

Leveraging dry spells analysis to mitigate climate change risks on maize crop farming in Lake Victoria Basin, Kenya

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ABSTRACT

Effects of climate change in the Lake Victoria basin are demonstrated using dry spell analyses for the maize growing seasons. The aim of the study was to establish the temporal and spatial characteristics of dry spells on maize crop during the growing season and assess farmers' adaptation approaches used to mitigate severe dry spells in the Lake Basin region, Kenya. The results were interpolated in ArcGIS 10 using ordinary kriging, with or without anisotropy, and severity zones for agricultural planning delineated. The results presented through both temporal and spatial techniques indicate that probability of dry spells occurrence increases with increase in dry conditions. The point specific analysis of agro-climatic parameters obtained is useful for agricultural planning. The region is important for grain production in Kenya hence the study has identified innovative adaptation approaches to enhance resilience to climate change effects. Suitable adaptation approaches identified for the region include conservation agriculture achieved through climate smart agriculture (supplemental irrigation, agroforestry, mixed cropping, rainwater harvesting, and growing drought resistant crops) and integrated soil fertility management. Upscaling the use of these approaches will increase resilience to climate change effects and unlock the agricultural production potential hence mitigate on food insecurity.

Keywords: Adaptation Approaches, Agro-Climatic Indices, Dry Spell Analysis, Food Security, GIS Mapping, Spatio-Temporal Techniques

I. INTRODUCTION

There has been increasing emphasis to the interactions of climate change with other stresses on the environment and human populations, as well as the linkage between climate change and sustainable development. Climate change adaptation at farm level has significant development outcomes in addition to reducing exposure to weather risks (Ali & Erenstein, 2017).

Climate changes affect productivity of crops differently in different regions (Nastis *et al.*, 2024). Many studies have assessed effects of climate change on agricultural productivity in different regions (Abid *et al.*, 2015, Abid *et al.*, 2016). In Italy, research has shown that the decrease in precipitation depends on the reduction in the number of wet days, as precipitation intensity displays a positive trend. Moreover, there is a tendency both toward an increase in heavy precipitation events and long dry spells (Bonaccorso *et al.*, 2005).

Most analyses on occurrence of water stress have focused on the occurrence of meteorological droughts. Previous analyses of meteorological dry spell occurrence are presented for different locations in Sub-Saharan Africa (Ochola & Kerkides, 2003). However, few analyses focused 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. This study endeavored to evaluate dry spell occurrence and linked it to potential impacts to maize growth.

The risk of climate change for agricultural production is studied in the context of defining a set of agrometeorological parameters that indicate the consequences of climate change for crop water requirements (Todisco & Vergni, 2008). The meteorological stations used in this study were based on the homogeneous zonation of the Lake Victoria basin Kenya (Awange *et al.*, 2013). Stations with long continuous data records were included in the analysis.

Agricultural productivity in Sub-Saharan Africa is affected by widespread spatio-temporal variability of rainfall, dry spells and recurrent droughts and floods (Laux *et al.* 2010). Crop failure and thus food shortages are attributed to both intra and inter-seasonal variability (Mishra *et al.*, 2008). Crop production in semi-humid areas is

strongly determined by rainfall distribution as opposed to the amount of rainfall. Crop yield is severely affected by intra-seasonal dry spells (Araya & Stroosnijder, 2011; Segele & Lamb, 2005; Meze-Hausken, 2004).

Dry spell is defined in relation to consecutive days without appreciable rainfall (Mugalavai *et al.*, 2008). Effective dry spell analysis needs to consider relationships between rainfall and reference evapotranspiration (Araya *et al.*, 2010). Araya and Stroosnijder (2011) define a dry spell as a dekad in which effective rainfall is less than 50% of the decadal reference evapotranspiration.

East Africa depends heavily on rainfed agriculture making rural livelihoods and food security highly vulnerable to climate variability such as shifts in growing season conditions (Inter-Governmental Panel on Climate Change-IPCC, 2001). Agriculture in this region contributes 40% of the Gross Domestic Product (GDP) and provides a living for 80% east Africans (International Food Policy Research Institute (IFPRI), 2004). However, due to temperature increase due to climate change, the region experienced a decline in long-cycle crops and rainfall between March and May from 1996 to 2003 (Funk *et al.*, 2005).

Mati (2000) carried out a study on the influence of climate change on maize production in the Semi-humid to semi-arid areas of Kenya. The study used stations from different agro-climatic zones however, the study failed to explore the spatial approach needed for planning at regional level. The study recommended the search for alternatives to rainfed maize production including the introduction of irrigation and runoff harvesting which was the focus of the current study.

Geographical Information Systems (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; Vicente-Serrano *et al.*, 2003; Geerts *et al.*, 2006; Haylock *et al.*, 2008).

Goovaerts *et al.* (2000) compared simple kriging with varying local means; kriging with an external drift; and collocated 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 current study undertook a seasonal and spatial analysis of dry spells with the aim of determining the spatial severity zones of dry spells in western Kenya through mapping for purposes of providing on-farm advisory on mitigation measures.

1.1 Research Objectives

The study aimed at:

- i. Establishing the spatial and temporal characteristics of dry spells on maize crop during the growing season within the Lake Victoria Basin Kenya.
- ii. Assess the farmers' adaptation approaches used to mitigate severe dry spells in the Lake Basin region, Kenya

III. METHODOLOGY

3.1 Study Area

This study was carried out in an area approximately 48000 km² that is bordered by Uganda to the west, Tanzania to the south and Lake Victoria basin boundaries to the north and the east (Figure 1). The Lake Victoria Basin region lies in the Western part of Kenya between 1° 30'N and 2° 00'S and between 34° 00'E and 35° 45' E.

