INTRA-SEASONAL RAINFALL CHARACTERIZATION FOR MAIZE AND SORGHUM PRODUCTIONS AT SORO WOREDA OF HADIYA ZONE, SOUTHERN ETHIOPIA

MSc THESIS

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I dedicate this thesis manuscript to my Almighty God and beloved father Kufebo Abba

STATEMENT OF THE AUTHOR

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The author was born on March 22, 1988 in Gimbichu, Soro Woreda, Hadiya Zone of SNNPR. He attended his primary education at Gimbichu Primary School and completed his secondary education at Gimbichu secondary and Preparatory School in 2008. After successful completion of his high school education, he joined Wollo University in 2009 and graduated with BSc degree in Soil and Water Resource Management on July 9, 2011.

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ABBREVIATIONS AND ACRONYMS

CV	Coefficient of Variation
DI	Drought Intensity
DM	Drought Magnitude
ENSO	El Nino Southern Oscillation
ET	Evapotranspiration
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
INSTAT	Interactive Statistical Processing Package
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
JJAS	June July August September
Kc	Crop Coefficient
LGP	Length of Growing Period
MAM	March April May
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
NMA	National Meteorological Agency
RSCZ	Red Sea Convergence Zone
SD	Standard Deviation
SMD	Standard Meteorological Dekad
SNNPR	Southern Nation Nationalities and People's Region
SPI	Standardized Precipitation Index
SSA	Sub Saharan Africa
SWADO	Soro Woreda Agricultural Development Office
SWFEDO	Soro Woreda Finance and Economic Development Office
WB	World Bank
WMO	World Meteorological Organization

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF TABLES IN THE APPENDIX

Appendix Table **Page**

LIST OF FIGURES IN THE APPENDIX

Intra-Seasonal Rainfall Characterization for Maize and Sorghum Productions at Soro Woreda of Hadiya Zone, Southern Ethiopia

ABSTRACT

Rainfall is the most important, but highly variable climatic resource for planning and management of the agricultural operations which principally affects the cropping calendar, production and productivity. Its variability in occurrence, amount and distribution coupled with high evapotranspiration has historically been the major cause of crop failure and food insecurity. Therefore, this study was conducted to analyze seasonal rainfall variability in terms of intra-seasonal rainfall indices and drought characteristics in Soro Woreda of Hadiya Zone, Southern Ethiopia. Thirty years climatic data (1987-2016) from NMA were used to determine seasonal rainfall variability by using statistical packages and the onset and end of the growing season, length of the growing period using FAO water balance and Reddy models, and INSTAT software. Markov Chain Model was used to analyze the distribution of dry and wet spells in the area. Mean statistical analysis result of observed rainfall data series revealed that long term mean annual rainfall varies ranging from 963 mm with a CV of 16% at Alaba Kulito to1537 mm with a CV of 30% at Hosanna station whereas longer rainy season (Kiremt) rainfall varies ranging from 399 mm with a CV of 31% at Alaba Kulito to 1027 mm with a CV of 19% at Hosanna station and shorter rainy season (Belg) rainfall varies ranging from 334 mm with a CV of 53% at Alaba Kulito to 429 mm with a CV of 39% at Fonko station. The mean onset of the long growing season was found to occur during the first meteorological decade of June and ended during the end of September. Similarly, the mean onset of Belg season was found to occur during the first decade of April at Alaba Kulito and second decade of April at both Fonko and Hosanna. Length of the growing period during the long rainy season (Kiremt) ranged from 133 days with a SD of 11 days and CV of 8.3% at Alaba Kulito to 180 days with a SD of 18 days and CV of 10% at Hosanna. The analysis results obtained from the Markov Chain model indicated that there were higher probabilities of dry spells during Belg, but it was minimal during the Kiremt season. Likewise, based on one, three, six and twelve month time scales analysis, SPI detected some drought events ranging from moderate to extreme in both season. The mean onset and cessation decades for maize was decade 10 and 22 at Alaba Kulito and decade 11 and 23 at both Fonko and Hosanna stations while for sorghum was decade 12 and 25 at Alaba Kulito and 11 and 26 at both Fonko and Hosanna stations. The water requirement of both crops is relatively high at Alaba Kulito following Fonko station and less at Hosanna station. Since maize and sorghum crops are long maturing crops, the seasonal rainfall variability and its implications for the production of these crops revealed that only Belg season rain cannot support most favorable growth of the crops. In general, during the occurrence of prolonged dry spells within the growing season, supplemental irrigation is important for the crops, particularly in Belg season to cope up with the problem of intra-seasonal rainfall fluctuations.

Key words: Rainfall variability, Onset, Cessation, LGP, Dry spell, Drought, SPI

1. INTRODUCTION

Nowadays, climate variability and change is recognized as one of the most serious challenges of 21st century in the world. It is anticipated to change intra-seasonal rainfall variability, arising from shifts in rainfall seasonality, frequency and intensity which are likely to have important ecological impacts on ecosystem (Kamara, 2016). In the Eastern Africa, particularly Ethiopia is one of the most vulnerable regions regarding the impacts of climate variability and change as the current climate change is characterized by the shorter rainfall seasons and erratic distribution (in time and space) with decreasing amount from year to year resulting in frequent droughts (Fazzini *et al*., 2015). It has multiple effects on basic human support systems such as agriculture, water resources and ecosystems, but the impacts are significantly negative on rain-fed agriculture on which the economy of most developing countries depends with the less adaptive capacity (Suryabhagavan, 2016).

Ethiopian agriculture under the influence of climatic resources follows rainfed agriculture and the agricultural system of the country has been dominated by, and highly sensitive to climate variability, mainly to the rainfall fluctuations. Agriculture in the country is almost completely dependent on the seasonal rainfall, and rain governs the lives and well-being of many rural Ethiopians. In fact, the dependence on rainfall and its erratic pattern has largely contributed to the crop failure and food shortage. As a result, majority of the people in the country suffer from food insecurity (MoA, 2010; Kassie *et al*., 2013; Getachew and Teshome, 2017).

Agriculture, largely rainfed agriculture is the mainstay of Ethiopian economy, has been the dominant source of food production. Different recent studies indicated that, this sector is still contributing more than 50% to GDP and about 60% to foreign exchange earnings and provides livelihood to more than 85% of the population (Yemanu and Chameda, 2010; Gebreegziabher *et al*., 2011; Hadgu *et al*., 2013; Kebede, 2013). Thus, in order for agriculture to meet the future food demand of the world, water productivity improvements need to be achieved not only in irrigated agriculture but also in rainfed areas due to the growing competition for water and high investments in irrigation development, and the scope for further expansion of irrigation is limited both in the country and in many parts of the world (Muktar and Yigezu, 2016).

In Ethiopia, rainfall and temperature are the most important factors that determine crop growth, crop type/variety choice and yield. High variability and unpredictable rainfall patterns have a great impact on the crops sowing date, with important implications for crop production, and spatial and temporal variability of the rainfall, reflected by dry spells within the growing season and recurrent droughts and floods, have been considered as the most key factors affecting agricultural productivity in different regions (Henok *et al*., 2015).

Rainfall is a seasonal phenomenon in tropical climate and occurs in spells. The start and end of rainy season; frequency, amount and intensity of rainfall, and duration of wet spells; duration and severity of intervening (between two rain spells) dry spells are characterized by large spatial and temporal variations. The variability of these parameters of the rainy season is useful information for scientists, engineers, planners and managers working in water related sectors (agriculture, ecology, hydrology and water resources); therefore, the determination of season wise starting and ending dates of the rainy season, dry and wet spells in the rainfall time distribution, and identification of drought characteristics is the fundamental issue of the problem (Zende and Atal, 2015). It is the most important input parameter of the hydrologic cycle varying in space and time that needs serious attention as it is considerably affected by climate change (Seyoum, 2015) which in turn extensively affects the success of rainfed crop production in farming areas and plays a significant role in sustaining lives and all creatures depend on water (Salem *et al*., 2016; Sifer *et al*., 2016). This implies that water resources planning and management is exceedingly variable over space and time since it has the largest effect in determining the probability of occurrence, sequence and timing of design operations (Kidane, 2010; Monika, 2017).

Based on the past records, proper agro-climatic zoning and seasonal climatic analysis through the identifying important characteristics of rainfall influencing production from the rainfed farming such as the date of onset, occurrence and duration of wet spells and intervening dry spells, distribution of rainfall and number of rainy days are vital for management of rainwater and agriculture as well as assessment of drought risks and nature of growing period (Devdatta, 2016). These are key factors in the relationship between climate and cultivation. For instance, if there is an unexpected break in rainfall early in the growing season, farmers may be able to recover and resume production despite the loss of some of their crops. However, if such a break occurs in the middle or later part of the growing season all the crops may suffer from irreversible damage with the entire economic consequence (Hulme, 1990). It is also important to know the chance occurrence of dry spells during the critical stages of the crops for deciding the sowing date, cropping pattern and planning for irrigation (Hansen, 2002). Moreover, previous studies in many parts of Ethiopia emphasized on the analysis of trends in annual and seasonal rainfall totals disregarding intra-seasonal rainfall variability and its effect on growing season which in turn results in crop water stress leading to complete crop failure (Getaneh, 2015), and also do not provide information on the much needed character of within season variability despite its critical influence on soil water availability and distribution (Makokha *et al*., 2011).

Rainfall related crop risks like prolonged dry spells, wet spells, untimely rainfall and seasonal rainfall variability are the challenges which affect crop production. Delay in sowing period due to rainfall variability can cause severe reduction in yield or entirely expose to loss of the rainfed crop production, mainly maize and sorghum productions, which leads farmers to be food insecure in the study area. In addition, there is no previous research work in the area to analyze the onset and cessation of the rainy season, to characterize dry and wet spells, to analyze drought characteristics as well as in-depth analysis and well-established scientific evidence on the nature and extent of seasonal rainfall variability, magnitude of impact on agricultural crops in the area is virtually lacking. Accordingly, information on intra-seasonal rainfall variability provides the best opportunity for the farmers to adjust time of sowing date, crop selection, farm management practices and other agricultural activities. A detailed analysis of the intra-seasonal rainfall variability within the growing season is crucial for optimal management of rainwater at farm level and to contribute to the efficiency of agricultural water management and to food and livelihood security in the area.

This study was, therefore, designed to analyze intra-seasonal rainfall variability and its effect on growing season of Maize and Sorghum productions of Soro Woreda with the following specific objectives:

- ✓ To determine the onset and cessation of growing season for maize and sorghum
- ✓ To analyze the distribution of dry and wet spells for Soro Woreda
- ✓ To analyze the drought characteristics in the study area

2. LITERATURE REVIEW

2.1. Characteristics of Climate System of Ethiopia

The climate of Ethiopia is characterized by diverse conditions ranging from warm and humid in the southeastern region to semiarid in the low-lying regions (Mekasha *et al*., 2014). Its climate system is basically dependent on seasonal migration of Inter-Tropical Convergence Zone (ITCZ), which follows the position of the sun relative to the earth and associated atmospheric circulation in conjunction with the complex topography of the country (NMA, 2001; Seyoum, 2015). The country's climate system is determined by the prevailing pattern of Sea Surface Temperature (SST), atmospheric wind, regional climate fluctuation in the Indian and Atlantic Ocean (Molla, 2016). As the country is located within the tropical region, it is influenced by weather systems of various scales, from mesoscale, such as thunderstorms, to large scale El Niño Southern Oscillation (ENSO) related phenomena. The major rain bearing system for the long rainy season (June to September) is the Inter-Tropical Convergence Zone (ITCZ). On the other hand, eastward moving mid-latitude troughs will facilitate the interaction between mid-latitude cold air and the tropical warm air so that unstable conditions will be created for the moisture that comes into Ethiopia from the Arabian Sea during the short rainy season, *Belg* (February to May) (IPCC, 2014; Gebreyesus, 2014).

Ethiopia has highly variable tropical climate due to rugged topography and highland regions are cool and host most of the country's population, while lowlands are warm with the hottest temperatures. Rainfall in the country is bimodal, with 60% occurring during the long rainy season. The onset and duration of the rainy seasons (as well as rainfall intensity and annual quantity) considerably vary seasonally as well as inter-annually, due to the movements of the Inter-Tropical Convergence Zone (ITCZ), which can lead to droughts in various parts of the country (WB, 2010).

2.2. Agro-climatic Zones and Seasons in Ethiopia

The climate of Ethiopia is rather complex, it has been the topic for the societal and scientific debates and several classification systems have been applied to the Ethiopian situation. The traditional climatic zone classification system uses, altitude and mean daily temperature to divide the country into five climate zones (Gebremichael *et al*., 2014). The agro-climatic zone is the most useful for agricultural purposes which uses the water balance concept, the length of the growing season (including onset dates) at certain probability levels (NMA, 1996; Deressa *et al*., 2010).

The season has different meanings, but meteorologically it is defined as a period when an air mass is characterized by homogeneous weather elements such as rainfall, temperature, relative humidity, wind etc; dominate a region or part of a country. Based on annual rainfall pattern season classification in Ethiopia is characterized by three distinct seasons: namely, dry season (*Bega*) from October to January, short rainy season (*Belg*) from February to May and long rainy season (*Kiremt*) from June to September (Seifu, 2004).

Three major climatic zones, which have been known since ancient times in Ethiopia due to varied topography are *Dega, Woyna dega,* and *Kolla*. The *Dega* (also known as the cool zone) occupies the central sections of the western and eastern parts of the northwestern plateau. The elevation of this region is mostly above 2400 m, and daily temperatures range from near freezing to 16ºC while the *Woyna dega* or the temperate zone ranges between 1500 m and 2400 m in elevation, and consists of parts of central plateau. The *Kolla* or hot zone generally comprises areas lower than 1500 m in elevation, the Danakil depressions and tropical valleys of the Blue Nile (Gebremichael *et al*., 2014).

2.3. Causes of Seasonal Rainfall Variability in Ethiopia

The spatial and temporal variability of rainfall over Ethiopia like any other countries in Africa is controlled by a number of global, regional and local systems (Alemayehu *et al*., 2015). The important weather systems that cause its variability are Sub Tropical Jet (STJ), Inter-Tropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and the Somalia Jet (Molla, 2016). Weather and climate of Ethiopia arises from the influence of tropical weather systems such as Inter-Tropical Convergence Zone (ITCZ), monsoon easterly waves and quasi-stationary sub-tropical anticyclones of both northern and southern hemisphere (NMA, 1996).

Seasonal rainfall in Ethiopia is driven mainly by the migration of the tropical rain belt, the Inter-Tropical Convergence Zone (ITCZ) (Seyoum, 2015). Moreover, the main rainy season (*Kiremt*) rain producing systems such as the ITCZ, cross equatorial flow from (Mascarene high) the southern Indian Ocean, moisture flow from the Atlantic Ocean and the monsoon low and the associated trough have a great role to play for main season (*Kiremt*) rainfall performance over Ethiopia (McSweeney *et al*., 2008; Getaneh, 2015). In line with this El-Niño Southern Oscillation (ENSO) has an impact on a seasonal shifting of the normal rainy seasons in some regions, as a result a shortening or lengthening of the rainy seasons, particularly over tropical regions (Gissila *et al*., 2004; Korecha and Barnston, 2007; Meresa, 2010).

2.4. Rainfall Variability and Agriculture in Ethiopia

Climate change poses huge challenges to Ethiopia and its people. The country is faced with increasingly unpredictable rains, and sometimes complete failures of seasonal rain problems which are linked to climate change. It is a country with large differences across regions which are reflected in the country's climate vulnerability. The lowlands are vulnerable to increased temperatures and prolonged droughts which may affect livestock rearing. The highlands may suffer from more intense and irregular rainfall, leading to erosion, which together with higher temperatures leads to lower total agricultural production. This, combined with an increasing population, may lead to greater food insecurity in many areas (Hayelom *et al*., 2017).

