Evaluation of dry spells during sensitive growth stages for maize crop in Western Kenya

Edward M. Mugalavai [a*], Emmanuel C. Kipkorir [b], and Charles K. Songok [c]
[a]Masinde Muliro University of Science and Technology (CDMHA), Kakamega, Kenya;
[b]Chepkoilel University College, Eldoret, Kenya; [c]Food and Agriculture Organization-Somalia
*Corresponding author: mugamus@yahoo.com; P.O. Box 190-50100, Kakamega, Kenya

The International Conference on Disaster Risk Reduction, and Conflict Resolution for Sustainable Development
18th—20th July 2012 @ Mmust, Kakamega, Kenya

Abstract
Evaluation of dry spells during the growing season of maize crop is done for the Lake Victoria basin in Kenya. The evaluation is based on suitable criteria for daily rainfall threshold (DRT) values that link the dry spells to the growing season. Three criteria: a) 1 mm DRT adopted from the Kenya Meteorological Department (KMD)-a storm of 1 mm is considered a wet day; b) 5 mm DRT that approximates to the mean reference evapotranspiration (ETo) of the region over the growing season; c) 10 mm DRT adopted from the region's rainfall onset criteria of 40 mm in 4 days, were tested by varying the durations of the dry spells between 7 to 30 days for the region. Dry spell analysis results obtained were interpolated in ArcGIS 10 using ordinary kriging, with or without anisotropy, and severity zones for agricultural planning mapped. The results presented through both temporal and spatial techniques indicate that probability of dry spells occurrence increases with increase in dry conditions. Results for the 5 mm DRT with durations of 7 days and 10 days are presented spatially to capture the severity of dry spells during germination and flowering stages of maize crop. The dry spells severity during germination stage is highest towards the northern part of Lake Victoria Basin (Kenya) and around the Lake shores with values ranging from (0-65%) and (0-59%) for the 7 and 10 days durations respectively. For flowering, the probability of dry spells range from (0-73%) and (0-65%) for the 7 and 10 days durations respectively with the highest severity occurring along Lake Victoria shores and the lowest around microclimatic (forests and topographic) features. These results indicate that point-specific analysis of agroclimatic parameters is crucial for agricultural planning since variations occur over short distances. The greater values fall within zones that produce a lot of maize hence the need for mitigation measures.

Keywords: Daily rainfall threshold; spatio-temporal techniques; GIS mapping; homogeneous zones; Dry spell severity

1. Introduction

Insufficient or lack of rainfall, at sensitive growth stages suppresses crop development and may even result in total crop failure. The most vulnerable growth stages to dry spells for maize crop are the germination and flowering. The crop initial stage (germination) is highly dependent on the crop, the crop variety, the planting date and the climate, consequently the effective full cover for many crops including maize occurs at the initiation of flowering (Allen et al., 1998).

Prolonged maize stress due to lack of soil moisture during important stages of crop development could have negative implications to crop yields. This prompted us to analyze the distribution of dry spell occurrences through the growing season. Alusa and Gwage (1978) analyzed the occurrence of dry spells during the East African long rains. The study revealed the association of dry spells with relief and mean annual rainfall distribution in the region. The results indicated that there is a low probability of dry spells (particularly of long durations) in the wetter areas of the region. However, the study was limited to seasonal dry spells without focusing on the sensitive growth stages that directly affect yield development and hence agricultural production. The study also used limited climatic data from only four stations (Kitale, Eldoret, Kericho and Kisii) within the western Kenya region which are not sufficient to generalize the whole region. The current study undertook a spatio-temporal analysis of dry spells within the region by considering both long and short rainy seasons and hence addresses the gaps in the earlier study.

A number of analyses of meteorological dry spell occurrences have been presented for different locations in Sub-Saharan Africa (e.g. Ochola and Kerkides, 2003) used a Markov chain simulation model for predicting critical wet and dry spells in Kenya. However, few analyses have been done on the occurrence of dry spells and management–related agricultural dry spells, their (potential) impact on crop growth and their relative importance for risk management among farmers (Kijne *et al.*, 2003). This study evaluated dry spell occurrences and linked them to potential impacts on the growing season.