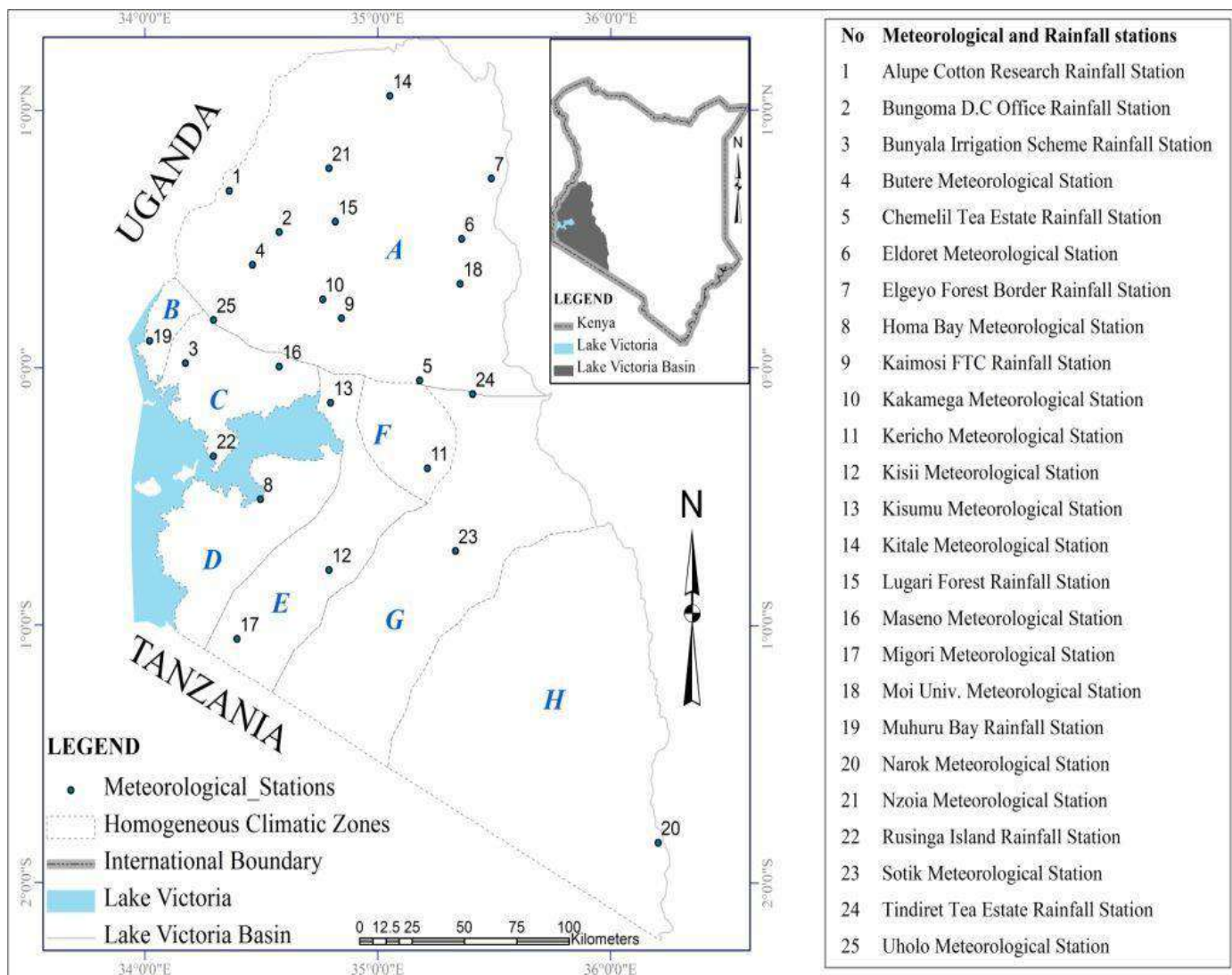


Figure 1
Location of Study Area Showing Homogeneous Zones

3.2 Evaluation of Dry Spells

Evaluation of dry spells during the growing season of maize crop for the Lake Victoria basin in Kenya was 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 (ET_o) 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 (Chumo et al.,2011), were tested by varying the durations of the dry spells between 7 to 30 days for the region.

In this study, a dry spell was defined as the elapsed time since the last day. The calculation of dry spells for each calendar day used a further development of the methods presented by Aviad *et al.* (2009). The procedure of computing the dry spells were as follows: rainy each day in which rainfall equaled or exceeded a specified DRT was allocated a value of “0”. 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 are cumulated, until the next rainy day, which again received the value “0”, and so on. 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.

The dry spell values were arranged in ascending order and the daily probability calculated (Eqn. 1):

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

Where:

p is the probability; *m* is the ranked value of each year; *n* is the number of analyzed years.

3.3 GIS Mapping

Dry spell severity zones were mapped using ArcGIS 10 (Environmental Systems Research Institute-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).

3.4 Dry Spells Mitigation

To leverage dry spells analyses on the adaptation strategies used in the Lake Victoria basin region, desktop review was carried out to establish the preferred approaches. Farmers in the region have already embraced a number of approaches suitable to their practices (Orchardson, 2019; Muinga, 2019). This study endeavored to explore how the dry spells results would be used in enhancing mitigation measures against climate change risks during the affected months of the year.

