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Chapter 5
Seasonal Rainfall Variability and Drought Characterization: Case of Eastern Arid Region, Kenya

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Abstract Drier parts of Embu County, Eastern Kenya, endure persistent crop failure and declining agricultural productivity which have been attributed, in part, to prolonged dry-spells and erratic rainfall. Nonetheless, understanding spatial-temporal variability of rainfall especially at seasonal level, is an imperative facet to rain-fed agricultural productivity and natural resource management (NRM). This study evaluated the extent of seasonal rainfall variability and the drought characteristics as the first step of combating declining agricultural productivity in the region. Cumulative Departure Index (CDI), Rainfall Anomaly Index (RAI) and Coefficients-of-Variance (CV) and probabilistic statistics were utilized in the analyses of rainfall variability. Analyses showed 90 % chance of below cropping-threshold rainfall (500 mm) exceeding 213.5 mm (Machanga) and 258.1 mm (Embu) during SRs for one year return-period. Rainfall variability was found to be high in seasonal amounts (CV = 0.56 and 0.38) and in number of rainy-days (CV = 0.88 and 0.27) at Machang'a and Embu, respectively. Monthly rainfall variability was found to be equally high even during April (peak) and November (CV = 0.42 and 0.48 and 0.76 and 0.43) with high probabilities (0.40 and 0.67) of droughts exceeding 15 days in Embu and Machang'a, respectively. Dry-spell probabilities within growing months were high (81 %) and (60 %) in Machang'a

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and Embu respectively. To optimize yield in the area, use of soil-water conservation and supplementary irrigation, crop selection and timely accurate rainfall forecasting should be prioritized.

Keywords Cumulative-departure-index · Drought-probability · Rainfall-anomaly-index · Rainfall-variability

Introduction

Understanding spatio-temporal patterns in rainfall has been directly implicated to combating extreme poverty and hunger through agricultural enhancement and natural resource management (IPPC 2007). The amount of soil-water available to crops depends on onset, length and cessation of rainy season which influence the success or failure of a growing season (Ati et al. 2002). It's thus palpable that, climatic parameters and rainfall in particular are prime inputs of improving the socio-economic wellbeing of smallholder farmers. This is particularly important in Sub-Saharan Africa (SSA) where agricultural productivity is principally rain-fed yet highly variable (Jury 2002). Drier parts of Embu County, Eastern Kenya experience unpredictable rainfall patterns, persistent dry-spells/droughts coupled with high annual potential evapo-transpiration (2,000–2,300 mm year^{-1}) (Micheni et al. 2004). There is generally enough water on the total; however, it is poorly distributed over time (Kimani et al. 2003) with 25 % of the annual rain often falling within a couple of rainstorms, that crops suffer from water stress, often leading to complete crop failure (Meehl et al. 2007; Recha et al. (2012) noted that, most studies do not provide information on the much-needed character of within-season variability despite its implication on soil-water distribution and productivity. There has been continued interest in understanding seasonal rainfall patterns by evaluation of its variables including rainfall amount, rainy days, lengths of growing seasons and even dry-spell frequencies. Studies by Sivakumar (1991), Seleshi and Zanke (2004) and Tilahun (2006) noted high variations in annual and seasonal rainfall totals and rainy days in Ethiopia and Sudano-Sahelian regions. Studies on rainfall patterns in the region have been based principally on annual averages, thus missing on within-season rainfall characteristics (Barron et al. 2003). Nonetheless, understanding the average amount of rain per rainy day and the mean duration between successive rain events aids in understanding long-term variability and patterns (Akponikpè et al. 2008). Hitherto, the much-needed information on inter/intra seasonal variability of rainfall in the region is still inadequate despite its critical implication on soil-water distribution, water use efficiency (WUE), nutrient use efficiency (NUE) and final crop yield. To optimize agricultural productivity in the region, there was need to quantify rainfall variability at a local and seasonal level as a first step of combating extreme effects of persistent dry-spells/droughts and crop failure. Since rainfall, in particular, is the most critical factor determining rain-fed agriculture yet not homogeneous, knowledge of its statistical properties derived from long-term observation could be utilized in developing variability and drought mitigation strategies in the area.

Materials and Methods

The Study Area

The study areas is covered by agro-ecologies classified as lower midland 3, 4 and 5 (LM 3, LM 4 and LM 5), Upper midland 1, 2, 3 and 4 (UM 1, UM 2, UM 3 and UM 4), and Inner lowland 5 (IL 5) (Jaetzold et al. 2007) and lies at an altitude of approximately 500–1,800 m above mean sea level (Fig. 5.1).

It has an annual mean temperature ranging from 21.7 to 22.5 °C and average annual rainfall of 700–900 mm. It has a population density of 82 persons per km^2 with an average farm size less than 5.0 ha per household. The rainfall is bimodal with long rains (LR) from mid-March to June and short rains (SR) from late October to December hence two cropping seasons per year. The soils are predominantly Ferralsols and Acrisols (Jaetzold et al. 2007). Various agricultural-based studies have been carried out in the region hence the rationale behind its selection. According to Mugwe et al. (2009), the region has experienced drastic declines in its productivity potential rendering its populace resource poor. There is a secure tenure system on land ownership but underscore in productivity due to inadequate information on the rainfall patterns. The prime cropping activity is maize intercropped with beans though livestock keeping is equally dominant. Mbeere Sub-county represents a sub-humid climate region, with annual average rainfall of 781 mm while Embu is more humid with annual average rainfall above 1,210 mm (Table 5.1).

