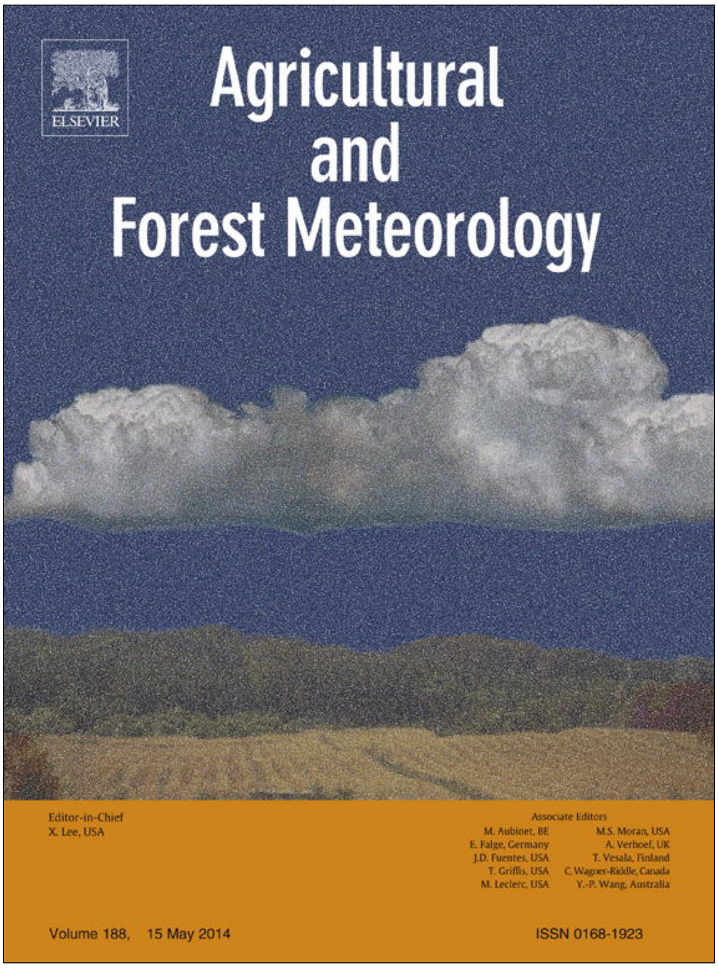

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Length of growing season, rainfall temporal distribution, onset and cessation dates in the Kenyan highlands

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ABSTRACT

Dependence on uncertain rainfall and exposure to unmitigated climate risk are major obstacles in efforts to sustainably intensify agricultural production and enhance rural livelihoods. There is generally enough seasonal total rainfall; the challenge is its poor distribution over time and across the season. The amount of water available to plants strongly depends on the rainy season's onset, length, temporal distribution and cessation and can indirectly indicate the climatic suitability of the crop and its chances of success or failure in a season. Thus, the objective was to determine rainfall pattern; temporal distribution, onset, cessation and length of growing seasons in the tropical sub-humid and a semi-arid regions with contrasting rainfall patterns and agricultural potential in central highlands of Kenya. The study was carried out in Maara and Meru South Sub-Counties in Tharaka Nithi County and Mbeere North and South Sub-Counties in Embu County of the central highlands of Kenya (CHK). Central highlands of Kenya cover both areas with high potential for crop production and low potential, attributed to rainfall differences. Meteorological data were sourced from Kenya Metrological Department (KMD) headquarters and research stations within the study areas. Length of growing season, onset and cessation dates for both Long (LR) and short (SR) rains seasons were determined based on historical rainfall data using RAIN software and derived using various spatial analysis tools in ArcGIS software and presented spatially. Generally there was high frequency of dry spells of at least 5 days length in all the sites with Kiamaogo site having the highest (84 occurrences during LR season) and Kiambere having the least (44 occurrences during LR season) in 10 years. The occurrence of dry spells longer than 15 days in a season was more rampant in the lower altitude parts (semi-arid regions) of the study area as reflected by the Kiambere, Kiritiri, Machang'a and Kamburu sites in both seasons. For the higher altitude regions, average LR onset, representative of the normal/conventional growing period, ranged from 22nd to 26th March to end of April in the region. For the lower altitude region, it ranged from 16th to 30th March. For SR, onset was generally earlier in the high altitude areas with Kiamaogo having the earliest on 13th October. In the low altitude region, onset was comparatively late compared to the higher potential region, but unlike the LR season, spatial and temporal variation was narrower. The high frequency of dry spells more than 15 days long, coupled with the generally low total amount of rainfall receive per season makes agriculture a risk venture. Homogeneity test revealed that the generated onset and cessation dates for the two rain seasons were homogeneous over the 10 years for each of the seven stations. This indicates that, there has been no shift in onset and cessation within the period under consideration. Dynamic derivation of the spatial onset and cessation data at a local scale can be useful in monitoring shifts in onset dates and hence advice small scale farmers and other stakeholders in agriculture sector accordingly in the quest for enhanced agricultural productivity.

1. Introduction

East Africa and Kenya in particular is characterised by high rainfall variability, part of which is caused by the El Niño/Southern Oscillation (ENSO) (Shisanya, 1996; Camberlin et al., 2001). Dependence on uncertain rainfall and exposure to unmitigated climate risk are major obstacles in efforts to sustainably intensify agricultural production and enhance rural livelihoods (Hansen

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et al., 2009) in most sub-Saharan Africa (SSA) countries. Strong dependence on rain-fed smallholder farming practices has resulted in a quasi-linear relationship between grain yields, seasonal rainfall receipts, and food deficits (Funk et al., 2008). High rainfall variability coupled with low adaptive capacity makes farmers vulnerable especially because of dependence on rainfed agriculture (Osman-Elasha, 2007) given that rainfall amount and distribution is the most important environmental factor controlling successful germination and subsequent crop establishment. Hence, agricultural capacity multiplied by percent normal rainfall is strongly related to per-capita production (Funk et al., 2008). For instance, in four out of sixteen rainy seasons of the past eight years, rainfed agriculture failed in high potential areas of the central highlands of Kenya (Meru South Sub-County) and in the low potential areas (Mbeere Sub-County), total crop failure occurs every other season while rainfall is erratic in the remaining seasons. The amount of water available to plants strongly depends on the rainy season's onset, length, cessation (Ati et al., 2002) and rainfall temporal distribution, hence can determine a success or failure of a season. For example, the failure of consecutive rainy seasons of the East African short rains (typically October–December) and subsequent long rains (March–May) plunged much of the region into severe drought, impacting millions of people and triggering a humanitarian crisis in 2011 (Lyon and Dewitt, 2012).

