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Integrating seasonal climate variability in sustainable agricultural planning of Lake Victoria Basin in Kenya

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Abstract:

Variability in agro-climatic parameters is increasingly a source of concern in the rainfed agricultural regions of the world. To a large extent, Kenya relies on rainfed agriculture for her food requirements. However, the agro-climatic characteristics within the Lake Victoria basin region of Kenya are quite variable. This study evaluated the variability of seasonal agro-climatic parameters in Lake Victoria basin region in order to understand how growing seasons influence sustainable agricultural planning. To evaluate these characteristics, analyses of the dry spells, reference evapotranspiration (ETo), rainfall characteristics (amount, onset, cessation and length) were done using H614 maize variety as the reference crop. Dry spells were analyzed using a daily rainfall threshold (DRT) of 5 mm, and dry spell trends interpolated in GIS. ETo was obtained using the ETo calculator while the rainfall characteristics were analyzed using the RAIN software package combined with descriptive methods. The results reveal that there exist variability in all agro-climatic parameters analyzed. It is shown that proper integration of agro-climatic variability into seasonal agricultural planning is needed for sustainable agricultural production. Re-introduction of indigenous crops will heavily depend on access to climate knowledge and proper dissemination of results, through technical advisory and extension services.

KEY WORDS: Agro-climatic parameters; sustainable agriculture; GIS; maize crop

1 INTRODUCTION

Although farmers continue to adapt their farming systems to both environmental and socio-economic change, yield levels are not increasing in step with population growth (Critchley, 2000; Mortimore and Adams, 2001). In the tropics intra-seasonal and inter-annual variability in climate, caused by prolonged dry spells, reduced rainfall amounts and natural shocks such as floods (Paeth and Hense, 2003; Usman *et al.*, 2005; Mishra *et al.*, 2008) still limit agricultural production. The effects of intra-annual rainfall distribution are well demonstrated (Sultan *et al.*, 2005). Crop suitability in any habitat is primarily determined by the distribution of climatic elements, soil characteristics, moisture availability, farm management, as well as socio-economic and catastrophic factors (Lobell and Burke, 2008).

In Kenya, the agro-climatic characteristics within the Lake Victoria basin region are quite variable. The erratic nature of rainfall distribution and amounts makes analysis of dependable rainfall important (Tesfay and Walker, 2004). Basing agricultural planning on the relationships between rainfall and reference evapotranspiration is more meaningful (Tilahun, 2006; Araya *et al.*, 2010) than using monthly and annual rainfall totals. To minimize risks, decadal data of effective rainfall are needed to study whether crop water requirements are optimally met at various stages of the crop. These concepts have extensively been studied (Dorenbos and Kassam, 1979, Raes *et al.*, 2006, Araya and Stroosnijder, 2011).

Most studies on the soil water availability to crops and analysis of dry spells have focused on dry land areas with little regard to rainfed agriculture regions (Geerts *et al*., 2006; Rockstrom *et al*., 2003; Rockstrom *et al.*, 2002). Given that climate change, differently affects crop production in different regions, a major challenge is to produce more food from less water by optimizing crop-water productivity (Kijne *et al.*, 2003). Short or long-term fluctuations in weather patterns, associated with climate change and variability (IPCC, 2001 a, b) reduce crop yields. In Kenya, adoption of agricultural innovations is sub-optimal, with irrigation rarely employed due to the high installation costs. Consequently, farmers elect to utilize available resources and operate within existing conditions to meet their domestic food requirements (Parry *et al.*, 2004; Maracchi *et al.*, 2005; Motha and Baier, 2005).

Theoretical and practical issues of different geostatistical techniques have been discussed in detail (Goovaerts *et al.*, 2000; Price *et al.*, 2000; Vicente-Serrano *et al.*, 2003; Lloyd, 2005; Geerts *et al.*, 2006). Spatial analysis uses statistical and mathematical functions of measured points to generate prediction and error or uncertainty surfaces. Several spatial interpolation techniques exist, although they differ in their assumptions, local or global perspective and deterministic or stochastic nature (Webster and Oliver, 2001; Hossein, *et al*, 2011). This study integrated variability of seasonal agro-climatic parameters in sustainable agricultural planning for Lake Victoria basin region.

2 MATERIALS AND METHODS

2.1 Study Area

The Lake Victoria basin in Kenya is classified into eight homogeneous zones based on seasonal climatic clusters (Figure 1). Daily records of meteorological and agro-meteorological parameters, spatially distributed based on homogeneous zones (Ogallo, 1980), were collected from sampled stations. The sampling design consisted of both simple random sampling (from all existing stations in each zone) and purposive sampling in order to meet the criteria for climatic analyses that required a minimum of 30 years of continuous data records.

2.2 Secondary Data Collection

Historical climatic data were obtained from Kenya Meteorological Department (KMD). For stations that collect most climatic parameters, the ETo calculator (FAO, 2009) was used to determine reference evapotranspiration (Allen *et al.*, 1998). The climatic parameters used included maximum and minimum temperature, sunshine hours, wind and mean temperature. It was observed that most stations lacked solar radiation data.

2.3 Intra-Seasonal Dry Spells

Reference evapotranspiration involved two analyses which included both the sensitive growth stages (germination and flowering) and monthly analyses for the Lake Victoria basin. The analyses targeted the maize growing seasons covering the period March to November using the available data. Analysis for germination and flowering stages was done at decadal (Mugalavai, 2013) time steps based on the region’s rainfall onset, focusing on the months of March and April (germination) and June and July (flowering). The monthly analyses captured all the phenological growth stages of the maize crop. Intraseasonal dry spells were also analyzed using rainfall.

2.4 Onset, Cessation and Length of the Growing Seasons

The actual onset, cessation and length of the growing seasons were generated using RAIN software (Kipkorir, 2005) RAIN is a software package designed to determine the onset, cessation and length of the growing season. It executes a frequency analysis of these three parameters, which are important variables in planning rainfed agriculture. The onset criterion of 40 mm in 4 days for the region (Mugalavai *et al*., 2008) was employed to determine seasonal rainfall onset. Cessation was quantified by considering the date on which the water stress in the root zone of a maize crop exceeds a threshold value. The length of the growing season (days) for a particular season or year was taken as the difference between the Julian day numbers of the determined cessation date and the determined onset date for that season or year (Hulme, 1987).

2.5 *Monthly Analysis of Reference Evapotranspiration*

The reference evapotranspiration (ETo) was calculated using the ETo Calculator (FAO, 2009) and dekadal and monthly values were derived (Barron *et al*., 2003). The monthly rainfall was converted into the monthly effective rainfall-M_{eff} (Barron *et al*., 2003) and used together with the monthly reference evapotranspiration to generate monthly crop evapotranspirative demand statistics.