IV. FINDINGS & DISCUSSION

4.1 Evaluation of DRT Criteria used in the Analysis of Dry Spells

Temporal dry spells analyses were used to test the different criteria of DRT values by varying the dry spell durations. The results clearly indicate that dry spell severity increases with increase in DRT. This study explored the various options by varying the durations and provides results that can be operationalized at field management level. The study linked dry spells to the maize cropping season-maize is the staple food for the region. Use of the 1 mm DRT (adopted from KMD) gives low probability of dry spell occurrences, which, cannot be relied on for agricultural planning since most of the rainfall received, could be lost through soil moisture evaporation and interception. Crop water stress (dry spells) is exacerbated in the region by the widespread environmental degradation experienced in most areas within the basin. Although the stations presented are from one region, there is high variability of dry spells between them, which underscores the need for point specific analyses. Analyses were done for 25 stations in the basin two representative stations from homogeneous zones have been presented.

4.2 Regional Analysis of Dry Spells

Analyses of the temporal distribution of dry spells using selected stations from homogeneous zones in the region revealed that dry spells increase with increase in dry conditions (Mugalavai et al., 2013). 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 DRT values. Representative stations (Kakamega, Eldoret, Kisumu, Homabay, Alupe, Rusinga and Narok) for the different climatic characteristics zones presented. Figure 2 and Figure 3 (Kakamega and Alupe) are representative of western Kenya. It is evident that Kakamega, which, is a humid station experiences less severe dry spells than Alupe-a transitional station at all DRT levels. Results for the other stations are not presented in this paper.