The uncertainty associated with rainfall variability is a disincentive to investment and adoption of agricultural technologies and market opportunities. It prompts the risk-averse farmers to favour precautionary strategies that buffer against climatic extremes over activities that are more profitable on average (Hansen et al., 2009) as available soil water in drought years limits returns on investment, for instance, the fertilizer. Dry spell analysis of weather data from a site in Machakos district with similar characteristics as low potential areas of the central highlands of Kenya reveals that, maize on a sandy soil is exposed to a dry spell exceeding 15 days in more than three out of five seasons (Barron et al., 2003). Analysing rainfall data from a nearby Murang'a district in central province, Ovuka and Lindqvist (2000) found that, farmers' perception that rainfall has decreased over the last 40 years is not reflected in a decrease of the total rainfall amounts, but there were indications for more frequent dry spells towards the end of the short rains season. This has considerable impact on agricultural productivity, market dynamics and hampers incentives for investments in agriculture.

Furthermore, future adaptations in response to climate change and rapid population growth are expected to intensify dependence upon rainfall in most smallholder farming systems in SSA (Mélanie et al., 2010). Besides rainfall variability, Kenya's extensive arid and semi-arid lands, characterised by dependence on low (690 mm year^{-1}) and unreliable rainfall, are representative of the extensive dryland regions of sub-Saharan Africa (Hansen et al., 2009). Given that food security critically hinges on investments in agricultural water management, with an emphasis on locally adapted rain water management measures (Hoff et al., 2010) there is need to understand the rainfall pattern. Onset and cessation are important variables to which all the other seasonal variables are related (Stewart, 1991). Onset seldom occurs abruptly and is often preceded by short isolated showers with intermittent dry spells of various lengths, which are often misinterpreted as the start of the rains (false starts) (Laux and Kunstmann, 2008). Knowledge of the onset, cessation, and, thus, of the length of the growing/rainy season significantly supports the timely preparation of farmland, mobilisation of seed/crop, manpower, and equipment, and most likely reduces the risk of planting and sowing too late or too early (Omotosho et al., 2000).

Uneven seasonal distribution of rainfall may expose agricultural practices to a range of mild to severe intra-seasonal dry spells, which may subsequently affect the agricultural productivity adversely. Different types of water limitation can seriously affect crop production. Dry spells are prolonged periods between rain events within the season (Fox and Rockström, 2005). According to Barron et al. (1999) and Fox and Rockström (2000), the period length of a dry spell will, for grain cultivation in semi-arid tropical conditions in Sub-Saharan Africa, generally range between 5 and 15 days. Dry spells affect crop production depending on their timing and magnitude with respect to crop growth stages and sensitivity to water stress (Ngigi et al., 2005). This implies that, understanding the nature and occurrence of dry spell is of importance especially for the rainfed farmers who has less access to irrigation facilities as they search for mitigation (Makurira et al., 2009).

Information about growing season characteristics in relation to rainfall pattern can help small scale farmers in making informed decisions in designing strategic planting management options that increase the chance for a successful and profitable season. Therefore, understanding the rainfall distribution within and between seasons as well as the onset and cessation of the rain contributes to knowledge of the length of growing period and indirectly indicates the climatic suitability of the crop (Araya et al., 2010). Hence, the objective of the study was to determine rainfall pattern; quantity, temporal distribution, onset, cessation and length of growing season.

2. Methodology

The study was conducted in the Central highlands of Kenya (CHK) covering four Sub-Counties: Maara and Meru South Sub-Counties in Tharak Nithi County and Mbeere North and Mbeere South Sub-Counties in Embu County. The CHK produces about 20% of the country's maize, cover both areas with high potential for crop production on inherently fertile Nitisols, and those of low potential attributed to lower rainfall and/or less fertile soils (Ferralsols, shallow and sandy soils) (Jaetzold et al., 2006). Rainfall pattern of CHK is bimodal with long rains (LR) coming from mid March to June and short rains (SR) from mid October to February, hence two cropping seasons per year. Just like rainfall patterns over much of East Africa, the bimodal rainfall regime moderated by coastal and topographic influences (Mutai et al., 1998).

Mbeere North and South Sub-Counties in Embu County lie on the South-Eastern slopes of Mount Kenya in the Lower Midland Agro-ecological Zone 3, 4 and 5 (LM3, 4, and 5). The LM 3 is a cotton (*Gossypium hirsutem*) zone while LM4 and LM5 are Marginal Cotton and livestock-millet zones, respectively, characterised by a short to very short cropping season (Fig. 1a). These zones are suitable for common beans (*Phaseolus vulgaris*), Dry land Composite and hybrid maize (*Zea mays*), sorghum (*Sorghum bicolour*) green grams (*Vigna radiata*), cowpeas (*Vigna unguiculata*), chick peas (*Cicer arietinum*) among other pulses (Jaetzold et al., 2006). Mean annual temperature ranges from 20.7 to 22.5 °C with average annual rainfall ranging between 700 and 900 mm. The Sub-Counties are characteristic of marginal region with low agricultural potential. Currently, it is experiencing increase in population pressure resulting from an influx of immigrants from the over-populated neighbouring high potential areas. It is representative of semi-arid agro-climatic conditions with relatively low agricultural production potential. Although the region is more suitable for drought tolerant crops and livestock rearing (Jaetzold et al., 2006), major crops grown by most households are maize (*Zea mays*), cowpeas (*Vigna unguiculata*), pigeon peas (*Cajanus cajan*) and common beans (*Phaseolus vulgaris*).

Meru South and Maara South Sub-Counties lie on the eastern slopes of Mount Kenya and are representative of the densely populated high potential humid area (Fig. 1a). Annual mean temperature

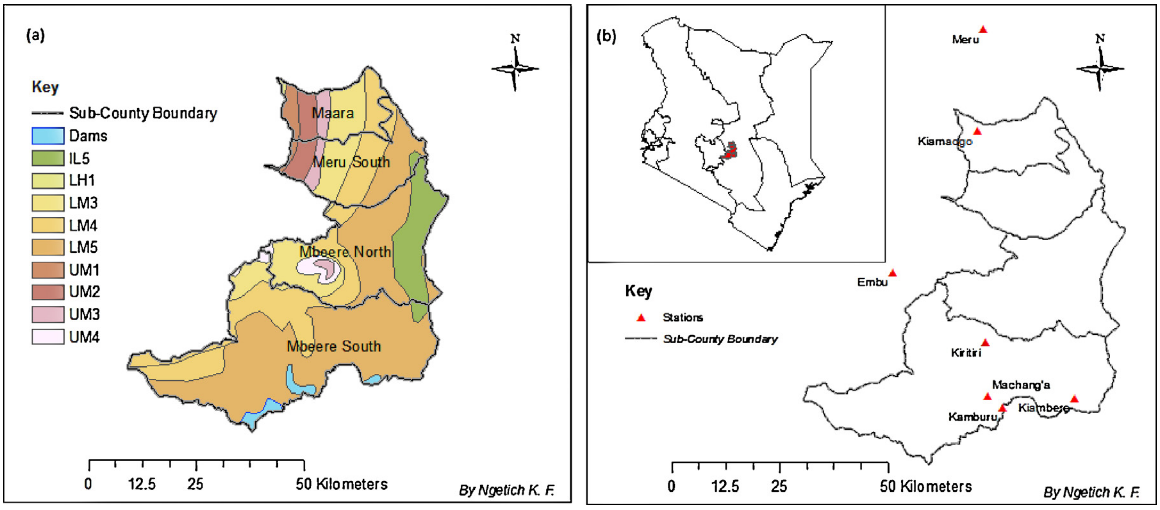

Fig. 1. Maps showing the prevailing agro-ecological zones (a) and the rain gauged stations (b) of the four Sub-Counties; Maara, Meru South, Mbeere North and Mbeere South.