2.6 *GIS Mapping*

In this study, dry spell severity zones were mapped using ordinary kriging (OK) function in ArcGIS 10.0. OK uses a linear combination of weights at known points to estimate values at unknown points (Price *et al*., 2000). OK measures the spatial autocorrelation between points, such that weights change based on the spatial arrangement of samples (García-León, *et al.*, 2004; Ishida and Kawashima, 1992). OK was preferred for interpolating dry spells since it gave a lower standardized root mean square errors and was suitable for sparsely distributed sample points (Lloyd, 2005; Haberlandt, 2007).

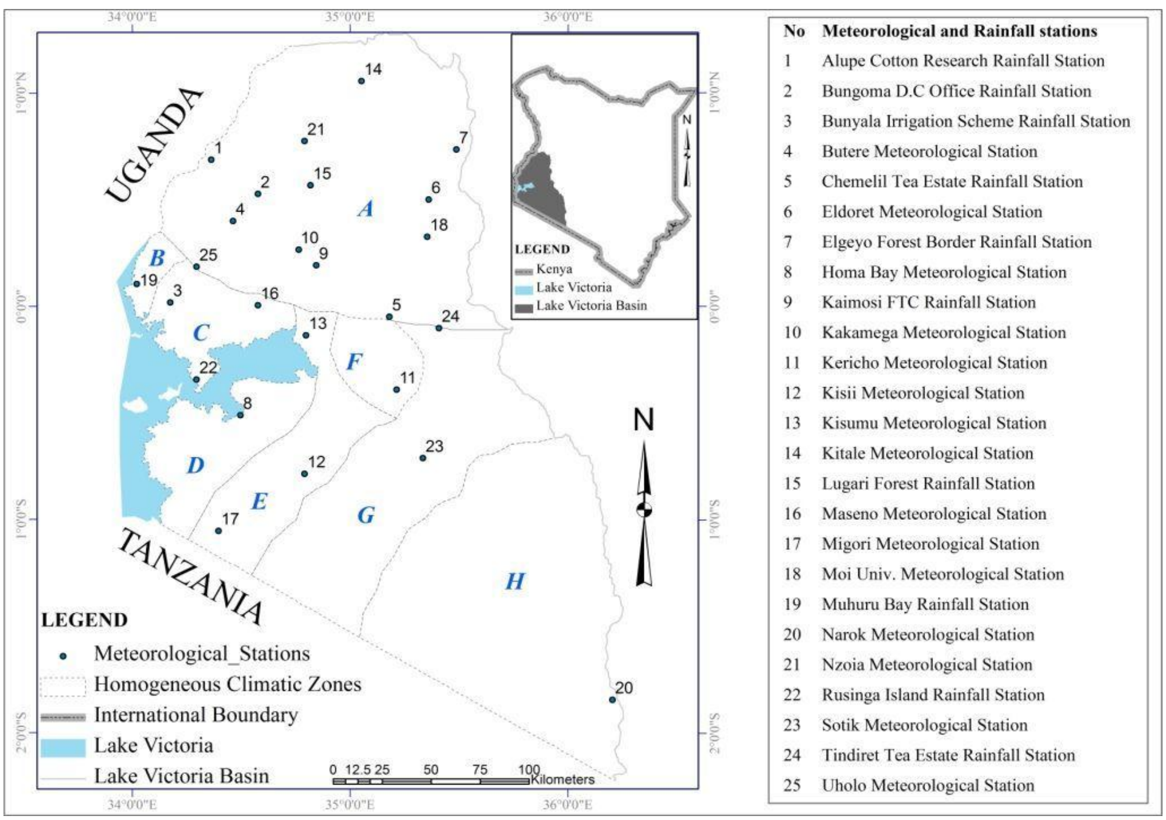


Figure 1: Location of study area showing homogeneous zones (Ogallo, 1980)

2.7 Integrating Climate Variability in Agricultural Planning

Integration entails understanding the characteristics of the agroclimatic parameters and their relationship(s) with the growing seasons, and tries to fit agricultural planning into the existing climatic conditions without much modification. It involved comparing the obtained agro-climatic parameters with the WMO established regional trends with the aim of incorporating these parameters into the agricultural practices. If adopted, this can reduce production costs and thus promote sustainability while increasing crop yield (Mugalavai and kipkorir, 2015). Integration also calls for enhanced research into high yielding varieties of crops that flourish under natural conditions.

3 RESULTS AND DISCUSSION

3.1 Monthly Analysis of Reference Evapotranspiration

The monthly reference evapotranspiration analyses for the western Kenya zone (Kakamega, Kisumu and Kisii) show lower variability during the flowering stage (June) compared to the dekadal analysis during the germination stage (Mugalavai, 2013). Uncertainties in the onset of the rainy season (March) require continuous monitoring of the dekads to establish the true onset (Mugalavai, 2008). Results reveal that the crop at the germination stage is more vulnerable to dry spells. Monthly analyses of reference evapotranspiration (Table 1 and Table 2) were vital in establishing the evapotranspirative demands for all the phenological stages (germination through grain filling).

Kakamega station is free from severe water stress between April and September (active maize growing season). Water stress occurs during the short rains season in October and November. Kisumu station is free from severe water stress in April. However, water stress occurs in March and from May through November. Kisii station is free from water stress for most of the year except during the months of June and July (Table 1 and Figure 2).

The monthly analysis of ETo indicates that during the germination period (March) dry spells occur in Kakamega and Kisumu, while Kisii was free from dry spells. Stations in western Kenya zones could employ different strategies to mitigate water shortages. During the flowering stage (June), Kakamega and Kisii stations were free from dry spells while Kisumu registered higher evapotranspirative demand levels compared to the effective rainfall (Figure 3).

These findings strengthen the need for supplemental irrigation requirement for Kisumu station and its environments. On the other hand, field management practices involving runoff water harvesting and conservation agriculture could be applied to mitigate dry spells in Kakamega and Kisii stations.

The monthly analysis for stations in the Rift Valley zone show that Kitale experiences water stress in March and from June to November (Table 2 and Figure 4). Kericho station is free from water stress for most of the year with dry spells occurring towards the end of the season in November. Eldoret and Moi University stations experience water stress between March and June (germination and vegetative stages) and from September to November (grain filling stage). The months of July and August (flowering stage) show low evapotranspirative demands. Narok station indicates high evapotranspirative demands throughout the period (March to November) considered (Table 2).

The germination stage for the Rift Valley zone indicates that Eldoret, Moi University and Narok have a higher evapotranspirative demand during the month of April (germination stage). The analysis however, shows that only Kericho station is free from water shortages (Figure 4). Kitale and Narok stations show a higher evapotranspirative demand during the flowering stage (July) while Kericho, Eldoret, and Moi University are free from water stress (Figure 5).