Knowledge of wet and dry spells and the weather cycle in advance is very useful for crop planning. Aviad et al. (2009) examined the variations of dry days since last rain (DDSLR) as a measure of dryness along a Mediterranean arid transect, their findings revealed that DDSLR values increased with increasing aridity. An assessment of drought risk and irrigation in Ethiopia shows that severe dry spells during the growing season can be managed effectively by use of supplemental irrigation (Araya and Stroosnijder, 2011).

In recent years, GIS has become useful in approximating the spatial and spatio-temporal distribution of climatic phenomena in a multi-dimensional space (Price et al., 2000; Vizuete et al., 2002). The 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; Geerts et al., 2006; Hofstra et al., 2008).

Ordinary Kriging (OK) considers the distances between sampled points and uses a semivariogram to measure the spatial autocorrelation between points, such that weights change according to the spatial arrangement of the samples (García-León, et al., 2004). Several studies have used OK in climate studies however; the advantage of ordinary kriging is the estimation of kriging variance, which quantifies the uncertainty of the interpolation.

Goovaerts et al. (2000) compared simple kriging with varying local means; kriging with an external drift; and colocated cokriging to generate precipitation grids with satisfying results. Vicente-Serrano et al. (2003) obtained good outcomes from the interpolation of annual precipitation data in Spain where geographic and climatic differences were significant. The objectives of this study were to: (1) test daily rainfall threshold (DRT) criteria for use in dry spell analysis; (2) evaluate the point specific occurrence of dry spells during the maize growing season; (3) determine the spatial severity zones of dry spells in western Kenya through mapping for purposes of providing on-farm advisory on mitigation measures.

2. Materials and methods

2.1 Study area

This study was carried out in an area approximately 48000 km^2 which is bordered by Uganda to the west, Tanzania to the south and Lake Victoria basin boundaries to the north and the east (Fig 2.1). The Lake Victoria Basin region lies in the Western part of Kenya between 1^{o}30’N and 2^{o}00’S and between 34^{o}00’E and 35^{o}45’ E.