is 20 °C and total annual rainfall range from 1200 to 1400 mm with an altitude ranging from 600 to about 2000 m above the sea level. Major crops grown are beans (*Phaseolus vulgaris*), Irish potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), cabbages (*Brassica oleracea*), kales (*Brassica oleracea L.*), tomatoes (*Solanum lycopersicum*), onions (*Allium Cepa*), maize (*Zea mays*). It is a predominantly maize growing zone with smallholdings ranging from 0.1 to 2 ha with an average of 1.2 ha per household. The four Sub-Counties are representative of both semi-humid and semi-arid agro-climatic conditions of the central Highlands of Kenya and those of East Africa at large where rainfed agriculture is predominant. The farmers in the region primarily rely on small-scale rainfed farming, which is mostly non-mechanized and involves minimal use of external inputs.

2.1. Data

Daily rainfall data used in this study were obtained from the Kenya Meteorological Department (KMD) and research stations within the study region. Rainfall stations with at least 10 years old daily rainfall data and minimal missing values were selected. Missing values at all stations were estimated by using the inverse distance weighting methodology (Longley et al., 2001) (Eq. (1)).

$$y_t = \frac{\sum_{i=1}^{m} x_t^i / D_i^2}{\sum_{i=1}^{m} 1/D_i^2} \qquad (1)$$

where y_t is the estimated value of the missing data, x_t^i is the value of the ith nearest weather station, m ranges from 2 to 5, and D_i is the distance between the target station and the ith nearest weather station.

Based on the above criteria, seven meteorological stations were selected (Fig. 1b). The stations were: Embu, Kamburu, Kiamaogo, Kiambere, Kiritiri, Machang'a and Meru. Other characteristics of the stations are presented in Table 1.

2.2. Analysis temporal distribution and dry spells

Temporal distribution of the average daily rainfall in the selected stations was done by first separating the daily rainfall data according to the LR and SR seasons. Cumulative precipitation throughout the season was then calculated. To highlight the rainfall distribution over time, daily rainfall was presented cumulatively as a fraction of the total received rainfall per season per station. Although the definition of a dry spell may vary, depending on the aims and methodology used in each study, it generally refers to n consecutive days without appreciable rainfall. An important aspect is the definition of a significant rainfall threshold in the typification of a dry day (Angel, 2004). There are various thresholds in use, for instance, Martin-Vide and Gomez (1999) used 0.1 mm, a threshold often used with respect to the usual precision of raingauges. Lazaro et al. (2001) employed a threshold of 1 mm, based on the assumption that rainfall less than this amount is evaporated off directly. Perzyna (1994) used a threshold of 2 mm in order to remove any events featuring less rainfall and with very little significance in river flow, due to losses by interception and evaporation. Here, we adopted a threshold of 1 mm, based on the same argument as that of Angel (2004); with rainfall lower than that figure, the water remains at the surface of the soil or on its plant cover, from where it readily returns to the atmosphere through evapotranspiration. The number of times when dry spells exceeded 5, 10 or 15 consecutive days during long and short rains seasons for the selected climatic stations were computed.

2.3. Onset, cessation and length of growing season, frequency analysis

The parameters computed were: onset, cessation and length of growing season. Given that frequency/statistical analysis of rainfall data requires that data be homogeneous and independent, homogeneity test was done. Homogeneity test was conducted using RAINBOW software (Raes et al., 2007) which is based on the cumulative deviations from the mean (Eq. (2)).

$$S_k = \sum_{i=1}^{k} (X_i - \bar{X}) \quad k = 1, \ldots, n \qquad (2)$$

where X_i are the records from the series $X_1, X_2, \ldots, X_n$ and the mean. The initial value of S ($k = 0$) and last value S ($k = n$) are equal to zero. For a homogenous record it is expected that the Sk's fluctuate around zero since there is no systematic pattern in the deviations of the X_i's from their average value $\bar{X}$.

To test the homogeneity of the data set, the cumulative deviation is rescaled and plotted. By evaluating the maximum (Q) or the range (R) of the rescaled cumulative deviations from the mean, the homogeneity of the data of a time series was tested (Eqs. (3) and (4)). High values of Q or R are an indication that the data of the time series is not from the same population and that the fluctuations are

Table 1
Characteristics of the seven meteorological stations used in the study.

Station name	Record (years)	Mean annual rainfall (mm)	Climate	Data
Embu	10	1210	Humid	*P*, *Temp*
Kamburu	10	654	Semi-humid	*P*
Kiamaogo	11	1839	Humid	*P*
Kiambere	10	1041	Semi-humid	*P*
Kiritiri	10	934	Semi-humid	*P*
Machang'a	11	781	Semi-humid	*P*, *Temp*
Meru	11	1243	Humid	*P*, *Temp*

not purely random. Homogeneity of the data set can be rejected with 90, 95 and 99% probability, respectively.

$$Q = \max\left[\frac{S_k}{s}\right] \tag{3}$$

$$R = \max\left(\frac{S_k}{s}\right) - \min\left(\frac{S_k}{s}\right) \tag{4}$$

Frequency analysis and determination of onset and cessation was done using RAIN software (Kipkorir, 2005). In the analysis, it was assumed that the onset of rains and the start of growing season were identical and were defined as receipt of sufficient rain for survival of seedlings after sowing. Given that there are several ways of determining onset of growing period (Marteau et al., 2009, 2011; Raes et al., 2004; Frère et al., 1990; Stewart, 1991; Sivakumar, 1988) the criteria of determining onset date is ambivalent. Since several definitions exist at different scales and its estimation always need subjective tuning; namely amount of rainfall and length of the initial wet spell, length and intensity of post-onset dry spell, etc. (Marteau et al., 2011) the choice of a criteria used was guided by the prevailing agro-climatic conditions of the study area. The criterion used in defining the onset was based on agroclimatic onset concept of Sivakumar (1988), Marteau et al. (2009, 2011). It was defined as the first wet day with at least 25 mm accumulated rainfall received for the semi-humid region and 30 mm for the humid during a maximum of 3 and 5 successive days, respectively, from new rains. Lag time of the season was set at 7 days after onset. The threshold for a rainy day was set at 0.85 mm (Shisanya, 1996). For cessation criteria, soil water balance was used to determine the date on which the set threshold water stress coefficient (Ks) was exceeded. It was assumed that Ks below 40% caused rapid water stress to crops and hence, the end of a growing season was taken as the date when Ks was less than 40% (Mugalavai et al., 2008). Prior to the actual determination of the onset and cessation of the growing season, search dates were specified that encompass the normal rainy period, that is; average early date at which the rainy season starts and the onset criteria were specified only in terms of the rains thereafter.