Table 1: Mean monthly rainfall and ETo statistics (Western Kenya zone)

Station	Month	M_{rain} (mm)	Mean monthly rainfall and ETo statistics				
			M_{eff} (mm)	ETo (mm/day)	M_{eff}/ETo	SD (mm)	CV (%)
Kakamega	March	172.0	129.0	145.6	0.9	88.1	0.7
	April	259.0	194.3	119.3	1.6	93.5	0.5
	May	255.5	191.6	108.8	1.8	75.0	0.4
	June	156.0	117.0	103.8	1.1	62.9	0.5
	July	157.8	118.4	107.3	1.1	72.3	0.6
	August	212.5	159.4	115.7	1.4	91.4	0.6
	September	177.8	133.4	122.4	1.1	71.4	0.5
	October	160.1	120.1	127.6	0.9	58.3	0.5
	November	152.7	114.5	117.7	1.0	76.4	0.7
Kisumu	March	138.5	103.9	157.1	0.7	61.7	0.6
	April	204.1	153.1	134.0	1.1	73.1	0.6
	May	157.9	118.4	125.3	0.9	54.3	0.6
	June	86.8	65.1	118.8	0.5	41.8	0.6
	July	72.9	54.7	125.9	0.4	49.5	0.6
	August	79.8	59.8	137.0	0.4	48.8	0.6
	September	84.6	63.5	141.9	0.4	46.8	0.6
	October	113.5	85.1	149.0	0.6	57.7	0.6
	November	148.0	111.0	134.0	0.8	88.5	0.6
Kisii	March	243.8	182.8	134.2	1.4	83.4	0.5
	April	276.6	207.4	111.1	1.9	79.0	0.4
	May	221.7	166.3	113.6	1.5	76.4	0.5
	June	141.6	106.2	109.5	1.0	63.6	0.6
	July	118.5	88.9	112.6	0.8	42.7	0.5
	August	175.1	131.3	114.3	1.1	45.0	0.3
	September	170.6	128.0	126.8	1.0	71.7	0.6
	October	193.7	145.3	123.5	1.2	53.0	0.4
	November	172.5	129.4	109.5	1.2	69.8	0.5

M_{eff} (mm): Monthly effective rainfall; ETo (mm/day): Monthly ETo; M_{eff}/ETo: Ratio of M_{eff} to ETo; SD (mm) Standard deviation; CV (%): Coefficient of variation

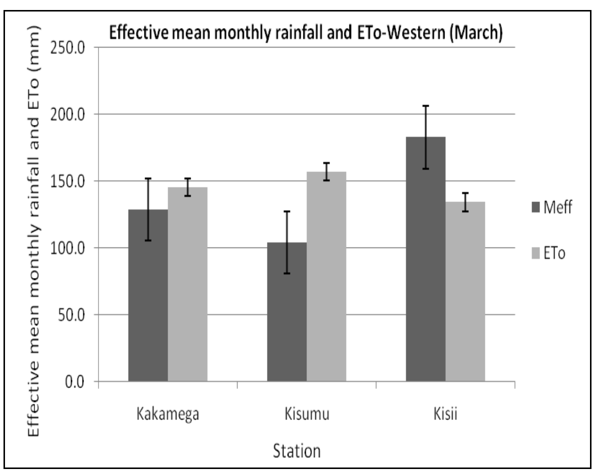


Figure 2: Effective mean monthly rainfall and ETo-Western March); error bars show standard deviation with standard error.

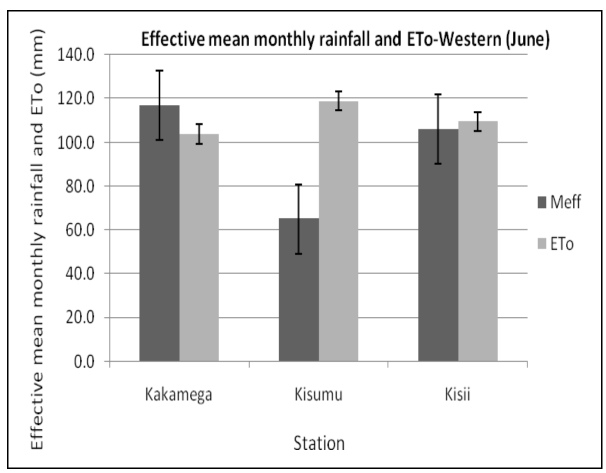


Figure 3: Effective mean monthly rainfall and ETo-Western (June); error bars show standard deviation with standard error.

Table 2: Mean monthly rainfall and ETo statistics (Rift Valley zone)

Station	Month	M_{rain}	Mean monthly rainfall and ETo statistics				
			M_{eff} (mm)	ETo (mm/day)	M_{eff}/ETo	SD (mm)	CV (%)
Kitale	March	76.3	57.2	137.1	0.4	51.2	0.9
	April	170.0	127.5	113.3	1.1	66.1	0.5
	May	148.7	111.5	111.0	1.0	81.5	0.7
	June	88.8	66.6	99.6	0.7	46.8	0.7
	July	110.0	82.5	101.3	0.8	58.7	0.7
	August	133.9	100.4	111.1	0.9	57.1	0.6
	September	96.5	72.3	115.3	0.6	66.0	0.9
	October	111.0	83.3	120.7	0.7	66.9	0.8
	November	87.8	65.8	112.7	0.6	58.2	0.9
Kericho	March	215.6	161.7	131.2	1.2	125.2	0.8
	April	282.2	211.6	104.4	2.0	86.2	0.4
	May	227.3	170.5	100.2	1.7	97.5	0.6
	June	166.0	124.5	96.0	1.3	64.4	0.5
	July	182.2	136.6	97.0	1.4	59.6	0.4
	August	204.5	153.4	103.1	1.5	84.6	0.6
	September	162.6	121.9	111.7	1.1	62.8	0.5
	October	158.5	118.9	113.7	1.0	70.9	0.6
	November	133.0	99.8	105.4	0.9	107.9	1.1
Eldoret	March	94.0	70.5	145.3	0.5	65.2	0.9
	April	159.6	119.7	121.2	1.0	76.8	0.6
	May	124.3	93.2	119.3	0.8	69.8	0.7
	June	114.0	85.5	107.0	0.8	57.6	0.7
	July	171.4	128.6	109.7	1.2	71.4	0.6
	August	170.1	127.6	112.0	1.1	78.3	0.6
	September	76.8	57.6	123.0	0.5	44.4	0.8
	October	83.4	62.5	129.0	0.5	74.2	1.2
	November	71.6	53.7	124.3	0.4	58.6	1.1
Moi Univ.	March	88.1	66.1	151.4	0.4	62.4	0.9
	April	159.0	119.3	128.5	0.9	74.8	0.6
	May	136.2	102.1	125.6	0.8	64.7	0.6
	June	122.9	92.2	112.8	0.8	52.0	0.6
	July	170.9	128.1	116.0	1.1	71.5	0.6
	August	177.3	133.0	121.8	1.1	69.0	0.5
	September	87.7	65.8	130.7	0.5	58.2	0.9
	October	84.8	63.6	135.6	0.5	60.6	1.0
	November	65.5	49.2	124.0	0.4	57.9	1.2
Narok	March	97.5	73.2	151.7	0.5	69.2	0.9
	April	149.5	112.2	123.4	0.9	87.1	0.8
	May	65.7	49.3	110.8	0.4	49.5	1.0
	June	21.8	16.3	99.0	0.2	24.4	1.5
	July	21.6	16.2	108.0	0.1	22.7	1.4
	August	26.8	20.1	119.0	0.2	24.4	1.2
	September	23.0	17.3	135.8	0.1	17.3	1.0
	October	27.5	20.6	148.4	0.1	22.0	1.1
	November	87.4	65.5	135.6	0.5	71.5	1.1