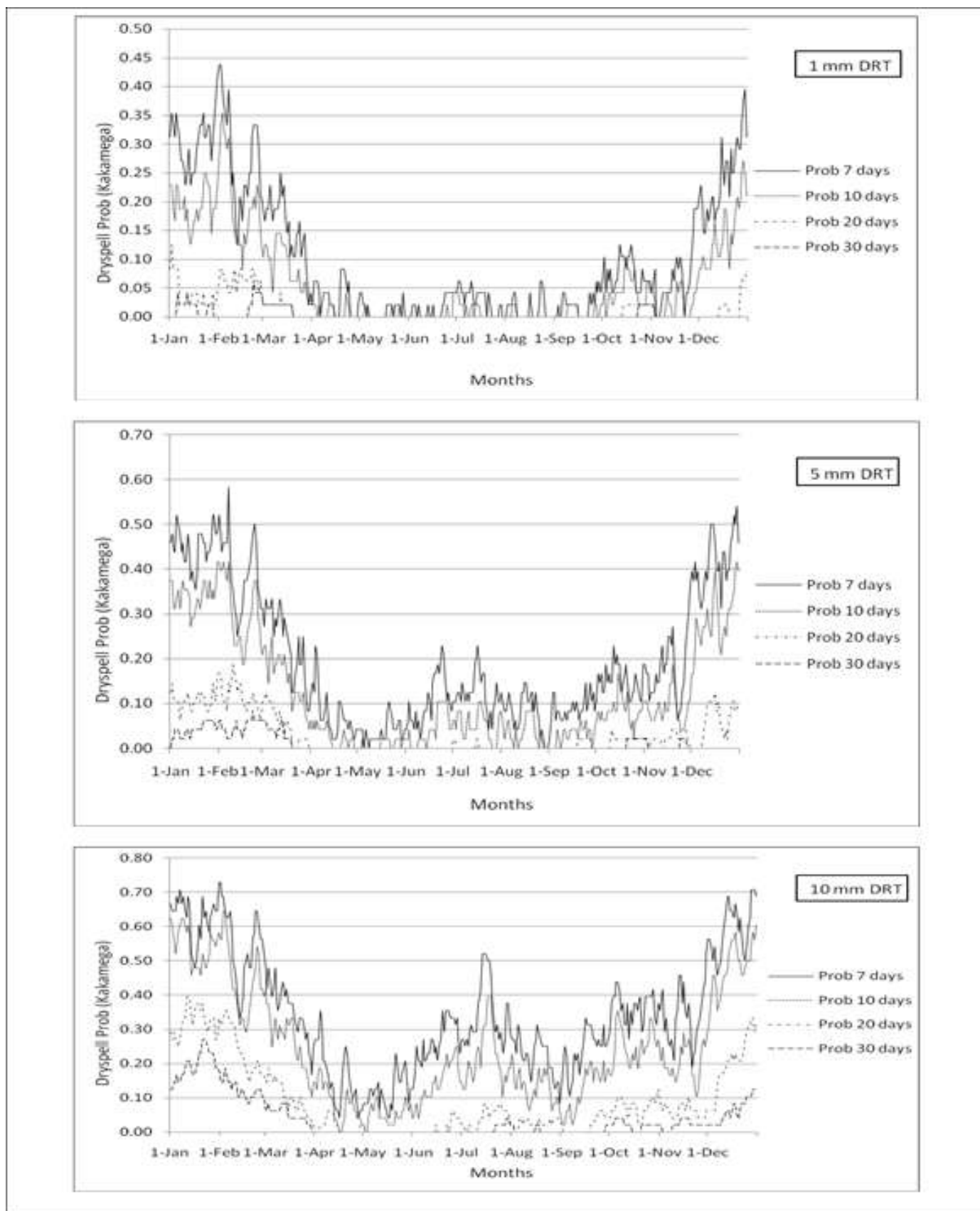


Figure 2
Dry Spell Analysis (1mm; 5 mm and 10 mm DRT) for Kakamega

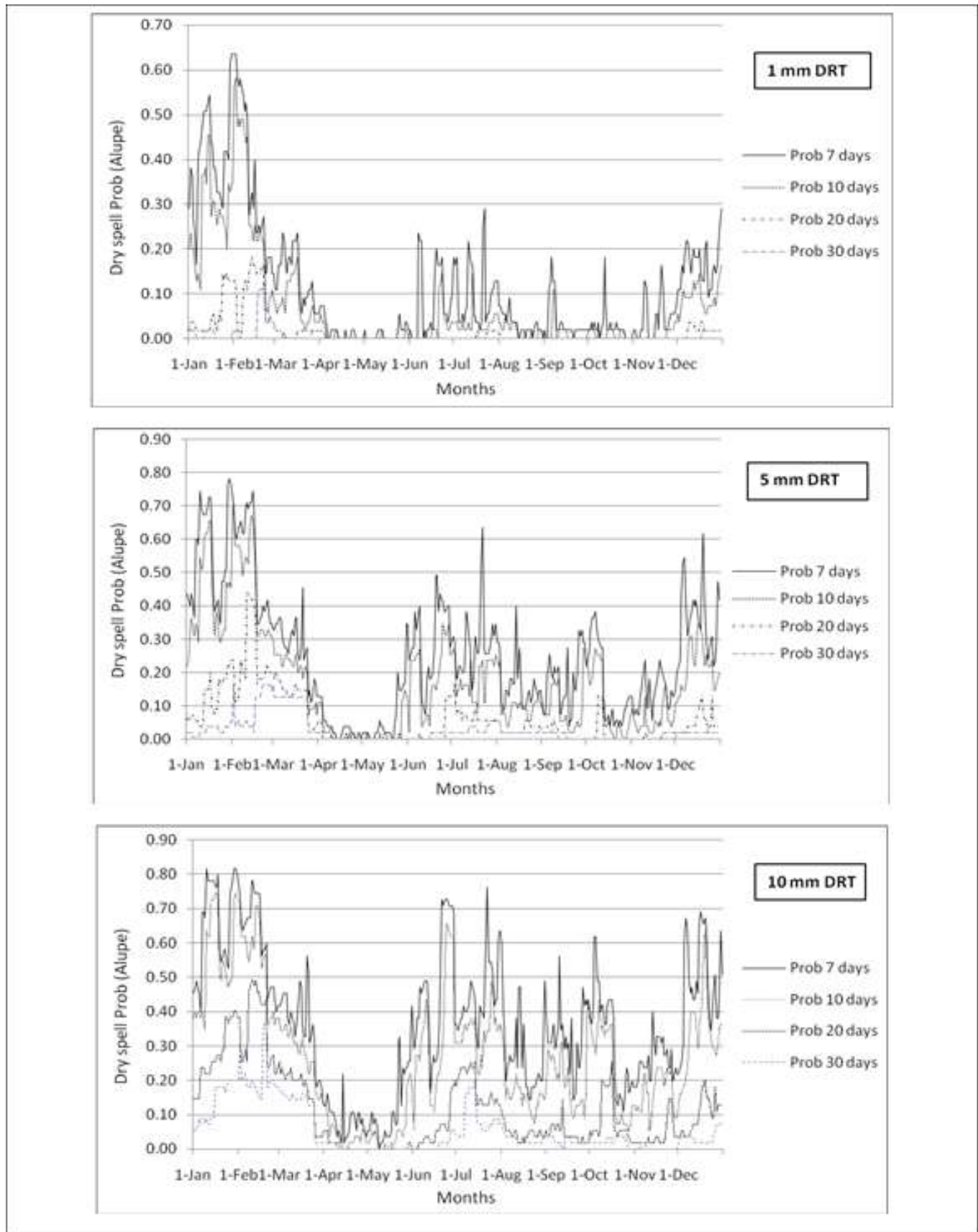


Figure 3
Dry Spell Analysis (1mm; 5 mm and 10 mm DRT) for Alupe

4.3 Dry Spell Mapping

To identify dry spell severity zones, mapping was done for the 7 and 10 days durations at 5 mm DRT using the results generated from the dry spell analyses for the region. The maps show that severity of dry spells in percentage increase with increase in dry conditions. The maps presented here cover the germination stage (second dekad of March to second dekad of April)-onset window and second dekad of June to second dekad of July (Fig. 4 a, b, c and d)-representing flowering stage for stations that grow the long season H614 maize crop variety for the western and Rift Valley zones. It is observed that stations falling within the humid zones are not severely affected by the dry spells whereas those in the sub-humid zones require mitigation since the dry spells could cause stressful conditions that adversely affect the yields.

The results show that the dry spell severity for the germination stage increases towards the north following the pattern for the rainfall onset in the region (Mugalavai et al., 2008). However the severity of dry spells during the flowering stage decreases towards the north. These patterns break at important topographic (mountains) and environmental (water body and forests) features. The monthly analysis results were also mapped to establish whether patterns exist for the region. Similar patterns (Figure 4) to those of the dekad analysis were observed at monthly intervals but with slightly lower probabilities of dry spells to capture the monthly spatial distribution for the whole season, mapping was also done for the period May-November not shown. The monthly analysis of dry spells confirms that the vegetative, flowering and grain filling stages (June, July and August) for Western zone and (July, August, September and October) for Rift Valley zone experience water stress requiring supplemental irrigation. Spatial patterns for the severity of dry spells are similar to those of the dekad analysis but the percentage probability levels vary.