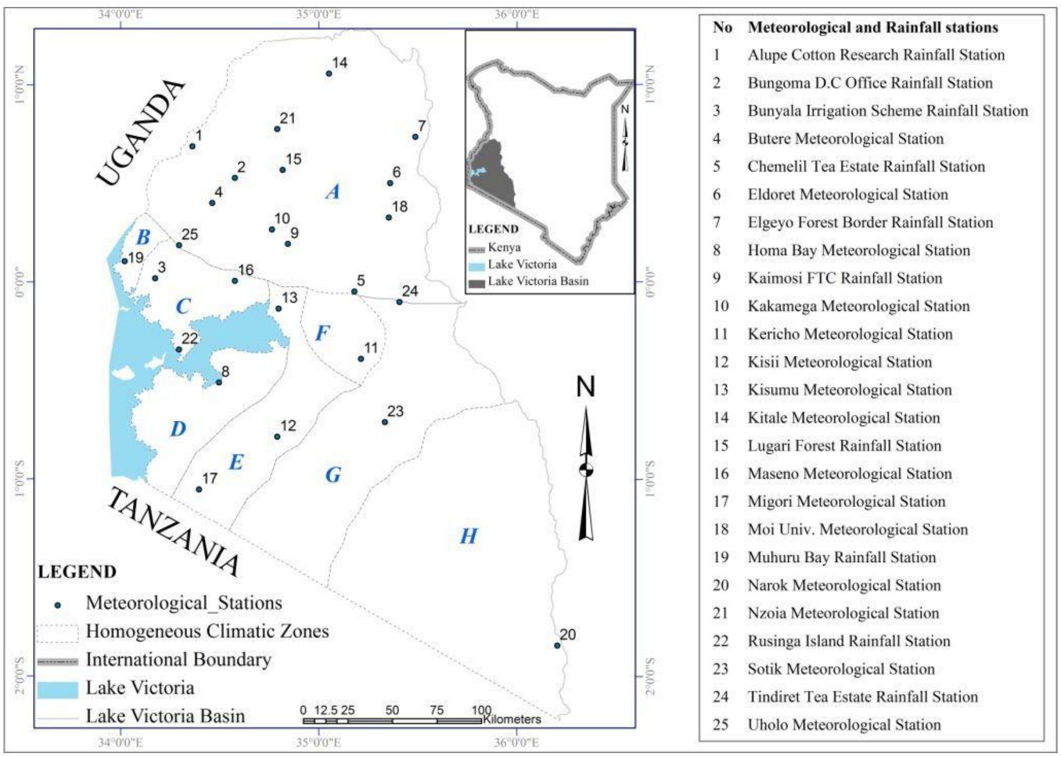


Fig. 2.1: Location of study area showing homogeneous zones

2.2 Reference evapotranspiration

Crop evaporative demand is an important indicator for dry spell occurrences. To evaluate the occurrence of dry spells during the sensitive growth stages of maize crop in western Kenya, reference evapotranspiration for germination (onset window) and flowering stages were analyzed. The daily reference evapotranspiration (ETo) was calculated using the ETo Calculator (FAO, 2009) and decadal values for the sensitive stages were then derived. Germination is closely linked to the rainfall onset for the region (Kipkorir *et al.*, 2007; Mugalavai *et al.*, 2008). The current analysis focused on the second (D2) and third (D3) dekads of March for stations in western Kenya zone and the first (D1) and second (D2) dekads of April for stations in the Rift Valley zone. Likewise the flowering stage was analyzed by considering the second (D2) and third (D3) dekads of June to represent flowering of the western zone stations and the first (D1) and second (D2) dekads of July representing the flowering in the Rift Valley zone (Table 2.1).

Table 2.1: Long-term dekadal effective rainfall (D_{eff}); dekadal reference evapotranspiration and coefficient of variation for eight stations in western Kenya

Station	Month	Dekad	Germination Stage					Flowering Stage						
			D_{eff} (mm)	ETo (mm/day)	D_{eff}/ETo	SD-D_{eff} (mm)	CV (%)	Month	Dekad	D_{eff} (mm)	ETo (mm/day)	D_{eff}/ETo	SD-D_{eff} (mm)	CV (%)
Kakamega	March	D2	38.8	47.3	0.8	28.3	72.9	June	D2	35.6	34.9	1.0	23.2	65.1
		D3	48.2	47.3	1.0	39.3	81.6		D3	39.8	35.1	1.1	30.7	77.2
Kisumu	March	D2	22.9	50.5	0.5	20.9	91.6	June	D2	19.6	39.2	0.5	19.2	98.1
		D3	50.4	49.3	1.0	41.8	83		D3	20.5	40.1	0.5	14.2	69.2
Kisii	March	D2	61.8	43.2	1.4	39.1	63.4	June	D2	36.7	36.5	1.0	23.8	64.9
		D3	88.4	42.1	2.1	50.1	56.7		D3	29	35.1	0.8	17.7	61.1
Kitale	April	D1	40.2	39.5	1.0	31.3	77.8	July	D1	24.4	33.1	0.7	17.2	70.4
		D2	33.1	38.7	0.9	28.6	86.3		D2	28.4	32.3	0.9	26	91.7
Kericho	April	D1	62.8	35.5	1.8	38.5	61.4	July	D1	46.3	31.6	1.5	23	49.6
		D2	79.2	35.3	2.2	36.3	45.8		D2	35.5	31	1.1	20.5	57.8
Eldoret	April	D1	29.1	43.2	0.7	26.8	92.2	July	D1	31.1	37.1	0.8	23.2	74.6
		D2	31.1	40.8	0.8	35.2	113.1		D2	42.7	34.8	1.2	21.6	50.7
Moi University	April	D1	38.1	44.7	0.9	18.8	49.2	July	D1	30.1	37.5	0.8	18	59.8
		D2	42.6	43.1	1.0	26.4	61.9		D2	30.8	37.5	0.8	20.7	67.3
Narok	April	D1	20.1	42.4	0.5	18.4	91.6	July	D1	5.5	34.3	0.2	14	256.7
		D2	42.6	42.6	1.0	47	91.4		D2	7.2	34.3	0.2	11.7	161.4
		Mean	**45.6**	**42.8**	**1.1**	**32.9**	**76.24**			**28.95**	**35.28**	**0.8**	**20.3**	**85.98**