M_{eff} (mm): Monthly effective rainfall; ETo (mm/day): Monthly ETo; M_{eff}/ETo: Ratio of M_{eff} to ETo; SD (mm) Standard deviation; CV (%): Coefficient of variation

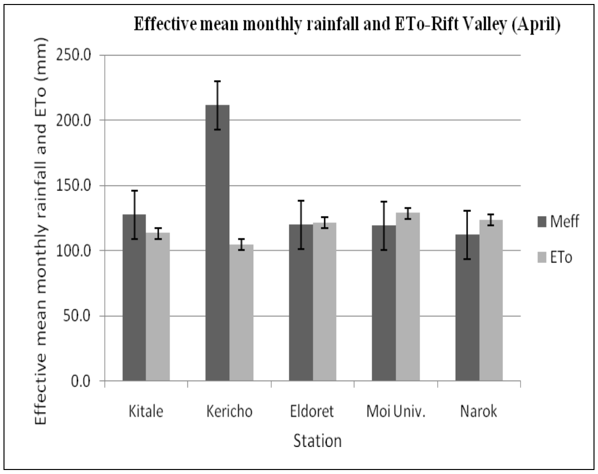


Figure 4: Effective mean monthly rainfall and ETo-Rift Valley (April); error bars show standard deviation with standard error.

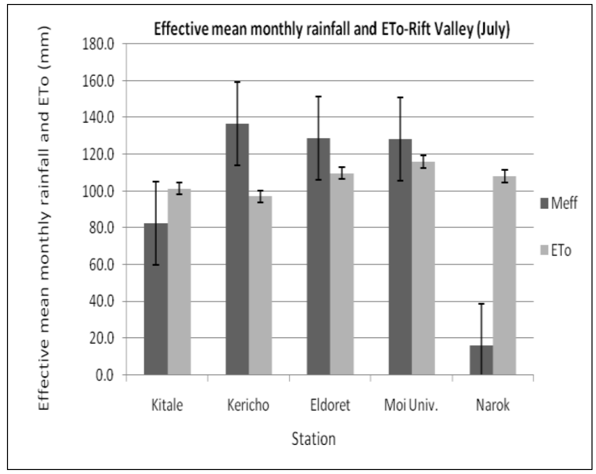


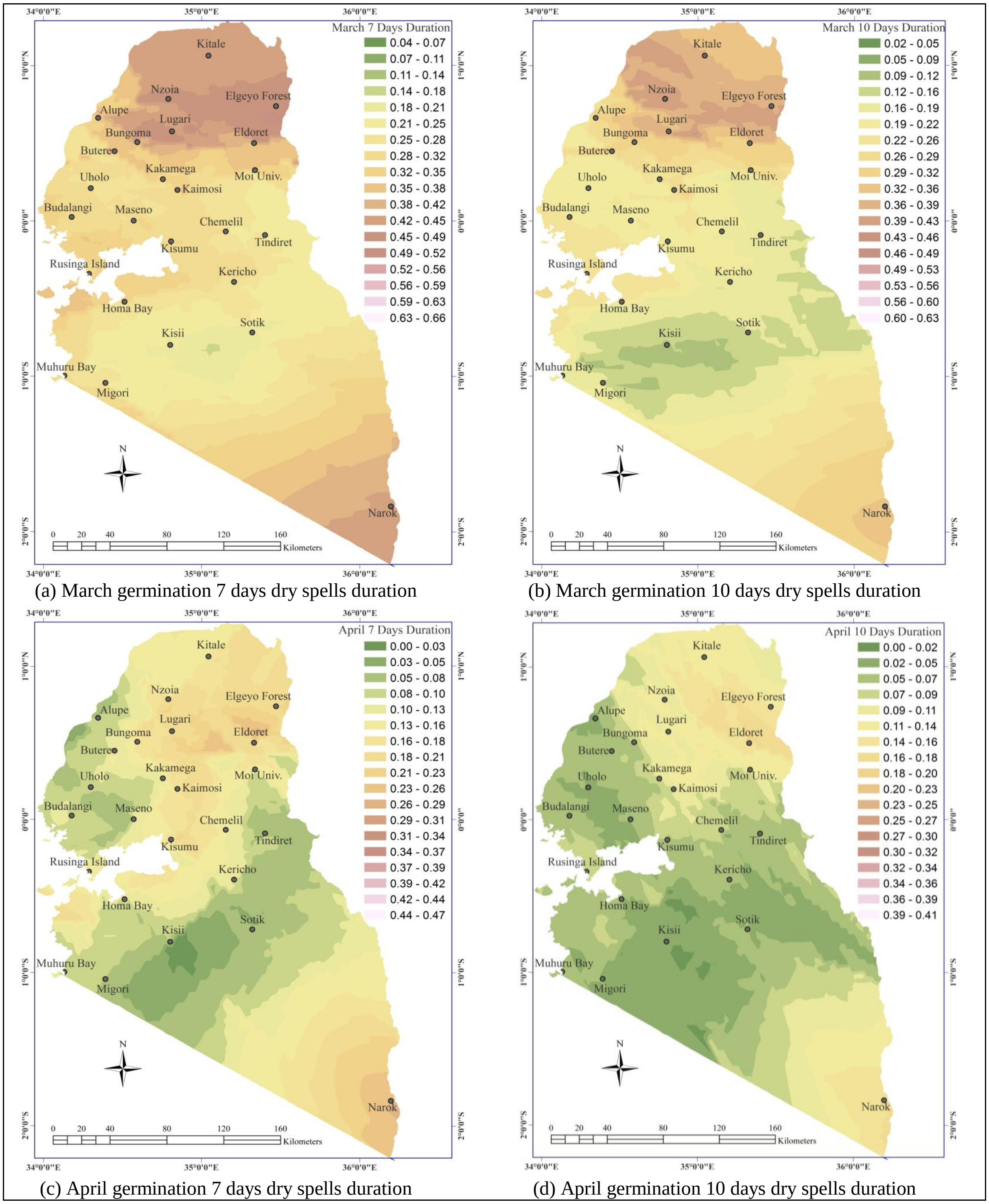
Figure 5: Effective mean monthly rainfall and ETo-Rift Valley (July); error bars show standard deviation with standard error.