Agriculture is one of the most weather dependent of human activities in Ethiopia serving as a backbone of the economy as well as ensures the main source of food production and income for about 80% of the labor force and 47.68% of the gross domestic product (GDP), given such a heavy dependence on rainfall, it is likely that climate extremes such as droughts or floods can pose significant health and economic threats to the entire nation, the availability of water resource is quite essential (Kebede, 2013; Daba, 2018). However, the sector is mainly depending on rainfed agriculture (Ayalew *et al*., 2012). For the management of rainwater and agriculture as well as estimation of the drought risk, the seasonal rainfall has to be evaluated regarding duration, onset and cessation of the rainy season and dry spell lengths based on the past records (Seleshi and Zanke, 2004; Kebede, 2013). Hence, a small proportions of its cultivated land is irrigated (only 5%) and food production is dependent mainly on the traditional rainfed agriculture (Awulachew and Ayana, 2011; Getachew and Teshome, 2017). Different studies (Bewket, 2009; Hagos *et al*., 2009; Sorecha *et al*., 2017) reported that rainfall variability poses challenges to the agricultural production, reduced by 20% and rises up the poverty level up to 25%. Thus, the success of agricultural production in the country is quantified with the amount of rainfall received.

The main weather parameters affecting crop growths are rainfall, temperature and radiation (Streenivas *et al*., 2010; Hadgu *et al*., 2014). The variability of rainfall at the start of the seasons as well as mid-season breaks in the rains often result in poor crop growth and yield reduction. For a better understanding of the issue of water availability in tropical rainfed agriculture, much more attention needs to be given to the quantification of within season rainfall variability. This will allow a prior assessment of the expected severity and duration of dry spells during the season and provide a sounder basis for developing improved water management technique in tropical agriculture. Thus, there is the need to define the onset of rainy season in order to avoid the false start owing to the variable nature of tropical rainfall. The false start is said to happen when rainfall meeting the chosen criterion is followed by a long dry spell (Laux *et al*., 2009). It is one of the most important climatic elements for rain-fed crop production as it assists in planning and decision making. From the analysis of recent rainfall conditions, rainfed agricultural crop production has a direct relationship with intra-seasonal to inter-seasonal rainfall since it is one of the sectors most vulnerable to seasonal rainfall variability. The impact is severing in Africa, where rainfed agriculture is important for daily subsistence, having low adaptive capacity (Mensah, 2014).

Rainfall variability is a prominent and unavoidable aspect of rainfed farming all over the world (Hansen *et al*., 2011). In Ethiopia it is characterized by seasonal and inter-annual variability and extreme climate events; particularly drought has been recurring phenomena. In the country it is highly variable both temporally and spatially, unpredictability with no obvious trend over the country, yet the country has experienced both dry and wet periods (Wodaje *et al*., 2016); hence, affecting agricultural activities and it is major climatic factor that determines success of crop and other socio-economic activities. For better planning of farming activities such as when to plant and the choice of right cultivar which is suitable for a particular region, it is always important to determine at a reasonable accuracy the probability levels of onset, cessation and duration of seasonal rainfall, as well as their inter-relationships (Sivakumar, 1988; Tadross *et al*., 2007; Mugulavai *et al*., 2008).

The uncertainty on the onset, cessation and length of the rainy season affect farm operations such as land preparation, choice of crops to grow, planting time, weeding, irrigation, etc which in turn undermines the food security situation while erratic and significant delays in rainfall affect the country's overall production of food and, in particular, cereals (maize, sorghum, *teff*, wheat etc), which form the main staple food in the country (Abayisenga, 2015). In addition, rainy season onset and cessation dates have an effect on the transmission of vector-borne diseases, as the life cycle of the disease-transmitting vectors is sensitive to the variability and changes in rainfall and temperature. For instance, the mosquito population is likely to increase rapidly during the warmer humid conditions (Leonard *et al*., 2015).

2.4.1. Intra-seasonal and inter-seasonal rainfall variability

Ethiopia is characterized by intra-seasonal, inter-seasonal and inter-annual climate variability, especially rainfall variability (Seleshi and Zanke, 2004; Eshetu *et al*., 2016). Despite the absence of significant trends in rainfall patterns, the high inter-annual variability, season to season and within season variation entails a challenge to rainfed agriculture. Inter-annual, inter-seasonal and intra-seasonal rainfall variability; declining rainfall amount, variability in the length of growing seasons and in season dry spells together with an increasing temperature generally indicate an increasing risk for rainfed crop production (Kassie *et al*., 2015).

Intra-seasonal variability refers to variation within a specific season while inter-seasonal to seasonal variability is to mean variability between season and among seasons (Mzezewa *et al*., 2010). Seasonal rainfall amount, intra-seasonal rainfall distribution and dates of onset or cessation of the rains determine cropping calendar and influence crop yields (Traore, 2014). Inter-annual rainfall variations cause great stress to the farming activities, crop production and crop yield whereas intra-seasonal, inter-seasonal to seasonal rainfall variability over total annual rainfall is important in determining crop production and consequently livelihood and food security outcomes. Time of seasonal onset can be considered as a predictor of seasonal rainfall behavior that is to say early onset believed to be more rainfall and late onset less seasonal rainfall which is not always true. Initial decisions are kept open to facilitate revision of earlier decisions based on relationships between rainfall received early in the season and eventual total seasonal rainfall (Chaka, 2016).

2.4.1.1. *Belg* (March to May) rainfall variability

Belg is a short rainy period. It covers the period from February to May. Rainfall during this season is highly variable both in time and space and high maximum temperature values are common, and much of the country receives shorter lived, but agriculturally important rains. The amount of *Belg* rainfall is more than that of *Bega* and maximum value occurs over southern and southwestern regions (Bale, Gamo Gofa and Kafa). It is the most important for long duration crops like maize and sorghum (Mesay, 2006).

According to Kassa (2015); Tesfaye and Walker (2004) *Belg* season rainfall (M, A, M) makes a significant contribution to total annual rainfall in the northeast, east and central portions of Ethiopia, as seen clearly in the annual rainfall cycle. Inhabitants of these parts of the country are agricultural and hydrological beneficiaries despite that the largest share of rainfall occurs during *Kiremt* season (J, J, A, S). However, during *Belg* the southern and southeastern parts of the country enjoy their main rainy season.

During this season the major synoptic features that influence the weather of Ethiopia include easterly wave, Sub-tropical jet stream (STJ), extra-tropical troughs, Red Sea Convergence Zones (RSCZ), anticyclone over the Indian Ocean and the Mediterranean depression. The rains have their origins partly from Congo forest basin and partly from the Indian Ocean (NMA, 1996). Moreover, the intensity and areal coverage of the rain is associated, to a great extent with the intrusion and passage of the north-south oriented mid-latitude trough in the westerly wind field. When the trough deepens and its extension approach equator, it interacts with ITCZ and causes widespread rains over most places particularly along the highlands. When the trough becomes weaker much of the rainfall activity concentrates, but not limited to, over southwest Ethiopia (Seyoum, 2015).

Belg rain is extremely important from agricultural as well as hydrological point of view. This rain produces *Belg* crops, which account for about 5-15% of the national food crop. Apart from this, long season crops like maize and sorghum that constitute a major food crop of the country are planted during this season. A delay or deficient *Belg* rain means the absence of water and pasture, which may result in deaths of thousands of animals (Degefu, 1987).

2.4.1.2. *Kiremt* (June to September) rainfall variability

Among other seasons, *Kiremt* is the most important for the country as nearly 95% of the crop production is produced in this season (Mesay, 2006). *Kiremt* (summer) season refers to the long and main rainy season, which occurs from June to September over Ethiopia. J, J, A, S seasonal rainfall, except the south and southeast other portions of the nation benefited, particularly for southwest, west, north, central and east regions of Ethiopia (Korecha and Barnston, 2007). In line with this (Gissila *et al*, 2004; Segele and Lamb, 2005; Zeleke, 2013) reported that most devastating Ethiopian droughts are associated with failure of summer (*Kiremt*) rains that account for 65-95% of total annual rainfall. Furthermore, local experts usually attribute *Kiremt* failures to delayed onset and/or early cessation. Despite this situation, the fundamental understanding of the patterns and causes of the seasonal to inter-annual variability of *Kiremt* rainfall have remained conspicuously absent. Here, for the first time, they documented the mean seasonal cycle and inter-annual variability of *Kiremt* rains in terms of onset, cessation, dry spells, and hence growing season duration. These *Kiremt* rainfall characteristics are crucial for Ethiopia's food supply to achieve food security in the country.

2.4.2. Impact of rainfall on crop planning and production

The climate of Ethiopia is characterized by high rainfall variation. Such climatic conditions have caused major constraints to agricultural development since agricultural production in Ethiopia is predominantly rainfed. Variation of rainfall in space and time affects agricultural production system in the country. This needs accurate measurement of rainfall and close study of rainfall variation (Seifu, 2004).

According to Singh *et al*. (2005); Hadgu *et al*. (2013); Henok *et al*. (2015) rainfall being an important climatic element, the study of its variation and the consequent impact on agricultural production are paramount importance as it is one of the most important weather factors that control the crop productions in rainfed areas. It serves as the main source of water for agriculture. On the other hand, the availability of water for crops in a season depends on the distribution and variability of rainfall; the studies of intra-seasonal rainfall are useful for crop planning, scheduling farm operations and land-use operations. Rowhani *et al*. (2011) examined the relationship between seasonal climate and crop yields, focusing on maize and sorghum. The results also indicated that both intra-seasonal and inter-seasonal changes in temperature and precipitation influence cereal yields. Potential changes in the seasonal total rainfall as well as intra-seasonal temperature and rainfall variability may also impact crop yields. The result revealed that changes in inter-seasonal variability of weather may affect the growing season.

2.5. Effect of Climate Variability on Maize and Sorghum Crops

The effect of climate variability was found to be very high in Ethiopian agriculture. There is an argument that in Ethiopia, the occurrence of drought is recurrent and repeated at least once in 10 years. One of the characteristics of rainfall in Ethiopia is that it exhibits high variability in time and space. Climate variability plays an important role on agricultural productions with a significant impact on crop growth, development and yield, making the agricultural activity one of the most sensitive and vulnerable sectors among human activities (Ventrella *et al*., 2012). For the agricultural sector, which is the main source of livelihood for the majority of the region's population, it is crucial to understand how rainfall characteristics are changing, particularly those affecting planting dates and the crop growth cycle e.g. the start of the rains or frequency and intensity of dry spells and daily rainfall, that can damage crops if they occur at critical stages of crop growth (Tadross *et al*., 2007). The amount of water available to plants strongly depends on the rainy season's onset, cessation, length and temporal distribution can indirectly indicate the climatic suitability of the crop and its success or failure in a season. Therefore, any adverse changes in rainfall would have a serious effect on crop production and livelihoods (Ngetich *et al*., 2008).

2.5.1. Influence of climate variability on maize (*Zea mays* L.) production

Rainfall is the most important climatic factor that influences the pattern and productivity of rainfed maize in Sub-Saharan Africa (SSA). Climatic factors such as low and erratic rainfall, constant low humidity and high temperatures during the growing season have influenced crop growth conditions. Hence, to avoid coincidences of moisture stress at these critical stages need thoroughly analysis of the most important climatic parameters such as onset, cessation, total amount and distribution of rainfall, probability of the prevalence of prolonged dry spell and length of the growing period are among the fundamental climatic resources which influence production and should be considered to reduce risk (Kholofelo, 2011). Maize production under rainfed conditions could be affected by the timeliness, adequacy and reliability of seasonal rainfall. Its production is also severely impeded by water stress and high temperatures even if the soil water is full at the beginning of the growing season (Ramadoss *et al*., 2004).

Maize is the most widely cultivated crop in Ethiopia and grown under diverse agro-ecologies and socio-economic conditions, typically under rainfed productions. Successfully, it can be grown in a wide range of altitude ranging from lowland areas below 1000-1800 m above sea level, preferably in areas where annual rainfall reaches on average 800 mm evenly distributed over the whole growing period, and a major conclusion of research findings in Ethiopia is that yield is generally influenced more by the date of sowing than any other factors (Abate *et al*., 2015). Estimated duration of the growing period is about 4 to 5 months even if it depends on the variety planted and temperature. For maximum production a medium maturity maize grain crop requires 500-800 mm per total growing period which is mainly acquired from the soil moisture reserves FAO (1986).

2.5.2. Influence of climate variability on sorghum (*Sorghum bicolor* L.) production

Sorghum is one of the most important crops grown in wide agro-ecological zones throughout the world. This crop is considered as a potential adaptation option for millions of farmers hit hard by climate change. The crop appeared to have been domesticated in Ethiopia about 5000 years ago (Tigist, 2011). Currently, large part of sorghum production areas in Ethiopia fall under the arid and semi-arid regions of the country that are characterized by high rainfall variability and low soil water storage capacity. It is widely grown in low moisture areas due to its high capacity to tolerate soil water deficit and a wide range of ecological diversity (Abebe, 2012). Despite its significant area coverage; however, national average sorghum productivity is estimated to be 1.84 million metric tons annual production. Unreliable and poor distribution of rainfall is one of the major causes for low yields of sorghum in Ethiopia and it is a staple food crop for millions of people.

Sorghum is grown mainly as a rainfed crop in the semi-arid areas. In these areas, sorghum production is being limited by water stress due to low and variable rainfall between season and within season, and hence sorghum yields vary considerably between years. Supplementary irrigation such as small scale irrigation and water harvesting methods have been undertaken to cope with the water stress problem during the crop growing period (maize and sorghum). Estimated duration of growing period is about 3 to 5 and for maximum production a medium maturity grain crop requires about 450-650 mm of water per total growing period depending on climate FAO (1986). Localized temporal rainfall and temperature variation during cropping season induces an important challenge to sorghum production and in turn to food security. Therefore, apart from understanding meteorological variability and change on crop production and productivity, it is important to study the interactions among climatic variables and agricultural production in order to assess impact of climate change on agriculture (MoARD, 2007).

2.6. Impact of Onset and Cessation of Seasonal Rainfall on Crop Production

Rainfall and temperature are key climatic parameters jointly influence the length of growing period, time of critical growth rate, increased evapotranspiration and hence seriously reduced and in some cases cause complete crop failure. For instance, temperature is one of the most important determinants of crop growth over a range of environments. Thus, an increase or decrease in temperature may have a significant effect on the growth and yield of crops. At the same time, higher temperatures increases evaporation and transpiration which also has an adverse effect on soil water availability and crop growth (Lemma *et al*., 2016).

The impact of rainfall on crop production can be related to its total seasonal amount or its intra-seasonal distribution. Hence, farmers are more concerned about the within-season characteristics (onset, cessation, and likelihood and severity of mid-season dry spells) of rain than total seasonal rainfall, which will help them for planning properly in terms of the timing of planting to avoid crops reaching the critical stages at times when there are high probability of dry spells. Reliable prediction of rainfall characteristics, especially onset date of the rain, is needed to determine a less risky planting date or planting method, or sowing of less risky types/varieties of crops in responsive farming (Abdisa, 2015).

In the extreme case of droughts, with very low total seasonal amounts, crop production suffers the most. But more subtle intra-seasonal variations in rainfall distribution during crop growing periods, without a change in total seasonal amount, can also cause substantial reductions in yields. This means that the number of rainy days during the growing period is as important, if not more, as that of the seasonal total and even in wet areas rainfall variability at the daily time scale is critical to plant growth, particularly in the early part of the rainy season before soil moisture reserves have been built up. Despite the tremendous improvements in technology and crop yield potential because of the attention recently given to the concept of agricultural sustainability, food production remains highly dependent on climatic resources, primarily rainfall (Bewket, 2009).

Among climatic parameters involved in crop production, water supply from natural rain is generally the major agro-meteorological factor limiting crop production where irrigation is not available, particularly in Africa where agricultural activities are largely rainfed. Currently, one major persistent problem for agriculture is that of rainwater supply which is manifested by the seasonal variability of rainfall. Rainfall variability is not limited to seasonal fluctuations but also includes year to year variability in the onset, cessation and duration of the rains which are also characterized by dry spells of unpredictable magnitude which may last for a few days to more than three weeks. The incidence of wet season dry spells during the full vegetative stage when evaporative demand is high can lead to retardation of crop yield (Eruola *et al*., 2014).