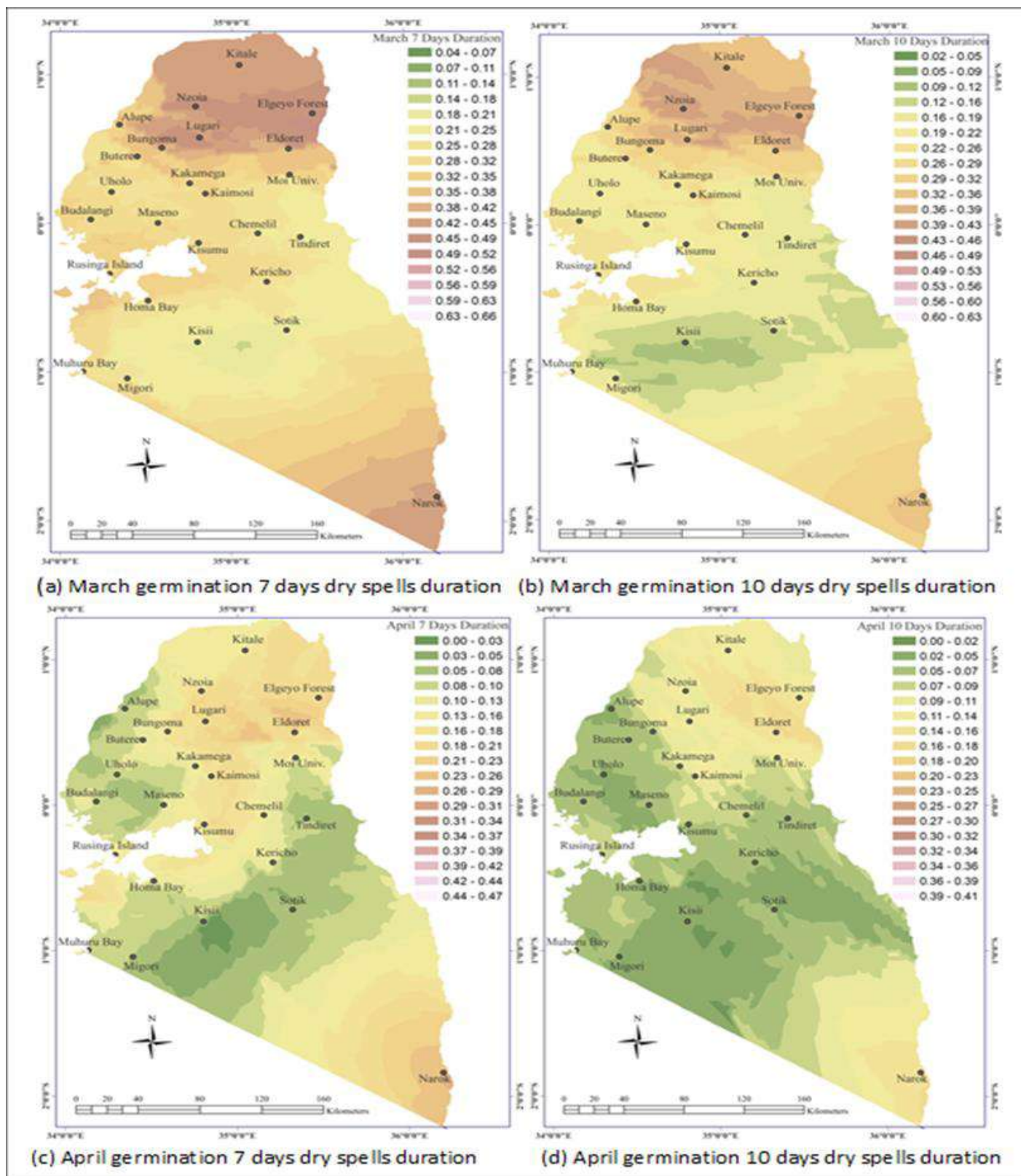


Figure 4
Monthly Analysis of Dry Spells for germination Stage for the Lake Basin Region (%)

4.4 Spatial Distribution of Dry Spells

The results generated from the spatial analyses have delineated zones with varying probability of dry spells occurrences. This is important for use in operationalizing the field management strategies by simultaneously using them in combination with the temporal dry spells results. Agro-climatic suitability mapping identifies zones with high vulnerability to dry spell conditions, for use in both supplemental irrigation and other field management strategies

(Geerts et al., 2006). The maps obtained are helpful in determining the location of stations with similar dry spell characteristics and hence offer relevant guidelines to farmers in those particular areas. Maps for other critical phenological phases of maize crop, such as flowering and grain filling were also generated (Figure 5 and 6 respectively). Using the results obtained on the dry spell probability for each zone, coupled with the guidance and advisory of extension officers, farmers will be able to devise suitable adaptation approaches and timing of operations in order to cope with the dry spells. Indeed this makes the field management options specific to individual zones. The results obtained show that the dry spell severity in this region can be managed through supplementing moisture requirements and the use of farm management practices (Mamo *et al.*, 2021).