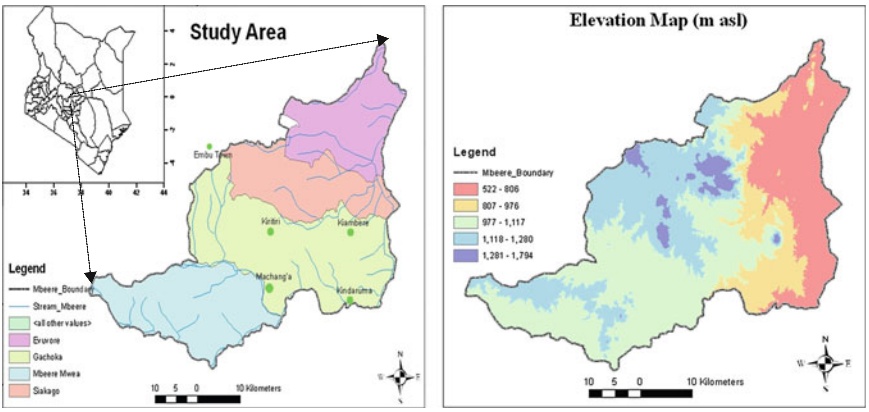

Fig. 5.1 Map showing the study area and its elevation with selected point gauged rainfall data; Machang'a and Embu, Kiritiri, Kindaruma and Kiambere

Table 5.1 Selected agro-climatic characteristics of the meteorological stations (Embu and Machang'a) used in the study

Station	Latitude	Longitude	Altitude	Period of record	Rainfall	Climate	Data
Embu	0°30′S	37°27′E	1409	13	1,210	humid	R
Machang'a	0°46′S	37°39′E	1,106	13	781	s-humid	R

Daily rainfall, and maximum/minimum temperature and solar radiation data were sourced from both the Kenya Meteorology Department and research sites with primary recording stations within Mbeere Sub-county. The choice of rainfall stations used relied on the agro-ecological zones, the percentage of missing data, [less than 10 % for a given year as required by the world meteorological organization (WMO)].

Data Analyses

Daily primary and secondary rainfall time series were captured into MS Excel spread-sheet where seasonal rainfall totals for both Short Rains (SR) and Long Rains (LR) [that is, March-April-May (MAM) and October-November-December (OND) respectively], annual average and number of rainy days were computed. Multiple imputations were utilized to fill in missing daily data through creation of several copies of datasets with different possible estimates. The multiple imputation method was preferred to single imputation and regression imputation as it appropriately adjusted the standard error for missing data yielding complete data sets for analysis (Enders 2010). Being a season-based analysis, the cumulative impact of rainfall amount was underpinned. A rainy day was considered to be any day that received more than 0.2 mm of rainfall. Daily rainfall data were captured into the *RAINBOW software* (Raes et al. 2006) for homogeneity testing based on cumulative deviations from the mean to check whether numerical values came from the same population. The cumulative deviations were then rescaled by dividing the initial and last values of the standard deviation by the sample standard deviation values; as in the Eq. (5.1) below;

$$S_k = \sum_{i=1}^{k} \left(X_i - \overline{X}\right) \qquad \text{when } k = 1, \ldots, n \tag{5.1}$$

where S_k is the Rescaled Cumulative Deviation (RCD), n represents the period of record for $K = 1$ and also when $K = 14$.

The maximum (Q) and the range (R) of the rescaled cumulative deviations from the mean were evaluated based on number of Nil Values, Non-Nil values, Mean and Standard deviations as well as K–S values (Eqs. (5.2) and (5.3)) to test homogeneity. Low values of Q and R would indicate that data was homogeneous.

$$Q = \max\left[{}^{S_k}/_{S}\right] \tag{5.2}$$

$$R = \max\left[{}^{S_k}/_{S}\right] - \min\left[{}^{S_k}/_{S}\right] \tag{5.3}$$

where Q is maximum (max) of S_K and R in the range of S_K and Min is Minimum.

The frequency analyses were based on lognormal probability distribution with $\log_{10}$ transformation using cumulative distribution function (CDF) for both LR and SR rainfall amounts. The Weibull method was used to estimate probabilities while the Maximum Likelihood Method (MOM) was utilized as a parameter estimation statistic. Homogeneous seasonal rainfall totals for both LRs and SRs was then subjected to trend and variability analyses based on Cumulative Departure Index (CDI) and Rainfall Anomaly Index (RAI) as described in Tilahun (2006). Trend analyses based on CDI utilized normalized arithmetic means for seasonal and annual rainfall for the period of record (14 years) using Eq. (5.4).

$$CDI = (r - R)/S \tag{5.4}$$

where r is actual rainfall (seasonal or annual), R is the mean rainfall of the total length of period recorded, S is the standard deviation of the total length of period of record.

Seasonal Variability was computed in tandem with annual averages for both positive (Eq. 5.5) and negative (Eq. 5.6) anomalies using RAI.

$$RAI = +3\left(\frac{RF - M_{RF}}{M_{H10} - M_{RF}}\right) \tag{5.5}$$

$$RAI = -3\left(\frac{RF - M_{RF}}{M_{L10} - M_{RF}}\right) \tag{5.6}$$

where M_{RF} is mean of the total Length of record, M_{H10} is mean of 10 highest values of rainfall of the period of record, M_{L10} is the lowest 10 values of rainfall of the period of record.

The Coefficient of Variance (CV) statistics were utilized to test the level of mean variations in LR and SR seasonal rainfall, number of rainy days (RD) and Rainfall Amounts (RA) and t-test statistic to evaluate the significance of variation.