2.4. Spatial presentation of onset and cessation dates

Once the onset and cessation dates of the selected (point data) stations were determined, they were used as input in generating their spatial representation (maps) of both long and short rains seasons throughout the study area. Digital elevation model (DEM) raster was used to generate a 200 m interval contour feature in ArcGIS 9.3, which was further converted to point feature in order to generate substantial elevation points (1921) within the study area (Fig. 2a). The process resulted to numerous elevation data points (Fig. 2b).

Onset and cessation dates derived from the RAIN software were plotted and best fits were generated using scatter plot and trend lines in MS excel spread sheet. Based on goodness of fit of the relationship between the dates and elevation, the resulting functions were used to generate onset/cessation for elevation points by adding fields (Onset LR and SR; Cessation LR and SR) into the contour point feature shapefile attribute table and applying the functions using field calculator with the elevation point being *x* in ArcGIS 10.1 environment. Kriging method of interpolation in spatial tools was applied to generate the maps. For simplification purposes, hierarchical process followed is shown in a flowchart, Fig. 3.

3. Results and discussion

The length of dry spells can strongly affect crop growth and productivity. Table 2 shows the *n* number of times when dry spells exceeded 5, 10 and 15 consecutive days during long and short rains

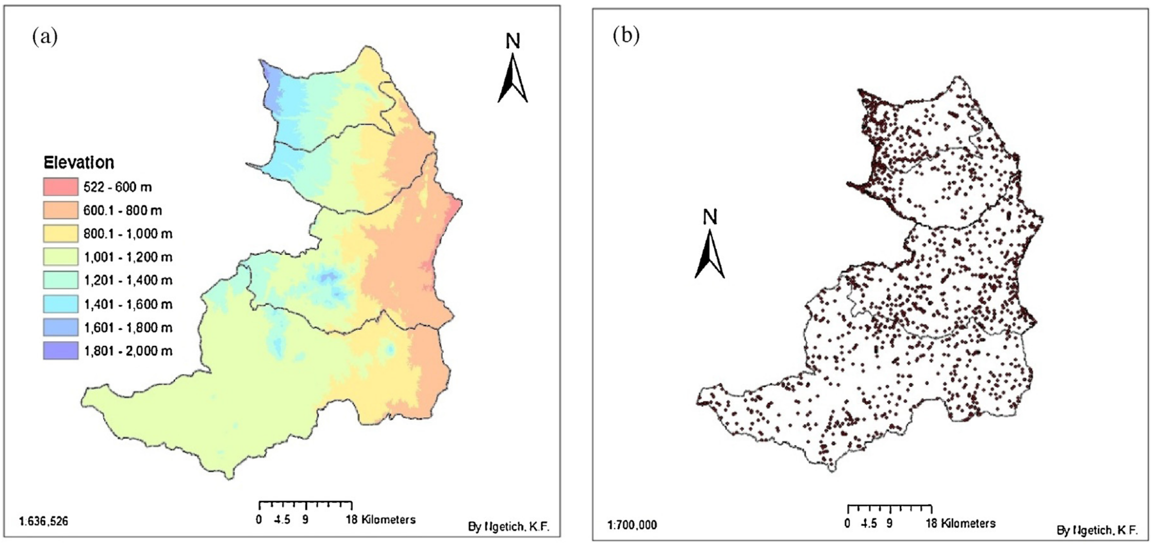

Fig. 2. Classified (200 m interval) elevation (a) and contour points (b) maps of the study area.

Table 2
Number of times when dry spells exceeded 5, 10 and 15 consecutive days during long and short rains for the selected climatic stations.

Year	Site																										
	Embu				Kamburu				Kiamaogo				Kiambere				Kiritiri				Machang'a				Meru		
	>5	>10	>15		>5	>10	>15		>5	>10	>15		>5	>10	>15		>5	>10	>15		>5	>10	>15		>10	>5	>15
Long rains season																											
1999	6	1	1		5	3	3		10	1	1		4	3	3		7	4	4		8	5	1		7	4	3
2000	9	3	1		4	3	3		9	2	2		1	1	1		7	6	4		4	3	1		8	4	3
2001	10	1	1		7	4	3		8	2	1		4	2	2		6	3	3		9	6	1		6	3	2
2002	7	2	1		4	2	2		7	3	2		5	2	2		6	3	3		6	5	1		3	3	2
2003	7	2	1		5	3	3		7	4	2		4	4	3		7	4	2		4	4	1		7	4	3
2004	8	4	1		3	3	2		7	6	4		4	3	2		8	3	3		3	4	1		7	6	4
2005	4	1	0		8	4	2		9	3	1		7	2	3		10	6	2		8	7	1		6	3	1
2006	4	1	0		4	2	2		8	3	2		4	3	2		9	5	2		6	2	1		4	3	3
2007	4	2	2		8	5	3		7	2	2		7	5	3		5	3	2		10	5	1		7	3	1
2008	5	1	1		3	3	1		6	2	1		3	2	1		3	1	1		3	2	1		7	5	2
2009	3	1	1		1	1	1		6	2	1		1	1	1		1	1	1		7	4	1		9	3	1
Total	67	19	10		52	33	25		84	30	19		44	28	23	0	69	39	27		68	47	11		71	41	25
Short rains season																											
2000	4	1	1		3	2	2		3	2	2		6	4	2		5	2	2		4	3	1		4	3	3
2001	9	3	2		7	5	3		8	5	1		4	3	2		7	5	2		4	1	1		8	3	2
2002	5	4	2		6	3	2		5	2	2		5	3	3		5	3	2		7	3	1		4	2	1
2003	3	1	1		5	3	3		6	2	1		7	3	3		6	4	3		5	4	1		2	2	1
2004	6	4	2		7	4	4		6	5	4		6	4	3		6	4	4		6	3	1		7	3	1
2005	4	4	3		5	4	3		9	4	2		8	4	3		6	4	2		6	3	1		5	2	1
2006	9	4	2		7	4	3		7	3	1		8	6	3		8	5	3		6	4	1		7	3	3
2007	5	3	1		4	2	1		5	2	1		6	3	1		7	4	3		5	2	1		4	1	0
2008	4	3	2		6	3	2		5	3	2		6	4	1		5	3	3		8	5	1		3	2	1
2009	6	5	3		1	1	1		9	2	1		1	5	2		1	1	1		9	5	1		4	2	1
2009	5	1	2		1	1	1		4	3	3		1	1	1		1	1	1		4	4	1		6	1	1
Total	60	33	21	0	52	32	25	0	67	33	20	0	58	40	24	0	57	36	26	0	64	37	11	0	54	24	15