For each of these analyses, effective rainfall per dekad (Barron et al., 2003) was calculated (Eq. (1)) based on the relationship:

$$D_{eff}=D_{rain} \times (1-0.25) \qquad \text{Eqn. (1)}$$

where D_{eff} is the dekadal effective rainfall (mm). D_{rain} is the decadal rainfall; the factor 0.25 accounts for the estimated average runoff of 25% (Araya and Stroosnijder, 2010). Dry spell occurrence was analyzed and presented as the ratio of decadal effective rainfall to the decadal reference evapotranspiration. When this ratio is <0.5 in any one of the dekads, then the dekad is said to have a dry spell. The interannual dekadal rainfall analysis was also done to establish annual variations by use of the coefficient of variation (Eq. (2)):

$$CV = \left[\frac{S}{\overline{X}}\right] \times 100 \qquad \text{Eqn. (2)}$$

where CV is the coefficient of variation; $\overline{X}$ is the average long term rainfall over the given dekad and S is the standard deviation of the decadal rainfall. Due to high rainfall variability caused by climate change, this analysis was necessary.

2.3 Analysis of dry spells

In this study, a dry spell was defined as the elapsed time since the last rainy day. The calculation of dry spells for each calendar day used a further development of the method presented by Aviad *et al.* (2009). The procedure of computing the dry spells was as follows:

i) Each day in which rainfall equaled or exceeded a specified DRT was allocated a value of "0".
ii) The first day in which no rain or with less than the specified DRT was recorded, after a rainy day, received the value "1", there after the days were cumulated, until the next rainy day, which again received the value "0", and so on.
iii) Dry spell duration was accumulated from one year to the next. Thus, 1st of January of each year (unless it rained on that day) was assigned a value according to that of the last rainy day.
iv) The dry spell values were arranged in ascending order and the daily probability calculated by Eq. (3):

$$p = \frac{m}{n+1} \qquad \text{Eqn. (3)}$$

where p is the probability; m is the ranked value of each year; and n is the number of analyzed years

2.4 GIS mapping

Dry spell severity zones were mapped using ArcGIS 10 (ESRI, 2011). Geostatistical analysis indicated that ordinary kriging performed better than inverse distance weighting for the two crop stages. Ordinary Kriging was preferred for dry spells interpolation since it gave a lower standardized root mean square error and due to its suitability where the sample points are not dense enough to depict the localized variations in the parameters (Haberlandt, 2007).

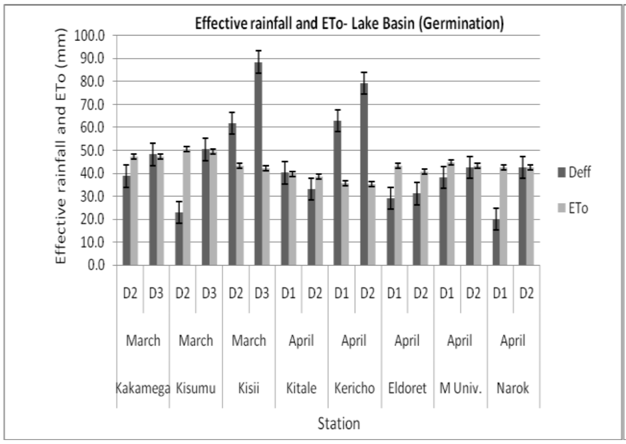
3. Results and Discussions

3.1 Results

3.1.1 Reference evapotranspiration

The analysis of reference evapotranspiration (ETo) for western Kenya is presented in (Table 2.1). Both stages indicate high coefficient of variation (CV) values for the decadal effective rainfall for sensitive growth stages of maize crop implying that there is a high interannual variability in dry spells. The eight stations analyzed were selected on the basis of the homogeneous zonation of the region (Ogallo, 1980).