Understanding seasonal rainfall variability and its patterns by evaluating variables including start and cessation of rainfall, lengths of growing seasons, rainy days, rainfall amount and dry spell frequencies is vital for crop production. However, recognizing the average amount of rain per rainy day and the mean duration between successive rain events aids to understand long term variability and patterns. The temporal variability and occurrence of various rainfall and temperature indices evaluated at weather stations based on the analysis of a set of indicators defining variation and extreme conditions (Trnka *et al*., 2011; Vergni and Todisco, 2011). A number of studies (Barron *et al*., 2003; Girma, 2005; Mesay, 2006; Moffat, 2015) indicated that a pronounced seasonal and inter-annual rainfall variability as well as extreme events, production risks and stresses to which the farming systems are exposed can arise from a wide variety of sources. Evidences indicate that daily records of the past rainfall episodes can be examined and combined effectively so as to eventually reveal certain useful pattern pertaining to farm level strategic and planned decision making. Therefore, determining the possible ranges of rainfall onset date, end date, duration (LGP), seasonal totals and dry spell length, which together make up the overall rainfall features, can provide deep insight into transformation of the rainfall variability into the field level management options through the practical responses.

2.7. Determination of the Growing Period

Understanding when is a suitable time of crop growth have been occurred help researchers, policymakers, and farmers to better manage their land and water resources and to better know how variability in climate affects the ability of farmers to plant, grow, and harvest specific crops. The concept of growing season takes into account seasonality and length of potential growing periods during the year. The growing periods can also be determined based on the start of the rainy season (rainfall amount divided by evapotranspiration is equal to 0.5 mm) and temperature (Bewket, 2009; Yangyuoru *et al*., 2011).

Most of the areas in Ethiopia have two agricultural seasons that coincide with the two rainy seasons and play a significant role in the performance of rainfed agriculture. *Kiremt* season refers to long rainy season, which normally occurs from June to September, while *Belg* season refers to short rainy season, which normally occurs from February to May (CSA, 2001/2002). The *Belg* season is very important for the production of *Belg* crops in Southern Tigray region; Northwest Shoa, Arsi, Bale, East and West Hararghe zones of Oromia region; North Shoa, North and South Wollo zones of Amhara region; and Hadiya, North Omo and Kambata tambaro zones of SNNPR. Although the contribution of *Belg* cropping season accounts for 5-10% of the country’s overall crop, it covers from 25 to 60% of the food need of the area mentioned above (Seifu, 2004). According to Reddy (1990), a year with LGP of below 90 days was considered as a drought year. Most crops grown in Ethiopia with the exception of some pulses require a growing period of at least 90 days.

According to Rita (2007) the main concern of agriculturist is the start, end and length of rainy season, the distribution of rainfall amount throughout the year and the risk of dry spells. These parameters have been observed to affect the growing period and variations in agricultural production have been related to the deviation from normal seasonal climate best described by the term growing period. The scarcity of water because of the uncertainties of the rainfall receipt, presents a major challenge to the rational development of agriculture. Hulme (1990), reported that monthly rainfall amount of minimum threshold of 60 mm and 30 mm is used to determine the onset of rainy season and Davey *et al*. (1976) defined onset of growing season as the first ten day period of 20 mm of rain, but they did not consider the possibility of the dry spell following its determined date. Stern *et al*. (2003) improved the definition by defining the onset of the rain as 20 mm in one or more date(s) within the next thirty days. Ati *et al*. (2002) onset date study showed that there had been a statistical decreasing trend in the series of annual rainfall while there was no statistically significant trend in that of onset date and there was a strong negative correlation between the rainfall and onset series. Effective rainfall is the amount of rainfall all of which neither evaporated nor percolated beyond the reach of the plant root and therefore, it is available for crop production.

Many definitions are in use to define growing season (Singh, 1986; Shaw, 1987; Hulme, 1990). Hulme (1990) classified the numerous approaches to growing season determination into two categories. The first group is those formulated based on absolute daily or monthly total and the other category of the definitions include those that are formulated in relation to standardized parameters such as evapotranspiration, magnitude of annual rainfall. Hulme (1990) designed a soil water balance model using pentad rainfall potential evapotranspiration (PET) and certain assumptions about the soil moisture capacity, and defined the onset as the first pentad where 80% of the evaporative demand of the germinating sorghum was met by rainfall and soil moisture provided that the succeeding two pentads also met this condition.

Reddy *et al*. (2008) defined onset as the date when accumulated precipitation over 3 days is at least 20mm and no dry spell longer than 10 days appeared within the subsequent 30 days and the length of growing period (LGP) is obtained by subtracting the onset from the cessation.

Onset, cessation and length of rainy season of rainfall are major intra-seasonal rainfall indices having fundamental importance to the agriculture, particularly rainfed agriculture. They are fundamental occurrences to the farmers in rainfed farming areas (Yemenu and Chemeda, 2010). Farmers benefit from lower rates of evaporation during an early onset since they are able to plough land and plant earlier. Late onset on the other hand can result to the critical stages of the plant which are sensitive to water stress to be aligned with months of lower rainfall and higher evaporative demand (Moeletsi and Tongwane, 2014). Early cessation may result in short growing period affecting the long season crop varieties while late cessation favors the long season crop varieties. Availability of agro-meteorological information about the behavior of the seasonal rainfall should be able to minimize crop losses (Sivakumar, 1990; Raes *et al*., 2004). Generally, understanding the start and end of season, rainfall amount and distribution is essential for altering the crop production system, depending on the length of growing period of the crop and its water requirement. Therefore, for the crop planted at the end of the season and short rainfall to satisfy the crop water demand under changing climate depending on the crop type and growth stage, supplementary irrigation is very crucial for better crop production and productivity (SWADO, 2010; Lemma *et al*., 2016).

2.7.1. Onset of the growing season

The onset of the rainy season is a decisive event for the farmers in Sub-Saharan Africa (SSA). The onset of rain marks the beginning of main agricultural activities such as land preparation, sowing/planting, weeding and harvesting (Omotoshow *et al*., 2000). This enables to determine the socio-economic life and survival of the farming households. Sowing that depends and is influenced directly by the onset of the rainy season is the first activity, which the other two activities are based. Significant shifts in the onset of rains will, therefore, affect both agriculture and other non-agricultural activities of small-scale farmers. Several researchers have reported how the variability of the onset and cessation of the rainy season in the tropical region pose a serious challenge in the process of determining when the rainy season/planting season begins (Oladipo and Kyari, 1993; Tura, 2017).

The rainy season onset and cessation are defined in different ways by different authors. Climatologists, agronomists and hydrologists have proposed various definitions (Sifer *et al*., 2016). For instance, agro-climatologists usually define the onset at the rain gauge scale, using a variety of empirical thresholds Sivakumar (1988). They consider that the rainy season onset is the first wet day of a spell receiving a given rainfall amount and not followed by a long dry spell during the subsequent weeks. The rainfall thresholds are determined empirically in order to fit the requirements of a given crop and are adjusted to account for local-scale climatic conditions. The analysis of rainfall for agricultural purposes includes the trend, start, and end, length of the rainy season, distribution of rainfall and the risk of dry and wet spells. Thus, defining the onset date of the rainy season can sometimes be very challenging, as the onset characteristics can vary drastically with isolated showers or heavy rainfall of varying intensity being accompanied by extended dry spells (Leonard *et al*., 2015).

Taye and Ferede (2012) indicated that characterizing the onset date and cessation date of rainfall for a specific area and the main rainy season day was fixed for the onset day and cessation dates. The variability of rainfall for the period of onset of the rainy season was high and even difficult to find the exact day for some years, especially during drought periods. The beginning of the growing period is taken as the time (in days) when moisture supply from rainfall and soil storage just exceeds half potential evapotranspiration. This premise takes into account the fact that the amount of moisture required to sustain the crop germination and emergence is much below potential evapotranspiration and during crop emergence and establishment in the field, it is approximated to be 0.5 ET_o. Therefore, the amount of moisture supply that is equal to (or greater than) 0.5 ET_o has been considered as being sufficient to meet the water requirements of establishing field crops. Akinseye *et al*. (2015) indicated that the FAO simple soil water balance model, the time when moisture supply is 0.5 ETo is taken as the reference beginning of the growing period. However, there is still no consensus answer in the literature about the question of how much rain and over which period defines the onset of rainy season (ORS) for the agro-climatological impact studies.

2.7.2. Cessation of the growing season

The cessation date is defined as the last date on which the threshold amount is exceeded (below 0.5 ETo) Stern *et al*. (2003). It is also defined as a decadal rainfall amount is less than half of the corresponding reference evapotranspiration at the end of rainy season and length of the growing period is the difference between cessation and onset of rainfall. The minimum decadal rainfall threshold of 30 mm is used to determine the termination of the growing season. In the procedure, the soil is assumed to be at field capacity of 100 mm on the last day of rain that is greater than half ETo provided that the date is not proceeded by a dry spell (less than 1mm average daily rainfall); it is assumed that the depletion of available soil moisture below 40% of its field capacity will cause a rapid reduction in water availability to crops (Yemanu, 2009).

2.8. Dry and Wet Spells Distribution Analysis for Drought Assessment

Dry and wet spells are two main physical characteristics of rainfall occurrence, and the amount of rainfall in a given area depends on the distribution of such spells (Kumar and Rao, 2005). It is, therefore, important to investigate the occurrence patterns of the dry and wet spells scientifically through model based analysis which consists of studying the statistical properties of two common indicators, the spell length and frequency. Such studies are essential for agricultural planning, water resource management, and other interests such as fisheries, health, ecology, environment, etc (Fischer *et al*., 2013; Mirmousavi, 2015). The probability analysis of dry and wet spell distribution is believed to help in support of planning agricultural water management, particularly during the rainy season (Mesay, 2006).

2.8.1. Dry spells, number of rainy and dry days

2.8.1.1. Dry spells

Natural rainfall is the main source of water for the agricultural sector in a predominantly agricultural system, and absence or minimal rainfall results in drought. Dry spell is a period where the weather has been dry for an abnormally long time, shorter than and not as severe as a drought. It has been noted that in tropics and subtropics the long dry spells bring up heavy costs to the affected societies and the success or failure of the crops is highly related with the occurrences of dry spells (Sorecha and Bayissa, 2017). Although the definition of a dry spell may vary depending on the aims and methodology used in each study or is based on the length of the consecutive dry days. A dry spell was first defined and used in British rainfall in 1919 as a dry spell being a period of at least 15 consecutive days to none of which was credited ≥ 1 mm. Thereafter, various definitions of a dry spell were used by the different authors along with different threshold values (Ceballos and Martinez, 2003; Usman and Reason, 2004). It should be pointed out that, unlike a dry day, the minimum number of consecutive dry days are required to define a dry spell has to be identified in a meaningful manner depending on the practical problem.

Most of the dry spell studies carried out in various part of Africa pointed out the importance of a clear understanding of the length and number of dry spells, and their probabilities for assessing of recurring droughts and decreasing agricultural productivity. Many authors define a dry spell with different threshold values of rainfall at a dry day. In this study, rainfall amount of 1 mm per day was used as the threshold, often 0.1 mm used with respect to the common precision of rain gauges. Some studies employed a threshold of 1 mm, on the assumption that rainfall less than this amount is evaporated off directly (Mupangwa *et al*., 2011; Kebede, 2013). Ndamani and Watanabe (2013) analyzed the influence of rainfall on crop production in Lawra district and the results reveal that rainfall amount and rain days tend to decrease in June which may result in dry spells. July and August are observed to have higher amount of rainfall and this has high possibility of causing water logging of farm lands. Rugumayo *et al*. (2003) findings on rainfall variability and its relationship with crop production should provide the basis on which agricultural policy makers can plan for irrigation to respond to the incidence of recurring droughts. The findings of this study point to the need for farmers to adopt water harvesting technologies in order to deal with incidences of dry spells during the production season.

Detailed knowledge of the length of dry spells could be used for making decision with respect to supplementary irrigation and field operations in agriculture. Additionally, deciding on suitable crop type to be considered in a particular area can be done consistently with the knowledge on distribution of dry spells. In irrigation schemes, planning for supplementary irrigation during a rainy season as well as estimating irrigation demand can only be reliable with the knowledge of dry spell distribution (Zende and Atal, 2015). Prior information of dry spell studies can be applied to generate synthetic sequences of rainfall and to the estimation of the irrigation water demand (Sahoo *et al*., 2018). Crops are more likely to do well with uniformly distributed light rains than with a few heavy rains interrupted by dry periods. The timing of breaks in rainfall (dry spells) relative to the cropping calendar rather than total seasonal rainfall is fundamental to crop viability. The longest period of several long dry spells is of crucial importance in planning agricultural activities and managing the associated water supply systems (Sivakumar, 1992). Seleshi and Camberlin (2006) analyzed dry spells based on the maximum number of consecutive days with rainfall less than 1mm all over Ethiopia using 11 synoptic stations. They found no trends in the annual maximum length of dry spells during the rainy season over Ethiopia. The main limitation of this work is the definition of the beginning and end of rainy season was not computed per year, but taken as constant depending on the location within Ethiopia. Besides, they indicated that their study was limited to small number of stations as compared to huge size of the investigated area. Such study at the whole country level which has different rainy season is not supportive for decision making at local level (zone scale).

2.8.1.2. Number of rainy days

Different studies have shown that the number of rainy days serves as a marker that can be used to verify the distribution of rainfall. During the length of growing season of crops, farmers expect a balance between the distributions of rain days and moderation in rainfall amounts per rain days throughout the season. A fall in the number of rain days associated with an increase rainfall per rainy day signifies an increase in the intensity of rainfall and an increase in the intensity of rainfall may result in a potential serious risk of an increased flood frequency and severity for most regions of the world (Fitsum, 2015).

High daily rainfall may be responsible for potentially destructive to agriculture in sensitive areas that are prone to flood. This situation could compound the problem of food shortages and led to unprecedented food price increases (Gebrehiwot *et al*., 2011). Sivakumar (1988) also showed that increase in the number of rain days does not depict high amount of rainfall. The onset of rains, which is defined as the first occasion after a selected date when the rain accumulated over 3 consecutive rainy days is at least 20 mm and no dry spells of more than 7 days in the next 30 days was used as a successful planting date.

2.8.1.3. Dry days

A broad definition of a number of consecutive dry days is not appropriate, as the impact on crop growth will depend on agro-ecological conditions (antecedent soil water content) and growth stage. Farmers are not necessarily too concerned with the occurrence of consecutive dry days, generally defined as day with zero or trace of rainfall. Their concern is rather on the occurrence of actual crop water stress (i.e. deficit of plant accessible soil water) and the timing of crop water stress (i.e. in which growth stages is the crop most likely to suffer from stress) (Barron *et al*., 2003). In general, the definition of a dry day is zero rainfall per day taking threshold value of zero rainfall. However, different authors have used different threshold values to define a dry day. Even though the smallest recorded rainfall amount is 0.1 mm, a threshold value 1mm was used to determine wet and dry days. This is because 0.1 mm rainfall has almost no effect on growth of crops (Getaneh, 2015). The use of high value threshold eliminates the excessive weight that some isolated rainy days with small amounts have in breaking the long dry spell. However, the threshold value should not be selected in subjective manner, but it should be related to the type of the application (Oscar *et al*., 2014).

2.8.2. Markov Chain modeling

The Markov chain model has been extensively used to study spell distribution and other properties of rainfall occurrence, long term frequency behavior of wet and dry weather as well as for computation of probability of occurrence of daily precipitation (Dabral *et al*., 2014).

A Markov chain can be defined as a type of time ordered probabilistic process that goes from one state to another according to the probabilistic transition rules that are determined by the current state only. That is, the probability of a day being in a certain state (either wet or dry) is conditioned on the states of the previous periods, where the number of previous periods is termed as the order of the chain (Mirmousavi, 2015). The first order Markov chain analysis deals with computation of chances of rain depending on whether a previous date was dry or wet and before dealing with the conditional one, it is good to show the overall chance of rain which is called initial condition (unconditional probability). Many times decisions are made based on the probability of receiving a certain amount of rain during a given time that is the unconditional probability (Vicente *et al*., 2010).

2.8.3. Estimation of rainfall probabilities by Markov Chain model

Many studies in different parts of the world showed that the probability of getting rain at a particular time is dependent on conditions of the previous dates. These kinds of probabilities are called conditional (Engida, 2005). Estimation of rainfall probabilities by Markov chain is an indirect method of rainfall data analysis. This approach, by making use of statistical models summarizes a large amount of data as concisely as possible, by modeling daily rainfall using Markov chains. This method enables fitting of Markov chain models of different order into the probability of occurrence of rain and means rain per rainy dates, and also computation of the probability of rain is useful in the study of the distribution of rainfall in time (Stern *et al*., 2003).