3.2 Monthly Dry Spell Mapping

The monthly analysis results of dry spells were mapped to establish whether patterns exist for the region. Similar patterns (Figure 6*a* to 6*d*-germination and Figure 6*h* through 6*j*-flowering) to those of the dekadal analysis (Mugalavai, 2013) were observed at monthly intervals but with slightly lower probabilities of dry spells for the Rift Valley zone (March to July). The monthly analysis of dry spells confirms that the vegetative, flowering and grain filling stages in June, July and August, for Western Kenya zone, and in July, August, September and October for the Rift Valley zones, experience water stress requiring adaptation strategies or supplemental irrigation. Studies that have been done reveal that crop yield is severely affected by intra-seasonal dry spells (Araya and Stroosnijder, 2011; Barron *et al*., 2003; Segele and Lamb, 2005; Meze-Hausken, 2004). Understanding both temporal and spatial characteristics of dry spells is therefore important in agricultural planning. Spatial patterns (Figures 6*e*, 6*f*, 6*k*, 6*l*, 6*m*, 6*n* through *6r*) for the severity of dry spells are similar to those of the dekadal analysis. A similar approach of agro-climatic suitability mapping has been employed to identify zones with high vulnerability to dry spell conditions for use in both supplemental irrigation and other field management strategies (Geerts *et al.*, 2006).

3.3 Integrating Climate Variability in Agricultural Planning

The analyses of agro-climatic parameters in western Kenya zone depict seasonal variability in their characteristics. It is necessary to link crop characteristics with the agro-climatic conditions in different zones. Considering the most commonly grown crops such as maize, stations in western Kenya zone (Kisumu, Kakamega and Kisii) need to exploit short season varieties that mature in 105 days (Table 3). The amount of rainfall received within the season varies from 530 mm to 730 mm (Table 4), which approximates to the seasonal rainfall threshold of 750 mm (Allan, 1972) for maize crop.



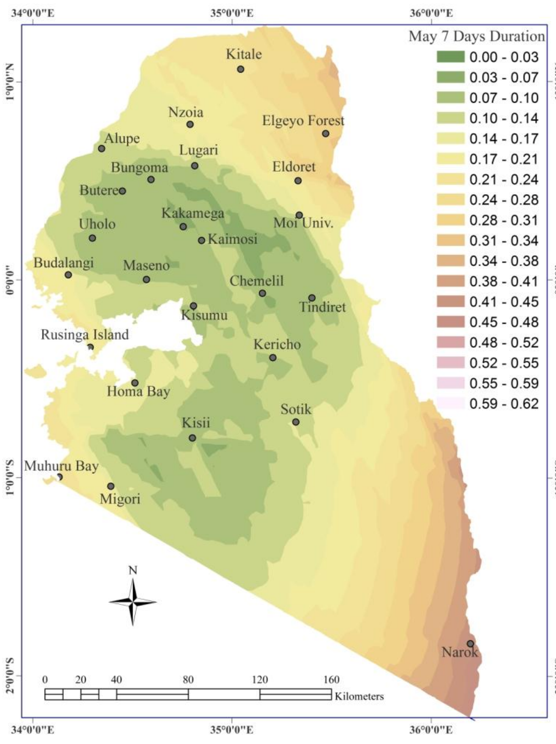
(a) March germination 7 days dry spells duration

(b) March germination 10 days dry spells duration

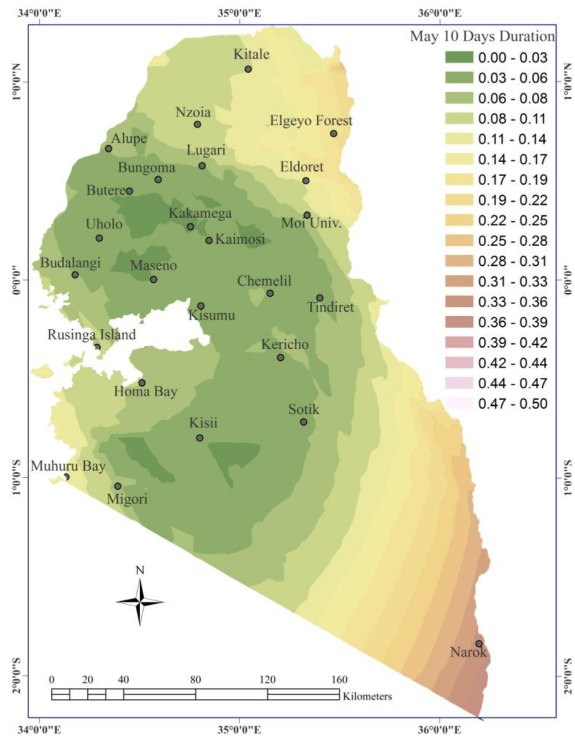
(c) April germination 7 days dry spells duration

(d) April germination 10 days dry spells duration

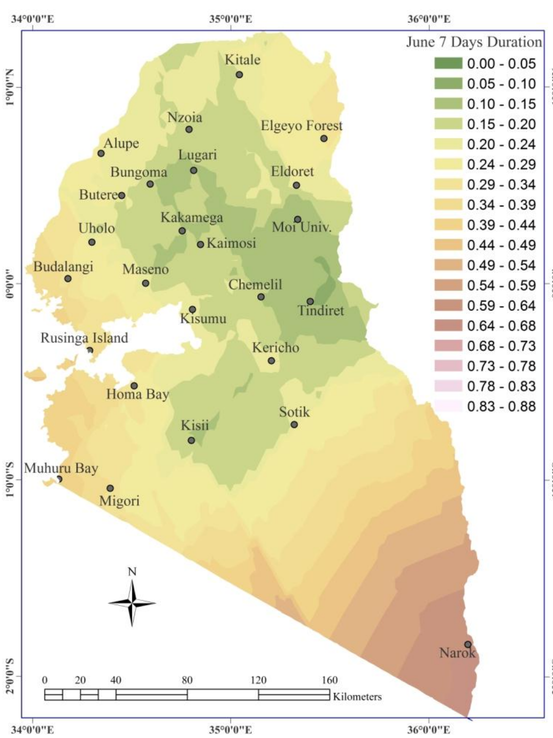
Figure 6:



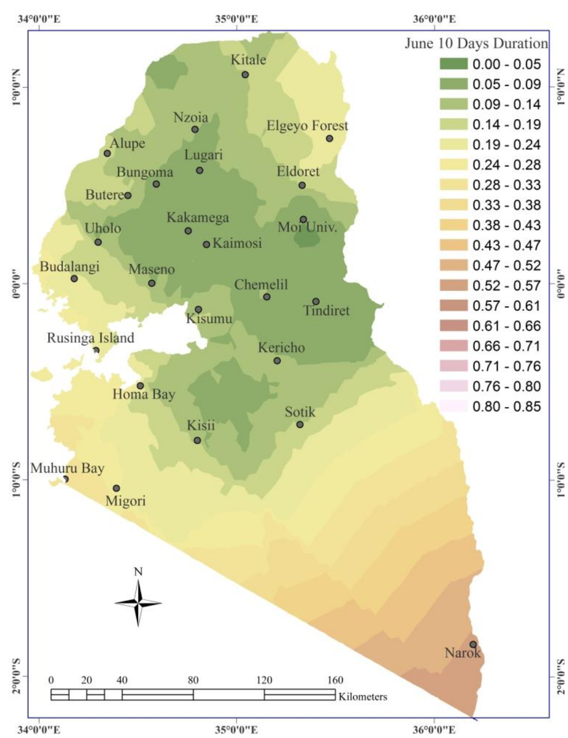
(e) May 7 days dry spells duration



(f) May 10 days dry spells duration

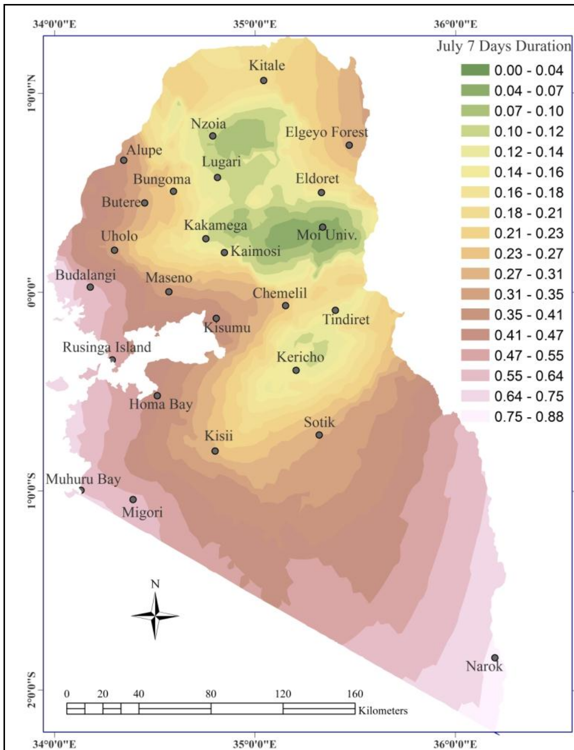


(g) Flowering stage June 7days dry spells duration

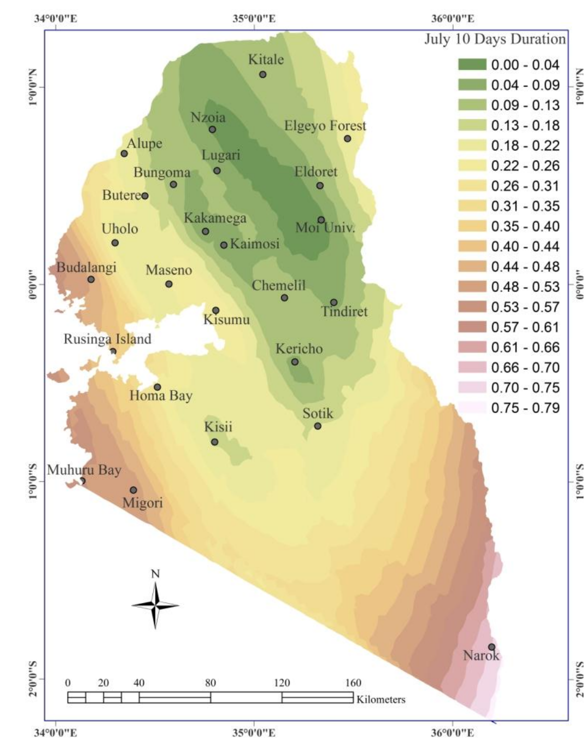


(h) Flowering stage June 10 days dry spells duration.

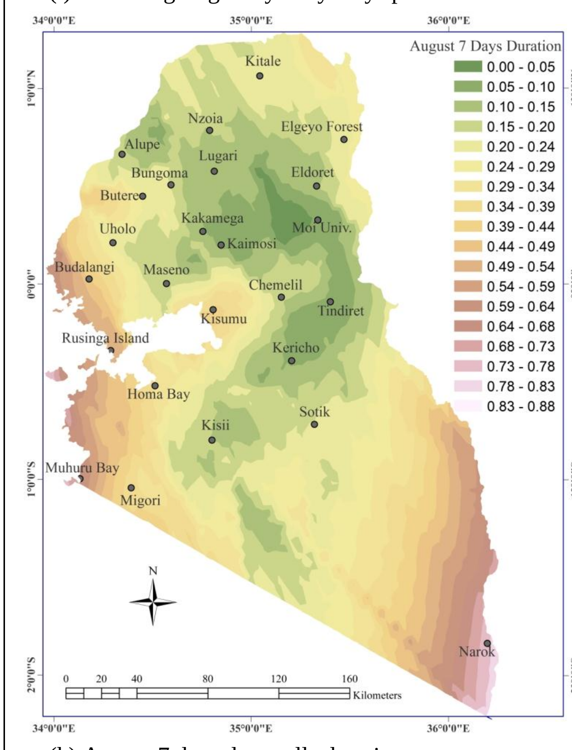
Figure 6: (Continued)



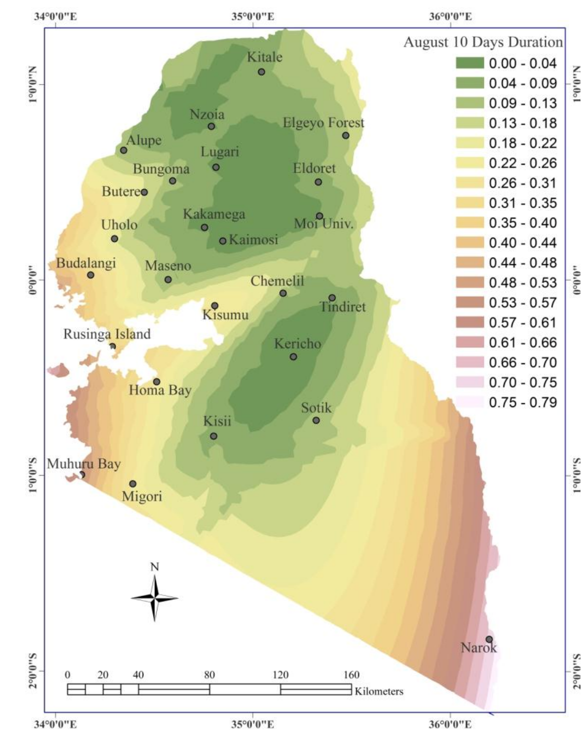
(i) Flowering stage July 7days dry spells duration



