uganda. Seventh Eastern and Southern African Regional Maize Conference, 11–15 February 2001, pp 260–262.

Available at (http://www.cimmyt.org/english/docs/proceedings/africa/…/54_Komutunga1.pdf). Accessed 05 Jan 2009

UN (2005). The millennium development goals report.

Vogel C, Moser SC, Kasperson RE, Dabelko GD (2007) Linking vulnerability, adaptation, and resilience science to practice: pathways, players and partnerships. Glob Environ Chang 17:349–364

Washington R, Harrison M, Conway D, Black E, Challinor A, Grimes D, Jones R, Morse A, Kay G, Todd M (2006) Africa climate change: taking a shorter route. Am Meteorol Soc 87(10):1355–1366

Wisner B (1977) Constrictions of a livelihood system: the peasants of Tharaka division, Meru district, Kenya. Econ Geogr 53(4):353–357

Yasunaka S, Hanawa K (2005) Regime shift in the global sea-surface temperatures: its relation to El Nino-Southern Oscillation events and dominant variation modes. Int J Climatol 25:913–930