2.9. Drought Occurrence in Ethiopia

Drought is a common issue that takes place nearly every year in many areas of the world and varies significantly from one region to other (Opiyo *et al*., 2015; Tura, 2017); however, its impact is higher when it occurs in developing countries, especially African countries like Ethiopia. It is considered as one of the major natural hazards with significant impact on agricultural water resources, society and economy as it damages the national economy. Ethiopia is one of the worst drought affected countries in Africa (Gidey *et al*., 2017). Drought affects sustainability of agriculture resulting in environmental degradation of the region and knowing its characteristics is critical in design, planning and management of water resources (Kyambia and Mutua, 2014; Wanjuhi, 2014).

In Ethiopia, climate related risks are the major determinants for the occurrence of droughts. Historical records reveal that there were about 30 major drought events facing the country in the past nine centuries and 13 of these drought events are known to have covered the entire nation caused severe economic losses and destroyed crops contributed to the death of people and livestock (Estifanos, 2013). Furthermore, drought prediction plays a critical role in the planning and management of the now scarce water resources. Drought indicators commonly computed include severity, duration, the location of the drought in absolute time (initial and termination time points), magnitude of the drought calculated by getting the ratio of severity to duration and area affected by drought (Gebrehiwot *et al*., 2011).

Three different operational definitions are presented, namely meteorological or climatological, agricultural or agro-meteorological and hydrological drought. Except meteorological, the other types of drought emphasize on human or social aspects of drought in terms of the interaction between the natural characteristics of meteorological drought and human activities (Zargar *et al*., 2011; Masupha, 2017).

Meteorological drought. It is defined as the degree of dryness specified due to the deficiency of the precipitation and dry period duration (Sun, 2009). This indicates that rainfall is the primary driver of meteorological drought (WMO, 2012; Rivera *et al*., 2014).

Agricultural drought: occurs when there is deficiency in soil water content over a particular period, significantly affecting crop production, pastures and livestock holdings (Masupha, 2017). It links some characteristics of meteorological and hydrological drought which have agricultural impacts, giving more focus to precipitation shortages, difference between actual and crop evapotranspiration, soil water deficits and others consequently affecting agricultural activities (Das, 2012).

Hydrological drought. It is normally defined by the departure of surface and subsurface water resources from average conditions over a long period resulting from meteorological drought (Hayes, 2011). Like other droughts, hydrological drought originates from precipitation deficit, but this is more concerned with how the deficiency plays out through hydrological system (Fraisse *et al*., 2011).

Socio-economic drought. It is associated with the demand and supply aspect of economic goods together with the elements of meteorological, hydrological and agricultural drought. Socioeconomic drought occurs when the deficiency of precipitation starts to affect human health, wellbeing, and quality of life (Sun, 2009). It reflects the interrelation of meteorological, agricultural and hydrological drought to the vulnerability of human beings.

2.9.1. Characterization of drought and dry spells

A better understanding of the climate, current trends, changes in extremes events and its implications for crop productivity is critical in policy formulation, decision making and creating capacity in adapting to the changes to protect the livelihoods of the poor from climate shocks and to ensure food security in short and long-term (Suryabhagavan, 2016). Thus, to optimize rainfed agricultural production and productivity, there is a need to quantify rainfall variability at a local and seasonal level as a first step of combating extreme effects of long period dry spells/ persistent droughts and crop failure (Chaka, 2016).

The probability of occurrence of dry spells of various durations varied from month to month of the growing season. The probability of having a dry-spell increased with shorter periods (for instance, more chance of having 3-days than a 10-or 20-days dry spell). Probability of a dry spells of length days for, 5, 7, 9, 15, and 20, in each seasonal cropping month was analyzed based on rainfall data of meteorological stations. Knowing spell lengths and defining a dry day is a preliminary task, when looking at dry spells. The obvious definition is any day with zero rainfall. We usually use a value of just under 1mm and define a day to be dry if its value is less than this threshold (Gebrehiwot *et al*., 2011).

2.9.2. Drought indices to characterize dry and wet spells

Drought indices have been developed as a means to measure drought. Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), Surface Water Supply Index (SWSI) and Standardized Vegetation Index (SVI). Using SPI index one can develop climatology of the spatial extension and intensity of droughts which provides additional understanding of its characteristics and an indication of the probability of recurrence of drought at various levels of severity (Karavitis *et al*., 2011).

The Standard Precipitation Index (SPI) (McKee *et al*., 1993) was designed to quantify precipitation deficits for multiple time scales. It is defined as the number of standard deviation that the cumulative precipitation at a given time scale (usually 1, 3, 6 and 12 months) deviates from the long term mean. It is a powerful, flexible index that is simple to calculate. In fact, precipitation is the only required input parameter. In addition, it is just as effective in analyzing wet periods as it is in analyzing dry periods. The SPI can be computed for different time scales, provide early warning of drought and help assess drought severity. It is less complex than Palmer Drought Severity Index (PDSI) and many other indices. In order to determine SPI of a given time scale precipitation data are accumulated and fit to gamma distribution which is necessary for SPI (McKee *et al*., 1995).

The time series of the monthly rainfall data fit the gamma distribution function by the equation given by (Abramowitz and Stegun, 1965):

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{\frac{x}{b}} \quad (1)$$

where, $\alpha > 0$ is shape factor; $\beta > 0$ is scale parameter; x is precipitation amount

$$\Gamma(\alpha) = \int_0^{\infty} y^{a-1}\, e^{-y}\, dy \quad (2)$$

where, $\Gamma(\alpha)$ = gamma distribution function

The values of α and β in the function was estimated by using the following equation as,

$$\hat{\alpha} = \frac{1}{4} A[1+\sqrt{1+\frac{4A}{3}}] \qquad \beta = \frac{\bar{X}}{\hat{\alpha}} \quad A = \ln(\bar{X}) - \frac{\sum \ln x}{n} \quad (3)$$

where, x is the amount of precipitation and $\bar{X}$ is the mean precipitation of the time series

Since the gamma function is not defined for zero values and the cumulative probability of each rainfall event is defined by equation:

$$H(x) = q + (1-q)\, G(x) \tag{4}$$

where, q is the probability of zero which is estimated as the proportion of zeros in the rainfall data series.

SPI is computed by using the equation,

$$Z = SPI = +\left[t - \frac{C_o + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right], \text{ for } 0.5 < H(x) < 1 \tag{5}$$

$$Z = SPI = -\left[t - \frac{C_o + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right], \text{ for } 0 < H(x) \leq 0.5 \tag{6}$$

$$\text{where, } t = \sqrt{ln \frac{1}{(H(x))^2}} \text{ For } 0 < H(x) \leq 0.5 \tag{7}$$

$$\text{and } t = \sqrt{ln \frac{1}{1 - H(x))^2}}, \text{ For } 0.5 < H(x) < 1 \tag{8}$$

$C_o = 2.515517$ $C_1=0.802853$ $C_2=0.010328$ and $d_1=1.432788$ $d_2=0.189269$ $d_3= 0.00130$

The cumulative probability was transformed in to standard random variable, Z being described as the SPI values for each of the precipitation events of the desired time scale.

Table 1. SPI values and drought severity levels

SPI Values	Drought severity level
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

(McKee *et al*., 1993; 1995)

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Soro Woreda is one of the ten woredas of Hadiya Zone, SNNPR. It is located between 7º30'0" and 7º43'0" North Latitude and from 37º35'0" to 38º05'0" East Longitude bordered by Gombora woreda in the North; Oromiya Region and Yem special woreda in the West; Dawro Zone, Kambeta Zone, Duna woreda in South and Southeast; Lemo woreda and again Kambeta Zone in the Northeast and East. The area is located at 264 km South of Addis Ababa and about 200 km from Hawassa, the capital city of the SNNPR and its total area is about 58,061 hectares, of which flat and moderately steep slope land accounts for 35% and 65%, respectively. Its altitude ranges from 840 m to 2,850 m above sea level (SWFEDO, 2014; Zeleke, 2014).

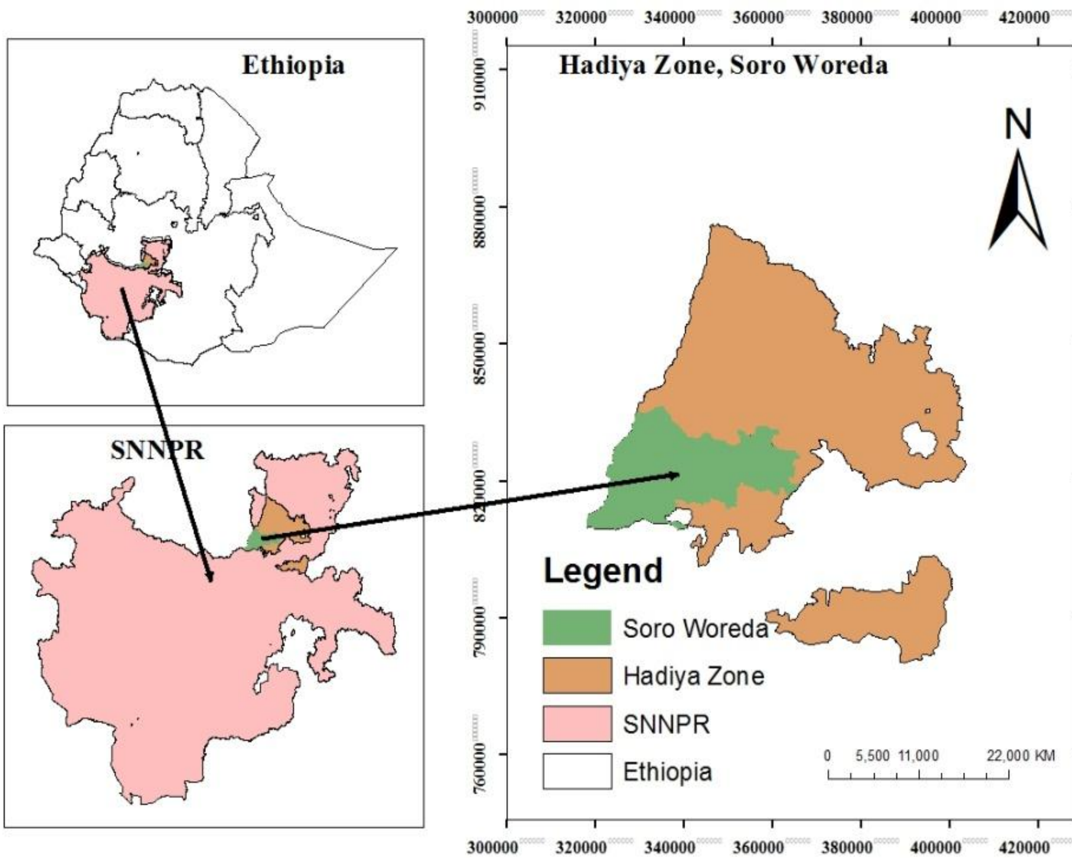

Figure 1**.** Location of the study area

3.1.2. Climate

Soro woreda is characterized by variable climatic condition and prone to rainfall and temperature variability. Mean annual rainfall is about 1260 mm with two peaks in April and August, and has an average temperature of 19ºC. The months January, February and beginning of March are months that exhibit very high temperature. More than 75% of the total rain falls during *Kiremt* season and the highest rainfall occurs in July and August (Mesfin, 2015).

3.1.3. Agro-ecology

Ethiopia has different agro-ecological zones, traditionally classified into five categories with traditional names assigned to each zone, based on altitude and temperature: *Bereha* (desert), *Kola* (lowland), *Woyna dega* (mid-land), *Dega* (highland) and *Wurch* (frost) (MoA, 2005). Similarly, the study area has typically 3 zones (8% highland, 55% midland and 37% lowland) and it is categorized under the moist mid-land agro-ecological zone (SWADO, 2010).

3.1.4. Land use/land cover

Agriculture serves as the means of livelihood to the majority of the people. It is characterized by traditional and mixed farming as it includes both crop and livestock production. It is also known mainly by the gradual prevalence of drought and crop failures. Dominantly growing crops in the study area include wheat, maize, sorghum, *teff*, barley, potato, bean, and *enset* (SWADO, 2010).

3.1.5. Soil type

The most common types of soil found in the study area are black (vertisol) (16.4%), reddish brown basaltic (nitosol) (27%), and red (chromic vertisol) (54.2%) and in some parts of the area alluvial soil (2.4%) are common, mainly along the river banks (Mesfin, 2015).

3.2. Software Used for the Study

To conduct this study the following software were used:

- ✓ Microsoft excel sheet
- ✓ XLSTAT 2014

- ✓ INSTAT+v3.37 software
- ✓ SPI-sl-extension
- ✓ DrinC (Drought Indices Calculator)
- ✓ ArcGIS10.1

3.3. Methods of Data Collection

In this study, meteorological data from NMA for the meteorological stations found around the study area were used. The major data types were decadal and monthly rainfall (mm), daily and monthly minimum and maximum temperature (ºC). The temperature data were used as input for the calculation of reference evapotranspiration (ET_o). Decadal (ten days) rainfall amounts were computed from the daily data set of 30 years using Standard Meteorological Decades (SMDs). Monthly ETo data were computed by Hargreaves equation (Allen *et al.*, 1998) using DrinC software due to the existing limited climatic data and was adjusted to daily values and again re-adjusted to the decadal values for the appropriate analysis.

$$ET_o = 0.0023(T_m + 17.8)(\sqrt{T_{max} - T_{min}})R_a \quad (9)$$

where, T_m = mean daily air temperature (°C)

T_{max}= daily maximum air temperature (°C)

T_{min}= daily minimum air temperature (°C)

Ra= extra-terrestrial radiation ($MJm^{-2}day^{-1}$)

Table 2. Geographical location of the meteorological stations

Station	Latitude (N^o)	Longitude (E^o)	Altitude (m)	Length of record
Alaba Kulito	7.64	37.97	1772	1987-2016
Fonko	7.31	38.09	2246	1987-2016
Hosanna	7.56	37.85	2307	1987-2016

3.4. Methods of Data Analysis

3.4.1. Estimation of missing data

The missed rainfall data were filled by the techniques of arithmetic mean method based on the existing percentage difference. Here the arithmetic mean was conducted since missed station's which had a percentage difference less than 10% with its normal rainfall (Richard, 1989).

Arithmetic Mean

$$P_x = \frac{P_1+P_2+P_3}{3} \quad (10)$$

where, P_x = the station rainfall with missing records

P_1, P_2, P_3 = the rainfall data for stations 1, 2 and 3, respectively

3.4.2. Consistency test of meteorological data

The consistency of the data set of the given stations was checked by the double mass curve method with in-reference to their neighborhood stations. The double mass curve was plotted by using the annual cumulative total rainfall of the base station as ordinate (average of all stations) and the average annual cumulative total rainfall of the neighboring stations as abscissa.

3.5. Analysis of Rainfall Variability

Statistical packages such as mean, standard deviation and coefficient of variation were used to analyze the variability of the collected historical daily climate data of the study area. Then after, variability of the rainfall was performed by using Microsoft office excel sheet and INSTAT+v3.37 statistical software.

Coefficient of variation

$$CV = \frac{SD}{\bar{X}} \times 100 \quad (11)$$

where, CV = coefficient of variation

SD =Standard deviation

$\bar{X}$= mean

$$SD = \sqrt{[\sum_{i=1}^{n} \frac{(Xi-\bar{X})^2}{n}]} \tag{12}$$

According to Hare (1983), CV<20% less variable, CV from 20%-30% moderately variable and CV>30% highly variable. Reddy (1990) developed a model to assess the stability of a growing period for a given region using the standard deviation of the average onset dates as SD <1 decade, stability is very high, 1-2 decades, stability is high, 2-4 decades, stability is moderate and >4 decades, stability is low.

3.6. Determination of Onset and Cessation of Growing Period

At each of the selected stations, intra-seasonal rainfall variability was analyzed in terms of onset, end, seasonal total rainfall (mm); length of rainy season; length of dry spell; coefficient of variation. For this study, determining the onset, end date and LGP was performed by adapting definition from Stern *et al*. (2006). A day with accumulated rainfall of 20 mm over two consecutive days that was not followed by greater than 9 days of dry spell length within 30 days from planting day was said to be onset date. The condition of having no dry spell of more than 9 days after the start of growing season eliminates the possibility of a false start of the season Stern *et al*. (2006). Reddy (1990) developed a model using a 3 mm rainfall depth per day (30 mm rainfall per decade) towards determining minimum threshold value for crops to satisfy their water requirement and to evaluate whether a decade is dry or wet.