(j) Flowering stage July 10days dry spells duration

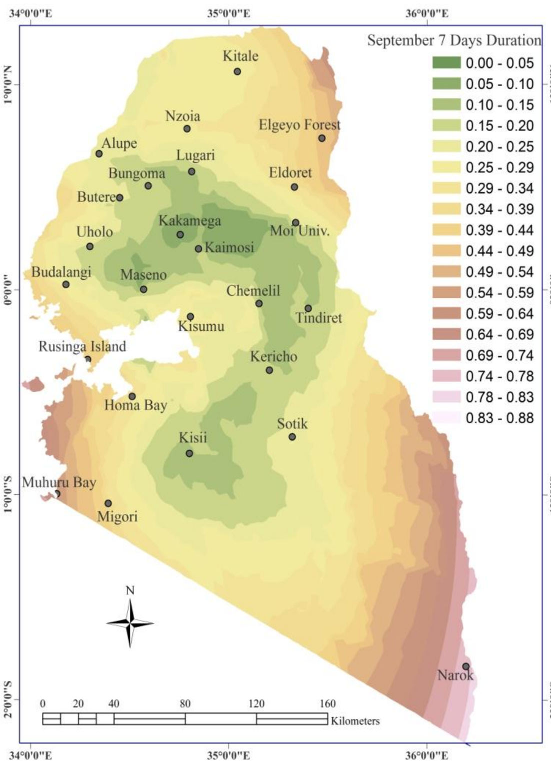


(k) August 7 days dry spells duration

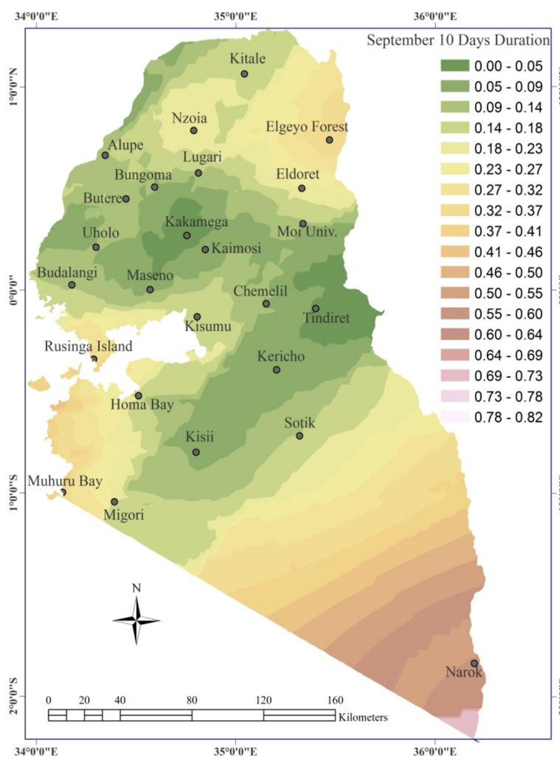


(l) August 10 days dry spells duration

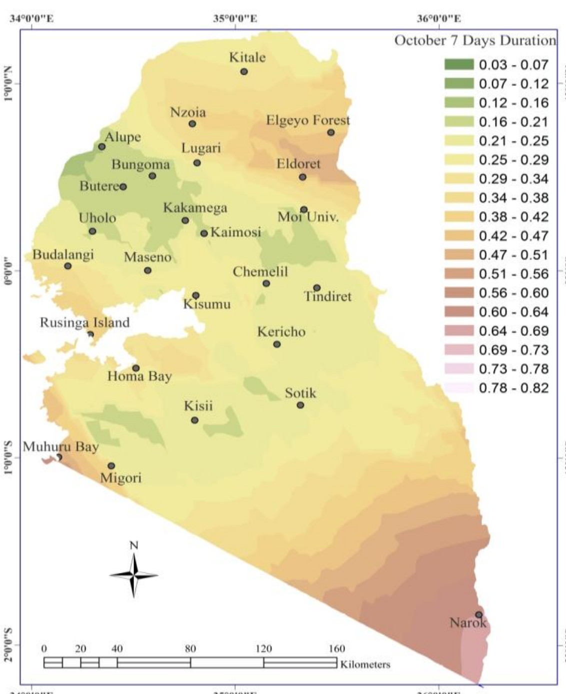
Figure 6: (Continued)



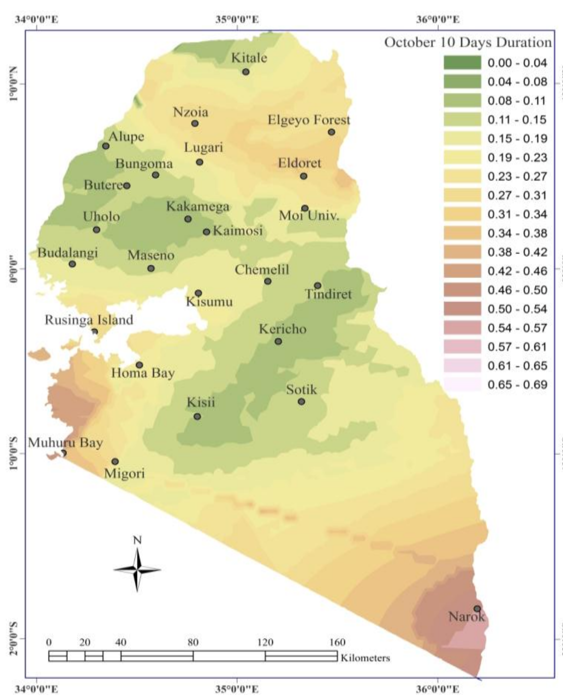
(m) September 7 days dry spells duration



(n) September 10 days dry spells duration.