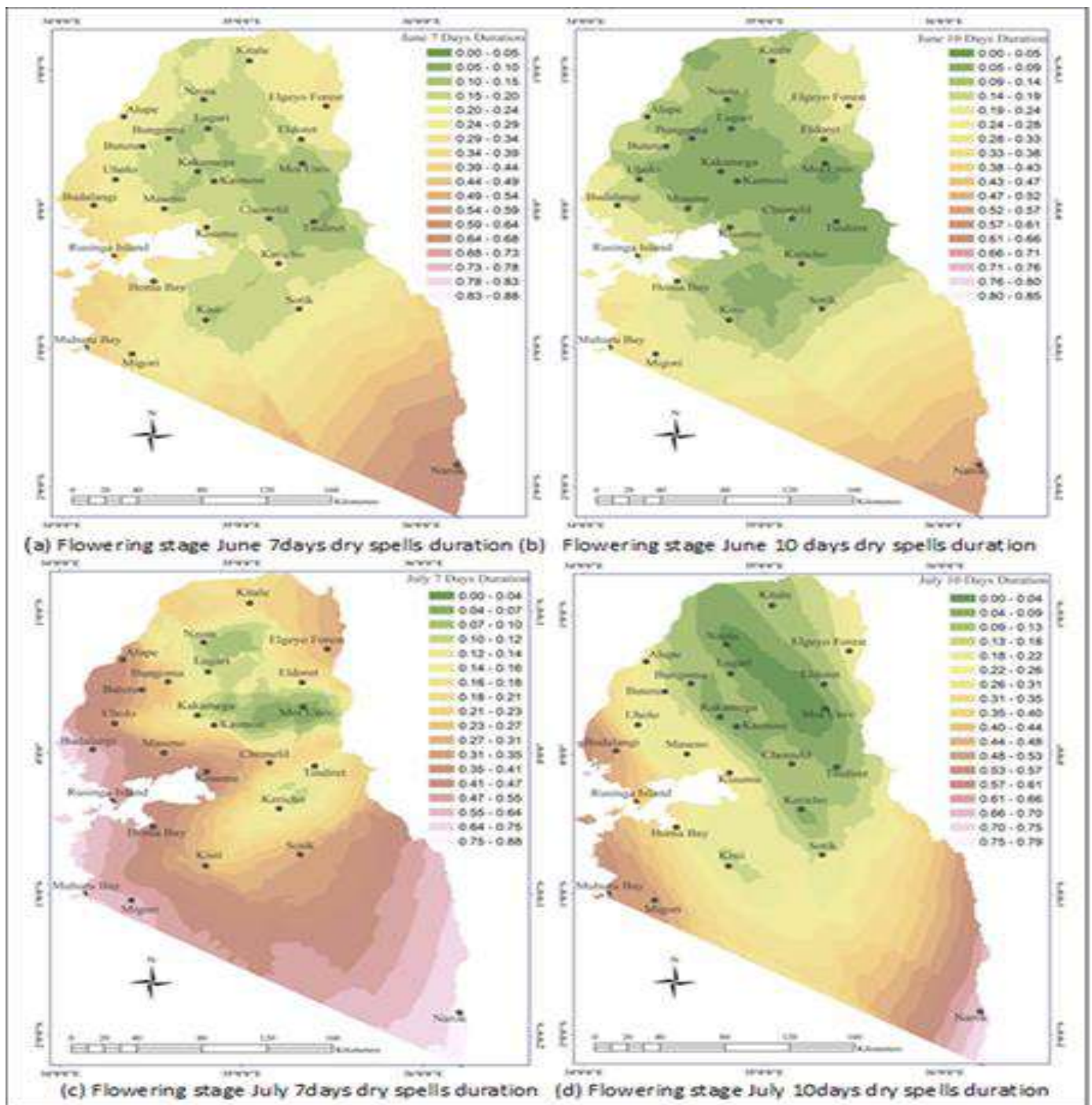


Figure 5
Monthly Analysis of Dry Spells for Flowering Stage in the Lake Basin Region (%)