A dry day was taken as a day that received less than 0.2 mm rainfall. A dry spell was considered as sequence of dry days bracketed by wet days on both sides (Kumar and Rao 2005). The method for frequency analysis of dry spells was adapted from Belachew (2000) as follows: in the Y years of records, the number of times (i) that a dry spell of duration (t) days occurs was counted on a monthly basis. Then the number of times (I) that a dry spell of duration longer than or equal to *t* occurs was computed through accumulation. The consecutive dry days (1 d, 2 d, 3 d, …) were prepared from historical data. The probabilities of occurrence of consecutive dry days were estimated by taking into account the number of days in a given month *n*. The total possible number of days, *N*, for that month over the analysis period was computed as, $N = n * Y$. Subsequently the probability *p* that a dry spell may be equal to or longer than *t* days was given by Eq. (5.7): The probability q that a dry spell not longer than t does not occur at a certain day in a growing season was computed by Eq. (5.8); and probability Q that a dry spell longer than t days will occur in a growing season was calculated by Eq. (5.9) and probability that a dry spell exceeding t days would occur within a growing season was computed by Eq. (5.10) as shown below:

$$P = {}^{1}\!/_{N} \tag{5.7}$$

$$q = (1 - p) = \left[1 - \frac{1}{N}\right] \tag{5.8}$$

$$Q = \left[1 - \frac{1}{N}\right]^{n} \tag{5.9}$$

$$p = (1 - Q) = 1 - \left[1 - \frac{1}{N}\right]^{n} \tag{5.10}$$

Results and Discussion

Homogeneity Testing

Homogeneity analyses had no NIL-values (values below threshold) but 100 % Non-Nil values (above threshold) showing high homogeneity. The standard deviations (SD) of the normalized means for both LR and SR seasons were low (SD = 0.2, and SD = 0.9 and 0.1) at Machang'a and Embu, respectively, indicating restriction of variations rescaled cumulative deviations (RCD), thus high homogeneity (Table 5.2).

Table 5.2 Mean, standard deviation and R2 values for Embu and Machang'a rainfall dailies for the period between 2001 and 2013

Season	Transformation	Nil values		Mean		SD		R^2 (%)	
		Mac	Emb	Mac	Emb	Mac	Emb	Mac	Emb
LR	Log_{10}	0	0	2.4	3.2	0.2	0.9	96	94
SR	Log_{10}	0	0	2.6	2.6	0.2	0.1	94	92

Mac Machang'a, *Emb* Embu and *SD* Standard deviation; *LR* Long rains and *SR* Short rains

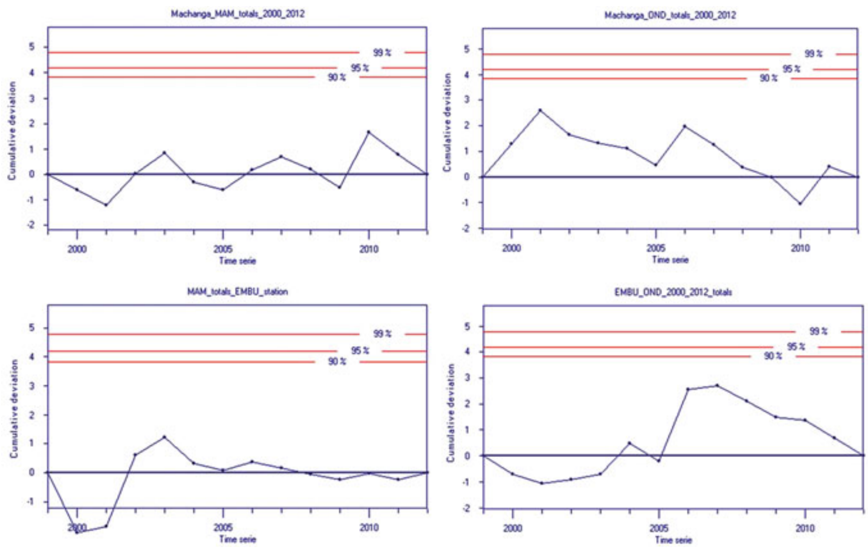

Fig. 5.2 Rescaled cumulative deviations for LR (MAM) and SR (OND) seasonal rainfall for the period between 2000 and 2013. **a** Machang'a LRs. **b** Machang'a SRs. **c** Embu LRs and **d** Embu SRs

A plot of homogeneity showed deviations from the zero mark of the RCDs not crossing probability lines thus, homogeneity was accepted at 99 % probabilities (Fig. 5.2). There was a normal distribution of the sampled-temporal rainfall data with high goodness-of-fit (R^2 = 92–96 %) of the selected distribution showing continuity of the data from mother primary data thus high homogeneity (Raes et al. 2006). Kolmogorov Smirnov values (one sided sample K–S test) showed K–S values (0.15–0.23) consistently lower than the K–S table value (0.302) for $n = 14$ at $\alpha = 0.005$ probability indicating that an exponential, continuous distribution of the studied datasets was statistically acceptable, based on the empirical cumulative distribution function (ECDF) derived from the largest vertical difference between the extracted (observed k-s value) and the table value (Table 5.3) (Botha et al. 2007; Mzezewa 2010; MATLAB Central 2013).

Frequency analyses of meteorological data require that the time series be homogenous in order to gain in-depth and representative understanding of the trends over time (Raes et al. 2006). Often, non-homogeneity and lack of exponential distributions between datasets indicate gradual changes in the natural environment (thus trigger variability) which corresponds to changes in agricultural production (Huff and Changnon 1973; Bayazit 1981).