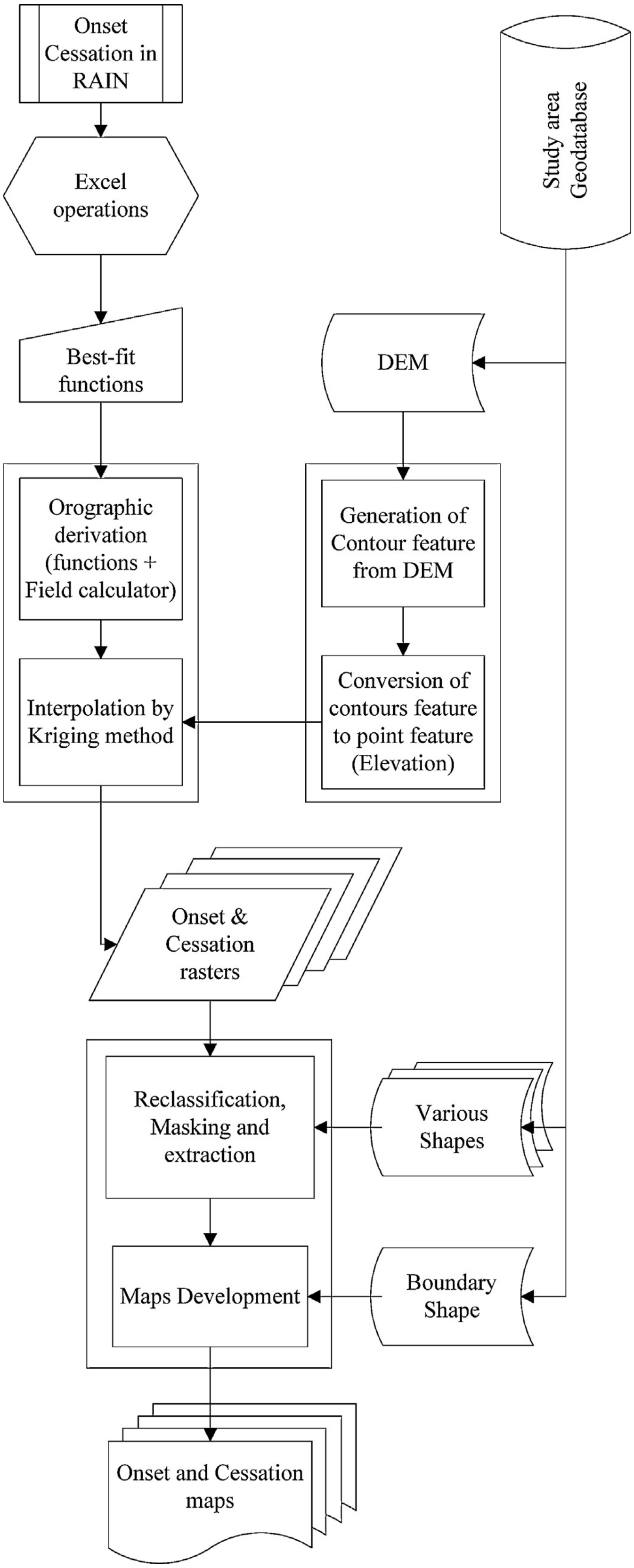

Fig. 3. Flowchart showing the process followed in onset and cessation map development.

seasons over time. Generally there was high frequency of dry spells of at least 5 days length in all the sites with Kiamaogo site having the highest (84 occurrences during LR season) and Kiambere having the least (44 occurrences during LR season) in 10 years. The high frequency in Kiamaogo was associated with the prevailing rainfall pattern which is on average evenly distributed and more rainfall events throughout the season as shown in Fig. 5. On the other hand, Kiambere site had lower rainfall events and experienced more frequent early cessations leading to most rainfall events being received within a short span of time at the beginning of the season (Figs. 5 and 7). Analysis of dry spell occurrence, which can be a measure of the risk of losing capital investment and food self-reliance, can guide in the choice and implementation of on-farm strategies that can mitigate against its effects (Fox and Rockström, 2005). It can be a starting point of overcoming the water for food challenge, which more over to large extent has to focus on upgrading rainfed smallholder farming in tropical sub-humid and a semi-arid characterised by water scarcity and frequent dry spells.

Homogeneity test of the rainfall data from the selected stations revealed that the generated onset and cessation dates for the long rains and short rain seasons were homogeneous over the past 10 years for each of the 7 stations. This indicates that there has been no shift in onset and cessation in the past 10 years. Probability analysis for a wet day for the selected climatic station for the two seasons categorised the data in a systematic manner in relation to elevation. Based on the probability Kiritiri, Machang'a, Kamburu and Kiambere showed lower probability for a wet day and even had zero values during off season while Embu, Meru and Kiamaogo stations' probability was higher, not only within the rainy season but throughout the entire year. In both regions, LR probability was generally lower while the SR was higher. The overall distribution of the probability exhibited the bimodal nature of rainfall in the central highlands of Kenya highlighting the existence of two seasons (Fig. 4).

The results showed that the temporal distribution of rainfall in the selected sites varied significantly. Kiamaogo site showed a wider distribution with 50% of the rainfall occurring as early as 18th April and 22nd October and 90% on 8th June and 16th January for LR and SR seasons, respectively (Fig. 5). On the other extreme was the Kiambere site, LR season with most of the rainfall events occurring too early compared to the other stations and SR season; 50% and 90% of the total rainfall was received by 8th April and 7th May, respectively. On average, LR season showed a more erratic rainfall pattern and a shorter rainy length in the different sites compared to the SR season. This is also reflected in the length of the rainy season as shown in Table 3 that reflects SR to be superior season compared to LR. The observation conforms Meehl et al. (2007) that, there is generally enough water on the total, it is simply very poorly re-distributed over time, with often 25% of the rain falling within a couple of rainstorms, that crops suffer from water stress, often leading to complete crop failure.

For the high potential area, average LR onset, representative of the normal/conventional growing period, ranged from 22nd to 26th March to end of April in the region (Table 3). For the low potential region, it ranged from 16th to 30th March depicting higher spatial and temporal variability. For SR, onset was generally earlier in the high potential area with Kiamaogo having the earliest on 13th October while Meru was latest on 22nd October. In the low potential region, Mbeere, onset was comparatively late compared to the higher potential region, but unlike the LR season, spatial and temporal variation was narrower (Table 3).

Based on Lyon and Dewitt (2012) study on recent and abrupt decline in the East African long rains, the rainfall variability of SR can be explained by increased tropical Atlantic or Indian Ocean sea surface temperatures (SSTs) while for LR it appears to be primarily forced by large scale SST changes mainly in the tropical Pacific.