The analysis further shows that the dekadal effective rainfall for some stations in the region fall short of the mean dekadal ETo during the germination and flowering stages of maize crop-a situation that results to stressful conditions. The high variability in dry spells requires responsive measures which in turn need continuous monitoring of these characteristics. Since most parts of western Kenya region are known to have a reliable rainfall regime in terms of amount (Mugalavai *et al.*, 2008) to determine variations in dry spells, plots of dekadal effective rainfall versus mean dekadal reference evapotranspiration were used to analyze long-term trends, the error bars show standard deviation with standard error (Figs. 3.1 and 3.2).



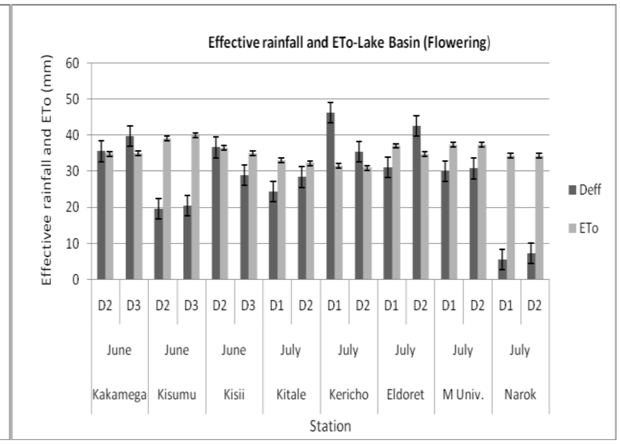
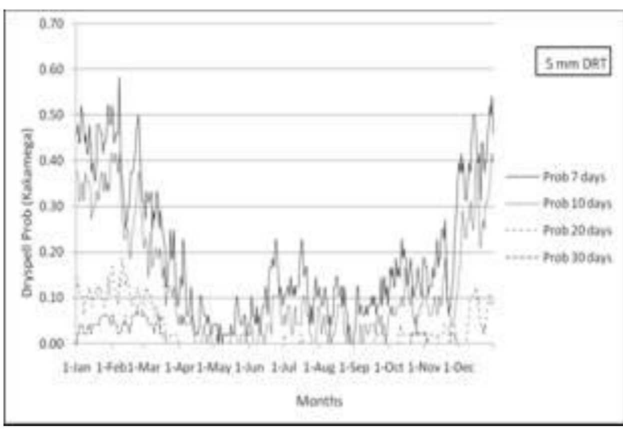


Fig. 3.1: Long-term (1982-2009) dekadal effective rainfall versus mean dekadal reference evapotranspiration during germination stage for the stations analyzed; Error bars show standard deviation with standard error.

Fig. 3.2: Long-term (1982-2009) dekadal effective rainfall versus mean dekadal reference evapotranspiration during flowering stage for the stations analyzed; Error bars show standard deviation with standard error.

3.1.2 Temporal variations of dry spells based on homogeneous zones

Dry spell results obtained using the 5 mm and 10 mm DRT values are compared with the 1 mm Kenya Meteorological Department (KMD) standard threshold value for a wet day. The stations used were categorized into humid, sub-humid, semi-humid, and transitional zones. In order to capture the possible severity of the water stress conditions based on lengths of dry spells at different DRT values, the analysis was further categorized into 7, 10, 20 and 30 day durations (Figs. 3.3 and 3.4).