Table 5.3 Homogeneity test for Embu and Machang'a rainfall dailies for the period between 2000 and 2013

Month	Transformation	(K–S)		N		K–S:T. value	
		Mac	Emb	Mac	Emb	Mac	Emb
LR	Log10	0.1479	0.2330	14	14	0.302*	0.302*
SR	Log10	0.1900	0.1722	14	14	0.302*	0.302*

K–S Kolmogorov Smirnov Test; *Table V* Table Value; (0.302* exponential distribution applies and accepted) *Mac* Machang'a, *Emb* Embu

Rainfall Seasonality Patterns

Results showed that there was at least 90 % chance of rainfall exceeding 172.2 and 213.5 mm during LRs in Machang'a and Embu, respectively, within a return period of about 1 year (Table 5.4). Nonetheless, there were observably low probabilities (10 %) that rains would exceed 449.8 and 763.0 mm during LR seasons in Machang'a and Embu, respectively for a 10-year return period (Table 5.4). Seasonal rainfall averages were equally low, especially in Machang'a (314.9 and 438.7 mm).

A study by Mzezewa (2010) established that seasonal rainfall amount greater than 450 mm is indicative of a successful growing season; and described it as a threshold rainfall amount. During this study, the probabilities that seasonal rainfall would exceed this threshold were quite low (at most 30 % for a return period of 3.33 years). Embu, being much wetter, would probably (50 %) receive above threshold rainfall amount (506.8 mm) after every 2 years (Table 5.4). Studies agreeing with these findings include Mzezewa (2010) who studied the semi-arid Ecotope of Limpopo South Africa. Mzezewa (2010) observed 47 % chance of seasonal-rainfall exceeding 580 mm but 0 % (no increase) of exceeding total annual rainfall for a 5-year return period.

Table 5.4 Probability of rainfall exceedance and return-periods for the LRs and SRs at Machang'a and Embu

Probability of exceedance (%)	Return period (year)	Magnitude of anticipated rainfall (mm)			
		LR		SR	
		Machang'a	Embu	Machang'a	Embu
10	10	449.8	994.7	763.0	628.8
20	5	381.4	788.9	613.1	541.2
30	3.33	338.7	667.5	523.7	485.7
40	2.50	306.0	578.8	457.7	442.9
50	2	278.2	506.8	403.6	406.3
60	1.67	253.2	443.5	356.0	372.8
70	1.43	222.8	384.5	311.1	339.9
80	1.25	203.1	325.4	265.7	305.0
90	1.11	172.2	258.1	213.5	262.5

LR Long Rains March-May-June and *SR* Short Rains October-November-December and (*mm*) millimetres

Trend of the Rainfall Events

Rainfall trends of the studied period showed that SRs and LRs in Machang'a were persistently above and below average respectively. In the former season, high rainfall was received between 2006 and 2007 (CDI = +2.5) while in the latter season, above average rainfall amounts were experienced only twice (2001 with CDI = +1 and in 2012 with CDI = +2) (Fig. 5.3). During the same period, high fluctuations in seasonal rainfall amounts were recorded in Embu. A general decline in LRs and annual averages was observed from 2003 (CDI = 1.5 and 0.5) to 2010 (CDI = −2 and −1), respectively (Fig. 5.4).

The high variability trends in seasonal and annual rainfall amounts observed in this study corroborate findings by Nicholson (2001), Hulme (2001) and Dai et al. (2004). In this study, the decade between 2000 and 2013 experienced marked increase in SRs and a decrease in LRs. Nicholson and Hulme (2001) attributed the decrease in LRs to the desiccation of the March-to-August rains in Sub-Saharan Africa (SSA). A study by Tilahun (2006) based on the cumulative departure index established that parts of Northern and Central Ethiopia persistently received below average rainfall for the rains received between February and August since 1970. While studying vegetation dynamics based on the normalized difference vegetation index (NDVI), Tucker and Anyamba (2005) noted persistent droughts and unpredictable rainfall patterns marked by reduction in the NVDI values during LRs for periods approaching the 21st century. On the other hand, it was apparent that SRs recorded consistent above-average trends during this study; indicating possibilities of a reliable growing season especially for the drier Machang'a region. In tandem with this observation, findings by Hansen and Indeje (2004) and Amissah-Arthur et al. (2002) observed that SRs constituted the main growing season in the drier parts of SSA and Great Horne of Africa for crops such as maize, sorghum, green grams and finger millet.

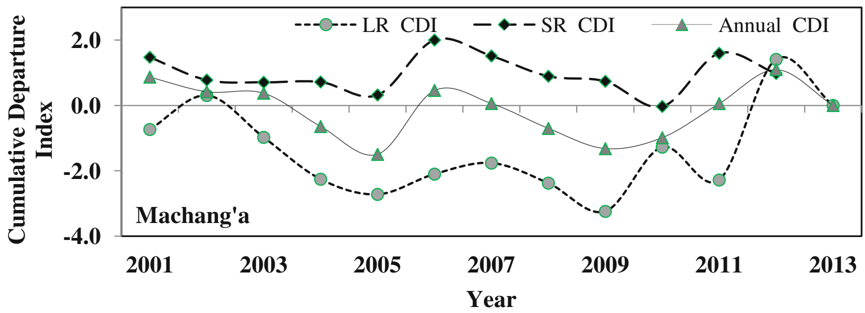

Fig. 5.3 Trend analyses based on cumulative departure index (*CDI*) for Machang'a rainfall station. (Fluctuations around, above and below the CDI zero mark corresponds to the deviations from the average rainfall for the period between 2001 and 2013)