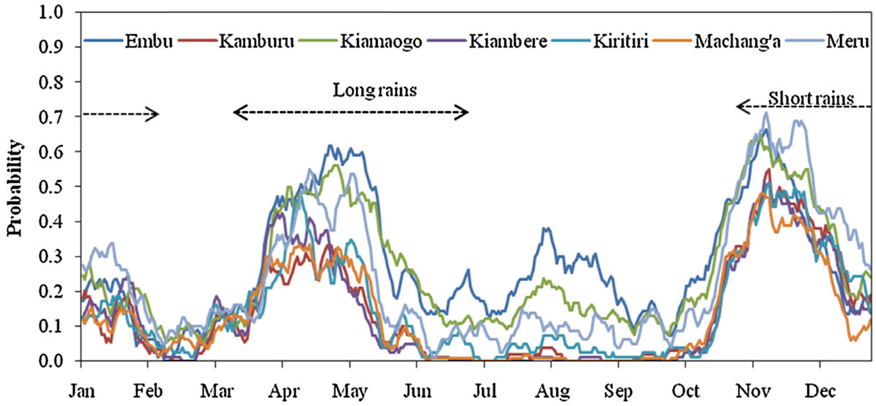

Fig. 4. Probability for a wet day for the selected climatic station for the two seasons.

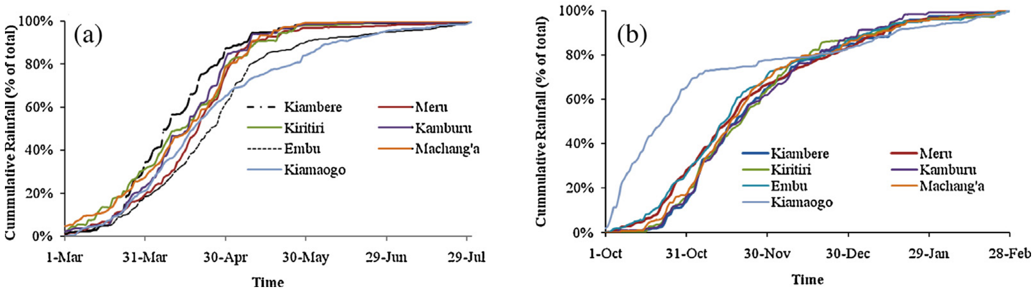

Fig. 5. Temporal distribution of average daily rainfall as a percentage of the total rainfall received over the LR (a) and SR (b) seasons in the selected climatic station.

Increasing SSTs in tropical Atlantic or Indian Ocean region favour a local enhancement of precipitation with the resultant latent heating altering regional wind and moisture flux patterns, ultimately reducing long rains precipitation (Funk et al., 2008) and hence the shorter growing length. Kiamogo had the latest cessation date on 28th May and Meru had the earliest, on 14th May in high potential area during the LR season. This resulted to a growing length of between 53 and 66 days of sufficient rainfall. In low potential area, Kiambere had the earliest cessation date (28th April) and kiritiri was the latest, even though the difference with Machang'a and Kamburu was one and two days (9th, 8th, and 7th May, respectively). Based on the growing length, Machang'a had the least (39 days) length while Kiritiri had the longest (48 days) in the region. Cessation and growing length during the SR season showed the same trend as that of LR in the high potential region while in the low potential region, Machang'a had the earliest cessation date (6th December) while Kamburu had the latest (20th December). Except for Kiritiri, the growing length during SR was generally longer for all the stations compared to the LR season.

During the LR season, the onset in the study area generally showed a gradual progression from the Eastern part of the study area towards the west. Towards the southern part, the onset dates were late and covered a larger area compared to the Northern part which is generally on a higher elevation. The existence of many onset dates on the Eastern part of the study area might be indicative of the erratic nature of rainfall, although there was a general indication of early onset dates (between 17th February and 11th March) (Fig. 6a).

On the North Westerly part, the onset dates were generally early. On average, LR season showed a wider planting dates spanning from mid February to Early April and higher spatial and temporal variations. Onset dates of SR season showed a comparatively reliable onset dates based on the early and latest onset (Fig. 6b). High potential area (Maara and Meru South) had the earliest onset dates spanning from 17th September to 20th October. In Mbeere South and North Sub-Counties, there were only 3 major onset dates from 18th October to 1st November, a small window of about 10 days. Based on the difference between the earliest and latest onset date, SR season seemed to have a more homogenous and fewer onset dates compared to LR.

Rainfall cessation for the LR was generally slow from the Eastern part towards North Western and ranged from early April to almost mid June (Fig. 7a). The direction of cessation with respect to time and due to the agro-climatic nature of the study area is probably due to orographic nature of rainfall. Cessation pattern during the SR exhibited higher homogeneity spanning from 8th December to

Table 3
Onset dates, cessation dates and length of the rainy LR and SR seasons for the selected climatic station.

Site	Onset		Cessation		Length	
	LR season	SR season	LR season	SR season	LR	SR
Embu	24th March	18th October	19th May	24th December	56	67
Kamburu	26th March	29th October	7th May	20th December	42	52
Kiamaogo	23rd March	13th October	28th May	22nd December	66	70
Kiambere	16th March	24th October	28th April	12th December	43	49
Kiritiri	22nd March	28th October	9th May	12th December	48	45
Machang'a	30th March	20th October	8th May	6th December	39	47
Meru	22nd March	22nd October	14th May	20th December	53	60

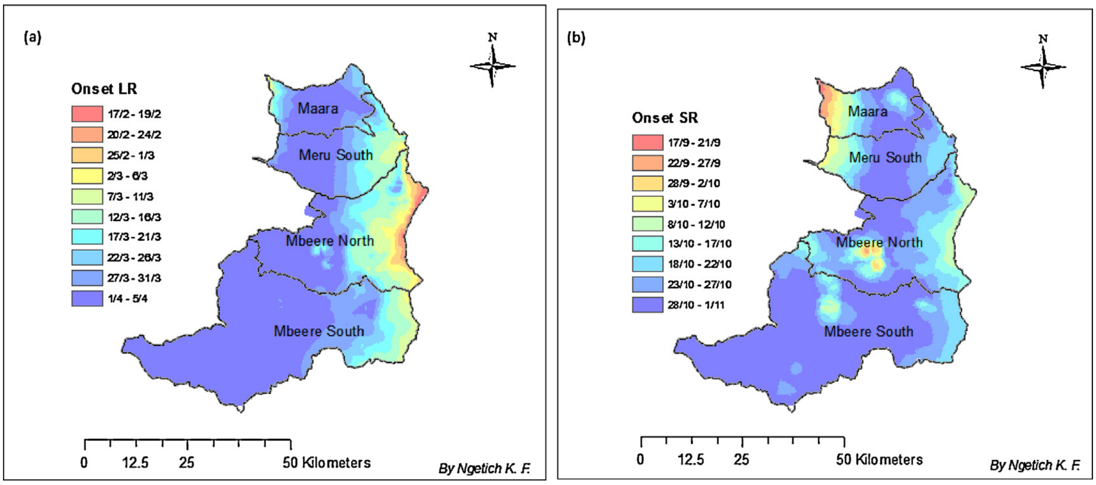

Fig. 6. Maps showing onset dates of LR (a) and SR (b) seasons of the study area.