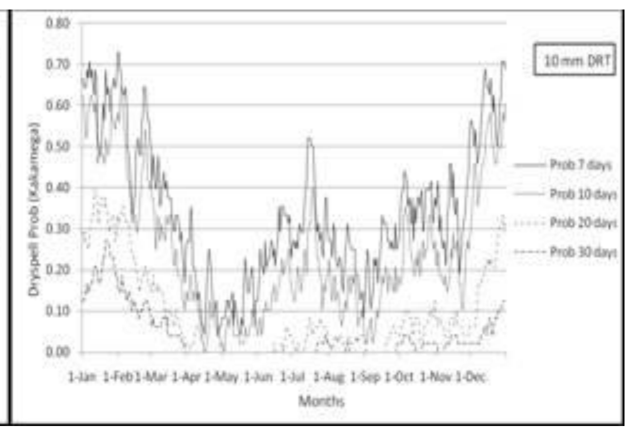


Fig. 3.3: Dry spell analysis for Kakamega 5 mm DRT

Fig. 3.4: Dry spell analysis for Kakamega 10 mm DRT

3.1.3 Regional analysis of dry spells

Analyses of the temporal distribution of dry spells using homogeneous zones in the region revealed that dry spells increase with increase in dry conditions. The dry spell occurrences were lower for humid stations (Kitale, Kericho, Tinderet, Butere, Kakamega, and Bungoma) and increased towards the transitional and semi-humid stations (Alupe, Bunyala, and Narok). The analyses also showed an increase in dry spells with increasing durations and DRT values (not shown for most stations). Spatial analysis results for the 7 and 10 days durations for the region are presented (Fig. 3.5 and Fig. 3.6; and Fig. 3.7 and Fig. 3.8) for germination and flowering stages respectively.

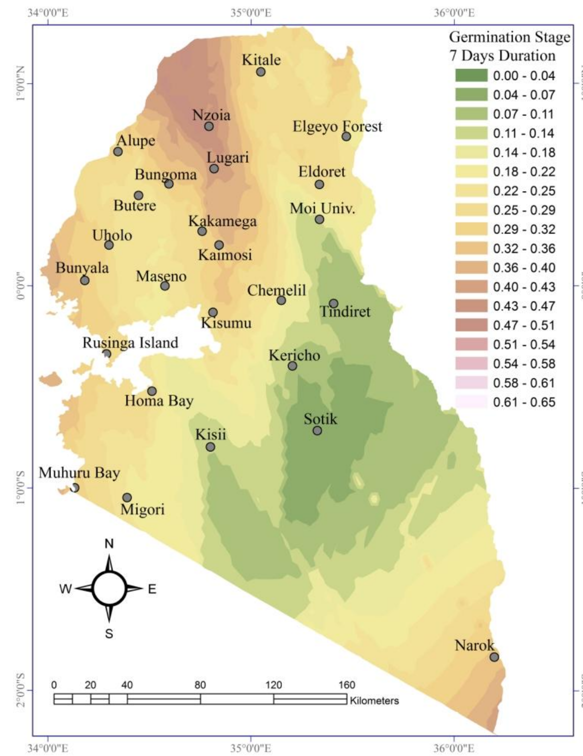


Fig. 3.5: Germination stage 7 days dry spells duration (%)

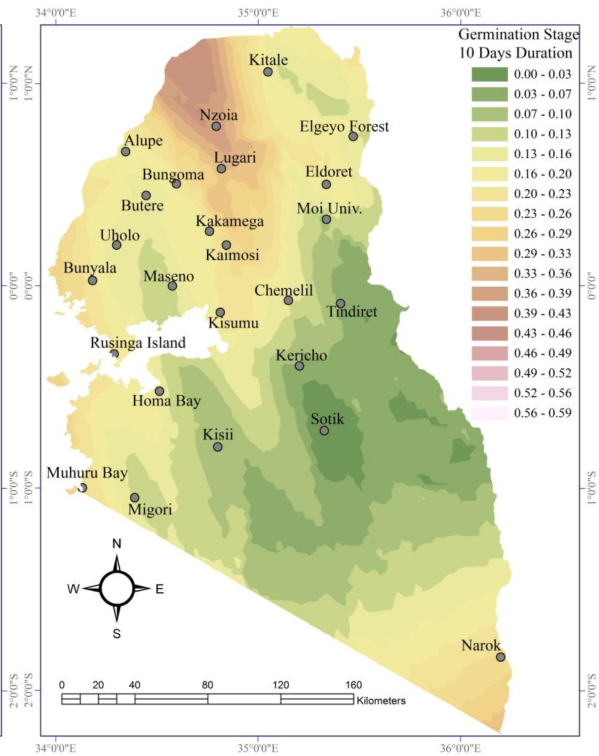


Fig. 3.6: Germination stage 10 days dry spells duration (%)