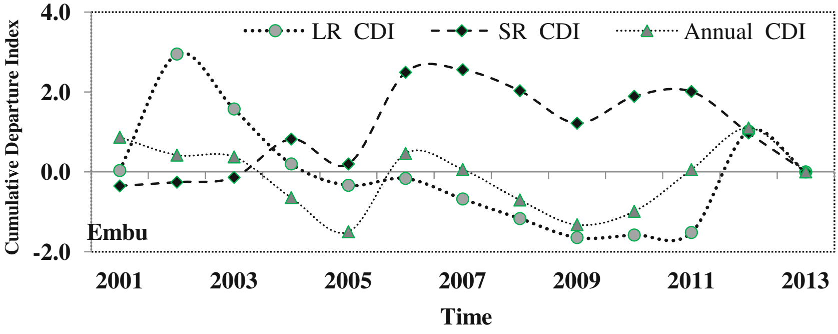

Fig. 5.4 Trend analyses based on cumulative departure index (*CDI*) for Embu rainfall station. (Fluctuations around, above and below the CDI zero mark corresponds to the deviations from the average rainfall for the period between 2001 and 2013)

Variability and Anomalies in Seasonal Rainfall Amount

There was high inter-seasonal variability and temporal anomalies in rainfall between 2001 and 2013. Results showed neither station nor season with persistent near average (RAI = 0) rainfall. The wettest LRs were recorded in 2010 (RAI = +4) while wettest SRs were recorded in 2001 (RAI = +4), 2006 (RAI = +3.8) and 2011 (RAI = +4) at Machang'a (Fig. 5.5). On overall, Machang'a recorded more negative anomalies in rainfall amount received compared to Embu.

In Embu, the highest positive anomalies (+5.0) were recorded in 2002, 2005 and 2007 during LRs (Fig. 5.6). There was an observable return period of positive anomalies after every two or three (years), e.g. 2002 (+5), 2005 (+5.0), and 2007 (+5.0) during LRs. No such distinct trend was observed in SRs (Fig. 4.5). Noticeably, Embu appeared to be receiving more near average rainfall during SRs (2002, 2003, 2007 and 2011) contrary to the trends observed in Machang'a.

An intra-station-seasonal comparison showed that SRs in Embu were less variable but more drier compared to LR seasons. Conversely, SRs in Machang'a were wetter than SRs in Embu but more variable in the former. Trends of more variable

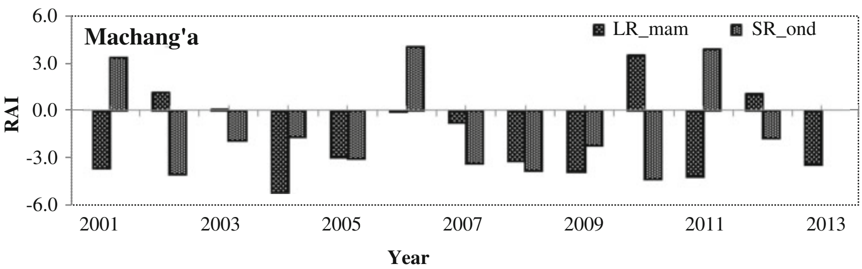

Fig. 5.5 Decadal rainfall anomaly index for both LR_MAM and SR_OND in Machang'a; Rainfall Anomaly Index (*RAI*)

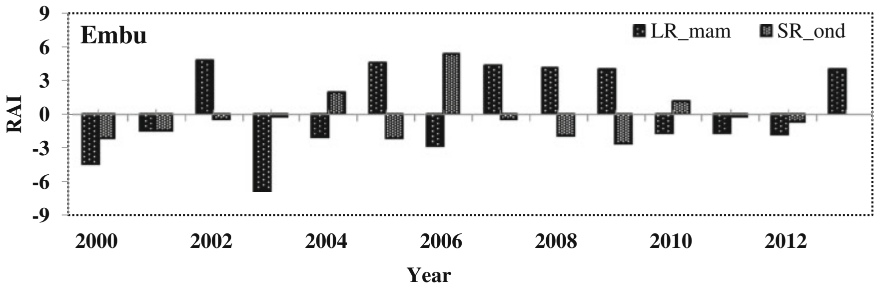

Fig. 5.6 Decadal rainfall anomaly index for both LRs and SRs in Embu site for the period between 2000 and 2013

but wetter SRs and less variable but drier LRs have been recorded in other studies such as Cohen and Lewis (1987); who documented the national drought of 1984 in Kenya, Shisanya (1990) and Recha et al. (2012). For instance, the failure of the LRs in 1984 prompted the Kenyan government to launch a national relief fund among other responses (Shisanya 1990). Akponikpè et al. (2008) concurred with this findings by reporting high variability (CV = 57 %) in temporal rainfall at annual (mono-modal rainfall between February and September), monthly and daily time-scales in the Sahel region. High variability (attributed often to La Nina, El Nino and Sea Surface Temperatures) could occasion rainfall failures leading to declines in total seasonal rainfall in the study area. According to Shisanya (1990), La Nina events significantly contributed to the occurrence of persistent droughts and unpredictable weather patterns during LRs in Kenya. In contrast, El Nino events (of 1997 and 1998) have been cited as the key inputs of the positive anomalies in SR seasonal rainfall in the ASALs of Eastern Kenya (Anyamba et al. 2001; Amissah-Arthur et al. 2002).