Determination of onset and end of the growing period was analyzed based on INSTAT+v3.37 package which was developed by the Statistical Services Center of the University of Reading Stern *et al*. (2006) and FAO (1978) water balance concept.

Onset of rainy season the growing period begins when

$$P_n = 0.5\ ETo \tag{13}$$

where, P_n= amount of decadal precipitation

ETo = decadal reference evapotranspiration

Wet period is defined as a period during which precipitation exceeds ETo. The beginning and ending date are the two periods where precipitation and ETo are equal.

$$P_n \geq 0.5ETo \tag{14}$$

where, P_n= amount of decadal precipitation during wet period of rainy season

ETo = decadal reference evapotranspiration during the same period

On the other hand, the end of the growing season was mainly governed by the stored soil water and its availability to the crops after the rain stops. It is when the soil water balance reaches zero. Then, the end of rainfall occurs where the precipitation crosses one half of ETo during the recession of the rainy season.

$$P_n \leq 0.5ETo \tag{15}$$

Whereas crop water demand of the selected crops was calculated using an equation

$$ET_{crop} = K_c \times ET_o \tag{16}$$

where, ET_{crop} = crop water requirement/ crop evapotranspiration

k_c = crop coefficient

The length of growing period (LGP) is duration of the growing period (in days) where crops get sufficient moisture continuously without interruption. It is also defined as a period between start and end of the rainy season plus the period required to evapotranspire 100 mm moisture stored in the soil during the rainy season. It is obtained by dividing the assumed 100 mm of soil moisture to average daily evapotranspiration of the given month (FAO, 1978; Girma, 2005; Yemanu and Chameda, 2010).

3.6.1. The probability of the dry spell lengths

The probability of dry spell of different lengths during the growing season were determined from the Markov chain model to obtain an overview of dry spell risks during the crop growing season. Daily rainfall data was fitted to a simple Markov chain model. Then, probability of dry spell lengths of 5, 7, 9, 10, 15 and 20 days during the growing season were determined from the Markov chain model to obtain an overview of dry spell risks during the crop growing season.

3.6.2. Frequency of onset of the growing period

Frequency analysis is the most common statistical method for analyzing hydrologic data. It predicts how often certain values of a variable (onset of rainy season in a specific decade) may occur and to assess the reliability of the precision. The frequencies of the onset of the growing period were computed by the formula (Yemanu, 2009)

$$F(\%) = \frac{n}{N} * 100 \quad (17)$$

where: n is the number of occurrences of the onset of a season in a particular decade.

N is the total number of years for which the decadal rainfall is available.

3.7. Characterization of the Rainy Season for Maize and Sorghum

The characteristics of rainy season for the selected crops grown in the woreda in terms of the onset, end and length of the growing season were analyzed using INSTAT+v3.37 software. Length of rainy season for the crops was analyzed as a period between start and end of the rainy season plus the period required to evapotranspire 100 mm moisture stored in the soil during the rainy season. A general figure of up to 100 mm stored moisture was assumed as being available to the crops. The choice of 100 mm is based on extensive evidence which indicates that annual crops grown during the rainy season (i.e. rainfed annual crops as opposed to annual crops wholly or largely produced from stored moisture in the dry season) can utilize stored moisture in the range of 75-125 mm by the time of maturity. Accordingly, the extra time taken to evapotranspire this 100 mm of available stored moisture was added to the duration of the rainy season to set the end of the reference growing period (Yemanu, 2009; Yemanu and Chameda, 2010).

Then, the length of growing period (LGP) for both crops was determined as the time from sowing/planting to harvest or the difference between the start and end of the season.

3.8. Dry and Wet Spells Analysis for Drought Assessment

Dry and wet spell analysis assists in estimating the probability of intra-seasonal drought and it was analyzed by using Markov Chain model. Analysis of the probability of rainfall at a specific time scale only gives general information about the rainfall pattern of a certain location. Therefore, there is a need for having specific information for critically planning agricultural operations for the benefit of increasing crop yield. In this regard dry and wet spell analysis at decadal time more or less satisfies the required supportive information for decision making in rainwater management and planning in agricultural sectors.

3.8.1. Markov chain modeling

Reddy (1990) and Yemanu and Chameda (2010) stated that on average a 3 mm rainfall depth per day, which means a 30 mm per decade is the minimum threshold value for the crops to satisfy their crop water requirement and to evaluate whether a decade is dry or wet . Therefore, Markov chain model was used to evaluate the dry and wet spells distribution on decadal basis using decadal rainfall and understanding it during the rainy period is essential for successful rainfed farming.

The different formulations of Markov chain model which were used in the assessment of the distribution of dry and wet spells are presented in the following series of equations given by (Reddy *et al*., 2008).

Initial probabilities

$$P_D = \frac{F_D}{n} \tag{18}$$

$$P_w = \frac{F_w}{n} \tag{19}$$

Conditional probabilities

$$P_{ww} = \frac{F_{ww}}{F_w} \tag{20}$$

$$P_{DD} = \frac{F_{DD}}{F_D} \tag{21}$$

$$P_{WD} = 1 - P_{DD} \tag{22}$$

$$P_{DW} = 1 - P_{WW} \tag{23}$$

where,

P_D= probability of a decade being dry

F_D= number of dry decade

P_w= probability of decade being wet

Fw = number of wet decade

n = number of observations

P_{ww} = probability of wet decade followed by another wet decade

P_{DD}= probability of a dry decade followed by another dry decade

F_{ww}=number of wet decade followed by another wet decade

3.8.2. Drought events occurrence, magnitude and intensity assessment by standard precipitation index (SPI)

To assess the occurrence of drought events, intensity and magnitude in the study area standard precipitation index (SPI) can be fit monthly rainfall and total precipitation in any desired period of time using an appropriate distribution function such as gamma distribution function (McKee *e al*., 1995).

Drought magnitude and intensity

In this case, the number of drought events of various severities levels at each time scale and was counted and divided by the number of total records to get intensity of drought.

The drought magnitude (DM) for the desired time scale was calculated as:

$$DM = -\left[\sum_{j=0}^{x} SPI_{ij}\right] \quad (24)$$

where, j starts from the first month of drought and continues to increase until the end of the drought x for any of the time scales. Whereas SPI was estimated by using equation (6)

The drought intensity was computed by the following formula as:

$$DI = \frac{DM}{N} \quad (25)$$

where, DI = drought intensity, DM = drought magnitude N = number of consecutive drought month

4. RESULTS AND DISCUSSION

4.1. Consistency and Homogeneity Test of the Observed Rainfall Data Series

4.1.1. Consistency test of rainfall data series

The analysis of intra-seasonal rainfall variability is conducted after quality control was done and missed data were filled. Double mass curve indicated that the rainfall data did not show inconsistency for the selected stations. The graph of the double mass curve plot was found to be almost linear for all stations with a coefficient of determination (R^2) ranging from 0.982 for Hosanna to 0.998 for Alaba Kulito stations. This implies that the rainfall data series were consistent over the considered period of time.

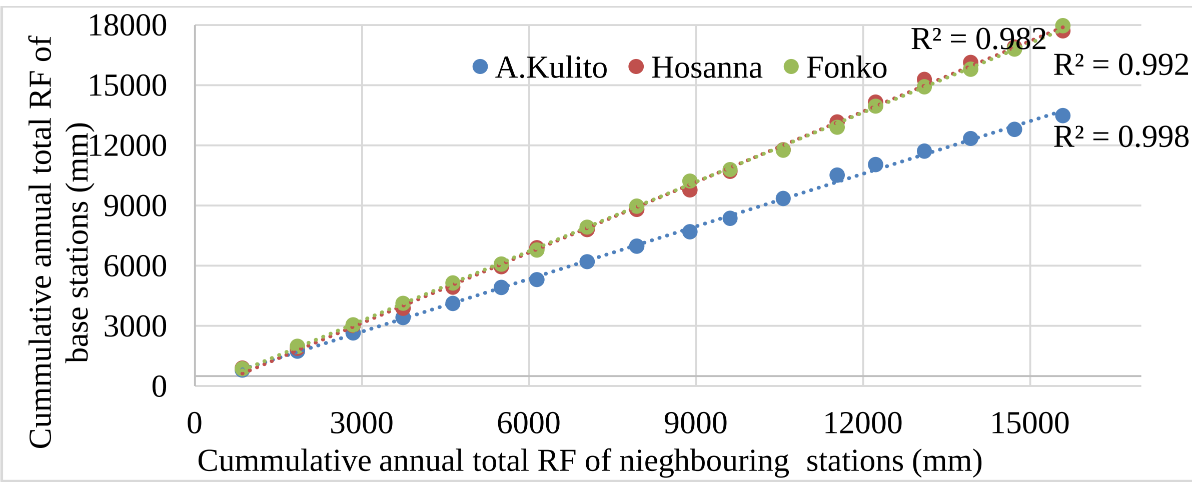

Figure 2. Double mass curve for the selected stations

4.1.2. Homogeneity test of rainfall data series

For the test of homogeneity of the rainfall data Standard Normal Homogeneity (SNHT) test which was developed by Amiri and Rosen (2011) was used for the selected stations and the test did not show heterogeneity (Appendix Figure 1 to 3). The basic statistics associated with this test was summarized in Table 3 for the stations under study. The test of the homogeneity of the rainfall data series based on the hypothesis made, the computed p-values of the selected stations was found to be greater than the significance level (alpha = 0.05); thus, annual rainfall data series exhibited trendless. From this one can infer that, the data series was homogenous and the rainfall data record has not been significantly affected due to systematic errors. So the data can be used in further analysis without requiring correction works.

Table 3. Summary of basic statistics of the selected stations

Statistics	Station		
	Alaba Kulito	Fonko	Hosanna
P-value (Two-tailed)	0.448	0.571	0.114
Alpha	0.050	0.050	0.050

4.2. Variability of Observed Rainfall Amount at Different Time Scales

In this study, the result of analysis revealed that the study area received long term mean annual rainfall (inter-annual rainfall variability) ranging from 963 mm at Alaba Kulito to 1537 mm at Hosanna for the period (1987-2016). The coefficient of variation observed was also varied ranging from 16% at Fonko (less variability) to 30% at Alaba Kulito (moderate variability) according to the Hare (1983) classification.

The result also indicated that the mean seasonal rainfall of longer rainy season (*Kiremt*) varied from 399 mm with a CV of 31% at Alaba Kulito to 1027 mm with a CV of 19% at Hosanna station. Similarly, the shorter rainy season (*Belg*) rainfall varies from 334 mm at Alaba Kulito with a CV of 53% to 429 mm with a CV of 39% at Fonko station indicating there was high variability of *Belg* rainfall at Alaba Kulito following Fonko station (Table 4). From this, it is noted that there was high rainfall fluctuation during *Belg* season in and around the study area. Similarly, mean seasonal rainfall amount of *Belg* around the area varies ranging from 334 mm with a SD of 178 mm and CV of 53% at Alaba Kulito station to 429 mm with a SD of 170 mm and CV of 39% at Fonko station implying that rainfall patterns could not be more understood and decisions pertaining to planting date as well as harvest could not be made more easily. Similarly, *Kiremt* mean rainfall amount varies from 399 mm with a SD of 124 mm and CV of 31% at Alaba Kulito to 1027 mm with a SD of 194 mm and CV of 19% at Hosanna station. Then again, CV is much higher for *Belg* total seasonal rainfall than *Kiremt* season rainfall entailing higher variability of the *Belg* total seasonal rainfall and during the shorter rain season (*Belg*), the decisions regarding to land preparation for sowing and related activities could not be easier and less risky.

From this, one can understand that Alaba Kulito area is susceptible to drought in both *Belg* and *Kiremt* season during the study period than others according to Hare (1983) classification.

Table 4. Summary statistics of annual, *Belg* and *Kiremt* rainfall variability characteristics

	Annual			*Belg*			*Kiremt*		
	Alaba Kulito	Fonko	Hosanna	Alaba Kulito	Fonko	Hosanna	Alaba Kulito	Fonko	Hosanna
Min	547	855	964	64	153	219	204	417	674
Mean	963	1230	1537	334	429	379	399	611	1027
Max	1805	1640	1993	652	805	575	1132	800	1447
SD	285	192	268	178	170	96	124	96	194
CV	30	16	18	53	39	25	31	16	19

Overall, *Belg* (shorter rain season) rainfall was more variable than *Kiremt* (longer rain season) in the area during the study period (1987-2016). This also showed that there was high rainfall fluctuation within the growing season and rainfall character of the area varied along time which needs further analysis of rainfall variability and determination of length of the growing period for decision making and planning agricultural activities in the area. The higher CV of the seasons implies that patterns could not be easily understood and decisions pertaining to rainfed crop production and related activities are possible with high risk. This shows that a *Belg* season was observed to fail to satisfy the water demand of Maize and Sorghum crops (availability of insufficient rain, which does not satisfy the 0.5 ET_0) during the study period. Comparable to the results of this study, Engida (1999), after analyzing rainfall data obtained from 419 stations in the country and Bewket (2009) 6 stations in Amhara Region reported that *Belg* season rainfall is more variable than *Kiremt* rainfall.

4.3. Characterization of the Rainy Season

Understanding monthly distribution of rainfall is paramount importance in the area because it tells how much water is available for each month during the growing period. From the Figure 3, one can clearly understand that at the selected stations the nature and pattern of the long term rainfall distribution were unimodal (March-September), and rainy season was assumed to close down after the end of decade 27 (30th September). It also shows the absence of true bimodal nature of the rainfall pattern in production terms that the seasonal rainfall pattern in the area does not have distinct bimodality. From this, it could be concluded that there is an overlap between the two rainy seasons illustrating that the main problem of the study area was not the total amount of annual rainfall, but the instability in onset dates and end dates of the farming period or more specifically delay of the starting dates and early cessation of rain relative to the average dates of the past.

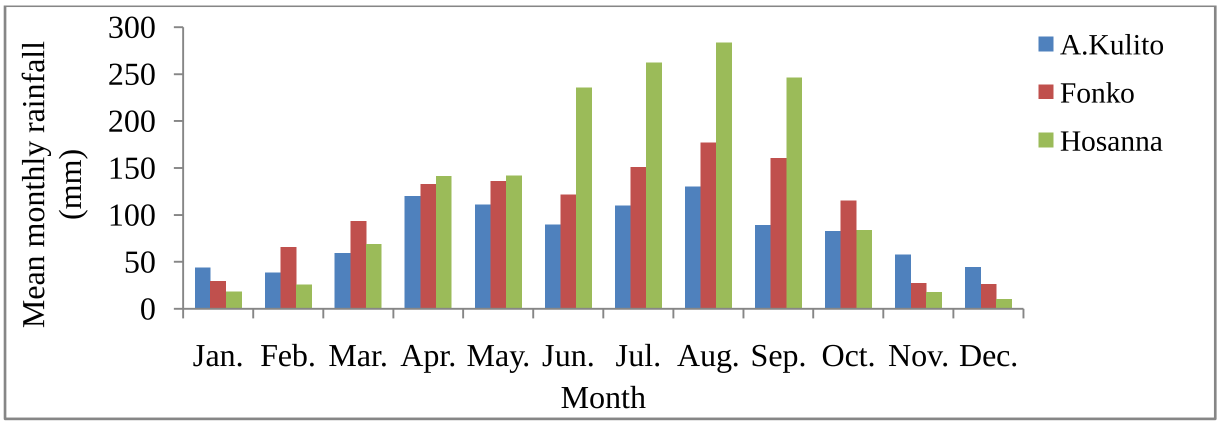

Figure 3. Monthly rainfall distribution pattern of the selected stations

The minimum mean decadal rainfall was recorded at the month of starting of rainy season (in the shorter season), rainfall is low, but evapotranspiration is high (Figures 4 to 6). The relationship between the decadal rainfall and reference evapotranspiration (ETo) is shown in (Figures 4 to 6), on average decadal rainfall amount was less than half of ETo from decade 7 to 10. The assessment result shows that evapotranspiration is higher in the dry months. In fact, the results implied that the soil moisture of the growing season in shorter rainy season is uncertain and subsequently planning of the agricultural activities related to crop production and management is difficult. Additionally, the rainfall depth is observed to be lower than the threshold of the crop water requirements (0.5ETo) in these decades. The result also revealed that rainfall is significantly a limiting factor for crop production in the beginning of this season and considerable amount of rainfall deficit is experienced during this particular season in and around the area.