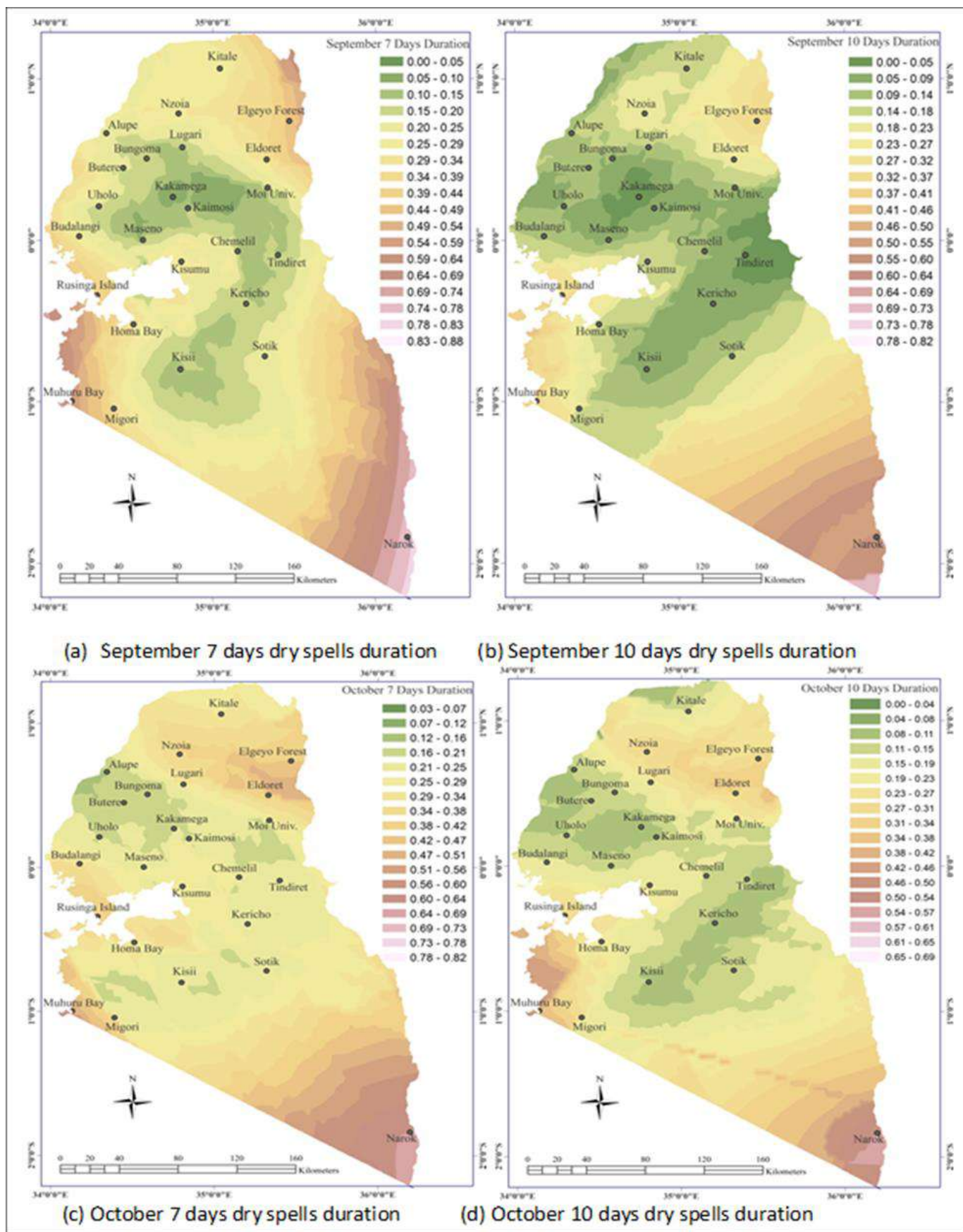


Figure 6
 Monthly Analysis of Dry Spells (September and October) for the Lake Basin Region during Grain Filling Phase (%)



4.5 Adaptation Approaches for Mitigating Dry Spells

Conservation agriculture (CA) is the main strategy identified for mitigating the effects of climate change in the region due to the moderate severity of dry spells during the sensitive growth stages of maize. CA is characterized by three linked principles, namely: continuous minimum mechanical soil disturbance; permanent organic soil cover; and diversification of crop species grown in sequences and/or associations (Jat *et al.*, 2020). Adoption of these strategies could maximize the use of available moisture while avoiding losses. Using the results from dry spells analyses, farmers are able to make informed decisions on when to apply different approaches in mitigating within season moisture deficits hence avoiding crop yield decline.

3.5.1 Irrigation

Irrigation is the artificial delivery of moisture for the benefit of growing crops. In the Lake Victoria basin where rainfed agriculture still thrives, this approach is useful in supplementing the moisture requirements during the periods of within season dry spells (FAO, 1997). Irrigation systems are simply the method a farmer employs to transport water from its source to their cultivated fields. Within the study area, there are abundant sources of water including groundwater sources, such as aquifers, springs and wells, or surface water sources, such as rivers, ponds, or lakes (Mamo *et al.*, 2021). Different irrigation approaches exist based on the farm sizes and the farmers' resource base. In the Lake basin region where the problem is linked to the rainfall distribution rather than amount, farmers leverage on the point specific dry spell analyses results to supplement the moisture deficit during sensitive phases (flowering and grain filling). Supplemental irrigation (SI) is a highly efficient practice with great potential for increasing agricultural production and improving livelihoods in the dry rainfed areas (Oweis and Hachum, 2006). Irrigation for large farms and crops that need large water supplies like rice require installation of irrigation infrastructure, whereas the small-scale garden farming can be achieved using simple methods.

4.5.2 Growing of Drought Resistant Crops

Drought resistant crops are grown in areas where the dry spell severity is high such as Elgeyo in the northern part of the Lake Victoria basin, some parts around the lake and in some islands within the lake. Through research drought resistant varieties suitable for such areas have been identified (Woomer, *et al.*, 2016). Crop varieties have been identified for different ecological zones in Kenya (Muinga *et al.*, 2019). Maize farming has been boosted by developing short season varieties which mature early hence avoiding the dry spells window. An understanding of dry spells characteristics also assists in decision making on the timing of planting to avoid risks (Kipkorir *et al.*, 2007). In order to assist the farmers there is need to strengthen the extension services in counties to enlighten them on the new and emerging technologies.

4.5.3 Rainwater Harvesting

The problem experienced in agriculture within the Lake Victoria basin is not entirely due to shortage of rainfall but rather the distribution of rainfall throughout the seasons. The seasonal rainfall received is not well distributed to support crops through the growing season. Using the dry spell analysis results obtained in the current study, management of the moisture deficit during critical growth stages is essential. This study therefore suggests harvesting of rainwater for use in supplementing the water requirements of the crops during dry spells especially considering the delicate phenological stages (germination and flowering) that require substantial amount of moisture (Oweis and Hachum, 2006). Roof catchment is useful for harvesting water for domestic purposes and use for garden irrigation. Water harvesting may be done from roofs, ground, or the watercourses (Eslamian *et al.*, 2021). Floodwater harvesting if explored in areas prone to flooding (Kano and Budalangi flood plains in western Kenya) could also be useful in mitigating against dry spells during the growing seasons.