Variations in Rainfall Amounts and Number of Rainy Days

On average, the total amount of rainfall received in Machang'a and Embu were below 900 and 1,400 mm per annum, respectively. Yet LRs contributed 314.9 and 586.3 mm while SRs contributed 438.7 and 479.1 mm (Table 5.5) translating to a total of 754 and 1,084 mm of seasonal rainfall in Machang'a and Embu, respectively (Table 5.5). These account for close to 90 % of total rainfall received annually; implying that smaller proportions of rainy days supplied much of the total amounts of rainfall received in the region. Generally, a Coefficient of Variation (CV) greater than 30 % indicates large variability in rainfall amounts and distributional patterns (Araya and Stroosnijder 2011). In Machang'a, rainfall amounts during LRs were highly variable (CV = 0.41) than those in Embu (CV = 0.36). This variability is simultaneously replicated in the CVs of rainy days (0.26 and 0.09),

Table 5.5 Variability analyses: coefficient of variations in seasonal rainfall amounts and number of rainy days for Machang'a and Embu for the period between 2000 and 2013

	LR				SR				M. variations
Station	RA	CV	RD	CV	RA	CV	RD	CV	T-test values
Machang'a	314.9	0.41	24	0.26	438.7	0.56	53	0.88	0.111
Embu	586.3	0.36	46	0.09	497.1	0.38	40	0.27	0.035*

MAM March-May-June and *OND* October-November-December and; *RA* Rainfall amount in (mm), *RD* Rainy days, *CV* Coefficient of variation and *M.variations* Mean variations; *Significant at 0.05 level

during the same season in the respective stations. Nonetheless, there exists a significant differences ($p = 0.035$ at probabilities of 0.05) in seasonal rainfall amounts in Embu but not in Machang'a ($p = 0.111$ at probabilities of 0.05) (Table 5.5).

It is evident that rainfall variability in both agro-ecological zones is markedly high. Analyses based on RAI indicated high variability in SR rainfall amounts in the two station (Figs. 5.5 and 5.6); which is further affirmed by high CV of SR rainfall amounts in the two stations (CV 0.56 in Machang'a and CV = 0.38 in Embu) (Table 5.5). In terms of variability in rainy days, SR recorded highest variability; probably an indicator of high rainfall variability in SSA during SR seasons. A study by Barron et al. (2003) reported similar findings in a station in Machakos; of Kenya which recorded variability in number of rainy days as CV = 53 and 45 % during SR and LR seasons respectively. Lack of notable significance in intra seasonal rainfall amounts in the drier parts of Kenya (represented by Machang'a in this study) was also reported by Recha et al. (2012). Regionally, findings of Seleshi and Zanke (2004) further showed that annual and seasonal rainfall (*Kiremt* and *Belg seasons*) in Ethiopia were highly variable with CV values ranging between 0.10 and 0.50.

Monthly Variations in Seasonal Rainfall Amounts and Number of Rainy Days

Understanding dynamics of rainfall amount variability at a season's monthly level and in number of rainy days can guide on the choice of planting time, crop variety as well as understanding of variations in onset, duration and cessation of seasonal rainfall. During this study, results showed that rainfall amounts received within seasonal months (March-April-May; LRs and October-November-December; SRs) were highly variable (all with CV > 0.3). Notably, coefficient of variation in Rainfall Amounts (CV-RA) were quite high during the months of March (CV-RA = 0.98) and December (CV-RA = 0.86) in Machang'a and CV-RA = 0.61 (March) and CV-RA = 0.97 (December) in Embu (Table 5.6). Least variability in CV-RA were recorded in the months of April (CV-RA = 0.42) and November (CV-RA = 0.43) in Machang'a and Embu, respectively (Table 5.6). Variability in the number of rainy days (CV-RD) was equally high in the two study stations. For

Table 5.6 Variability in seasonal months: coefficient of variation in rainfall amounts and rainy days for Machang'a and Embu for the period between 2000 and 2013

	Mar	April	May	Oct	Nov	Dec
Machang'a						
RA (mm)	85.5	160.2	69.2	98.9	267.9	72.0
CV-RA	0.98	0.42	0.69	0.80	0.77	0.86
RD	8	11	5	14	29	10
CV-RD	0.61	0.22	0.61	0.35	0.23	0.34
Embu						
RA (mm)	110.1	300.8	175.6	175.1	250.3	71.8
CV-RA	0.61	0.48	0.54	0.66	0.43	0.97
RD	20	14	12	10	13	17
CV-RD	0.47	0.27	0.27	0.59	0.25	0.83

RA (*mm*) Rainfall amount in millimetres; *CV-RA* Coefficient of variation in rainfall amounts, *RD* Number of rainy days; *CV-RD* Coefficient of variation in rainy days

instance, March (CV-RD = 0.61 and CV-RD = 0.47) and December (CV-RD = 0.34 and CV-RD = 83) had the highest variability in the number of rainy days in Machang'a and Embu, respectively (Table 5.6).

Generally, onset months (March and October) and cessation months (May and December) received highly variable rainfall amounts compared to mid months. Machang'a, though; being more of an arid region, it generally recorded lower variability in number of rainy days during SR seasonal months compared to those recorded at Embu during the same season, evidence of reduced variability and wetting of SRs in the region. Evidently, the amount of rainfall and number of rainy days received in the past decade at Machang'a have been more consistent (temporally) in April and November but highly unpredictable in March (basis of onset) and December (cessation). This significantly affects the cropping calendar in rain-fed agricultural productivity of the region. It has been shown that a CV > 30 % indicated large variability in rainfall amounts and distribution patterns (Araya and Stroosnijder 2011). By comparing the coefficient of variation of rainfall amounts (average CV-RA = 0.75) and that of rainy days (Average CV-RD = 0.39) at Machang'a and (CV-RA = 0.61; CV-RD = 0.45) at Embu, it is evident that there is high variability in amounts and days of rainfall received in the past decade as their variability exceeded 30 %.