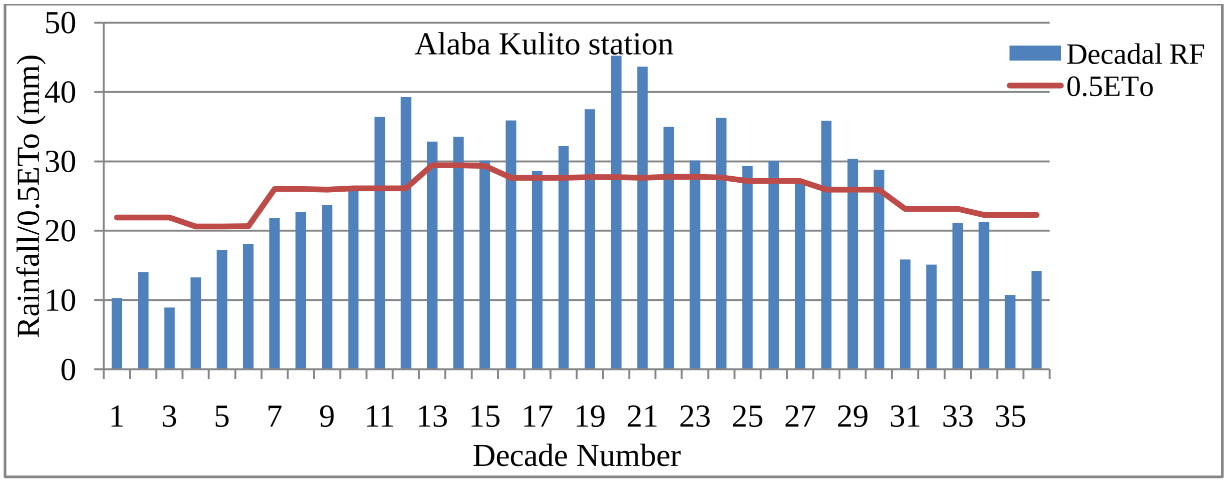

Figure 4. Growing season pattern at Alaba Kulito area

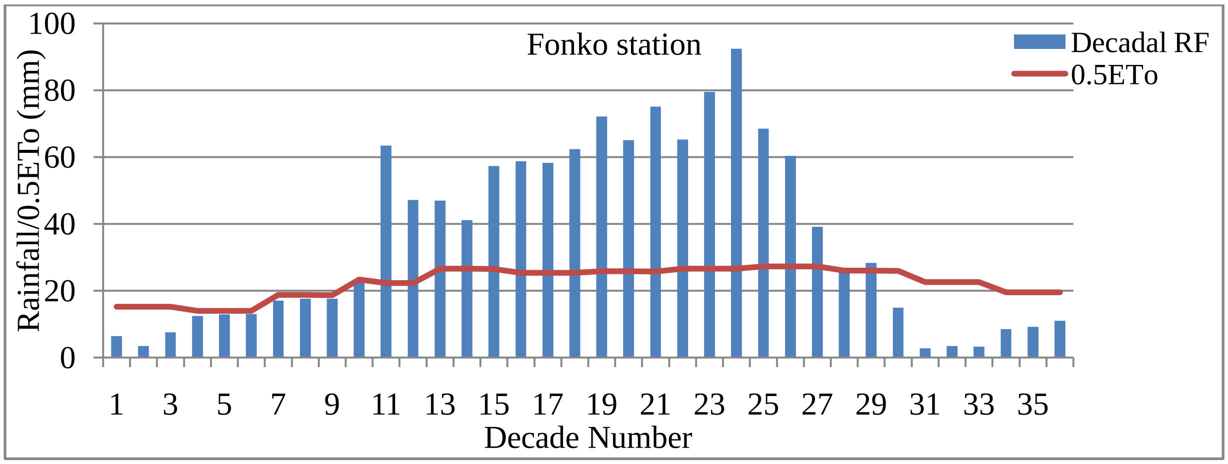

Figure 5. Growing season pattern at Fonko area

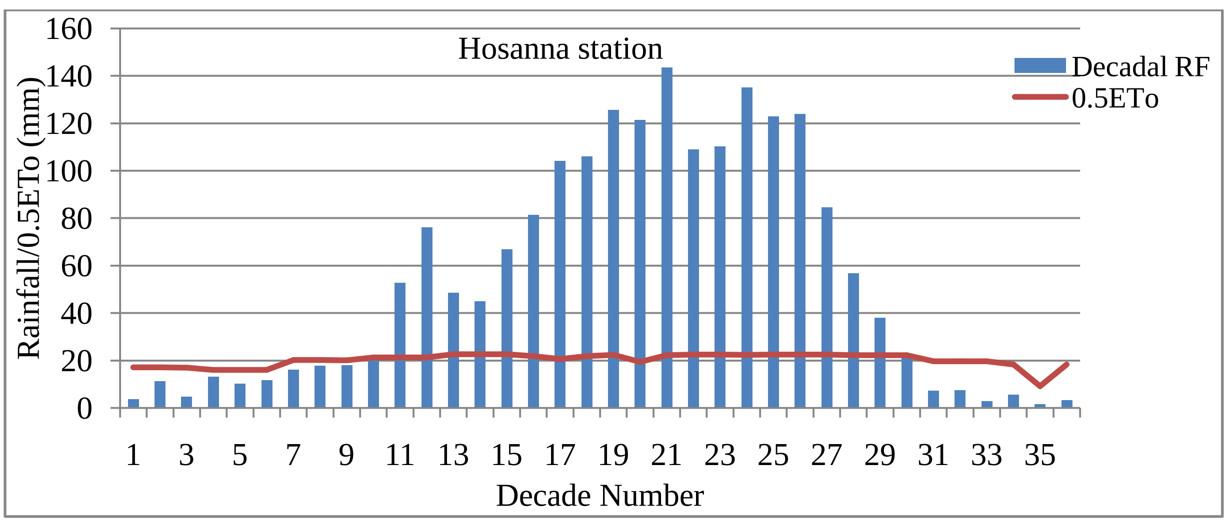

Figure 6. Growing season pattern at Hosanna area

From Figures 4 to 6, it could be noted that the nature and pattern of *Belg* season based on the average values of the rainfall and reference evapotranspiration can be seen that the decadal rainfall amount is less than the corresponding half of reference evapotranspiration in most of the decades in the beginning of the growing season. Even, April to September period is when the rainfall activities has better performance and all of the rainfed agricultural crop production activities take place in the area, delayed onset or false start of the rain during the start of the season affects LGP since late onset shortens the available length of the crop growing period and the potential to satisfy crop water requirement. From this, one can understand that planning for planting maize and sorghum crops instantly at the start of this shorter rain season is risky and may result in complete crop failure.

4.3.1. Onset, cessation and length of growing period variability

4.3.1.1. Onset and cessation of short rainy season (*Belg*)

Short rainy season (*Belg*), which is occurred from the month of March to May, received the highest amount of rainfall in April. It is relatively less stable when compared to the *Kiremt* season, is crucial for decision making purpose and planning agricultural water management.

The start of rain is defined as the first occasion of rain with more than 20 mm in 2 days period after 1st April and no dry spell of 9 days or more within the following 30 days Stern *et al*. (2006). Onset date is a key variable to which all other seasonal rainfall attributes are related. It is the onset relations that determine how the season's rainfall is expected to behave and the occurrence of *Belg* growing season as a whole is less frequent resulting in *Belg* is not suitable for rainfed agriculture (Mesay, 2006).

From Table 5, the mean onset decade of *Belg* for the area was on the first decade of April (decade 10) with a SD of 2.2 decades, CV of 22% and frequency of 27% at Alaba Kulito and second decade of April (decade 11) with a SD, CV and frequency of 2 decades, 18.2%, 13% and 2 decades, 18.2% and 20% at both Fonko and Hosanna stations, respectively. Similarly, Mesay (2006) reported that the onset of *Belg* is highly variable, with a standard deviation across the country ranging from 12 to 65%.

Table 5. Summary statistics of the mean onset decade for the short growing season (*Belg*)

Station	Mean onset (decade)	SD (decade)	CV (%)	Frequency (%)	Stability
Alaba Kulito	10	2.2	22	27	Moderate
Fonko	11	2	18.2	13	Moderate
Hosanna	11	2	18.2	20	Moderate

The result revealed that there was no distinct Belg cessation decade in the study area since the time gap between cessation of short rain season (M, A, M) and onset of long rain season (J, J, A, S) is very short and in most of the years it merges with main season (Figures 4 to 6). Therefore, the onset of *Belg* season is used to investigate changes in the start of the long cycle crops planting period and land preparation in the area and farmers are using sowing of long cycle crops such as sorghum and maize depending on the onset of *Belg* rain. The *Belg* rainfall is very important for crops like maize and sorghum which are known for their longer growing period, higher variability in the *Belg* rainfall will hinder the production of these crops. Accordingly, any sort of changes in the more variable shorter rain season pattern may cause complete crop failure and affects the livelihood of the farming community. In this case, supplementing the crops with irrigation water is imperative due to the occurrence of the prevailing dry spell risk.

4.3.1.2. Onset and cessation of long rainy season (*Kiremt*)

The longest rainy season which was occurred from June to September, locally called *Kiremt*, had received the highest amount of rainfall, mainly on the month of July and August. It is relatively stable when compared to the *Belg* season; however, irregularity and deficiency of the rainfall of this season affects the food production in the area. This season is helpful for agricultural production planning. Similarly, Hadgu *et al*. (2013) indicated that CV of rainfall was comparatively lower in *Kiremt* season than *Belg.*

The mean statistical analysis of 30 years daily rainfall data of the selected stations of the study area based on FAO (1978) simple soil water balance model revealed that long rainy season (*Kiremt*) started during the first meteorological decade of June (decade 16) at Alaba Kulito and second meteorological decade of June (decade 17) at both Fonko and Hosanna stations. Accordingly, cessation decade for the longer rain season (*Kiremt*) was found to be on the second meteorological decade of September at Alaba Kulito and the third meteorological decade of September at Fonko and the second meteorological decade of October at Hosanna station (Appendix Table 20 to 22). This result resembled with the findings by Kebede (2013) indicated that in the Upper Baro-Akobo Basin (Southwestern Ethiopia) long rainy season ends during the third decade of September at Gimbi and Yubdo stations while during the second decade of September at Bure and the first decade of October at Mettu station, and EPCC (2015) showed that the central and southern Ethiopia has cessation dates around second meteorological decade of September (September 17) and the second meteorological decade of October (October 20), respectively.

From this, one can infer that it is actually important from the crop planning and management point of view in that, crops sown early would escape the critical moisture stress in times of high dry decades immediately following the cessation of the long rainy season at the end of this season.

4.3.1.3. Length of growing period and its variability in long rainy season (*Kiremt*)

In this study, the result observed in Table 6 showed that the length of growing period of the long rainy season (*Kiremt*) at Alaba Kulito station ranges from 110 to 161 days with a mean, SD and CV of 133 days, 11 days and 8.5%, respectively. Similarly, in Fonko LGP varies ranging from 112 to 164 days with a mean, SD and CV of 145 days, 14 days and 10%, and in Hosanna it varies from 135 to 216 days with a mean, SD and CV of 180 days, 18 days and 10 %, respectively. The period includes duration of the time that 100mm of soil moisture reserve has already been evapotranspired after the end of the rainy season (FAO, 1978; Yemanu and Chameda, 2010).This results resembled with the findings of the EPCC (2015) that Southern and Southwestern parts of Ethiopia have the longest mean growing season varies ranging from 180 to 260 days, followed by central and Southwestern regions from 121 to 180 days and Wodaje *et al*. (2016) that LGP in Hosanna varies from 131 to 229 days with a mean of 183, CV 14% and SD of 26 days in Alaba Kulito it varies from 87 days to 252 days with a mean of 168 days, CV 20% and SD of 34 days.

Table 6. Summary statistics of onset, cessation and length of the growing period of long growing season (*Kiremt*)

		Station		
		Alaba Kulito	Fonko	Hosanna
Onset (decade)	Min	16	16	16
	Mean	16	17	17
	Max	18	18	18
	SD	1	0.8	0.7
	CV (%)	6	4.7	4
Cessation(decade)	Min	26	26	28
	Mean	26	27	29
	Max	29	29	33
	SD	0.7	1.2	1.5
	CV (%)	3	4	5
LGP (days)	Min	110	112	135
	Mean	133	145	180
	Max	161	164	216
	SD	11	14	18
	CV (%)	8.5	10	10

4.4. Characterization of the Onset, Cessation and LGP of Maize

In this study, the onset and cessation of rainy period compared with the water requirement of the crops at specific decade was done by crop coefficient and reference evapotranspiration values in the respective stages with the available rainfall in the specific decade. The onset decade for growing season based on the crops commonly grown which are the dominant and the most staple food crops in the study area was presented (Appendix Table 23 to 25). The analysis result revealed that the onset of the rain was stable within the decades 11 and 12 for the two major crops in the area. Most of the variability in length of growing period (LGP) was explained by the start of the season while it was less dependent on the end of the season. This was due to the reason that the end of season in the study area was more or less constant

(CV=1.2%) and hence, LGP becomes dependent on the onset of rainfall (Table 7). That means if the onset date is early the LGP becomes long while the reverse if it starts late. As a result, the *Belg* season onset decade has a significant contribution for land preparation and to start sowing activities for maize and sorghum in the study area since early onset of *Belg* rain may be a false start and be followed by prolonged dry spells for which its duration may last for one or two weeks. Hence, production of the crops in the area has been challenged by the risk of dry spell at the start of the season during the study period. Similarly, the result of Girma (2011) indicated that due to these phenomena yields would decline or crops fail completely with early planting.

The analysis result depicts that the mean onset decade for maize crop was found to be on decades 10, 11 and 11 while the cessation decade was on 22, 23 and 23 at Alaba Kulito, Fonko and Hosanna stations, respectively. The length of growing period varies ranging from 122 days with a SD of 5 days and CV of 4% to 123 days with a SD 11days and CV of 9% (Table 7). This result resembled with the study conducted by Molla (2016) concluded that the mean LGP of maize crop is 121 days in Alaba Kulito area. But, it is in contrary with the findings reported by Gebremichael (2014) that March 1st was taken as potential planting period for maize in Hosanna area and EPCC (2015) that LGP for maize in Hosanna area varies ranging from 124 to 253 days with a mean, SD and CV of 193 days, 35 days and 8%, respectively. However, in the study area, many agricultural practices (crop production), maize and sorghum production, in particular, are common staple food crops which require long growing period and mostly produced by rainwater, but farmers did not have precise information about the onset and cessation of rainfall and other critical indices of rainfall for the production of these crops.

Table 7. Summary statistics of onset, cessation and length of growing periods of maize crop at the selected stations

		Station		
		Alaba Kulito	Fonko	Hosanna
	Mean	10	11	11
Onset (decade)	SD	0.3	0.1	0.1
	CV (%)	3	10	10

	Mean	22	23	23
Cessation (decade)	SD	0.3	0.3	0.28
	CV (%)	1.2	1.3	1.2
	Min	111	98	99
	Max	130	136	141
LGP (days)	Mean	122	122	123
	SD	5	11	10
	CV (%)	4	9	8.5

4.5. Characterization of the Onset, Cessation and LGP of Sorghum

In the present study, the onset and cessation of rainy period for sorghum crop was presented (Appendix Table 25 to 28).

The analysis result of this study revealed that the mean onset decade for sorghum crop was found to be on decade 12, 11 and 11 whereas cessation decade was on 25, 26 and 26 at Alaba Kulito, Fonko and Hosanna stations, respectively. Mean LGP varies ranging from 128 days at Alaba Kulito with a SD of 5 days and CV of 4% to 146 days at both Fonko and Hosanna stations with a SD of 6.5 days and CV of 4.5% and SD of 6 days and CV of 4% implying the growing period for sorghum crop was longer at both Fonko and Hosanna stations than at Alaba Kulito station (Table 8). This result is in agreement with the FAO-56 recommendations for the East Africa regions that, April was taken as potential planting period for growing maize and sorghum crops (Allen *et al*., 1998).