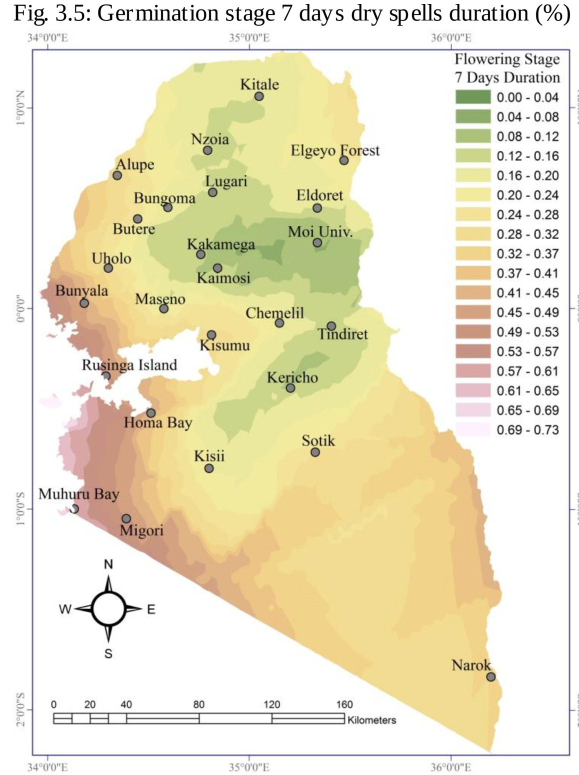


Fig. 3.7: Flowering stage 7 days dry spells duration (%)

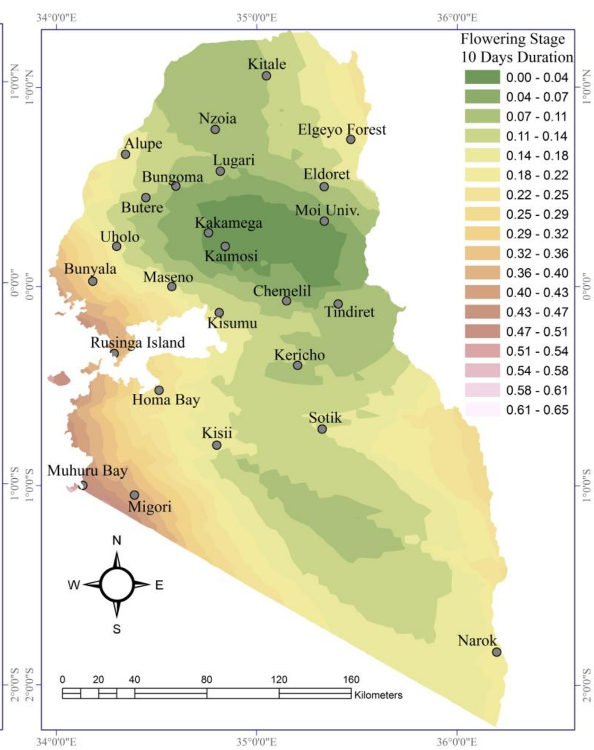


Fig. 3.8: Flowering stage 10 days dry spells duration (%)

3.2. Discussions

3.2.1 Temporal distribution of dry spells

Temporal dry spells analysis was used to test the different criteria of DRT values by varying the dry spell durations. The findings indicate that use of low DRT values give low probability of dry spell occurrences which cannot be relied on for agricultural planning since most of the rainfall received turns into runoff or is lost through evaporation hence leaving the root zone dry (Barron et al., 2003). The results clearly indicate that dry spell severity increases with increase in both DRT and durations of dry spells (Figs. 3.3 and 3.4). This study linked dry spells to the maize cropping season since maize is an important food grain for the region. Analyses were done for all the 25 stations spatially distributed in the basin as demonstrated by the results shown (Figs.3.3 and 3.4).