Nonetheless, lower values of CV-RD indicated that variations in rainy days have been fairly consistent compared to variations in rainfall amounts received. Notably, there seems to be simultaneous variability in the May rainfall amounts (CV-RA = 0.69) in relation to May rainy days (RD-CV = 0.61) at Machang'a but no clear trend at Embu would be established. This implies that variations in rainy days have been fairly proportional to the rainfall amount received in the month of May in Machang'a than Embu. However, its importance to the cropping calendar may not be quite significant because May is a cessation month. On the other hand, highly contrasting variability were observed for the month of December (CV-RA = 0.86 and CV-RD = 0.34) at Machang'a and April (CV-RA = 0.61 and CV-RD = 0.30) at Embu.

It would also appear that Machang'a receives more rainfall during SR season with November alone accounting for 60 % of total rainfall amount received while April accounts for 51 % of the LR rainfall in Machang'a. Conversely, Embu receives more rainfall during LRs with April accounting for about 52 % of total rainfall received. These findings at Machang'a corroborate those of Barron et al. (2003) and Amissah-Arthur et al. (2002) which demonstrated that parts of Eastern Kenya receive more SR than LR rainfall amounts. Mzezewa et al. (2010) also reported high coefficient of variation for annual (315 %) and seasonal (50–114 %) rainfall in semi-arid Ecotope, north-east of South Africa. Also, Sivakumar (1991) found that annual rainfall in the Sudano-Sahelian zone of West Africa is less variable than monthly rainfall.

Generally, SRs in (Machang'a) and LRs in (Embu) rainfall amount and rainy days are fairly spread through the season, potentially reducing the impact of within-season variability. Additionally, the rainfall amounts received in May and December (cessation) is little and might not be sufficient to buffer crops from agricultural drought, especially in Mbeere South (Machang'a) where soils are predominantly sandy loam and shallow (Acrisols, Ferralsols, and Cambisols) (Jaetzold et al. 2007). Also, the first and last months (of both seasons) are characterized by high CV for rainfall amount and rainy days. Similar findings are reported in Sivakumar (1991) in which onset (May) and cessation (October) months in Sudano-Sahelian zone are characterized by variations of over 100 %.

Probability and Frequency of a Dry-Spells and Implications on Crop Productivity

Dry-spells during cropping months are quite common that often trigger reduced harvests or even complete crop failures, especially in the drier arid parts of Eastern Kenya. Results showed that in Machang'a (AEZ 4 and 5) and Embu's (AEZ 1 and 2), the probability of occurrence of dry-spells of various durations varied from month to month of the growing season. Observably, lowest probabilities of dry-spells occurrence of all durations would be in April (LRs) and November (SRs) in both stations. High probabilities of dry-spells were in March (0.72 and 0.55) and December (0.8 and 0.6) in Machang'a and Embu respectively. The probability of having a dry-spell increased with shorter periods (for instance, more chance of having a 3 than a 10 or 21 day dry-spell) (Fig. 5.7). Probabilities of a 15-day dry-spell were relatively lower (0.4–0.6) in both stations. Similarly, the probabilities of experiencing a 21 day dry spell were 0.3 and 0.4 for Embu and Machang'a, respectively (Fig. 5.7).

On the other hand, the probabilities that dry spells would exceed these day-durations were equally high (Fig. 5.8). There was 70 % chance that dry spells

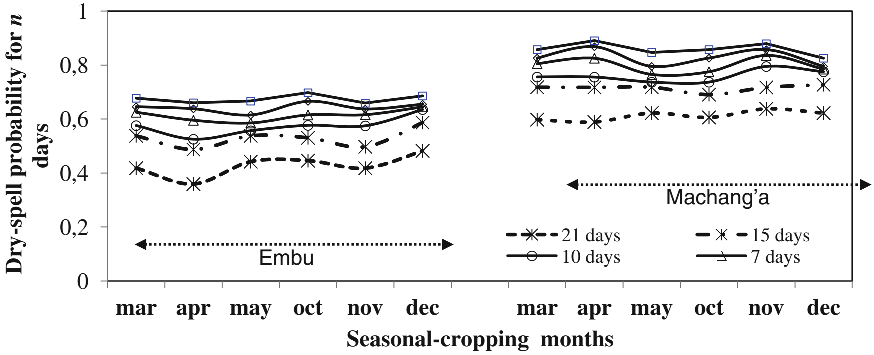

Fig. 5.7 Probability of a dry-spell of length ≥ n days, for n = 3, 5, 7, 15, 21, in each seasonal-cropping month, calculated using the raw rainfall data from 2000 to 2013 for stations in Machang'a and Embu

would exceed 15 days in Machang'a and 50 % in Embu (Fig. 5.8). It was also observed that April had high chances ($p = 0.85$) of its dry-spells exceeding 7 days in Machang'a while December recorded highest chances ($P = 0.6$) of its dry-spells exceeding 10 days in Embu; than any other month (Fig. 5.8).