Table 8. Summary statistics of onset, cessation and length of growing periods of sorghum crop at the selected stations

		Station		
		Alaba Kulito	Fonko	Hosanna
	Mean	12	11	11
Onset (decade)	SD	0.5	0.6	0.5
	CV (%)	4.5	5.5	4.5
Cessation(decade)	Mean	25	26	26
	SD	0.2	0.4	0.35

	CV (%)	0.8	1.6	1.4
	Min	115	128	134
	Max	135	153	153
LGP (days)	Mean	128	146	146
	SD	5	6.5	6
	CV (%)	4	4.5	4

4.6. Estimated Length of the Growing Period and Water Requirement of Maize and Sorghum

The fluctuation in ETc throughout the season is expected because of changes not only in the crop development but also daily changes in climatic resources, mainly rainfall and temperature (Table 9). Crop evapotranspiration (ETc) increases with increasing air temperature and solar radiation, the two primary drivers of ET (Abebe, 2012). The rising temperature and fluctuating rainfall patterns, including the amount of rainfall could adversely affect the productivity of crops. For instance, temperature is one of the most important determinants of crop growth and development.

Table 9. Approximated length of growing period (LGP) of Maize and Sorghum

Crop	Total growing period (days)	Approximate duration of growth stages			
		Initial stage	Crop development stage	Mid-season stage	Late season stage
Maize	125	20	35	40	30
Sorghum	130	20	35	45	30

Source: FAO, 1986

Table 10. Potential planting period for Maize and Sorghum in the study area

Crop	Planting date	Growth stage			
		Initial stage	Crop development stage	Mid-season stage	Late season stage
Maize	1Apr	1Apr-20Apr	21Apr-25 May	26May-4Jul	5Jul-4Aug

Sorghum	11Apr	11Apr-30Apr	1May-4Jun	5Jun-19Jul	20Jul-19Aug

Source: FAO, 1986; Allen et al., 1998

A given crop grown in a sunny and hot climate needs more water per day than the same crop grown in cloudy and cooler climate. There are; however, apart from sunshine and temperature other climatic factors which influence the crop water need. These factors are the humidity and wind speed. When it is dry, the crop water needs are higher than when it is humid. In windy climate the crops will use more water than in calm climates. The duration of the total growing season has great influence on the seasonal crop water need and time of the year during which crops are grown is also very important FAO (1986).

Table 11. Mean monthly ETo at the selected stations (mm/month)

Station	Month					
	Apr	May	Jun	Jul	Aug	Sep
Alaba Kulito	156.7	176.5	165.6	166.3	166.6	162.8
Fonko	133.7	159.5	152.4	155.0	160.0	163.8
Hosanna	127.9	135.8	130.9	133.8	134.8	134.6

From Table 12, one can clearly understand that the months and crop growth stages do not correspond, then ETo and Kc does not correspond each other; hence, ETc of the crops has to be determined on a monthly basis. It is thus required to determine Kc on a monthly basis as shown. In general, crop water requirement mainly depends upon climatic factor such as temperature, solar radiation, relative humidity and wind speed, and crop growth stages. Therefore, the computation of crop water requirement (ETc) based on the crop growth stage indicates that the differential water requirement of the crops throughout the course of crop development and the amount of water available to crops depends on the rainfall onset, length and cessation thus influencing the successfulness or failure of the growing season.

Table 12. Calculated Kc value for maize and sorghum at the selected stations

	Growth stages			
	Initial stage	Crop development	Mid-season	Late season

			stage	stage	stage		
		Apr	May	Jun	Jul	Aug	Sep
Kc per growth stage	Maize	0.4	0.8	1.15	0.7		
	Sorghum	0.35	0.75	1.10	0.65		
Kc per month	Maize	0.53	0.87	1.15	0.76	0.1	
	Sorghum	0.23	0.75	0.74	1.09	0.4	

From the analysis result, it could be noted that Maize and Sorghum crops need less water amount during the planting and initial stage, and their water need gradually increases to the maximum at the end of the crop development stage which is the beginning of the mid-season stage. Thus, the water demand of the crops is also minimal during the late season stages (Table 13). The analysis result of this study also revealed that the estimated seasonal crop water requirement of Maize crop during the total growing period ranges from 451.3mm at Hosanna to 570.2mm at Alaba Kulito whereas for Sorghum it ranges from 427.6mm at Hosanna to 538.8mm at Alaba Kulito implying Maize crop grown in Hosanna area requires significantly less amount of water during total growing period than Maize crop grown in Alaba Kulito and Fonko, and the same is true for Sorghum (Table 13). From this, one can clearly realize that a certain crop grown in a cooler climate and cooler months needs considerably less amount of water than the same crop grown in dry and hot climate, and during the hotter months as rainfall distribution and temperature have opposite impacts on rainfed crop production.

Table 13. Estimated seasonal crop water requirement (ETc) of Maize and Sorghum crops (mm/month)

Crop	Station	Apr	May	Jun	Jul	Aug	Total
Maize	Alaba Kulito	83.0	153.5	190.4	126.3	17.0	570.2
	Fonko	70.8	138.7	175.2	117.8	16.0	518.5
	Hosanna	67.7	118.0	150.5	101.6	13.5	451.3
Sorghum	Alaba Kulito	36.0	132.5	122.5	181.2	66.6	538.8
	Fonko	30.7	119.6	112.7	168.9	64.0	496.0
	Hosanna	29.4	101.8	96.8	145.6	54.0	427.6

4.7. Dry Spell Analysis Using Markov Chain Modeling

4.7.1. Initial and conditional probabilities of the occurrences of dry and wet decades

4.7.1.1. Short rainy season (*Belg*)

In this study, *Belg* season dry and wet spells distribution analysis result for Alaba Kulito station revealed that the probability of a decade being dry was high on decade 7, 8 and 9 with the probability of 84%, 84% and 82%, respectively. The probability of a decade being dry was relatively low on decade 11 with 67% while the probability of a decade being wet was high in decade 11(33%). In view of that, the probability of getting wet decade was below 50% for all the decades (Table 14). During this season, the occurrences of dry decade followed by another dry decade had a probability of greater than 50% in most of the decades, but the probability of wet decade followed by another wet decade was low for most of the decades except decade 10 and 14 which had a probability of 50% and 54%, respectively. From this, it could be noted that planning important agricultural operations except plowing could be some how difficult in and around the area (Table 14).

However, the occurrence of dry spell has a particular relevance for rainfed agriculture, but distribution of rainfall is variable temporally within the growing season, crops may start to wilt and cause damage to yield, but the extent of the damage depends on the re-occurrence of dry spells of different duration, which depends on the soil moisture holding capacity and the type of crop in Alaba Kulito area during the study period.

Table 14. Probability of dry and wet spells based on Markov Chain model during *Belg* at Alaba Kulito station

Decade	P-W	P-D	P-WW	P-DD	P-WD	P-DW
7	16	84	43	90	10	57
8	16	84	41	88	12	59
9	18	82	34	87	13	66
10	31	69	50	77	23	50
11	33	67	49	77	23	51
12	31	69	43	74	26	57
13	25	75	39	79	21	61

14	28	72	54	81	19	46
15	24	76	30	79	21	70

where P-W=probability of wet; P-D=probability of dry; P-WW=probability of wet followed by wet; P-DD=probability of dry followed by dry; P-WD=probability of wet followed by dry and P-DW=probability of dry followed by wet

Based on the result obtained in table 15, dry and wet spell distribution at Fonko area depicts that the probability of a decade being dry was the highest in decade 7 with a probability of 80%. On the other hand, the probability of being wet decade had the highest value in decade 11 and 15 relative to the other decades with the corresponding probability of 46% and 45%, respectively. The analysis result showed that in Belg season the probability of being wet season had below 50% probability to occur for all decades. The conditional probability of dry decade preceded by a dry decade (P-DD) was also high for both decade 7 and 8 with a probability of 90% implying planning for rainfed crop production was risky (Table 15).

This suggests that the success or failure of any crop depends not only on the total rainfall received during the crop season but also on its distribution during the sensitive growth stage of the crop. That is why the concept of estimating the probabilities of the occurrence of dry and wet spells and also probabilities of occurrence of consecutive dry and wet spells with respect to the threshold amount of rainfall is extremely useful for crop planning, farming operations, and uniform planting practices, common timing of field operations and designing of moisture conservation measures.

Table 15. Probability of distribution of dry and wet spells based on Markov Chain model during *Belg* at Fonko station

Decade	P-W	P-D	P-WW	P-DD	P-WD	P-DW
7	20	80	54	90	10	46
8	21	79	41	90	10	49
9	31	69	33	85	15	67
10	32	68	68	85	15	32
11	46	54	88	84	16	22
12	35	65	74	82	18	26
13	39	61	69	80	20	31

14	38	62	72	83	13	28
15	45	55	72	77	23	28

Analysis of the probability of dry and wet spell distribution by Markov Chain model revealed that the *Belg* season at Hosanna area showed that the driest decade was decade 8 with a probability of 79% (21% of wet occurrences) and decade 12 had the highest probability of getting wet decade with a probability of 59%. The highest probability of having wet decade after wet was observed on decade 15 with 87% of occurrences (Table 16). The result indicated that conditional probability of dry decade preceded by a dry decade (P-DD) was also high for both decade 8 and 9 with a probability of 93% and 91%, respectively. At the same time as, the start of the season had the highest probabilities of occurrences of the dry on decades 7, 8 and 9 with the corresponding probabilities of 78%, 79% and 72%, respectively.

Table 16. Probability of distribution of dry and wet spells based on Markov Chain model during *Belg* at Hosanna station

Decade	P-W	P-D	P-WW	P-DD	P-WD	P-DW
7	22	78	60	90	10	40
8	21	79	72	93	7	28
9	28	72	70	91	9	30
10	36	64	80	89	11	20
11	39	61	73	87	13	27
12	59	41	84	75	25	16
13	38	62	72	82	18	28
14	40	60	71	80	20	29
15	48	52	87	90	10	13

In general, the occurrence of a relative high probability of consecutive dry decades was recorded throughout the meteorological decades in this particular season (*Belg*) with the deficit rainfall. Thus, rainfed agriculture was at high risk for crop production purpose and this season cannot support favorable growth of crops that have high water requirements in and around the area. For that reason, more attention is needed for planning and management of agricultural water for crop production and introducing different agronomic practices that prolongs soil moisture holding capacity which reduce evaporation loss could be used as management options in order to counteract different magnitudes of dry spells. This is in agreement with the result reported by EPCC (2015) that consecutive dryness throughout the growing season constrains crop production retarding the growth of crops by limiting the water availability for the crops.

4.7.1.2. Long rainy season (*Kiremt*)

The analysis results of initial and conditional probabilities of dry and wet spell distribution by Markov Chain for the area during the longer rain season (*Kiremt*) at the selected stations for the period (1987-2016) was presented in table 17 to 19.

The result of the analysis for dry and wet spell distribution for Alaba Kulito point out that the probability of a decade being wet in the long rainy season (*Kiremt*) was found to be less than 50% throughout the meteorological decades and the probability of getting a wet decade after wet in the study area during the long rainy season was also found to be below 50% for most of the meteorological decades except decade 25 with a probability of 50% (Table 17).

The result further revealed that Alaba Kulito and the surrounding areas experience more dry and unusual wet decades. As a result, within the growing season, the area can receive poorly distributed wet spells as more wet spells can be experienced when crops are already affected adversely by drought. This also suggests that planning for sowing crops on decade 25 can be a good decision, but during other decades plants could suffer from low soil moisture as the plants may require more water as it develops. Therefore, some soil and water conservation techniques should be exercised during the wettest periods to conserve soil moisture.

Table 17. Probability of distribution of dry and wet spells based on Markov Chain model during *Kiremt* season at Alaba Kulito station

Decade	P-W	P-D	P-WW	P-DD	P-WD	P-DW
16	25	75	30	76	24	70
17	21	79	38	85	15	62
18	24	76	39	79	21	61
19	29	71	41	76	24	59
20	33	67	45	76	24	55
21	32	68	42	72	28	58

22	27	73	33	73	27	67
23	27	73	41	80	20	59
24	28	72	39	78	22	61
25	24	76	50	83	17	50
26	25	75	39	81	19	61
27	28	72	39	74	26	61

where P-W=probability of wet; P-D=probability of dry; P-WW=probability of wet followed by wet; P-DD=probability of dry followed by dry; P-WD=probability of wet followed by dry and P-DW=probability of dry followed by wet

The result of the probabilities of dry and wet spell distribution for Fonko illustrated that the probability of a decade being wet in the long rainy season (*Kiremt*) was found to be greater than 50% throughout the meteorological decades except decade 25 with a probability of 39% (Table 18) and the corresponding probability of almost all decades being dry was below 50% except decade 25(61%) indicating in most of the decades planning for crop production in and around the area can be done with limited risk.

On the other hand, the probability of a decade being wet followed by another wet decade was greater than 50% throughout the meteorological decades which was indicative of *Kiremt* season is having well moisture condition above the threshold limit for most of the years during the study period and crop production during this season is less likely affected by moisture stress (Table 18). This implies that this season is favorable for the crops as moist conditions permit agricultural crop production. Yemanu (2009) reported comparable result in Central Highlands of Ethiopia that crop production is affected less during *Kiremt* season.

Table 18. Probability of distribution of dry and wet spells based on Markov Chain model during *Kiremt* at Fonko station

Decade	P-W	P-D	P-WW	P-DD	P-WD	P-DW
16	58	42	76	70	30	24
17	59	41	80	72	28	20
18	61	39	80	66	34	20
19	61	39	67	51	49	33
20	58	42	71	56	44	29

21	59	41	72	61	39	28
22	60	40	66	55	45	34
23	67	33	75	51	49	25
24	68	32	78	54	46	22
25	67	33	81	57	43	19
26	58	42	77	64	36	23
27	39	61	69	79	21	31

The result of the probabilities of dry and wet spell distribution for Hosanna area revealed that the probability of a wet decade followed by another wet decade had the values above 80% throughout the meteorological decades (SMDs) during the study period (Table 19). On the other side, probability of dry decade followed by another dry decade had a probability of less than 50% for most of the decades except decade 16, 17, 26 and 27 with the probability of 77%, 50%, 54% and 62%, respectively. From this, it could be noted that there is chance of having good soil moisture conditions for planning agricultural operations during those periods. In other words, decision making with respect to growing crops is fairly less risky for the farmers in the area. Hence, the results found based on decadal time step illustrated that the probability of a decade being wet during long rainy season (*Kiremt*) had the highest probability during both decade 18 and 25 with 87% and the probability of a decade being wet had values reached maximum 87% ranging from 61% in decade 16. In the case of the probability of a decade being dry had probability of high values at the beginning of the decade with a percentage of 39% in decade 16 (Table 19).

Table 19. Probability of distribution of dry and wet spells based on Markov Chain model during *Kiremt* season at Hosanna station

Decade	P-W	P-D	P-WW	P-DD	P-WD	P-DW
16	61	39	81	77	33	19
17	84	16	90	50	50	10
18	87	13	90	35	65	10
19	85	15	91	42	58	9
20	82	18	89	47	53	11
21	84	16	87	44	56	13

22	79	21	87	44	56	13
23	80	20	83	36	66	17
24	86	14	90	46	54	10
25	87	13	92	44	56	8
26	86	14	93	54	44	7
27	80	20	92	62	38	8

In general, the analysis results from the above tables entail that decadal precipitation values are in excess of half of the reference evapotranspiration (>0.5ETo). This is an indicative of patterns could be easily understood. Accordingly, the decisions regarding planning cropping calendar, crop planting and related activities will be made with less risk.