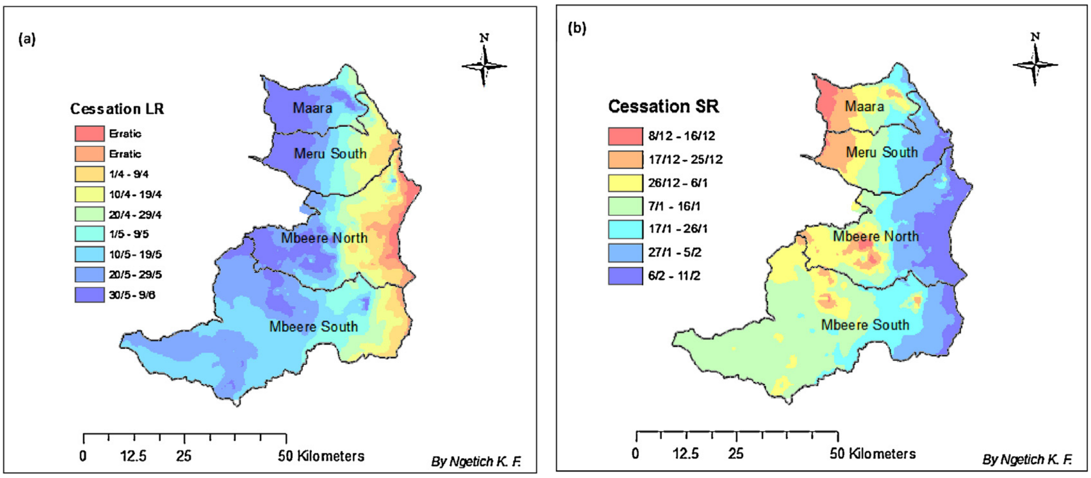

Fig. 7. Maps showing cessation dates of LR (a) and SR (b) seasons of the study area.

11th January. Unlike the LR, the direction of early and late cessation was generally from Western parts towards the Eastern direction in SR season (Fig. 7b). On the Western region, cessation was more homogeneous while in the Eastern parts, there were a number of cessation dates within narrower spatial span.

As observed by Recha et al. (2011), variations of onset and cessation 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. Late onset and early cessation as observed in both Mbeere South and North translates to shorter growing period and higher prevalence of crop failure as observed by Araya and Stroosnijder (2011). The potential impact on the smallholder farmers is increased susceptibility to food insecurity and reluctance to invest in agriculture related enterprises.

The occurrence of dry spells longer than 15 days in a season was more rampant in the drier parts of the study area as reflected by the Kiambere, Kiritiri, Machang'a and Kamburu sites in both seasons. The high frequency of more than 15 days long dry spells in the semi-arid areas of the study area, coupled with the generally low total amount of rainfall receive per season makes agriculture a risk venture. The dry spells can affect crop production depending on their timing and magnitude with respect to crop growth stages and sensitivity to water stress (Ngigi et al., 2005).

The rainfall analysis study established the most probable onset date, cessation date and growing length per season. It further boosted a better understanding of the spatial and temporal distribution of especially the onset of the rainy season as it appears to be the most crucial information (Barbier et al., 2009) for agricultural management as it determines the planting period (Omotosho et al., 2000) and hence the success or failure of a season. As Hansen and Indeje (2004) stated, 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.

4. Conclusion

On average, LR season showed longer onset dates ranging from mid February to Early April and higher spatial and temporal variations. Onset dates of short rains season showed a more reliable onset dates based on the early and latest onset compared to long rains season in both agro-climatic conditions. Unlike the long rains season, the direction of early and late cessation was generally from Western parts towards the Eastern direction in short rains season. On the Western region of the study area, cessation was more homogeneous while in the Eastern parts, there were a number of cessation dates within narrower spatial span. The generated onset and cessation dates for the two rain seasons were homogeneous over the 10 years for each of the seven stations indicating that there was no shift in onset and cessation within the 10 year period.

Besides establishing the most probable onset, cessation and the length of growing season for the study area, homogeneity test revealed that the generated onset and cessation dates for the two rain seasons were homogeneous over the 10 years for each of the seven stations. This indicates that there has been no shift in onset and cessation within the period under consideration. However, continuous monitoring should be done to detect any shift if it arises in the future.

The variation of rainfall onset window presents another farmers' dilemma – when to plant to reduce the impacts of dry spells and ensure better crop yields. The uncertainty of rainfall onset adds to the number of hydrological risks encountered by the smallholder farmers in sub-humid and semiarid areas of the tropics. The analysis highlights rainfall related risks faced by farmers in sub-humid and semi arid regions which can influence decisions they have to make to improve agricultural productivity under uncertain weather related conditions.

The homogeneity test, frequency analysis, onset, cessation and growing length determination can be utilised in ex-ante scenario analysis of the potential of alternative cropping strategies and water conservation options as a means of reducing the effects of prolonged dry spell and drought on agricultural productivity in the study regions. Although the findings indicated no shift on onset and cessation within the study period, continuous monitoring should be done to detect any shift if it arises in the future.

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References

Angel, M., 2004. Analysis of rainfall trends and dry periods on a pluviometric gradient representative of Mediterranean climate in the Duero Basin, Spain. Water 58, 215–233.

Araya, A., Stroosnijder, L., 2011. Assessing drought risk and irrigation need in northern Ethiopia. Agric. Forest Meteorol. 151, 425–436.

Araya, A., Keesstra, S.D., Stroosnijder, L., 2010. Agricultural and Forest Meteorology A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. Agric. Forest Meteorol. 150, 1057–1064.

Ati, O.F., Stigter, C.J., Oladipo, E.O., 2002. A comparison of methods to determine the onset of the growing season in northern Nigeria. Int. J. Climatol. 22, 731–742.

Barbier, B., Yacouba, H., Karambiri, H., Zoromé, M., Somé, B., 2009. Human vulnerability to climate variability in the Sahel: farmer's adaptation strategies in Northern Burkina Faso. J. Environ. Manage. 43, 790–803.

Barron, J., Rockström, J., Gichuki, F., Hatibu, N., 2003. Dry spell analysis and maize yields for two semi-arid locations in east Africa. Agric. Forest Meteorol. 117, 23–37.

Barron, J., Rockström, J., Gichuki, F., 1999. Rain water management for dry spell mitigation in semi-arid Kenya. East African Agric. Forestry J. 65, 57–69.