3.2.2 Spatial distribution of dry spells

The results generated from the spatial analyses using the 5 mm DRT have delineated zones with varying probability of dry spells occurrences. This analysis is important for use in operationalizing the field management strategies by simultaneously combining them with the temporal dry spell analyses results. Agroclimatic suitability mapping identifies zones with high vulnerability to dry spell conditions for use in both irrigation and other field management strategies (Geerts et al., 2006).

3.2.3 Crop evaporative demand

Results from the ETo analysis indicate that out of the eight stations analyzed, only two (Kisii and Kericho) are free from dry spells during the germination period (Fig. 3.1). Stations in the western zone (Kakamega and Kisumu) have dry spells during the second dekad of March whereas stations in Rift Valley zone do not show such a pattern with dry spells occurring in the second dekad of April for Kitale; first dekad of April for Moi University; and Narok. Eldoret has persistent dry spells in both first and second dekads of April and therefore requires mitigation.

For flowering (Fig. 3.2), Kakamega and Kericho do not suffer from dry spells in both dekads analyzed. Dry spells persist for both dekads analyzed: Kisumu in June, and Kitale; Moi University; and Narok all in the month of July. Kisii suffers from dry spells in the second dekad of June while the first dekad of Eldoret for July has dry spells during the flowering stage. Based on these results most stations are not subjected to severe dry spells however, there is need for responsive measures to ensure that the dry spells encountered do not lead to decline in crop yields.

It is further observed that despite the high rainfall amounts received in western Kenya, dry spells requiring mitigation are still experienced. Since ETo analysis in this study is based on specific phenological stages of maize growth, the results clearly show the dekadal severity of dry spells.

3.2.4 Mitigation of dry spells

It is evident that dry spells occur in the rainfed region within the Kenyan Lake Victoria basin. However, in areas with humid climate (Kitale, Kericho, Tinderet, Butere, Kakamega, Bungoma), supplemental irrigation might not be a viable solution to the moisture stress that crops experience over the dry spell period in this region. Moreover the probability of dry spells occurrence for some stations hardly exceeds 30% (1 mm and 5 mm DRT values) during the growing season.

Dry spell occurrences generally increase with increasing DRT values in the region and since effective rainfall for agriculture cannot be based on the 1 mm DRT, it means the higher DRTs are important for rainfed agricultural planning.

Farmers in humid regions need to employ microclimate management and manipulation methods in evading the effects of dry spells. Transitional and sub humid regions need to adopt strategies that employ supplemental irrigation techniques. Semi humid stations (Narok) are the worst affected by dry spell occurrences. This study has documented the dry spell characteristics and disaggregated the vulnerable periods during the growing seasons. Rotational water storage (bare fallowing) can conserve water for use during the sensitive dry spell periods.

4. Conclusion and recommendations

Since the Lake Basin is an important agricultural region especially for grain production, there is need to mitigate the dry spells. The results obtained from temporal dry spell analyses can be applied to other crops by identifying their growth seasons within the calendar year. Mapping of the Lake Victoria basin (Kenya) region into dry spell severity zones (Fig. 3.5, Fig. 3.6) and (Fig. 3.7, Fig. 3.8) will enable operationalizing of appropriate mitigation measures in the region. The study established that there is an increasing trend (germination) and a decreasing trend (flowering) in the dry spells severity towards the northern part of Lake Victoria basin (Kenya). This study explored both the meteorological and agricultural dry spells by using rainfall and reference evapotranspiration (ETo) data in the analyses. Sub-humid regions within the Lake Victoria Basin should invest in water harvesting for use in supplemental irrigation systems in order to improve on crop production.

Based on the results from the analyses, it is recommended that the 5 mm DRT be adopted for use in determining dry spells in the region since it is based on the crop evaporative demand which is important for agricultural planning. Although the main focus was on the maize growing seasons, there is need to extend the dry spell analyses results to cover other food crops for which the sowing dates and the lengths of the growing seasons for the specific crops are known. The trend established in the dry spells severity mapping could provide a basis for on-farm advisory through field extension services.

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