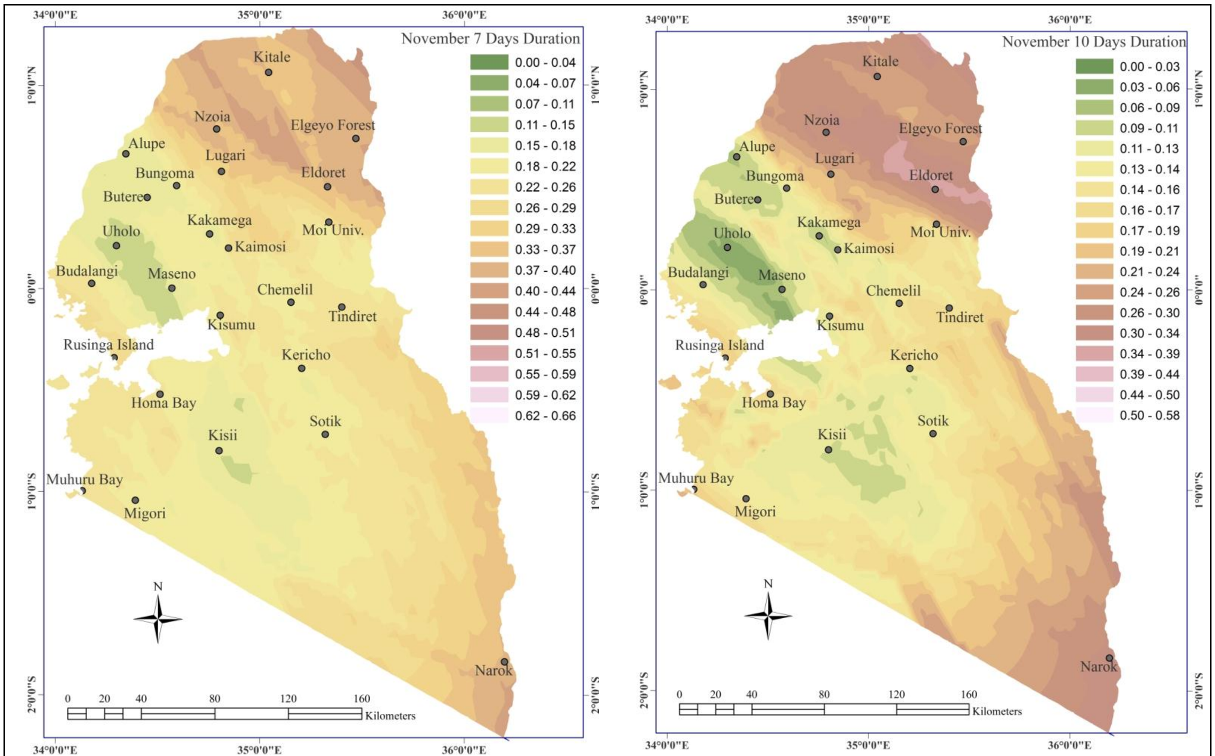


(o) October 7 days dry spells duration



(p) October 10 days dry spells duration

Figure 6: (Continued)



(q) November 7 days dry spells duration (r) November 10 days dry spells duration

Figure 6: (Continued)

Table 3: Lengths of crop development stages for various planting periods and climatic regions (days)

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Cassava	20	40	90	60	210	Rainy season	Tropics
Sweet potato	15	30	50	30	125	Rainy season	Tropics
Soybeans	15	15	40	15	85	Dec	Tropics
Wheat	15	30	65	40	150	July	East Africa
Maize (grain)-Short season	20	25	40	20	105	March/July	East Africa
Maize (grain)-Long season	30	50	60	40	180	April	East Africa
Millet	20	30	55	35	140	April	East Africa
Soghum	20	35	45	30	140	Mar/April	Arid region

Source: FAO 56, Allen *et al.*, 1978 (Eds)

Stations in kakamega and Kisii can also exploit the short rains by planting indigenous crops such as millet and sorghum whose growing length averages 140 days. Stations found in the Rift Valley zone (Narok, Moi University, Eldoret, Kitale and Kericho) could make use of one long growing season due to the high altitude that promotes low temperatures and hence lowers the growth rate of the crops. The length of the growing season for these stations varies from 146 days to 191 days, thus these stations could grow long season maize crop varieties that take 180 days to mature. All these stations have the required threshold for the long season maize crop.

Table 4: Characteristics of agro-climatic parameters

Station	Season	Onset (Date)	Cessation (Date)	Season length (Days)	Rainfall amount (mm)
Kakamega	Short Rains	(26/7)	(23/11)	(117)	JJA (535.4)
	Long rains	21/3	26/6	103	MAM (676.4)
Kisii	Short Rains	(24/8)	(13/12)	(112)	JJA (465.1)
	Long rains	17/3	5/7	155	MAM (730.7)
Kisumu	Short Rains	(9/11)	(30/11)	(20)	JJA (215.1)
	Long rains	30/3	31/5	62	MAM (531.2)
Kitale	Short Rains	(19/10)	(28/11)	(45)	MAM (382.8)
	Long rains	5/4	30/9	162	Season (799.8)
Kericho	Short Rains	(11/8)	(2/12)	(116)	MAM (570.1)
	Long rains	19/3	12/6	191	Season (1296.2)
Eldoret	Short Rains	(15/10)	(21/11)	(41)	MAM (420.3)
	Long rains	13/4	1/6	161	Season (766.2)
Moi Univ.	Short Rains	(17/10)	(18/11)	(31)	MAM (471.1)
	Long rains	1/4	14/6	161	Season (854.4)
Narok	Short Rains	(-)	(-)	(-)	(-)
	Long rains	12/1	29/5	146	Season (394.1)

Kericho station exceeds the optimum length of the growing season. The rest require field management strategies to counter intra-seasonal dry spells and sustain the crop through the 20 to 40 days water deficits (Table 3 and Table 4). However, it is clear that with suitable crop varieties there is potential for growing other crops that can be accommodated within the length of the growing seasons in both zones such as sweet potatoes (125 days); soybeans (85 days); wheat (150 days) and cassava (210 days). The importance of understanding the agro-climatic conditions is paramount to agricultural planning in Kenya.

4 CONCLUSION AND RECOMMENDATIONS

The results for agro-climatic parameters analyzed reveal that there is variability in all the parameters including rainfall amount, onset, cessation, length and dry spells for the growing seasons. The results further indicate that despite the observed variability, agricultural production can be improved by integrating agro-climatic variability in agricultural planning. Enhancing crop production requires the choice of high yielding crop varieties that can thrive within the prevailing conditions. This may involve changing the types of crops grown in order to accommodate unpredictable climatic conditions.

Re-introduction of indigenous crops such as millet and sorghum that mature faster and easily adapt to the changing climate is a feasible option. Multiple cropping could also be employed as a strategy to ensure that at least some crops survive the harsh conditions. Research into high yielding varieties that mature faster is recommended for the region since the lengths of the growing season continues to shrink with time. Farmers need regular trainings through extension services to enlighten them on the changing climate and appropriate mitigation measures.

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