Camberlin, P., Janicot, S., Poccard, I., 2001. Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. Int. J. Climatol. 21, 973–1005.

Fox, P., Rockström, 2000. WH for supplementary irrigation of cereal crops to overcome intra-seasonal dry spells in the Sahel. Phys. Chem. Earth (B) 25, 289–296.

Fox, P., Rockström, J., 2005. Risk analysis and economic viability of water harvesting for supplemental irrigation in semi-arid Burkina Faso and Kenya. Agric Systems 83, 231–250.

Frère, D.M., Littleboy, M., Smith, G.D., Coughlan, K.J., 1990. Optimising soil surface management in response to climatic risk. In: Russell, C., Muchow, Jennifer, A., Bellamy (Eds.), Climatic Risk in Crop Production. Brisbane, Australia, pp. 283–305.

Funk, C., Dettinger, M.D., Michaelsen, J.C., Verdin, J.P., Brown, M.E., Barlow, M., Hoell, A., 2008. Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proc. Natl. Acad. Sci. U. S. A. 105, 1–6.

Hansen, J.W., Indeje, M., 2004. Linking dynamic seasonal climate forecasts with crop simulation for maize yield prediction in semi-arid Kenya. Agric. Forest Meteorol. 125, 143–157.

Hansen, J.W., Mishra, A., Rao, K.P.C., Indeje, M., Kinuthia, R., 2009. Potential value of GCM-based seasonal rainfall forecasts for maize management in semi-arid Kenya. Agric. Syst. 101, 80–90.

Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L., Rockström, J., 2010. Greening the global water system. J. Hydrol. 384, 177–186.

Jaetzold, R., Schmidt, H., Hornet, Z.B., Shisanya, C.A., 2006. Farm Management Handbook of Kenya. Natural Conditions and Farm Information, 2nd edition. Ministry of Agriculture/GTZ, Nairobi, Vol. 11/C, Eastern Province.

Laux, P., Kunstmann, H., 2008. Predicting the regional onset of the rainy season in West. Int. J. Climatol. 342, 329–342.

Kipkorir, E.C., 2005. Software Package for Determination of Rainfall Parameters and Relative Yield Forecast. Moi University, Eldoret, Kenya, pp. 22.

Lazaro, R., Rodrigo, F.S., Gutirrez, L., Domingo, F., Puigdefafragas, J., 2001. Analysis of a 30- year rainfall record in semi- arid SE Spain for implications on vegetation. Journal of Arid Environments 48, 373–395.

Longley, P., Goodchild, Maguire, D., Rhind, D., 2001. Geographic Information Systems and Science. Wiley.

Lyon, B., Dewitt, D.G., 2012. A recent and abrupt decline in the East African long rains. Geophys. Res. Lett. 39, 1–5.

Makurira, H., Savenije, H.H., Uhlenbrook, S., Rockström, J., Senzanje, A., 2009. Investigating the water balance of on-farm techniques for improved crop productivity in rainfed systems: a case study of Makanya catchment, Tanzania. Phys. Chem. Earth 34, 93–98.

Marteau, R., Moron, V., Philippon, N., 2009. Spatial coherence of monsoon onset over Western and Central Sahel (1950–2000). J. Climate 22, 1313–1324.

Marteau, R., Sultan, B., Moron, V., Alhassane, A., Baron, C., Traoré, S.B., 2011. Agricultural and Forest Meteorology The onset of the rainy season and farmers' sowing strategy for pearl millet cultivation in Southwest Niger. Agric. Forest Meteorol. 151, 1356–1369.

Martin-Vide, J., Gomez, L., 1999. Regionalization of Peninsular Spain based on the length of dry spells. Int. J. Climatol. 19, 537–555.

Mélanie, B., Llovel, W., Cazenave, A., Gu, A., 2010. Comptes Rendus Geoscience Recent hydrological behavior of the East African great lakes region inferred from GRACE, satellite altimetry and rainfall observationsí centdela région des grands lacs d' Afrique de l' Est Comportement hydrologique ré. East. 342, 223–233.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, R.L., Watterson, I.G., Zhao, Z.C., 2007. Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change (2007): The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Mugalavai, E.M., Kipkorir, E.C., Raes, D., Rao, M.S., 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agric. Forest Meteorol. 148, 1123–1135.

Mutai, C.C., Ward, M.N., Colman, A.W., 1998. Towards the prediction of the East Africa short rains based on sea-surface temperature–atmosphere coupling. Int. J. Climatol. 18, 975–997.

Ngigi, S.N., Savenije, H.H., Rockström, J., Gachene, C.K., 2005. Hydro-economic evaluation of rainwater harvesting and management technologies: farmers' investment options and risks in semi-arid Laikipia district of Kenya. Phys. Chem. Earth 30, 772–782.

Omotosho, J.B., Balogun, A.A., 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.

Osman-Elasha, B., 2007. Africa's vulnerability to environmental stress and climate change. Tiempo 63, 3–9, www.tiempocyberclimate.org (accessed on 20.02.13).

Ovuka, M., Lindqvist, S., 2000. Rainfall variability in Murang'a District, Kenya: meteorological data and farmers' perception. Geogr. Ann. Ser. A 82, 107–119.

Perzyna, G., 1994. Spatial and temporal characteristics of maximum dry spells in Southern Norway. Int. J. Climatol. 14, 895–909.

Raes, D., Sithole, A., Makarau, A., Milford, J., 2004. Evaluation of first planting dates recommended by criteria currently used in Zimbabwe. Agric. Forest Meteorol. 125, 177–185.

Raes, D., Willems, P., Baguidi, G.F., 2007. RAINBOW–A software package for analyzing data and testing the homogeneity of historical data sets. In: Proceedings of the 4th International Workshop on 'Sustainable management of marginal drylands', Islamabad, Pakistan, 27–31 January 2006, pp. 41–55.

Recha, C., Makokha, G., Traore, P.S., Shisanya, C., Sako, A., 2011. Determination of seasonal rainfall variability, onset and cessation in semi-arid Tharaka district, Kenya. Theor. Appl. Climatol., 1–16.

Shisanya, C.A., 1996. Chances and risks of maize and bean growing in the semi-arid areas of SE-Kenya during expected Deficient, Normal and Above Normal rainfall of the short rainy seasons. Materialien zur Ostafrika-Forschung, Heft 14, Trier.

Sivakumar, M.V.K., 1988. Predicting rainy season potential from the onset of rains in Southern Sahelian and Sudanian climatic zones of West Africa. Agric. Forest Meteorol. 42, 295–305.

Stewart, J.I., 1991. Principles and performance of response farming. In: Muchow, Russell, C., Bellamy Jennifer, A. (Eds.), Climatic Risk in Crop Production. Models and Management for the Semi-Arid Tropics and Sub-Tropics. CAB International, Wallingford, pp. 361–382.