4.5.4 Climate Smart Agriculture (CSA)

Climate Smart Agriculture is a set of farming methods designed to increase the resilience and productivity of land affected by climate change (Orchardson, 2019). Among the CSA practices used in Kenya, include agroforestry; conservation tillage; the limited use of fire in agricultural areas; cultivation of drought-tolerant crops; water harvesting, and; integrated soil fertility management. These methods if employed support crops during the prolonged severe within season dry spells. The use of CSA enhances the adaptive capacity, strengthens the mitigation potential and sustains food security (Jat *et al.*, 2020).

CSA requires timely planting, which employs dry sowing once onset of the seasonal rains is predicted and disseminated, by the Kenya Meteorological Department to farmers through local (vernacular) radio stations (Jat *et al.*, 2020). Farmers may also integrate the use of indigenous methods by observing already established indicators that are site specific. Dry planting ensures early crop establishment and use of any available soil moisture from the beginning

of the season. CSA also involves use of simple mechanization techniques such as use of the direct seeder to address issues of labour shortage. Farm record keeping and timely application of farm management practices are important in ensuring proper monitoring of the crops through the phenological growth stages.

CSA ensures choice of the right varieties for different crop growing seasons (Muinga, 2019). Since the analysis of the severity of dry spells for the region has been done and areas with varying levels designated, the choice of the right crop variety is assured. Through CSA there is integrated pest and weed management which, is aided by the continuous monitoring of the farms.

4.5.5 Agroforestry

Agroforestry is a practice where trees are planted together with other crops on the same farm (FAO, 1997). If well applied, the method enhances integrated soil fertility management where plant roots hold soil together and the organic matter from the trees enrich the soil improving its water holding capacity. This is useful in ensuring that the soil has enough moisture to sustain crops through the dry spells period hence guaranteeing good harvest. Socio-economic factors such as education level, occupation, age, land size, income, gender, marital status, cultural beliefs and family size are linked to agroforestry adoption among smallholder farmers in Kenya (Syano *et al.*, 2022). The choice of good agroforestry tree varieties, which, offer multiple uses including; fodder for animals, woodlot for firewood, medicinal plants, timber for construction and fencing purposes, is encouraged. Indigenous tree varieties give the best choices for agroforestry tree species.

4.5.6 Use of Mixed Farming

In areas where dry spells are predominant, farmers are advised to employ mixed farming techniques where they practice multiple cropping (Jat *et al.*, 2020). This method involves planting several crop varieties on the same farm (Ditzler, 2023). Farmers within the Lake Victoria basin region distribute risk through mixed farming since they believe, with a level of certainty that, some of the varieties could survive periods of dry spells. Indeed this method ensures that a farmer does not miss on all crops and at least has food for self-sustenance. Mixed farming system is helpful in decreasing the cost of production per unit area, increasing income and productivity and reducing the risk of farmers (Ray *et al.*, 2020). In the Lake Victoria basin farmers have for a long time successfully intercropped maize, millet, sorghum among other crops. Due to the increased effects of climate change, such indigenous methods of farming are regaining their prominence in the region.

4.5.7 Integrated Soil Fertility Management (ISFM)

ISFM is a set of soil fertility management practices that include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions in order to maximize the agronomic use efficiency of the applied nutrients and improving crop productivity. It ensures all inputs are utilized for crop growth through sound agronomic practices' (Vanlauwe *et al.* 2010). Any of the interventions is required to increase the efficiency and profitability of food production as related to use of land, labour, fertilizer inputs, organic inputs, and improved germplasm and financial investments. Farmers in the Lake Victoria Basin practice mulching, terracing, crop rotation, use of organic manure; which all require a good understanding of the dry spell periods. The knowledge of dry spells achieved through this analysis, will enable farmers to make informed decisions based on their location and the severity of dry spells. Farmers will be better placed in terms of timing of the seasons and on when to apply different practices (Kiguha *et al.*, 2025) through the advisory of climate services and agricultural extension officers.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The study analyzed both the seasonal and spatial variability of dry spells, which are important for regional agricultural planning. Although the focus was on the maize growing seasons the dry spell analyses results are applicable to other food crops as long as the sowing dates and the lengths of the growing seasons for the specific crops are known. This study endeavored to capture the dry spells severity over the entire year (temporal) and their distribution over space (spatial).

The study established that there is an increasing trend in the dry spells severity towards the northern part of Lake Victoria basin (germination) and a decreasing trend towards the north (flowering), the pattern breaks at distinctive microclimatic (forests, large water bodies and topographic) features. The temporal analysis on the otherhand provides the point-specific characteristics for the various stations.



The study has identified innovative adaptation approaches to enhance resilience to climate change effects. Suitable adaptation approaches for the region include conservation agriculture achieved through climate smart agriculture (irrigation, agroforestry, mixed cropping, rainwater harvesting, growing drought resistant crops and integrated soil fertility management) practices.

5.2 Recommendations

Based on the significance of the Lake Victoria basin region in Kenya, as a high potential agricultural region especially for grain production, there is need to mitigate the dry spells. The dry spell analyses results should be applied to other food crops grown in the region in quest of attaining food security and industrial development in Kenya by the year 2030. Efforts towards enhancing the use of climate services and strengthening the involvement of extension services in the region are necessary to achieve the intended goals.

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