Rainfall being a prime input and requirement for plant life in rain-fed agriculture, the occurrence of dry-spells has particular relevance to rain-fed agricultural productivity (Belachew 2000; Rockstrom et al. 2002). It was observed that lowest probabilities of occurrence of dry-spells of all durations were recorded in the month of April (during LRs) and November (during SRs). The occurrence of dry-spells of all durations decreased from April towards May (LR) and November towards December (SRs). Indeed, the months of April and December coincides with the peak of rainfall amounts for both SR and LR growing seasons in the region

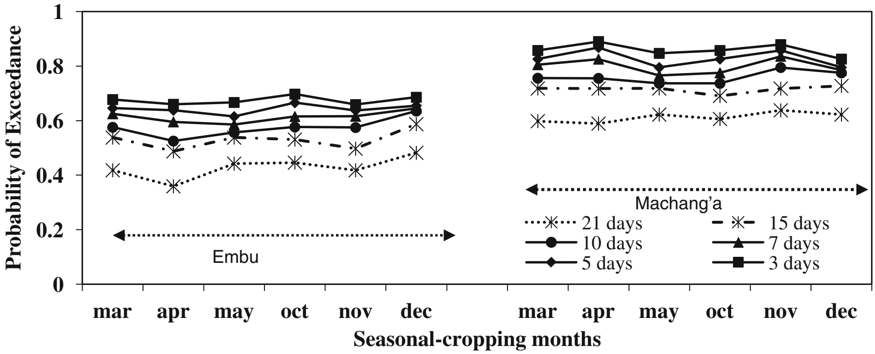

Fig. 5.8 Probability of dry-spells exceeding the *n* (3, 5, 7, 10, 15 *and* 21) days for each seasonal month calculated using the raw rainfall data from 2000 to 2013 for stations in Machang'a and Embu

respectively (Kosgei 2008; Recha et al. 2012). This trend is in line with works reported by several studies in SSA, including Kosgei (2008), Aghajani (2007) in Iran and Sivakumar (1992) in East Africa. Dry spells during SR season in Makindu and Katumani stations, lower eastern parts of Kenya had similar trends of high probabilities (avefinger milletng 88 %) in October. High probabilities of dry-spells occurring and exceeding the same durations show the high risks and vulnerability that rain-fed smallholder farmers are predisposed to in the study area. Often, prolonged dry-spells are accompanied by poor distribution and low soil moisture for the plant growth during the growing season. General high probabilities of persistent dry-spells in SSA have been reported by Hulme (2001), Dai et al. (2004) and Mzezewa (2010). Arguably, persistence of intermediate warming scenarios in parts of equatorial East Africa (Hulme 2001; Mzezewa 2010) may trigger increased dry-spells in months of May-August and January-March; further evidenced by the high probabilities of dry spells exceeding *n*th length days. Prolonged dry spells during cropping seasons directly impacts on the performance of crop production. For instance, high evaporative demand indicated by high aridity index ($P > 0.52$) in the drier parts of Eastern of Kenya implies that rain-water is not available for crop use and cannot meet the evaporative demands (Kimani et al. 2003). Thus, deficit is likely to prevail throughout the rain seasons as observed in other SSA regions (Li et al. 2003). Run-off collection and general confinement of rain-water within the crop's rooting zone could enhance rain-water use efficiency as demonstrated by Botha et al. (2007).

In most arid and semi-arid regions, soil moisture availability is primarily dictated by the extent and persistency of dry spells. It is thus essential to match the crop phenology with dry spell lengths based days after sowing to meet the crop water demands during the sensitive stages of crop growth (Sivakumar 1992). Knowledge of lengths of dry spells and the probability of their occurrence can also aid in planning for supplementary risk aversion strategies through prediction of high water demand spells. Information on lengths of dry spells also guides on the choice of crop types and varieties (Mzezewa 2010). For instance, probabilities of having dry spells exceeding 15 days is relatively low (23 and 15 % for Machang'a and Embu, respectively) during both SR and LR seasons. In this regard, the choice of crop variety and type should be based on the degree of its tolerance to drought (Sivakumar 1992; Mzezewa 2010). Most studies (including; Sivakumar 1992 and Belachew 2000) however indicate that decisions can be optimized if the probability of dry spells is computed after successful (effective) planting dates.

Conclusion and Recommendations

Decadal rainfall trends showed that both LRs and average annual rainfall have decreased in the past 13 years in both Embu and Machang'a. Machang'a appeared to have experienced pronounced declines in rainfall amounts especially those received during LRs. Nonetheless, rainfall amount during SRs markedly increased in both stations, with high amount gains established in Machang'a. Evidently, probabilities that seasonal rainfall amounts would exceed the threshold for cropping (500–800 mm) were quite low (10 %) in both stations. The amount of rainfall received during LRs and SRs varied significantly in Embu (t-test = 0.001 at $p < 0.05$) but not in Machang'a (t-test = 0.111, at $p < 0.05$). There was evidence of increasing rainfall variability for AEZ 1&2 (Embu) towards AEZ 4&5 (Machang'a) to as high as 88 % in CV. Probabilities that these AEZs would experience dry-spells exceeding 15 days during a cropping season were equally high, 46 % in Embu and 87 % in Machang'a. This replicates high chances that soil moisture could be lost by evaporation bearing in mind the high chances (81 %) the same dry-spells exceeding 15 days could reoccur during the cropping season. On the other hand, Kriging technique was identified as the most appropriate Geostatistical and deterministic interpolation techniques that can be used in spatial and temporal rainfall data reconstruction in the region. High rainfall variability and chances of prolonged dry spells established in this study demands that farmers ought to keenly select crop varieties and types that are more drought resistant (sorghum and millet) other than maize especially in the drier parts of Embu county (Machang'a). There is need for establishing further precise, timely weather forecasting mechanisms and communication systems to guide on seasonal farming.

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