4.7.1.3. The probability of dry spell lengths

Analyzing the length of dry spells could be used as a guide for planning supplementary irrigation because high water demand periods can be predicted, choice of planting date and crop selection can be made based on the length of dry spells. It is also helpful to manage water supply effectively and efficiently for irrigation as well. From this point different dry spell lengths probability was analyzed and high probability occurrence of long dry spell causes dry season while a very low probability of dry spell happens during rainy seasons (Appendix Figure 4 to 6). During main rainy season, the probability of 5 days dryness was about 99%, 30% and 2% at Alaba Kulito, Fonko and Hosanna stations, respectively. Similarly, the probability of dry spells of 5 and 7 days was high at Alaba Kulito relative to other stations. So Belg (shorter rain season) has higher probability of dry spells than the *Kiremt* (long rain season) at Alaba Kulito following Fonko and Hosanna stations though the probability of occurrence of longer dry spells (longer than 15 days) at Alaba Kulito station was about 30% in decade 10 and decreases to 0% from end of decade 18 to end of decade 21 and increases again after the end of decade 24 implying dry spell lengths are higher during shorter rain season than longer rain season in the area. The result also revealed that the probability of dry spells of 15 and 20 days is 95% and 65% during the dry months and their probability curves converge to their minimum during the peak rain season from end of decade 18 to end of decade 24 and starts increasing at decade 25, signaling the end of the growing season. Thus, the reason behind including the dry spell length conditions into the later months of the growing season is to provide a complete picture of how various dry spell lengths are distributed during the entire growing season as well as to examine the associated risks that might prevail at each site and specific time of the growing season indicating dry spell of short period has high probability of occurrence compared to long dry spells. As the length of dry spell threshold becomes short, the probability of dry spells occurrence increases and conversely, as dry spells threshold becomes longer, the probability of dry spells occurrence decreases within the growing season.

In most cases, *Belg* season has higher probability of dry spells than *Kiremt* and the alternating dry spell becomes critical in rainfed farming, particularly for the seedling establishment during the first 30 days or so after planting. In fact, a dry spell of any length could occur at any stage of crop growth. However, dry spells of short period of time are easy for decision making than dry spells of long period. Similarly, Stern *et al*. (2006) and Molla (2016) reported that long period of dry spell is potentially damaging if it coincides with the most sensitive growth stages of the crops.

4.8. Drought Analysis Using Standardized Precipitation Index (SPI)

4.8.1. Time series analysis of drought events occurrence, frequency and intensity

In the present study, recurrent annual drought years were identified as moderate to extreme drought events that were experienced at Alaba Kulito in the years 2012, 2015, 1990 and 1995, at Fonko it was in the years 1990, 1991, 2009, 1995 and 1994 and at Hosanna in the years 1997, 1998, 2007, 2008, 2009, 2010 and 2005, 2006, 2007, respectively (Appendix Table 14 to 19). In these years the annual rainfall showed below normal rainfall and seasons during these years were a clear confirmation of water stress and droughts in the area. From this, one can infer that agricultural activities were affected by delayed onset, early cessation and variable rainfall which affect more wide-ranging production of major crops. Thus, crop failure, reduction of yield and food insecurity in particular more aggravated during the drought years due to the moisture stress and shortage of time to carry out agricultural activities on time.

Based on 6-month time scale severe and extreme drought events were observed in the years 1990 and 1999 at Alaba Kulito, in 1995, 2012, 2014, 2016 and 1994 at Fonko and in 2005 and 2006 at Hosanna station, respectively. However, the three stations are not very far from each other, drought events occurrence and severity varies from year to year over the three stations.

For instance, relatively Fonko area was more affected than others (Appendix Table 14 to 19). The result obtained for the area revealed that severe or extreme drought occurs when complete failure of rainfall happens during the cropping season. If such situation continues agricultural operations would be greatly affected, then if the rain fails to occur above the minimum needed for agriculture, crops would suffer drastically and rainfall deficit results in damage to crops since there would be no reserve water in the soil implying the incidence of agricultural drought in the area as SPI 3- to 6- month time scales are common time scales for agricultural drought analysis.

4.8.1.1. Short rainy season (*Belg*)

The result of this work for *Belg* growing season point out that majority of the drought events observed in the study area were moderate drought events based on SPI-1, SPI-3 and SPI-6. Thus, the SPI-1 result illustrated that most of the drought events occurred were moderate, but extreme was observed in the month of May at Alaba Kulito, April at Fonko and April and May at Hosanna during the study period (Table 20).

Table 20. Frequency of occurrences of drought events during *Belg* growing season for different severity levels

Station	Month	Drought severity level			
		Moderate	Severe	Extreme	Total
Alaba Kulito	March	2	2	0	4
	April	2	2	0	4
	May	4	1	1	6
Fonko	March	6	0	0	6
	April	2	0	1	3
	May	5	1	0	6
Hosanna	March	2	2	0	4
	April	2	2	1	5
	May	3	2	1	6

During this season the highest drought magnitude of 3.70 (April) was recorded in 2016 at Fonko followed by 2.49 (March) at Hosanna in 1996. At Fonko station drought frequency and intensity was relatively less, particularly as compared to Alaba Kulito and Hosanna stations

(Appendix Table 14 to 19). From this, one can observe that there was a short term drought effect, mainly associated with soil moisture and the occurrence of meteorological drought in the area. Besides, based on 3-month time scale during this season relatively more drought events of different severity were detected at Alaba Kulito station (Appendix Table 14 to 19) implying that on a longer time scale (the 3-month), drought is detected less frequently, but lasts longer. In other words, on one-month time scale, drought becomes more frequent but lasts for shorter periods and there were a medium-term trend in rainfall and seasonal drought effects in the area.

4.8.1.2. Long rainy season (*Kiremt*)

Based on one month time scale of SPI analysis during the long rainy season (*Kiremt*) in the study area extreme drought event with a magnitude of (3.02) was occurred at Alaba Kulito whereas the highest frequency of moderate drought events (14) were occurred at Hosanna followed by Alaba Kulito (9) and Fonko (7) (Table 21).

In general, the study area experienced more occurrences of drought events during the *Kiremt* with equal magnitude in August and September (6) at both Alaba Kulito and Hosanna stations followed by Fonko in July amounting (2). Similarly, the highest drought magnitude of 3.69 was recorded at Fonko station in 2006 followed by 3.02 which was recorded in 1999 at Alaba Kulito while most of the drought events experienced at Hosanna station were moderate (Appendix Table 14 to 19).

Table 21. Frequency of occurrences of drought events during *Kiremt* growing season for different severity levels

Station	Month	Drought severity level			
		Moderate	Severe	Extreme	Total
Alaba Kulito	June	0	3	0	3
	July	2	1	1	4
	August	2	4	0	6
	September	5	1	0	6
Fonko	June	2	1	1	4
	July	0	0	2	2

	August	2	0	1	3
	September	3	0	1	4
Hosanna	June	2	1	1	4
	July	4	1	0	5
	August	4	2	0	6
	September	4	1	1	6

In this study, drought analysis for the area was done based on three month time scale for clarifying purposes. In the above tables, the result depicted that during the period of record, drought events with different severity levels were observed in about 11, 12 and 12 years during *Belg* season and 8, 8 and 8 years during the *Kiremt* season at Alaba Kulito, Fonko and Hosanna, respectively. During *Belg* season the highest drought magnitude of 4.35, 3.70 and 3.91 and intensity of 2.77, 3.70 and 2.49 were occurred at Alaba Kulito, Fonko and Hosanna stations, respectively. On the other hand, during *Kiremt* season the highest drought magnitude of 6.68, 5.09 and 4.87 and intensity of 2.26, 3.69 and 3.62 Alaba Kulito, Fonko and Hosanna stations, respectively (Table 22 to 24).

Overall, the above results revealed that there are more drought occurrences in *Belg* during the period of record; as a result, risks were entailed in planting of crops in *Belg* season. Hence, one can pin point that the pattern of rainfall occurrence is unpredictable within the *Belg* season in and around the study area.

Table 22. Number of drought events, magnitude and intensity during *Belg* and *Kiremt* season on three month time scale at Alaba Kulito station

	Season					
	Belg			*Kiremt*		
Year	No of events	DM	DI	No of events	DM	DI
1987	1	1.50	1.50	1	1.90	1.90
1988	0	*	-	0	*	-
1989	0	*	-	0	*	-
1990	0	*	-	1	1.52	1.52
1991	0	*	-	0	*	-

1992	0	*	-	0	*	-
1993	0	*	-	2	2.34	1.17
1994	1	1.01	1.01	1	1.64	1.64
1995	0	*	-	2	2.76	1.38
1996	0	*	-	0	*	-
1997	0	*	-	0	*	-
1998	0	*	-	0	*	-
1999	1	2.77	2.77	3	6.68	2.26
2000	1	1.50	1.50	0	*	-
2001	0	*	-	0	*	-
2002	1	1.29	1.29	0	*	-
2003	0	*	-	0	*	-
2004	0	*	-	0	*	-
2005	0	*	-	1	1.16	1.16
2006	0	*	-	0	*	-
2007	2	2.89	1.44	0	*	-
2008	1	1.45	1.45	0	*	-
2009	0	*	-	2	3.47	1.73
2010	0	*	-	0	*	-
2011	1	1.03	1.03	0	*	-
2012	3	4.35	1.45	0	*	-
2013	1	1.48	1.48	0	*	-
2014	0	*	-	0	*	-
2015	2	2.44	1.22	0	*	-
2016	0	*	-	0	*	-

* Years without drought occurrence

Table 23. Number of drought events, magnitude and intensity during *Belg* and *Kiremt* season for three month time scale at Fonko station

	Season					
	Belg			*Kiremt*		
Year	No of events	DM	DI	No of events	DM	DI
1987	0	*	-	1	2.11	2.11
1988	0	*	-	0	*	-
1989	1	1.48	1.48	0	*	-
1990	0	*	-	1	1.85	1.85
1991	0	*	-	0	*	-
1992	0	*	-	0	*	-
1993	1	1.28	1.28	0	*	-
1994	0	*	-	1	1.12	1.12
1995	0	*	-	0	*	-
1996	0	*	-	0	*	-
1997	0	*	-	0	*	-
1998	0	*	-	0	*	-
1999	2	2.46	1.23	0	*	-
2000	1	1.28	1.28	1	1.07	1.07
2001	0	*	-	0	*	-
2002	0	*	-	0	*	-
2003	0	*	-	0	*	-
2004	0	*	-	0	*	-
2005	1	1.09	1.09	0	*	-
2006	0	*	-	1	3.69	3.69
2007	0	*	-	0	*	-
2008	1	1.13	1.13	0	*	-
2009	2	2.27	1.13	0	*	-
2010	1	1.32	1.32	1	1.24	1.24
2011	0	*	-	0	*	-

2012	0	*	-	0	*	-
2013	2	2.96	1.48	0	*	-
2014	1	1.41	1.41	2	5.09	2.54
2015	1	1.28	1.28	0	*	-
2016	1	3.70	3.70	1	1.41	1.41

* Years without the occurrence of drought

Table 24. Number of drought events, magnitude and intensity during *Belg* and *Kiremt* season for three month time scale at Hosanna station

	Season					
	Belg			*Kiremt*		
Year	No of events	DM	DI	No of events	DM	DI
1987	0	*	-	0	*	-
1988	0	*	-	0	*	-
1989	0	*	-	0	*	-
1990	0	*	-	0	*	-
1991	0	*	-	0	*	-
1992	0	*	-	0	*	-
1993	0	*	-	0	*	-
1994	2	3.07	1.53	1	1.11	1.11
1995	0	*	-	0	*	-
1996	1	2.49	2.49	0	*	-
1997	0	*	-	1	1.25	1.25
1998	1	1.39	1.39	3	4.87	1.62
1999	0	*	-	0	*	-
2000	0	*	-	0	*	-
2001	0	*	-	1	1.08	1.08
2002	1	1.23	1.23	0	*	-
2003	1	1.26	1.26	0	*	-
2004	0	*	-	0	*	-
2005	2	2.61	1.30	2	2.89	1.45

2006	2	3.91	1.95	2	2.61	1.30
2007	1	1.73	1.73	0	*	-
2008	1	1.21	1.21	3	4.69	1.56
2009	1	1.06	1.06	0	*	-
2010	0	*	-	2	3.13	1.56
2011	1	2.04	2.04	0	*	-
2012	0	*	-	0	*	-
2013	0	*	-	0	*	-
2014	1	1.91	1.91	0	*	-
2015	0	*	-	0	*	-
2016	0	*	-	0	*	-

* Years without the occurrence of drought

4.9. Seasonal Rainfall Variability: Implications for Maize and Sorghum Productions

Time series analysis of mean seasonal and annual rainfall total was done to reveal the general trends of rainfall amounts over the area. The result revealed that there was a decreasing of seasonal rainfall amount, high rainfall amount and intensity variability for the last 30 years.

Based on the results obtained above, rainfall variability indicates the unreliable onset of *Belg* season which determines the planning time for growing period of the crops. However, Maize and Sorghum productions are particularly related to the *Belg* rains, Maize appears to require a more even distribution of rainfall throughout the *Belg* and *Kiremt* seasons due to the fact that both crops are sown in early May or even late April, which makes the *Belg* rainfall critically important. It is only that one can confidently identify the most suitable maturity crop to be planted in seasons with different onset date conditions.

Most of the time, for the productions of both Maize and Sorghum, which are long cycle crops sown early from the *Kiremt* rain, the implications of *Belg* rainfall is quite obvious; however, *Belg* season mean rainfall which varies from 334 mm at Alaba Kulito to 429 mm at Fonko is slightly lower than the crop water demand threshold of maize (500-800 mm) and Sorghum (450-650 mm) implying only *Belg* season rainfall is can not to support the production of these crops since at the beginning of the season, which follows the long dry season of *Bega*, soil moisture is virtually nil. Thus, the occurrence of adequate rainfall in the early periods of the season (*Belg* season) is vital for Maize and Sorghum productions in the area. This suggests that the crops are frequently exposed to moisture stress at critical stages of growth, mostly at the lowlands in the area. But, during the *Kiremt* season not only that mean rainfall varying from 399 mm at Alaba Kulito to 1027 mm at Hosanna, the occurrence is likely to become more common but also that soil moisture reserves will be sufficient to support plant growth during any dry spells, but crop water demand of both crops is not satisfied at Alaba Kulito and its surrounding areas by only rainfed production, as the area is prone to drought indicating that supplementing the crops with irrigation water is crucial to reduce the problem of crop water stress and crop failure in the area.

Moreover, Sorghum, in particular, has a good tolerance for water stress caused by prolonged dry spell occurrences than Maize since it requires less water during its growth period. Similarly, Sorghum tolerates end of season dry spells (rainfall shortage in September) than Maize, thus it is more sensitive to rainfall in *Belg*, while Maize is more sensitive to dry spells throughout its growing period beginning in *Belg* and until the end of *Kiremt*. From this, one can clearly infer that supplementing the crops with irrigation and using different soil moisture management options are crucial to avoid the crops from water stress and reduce complete crop failure during *Belg* and end of *Kiremt*. Molla (2016) reported comparable result at Shashogo Woreda of Hadiya Zone that decrease in rainfall amount, drought, delayed onset, early cessation, and heavy and unexpected rainfall are climate related hazards and key challenges of maize and sorghum productions that mainly faced and caused complete crop failure, reduced yield, delayed maturity and increased crop pests/diseases.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Summary and Conclusion

Comprehensive knowledge of seasonal rainfall variability in terms of *Belg* and *Kiremt* rainfall amount is paramount importance in rainfed agriculture of Ethiopia since more than 85% of the population depends on it. Due to seasonal rainfall variability, the country in general and the study area in particular, affected by frequent drought and crop failures. This study provides an outline of intra-seasonal rainfall characteristics and its effect on the growing season of Maize and Sorghum production at Soro Woreda of Hadiya Zone, SNNPR Ethiopia. Accordingly, the present study aimed on characterization of the intra-seasonal rainfall indices such as onset, cessation, dry and wet spells, and drought conditions in the study area.

Thirty years rainfall data of Alaba Kulito, Fonko and Hosanna stations were used for the rainfall variability analysis using statistical packages, initial and conditional probability of dry and wet spells using Markov Chain model, drought characteristics and severity level analysis based on Standardized Precipitation Index (SPI). The onset, cessation and length of growing periods were analyzed using the FAO (1978) water balance, Reddy (1990) models and INSTAT software. The long rainy season (*Kiremt*) which contributes largest to the annual rainfall in all the three stations shows less variation than *Belg* season rainfall. The mean onset decade of the short growing season (*Belg*) was on the first decade of April at Alaba Kulito and second decade of April at both Fonko and Hosanna. It was variable with a CV value of 22%, 18.2% and 18.2% at Alaba Kulito, Fonko and Hosanna, respectively. The mean onset decade of long growing season (*Kiremt*) for an ideal crop starts on the decade 17 at Alaba Kulito, decade 16 at both Fonko and Hosanna whereas; end of the long rainy season was observed on decade 27, 28 and 30 at Alaba Kulito, Fonko and Hosanna, respectively. The mean onset decade for growing Maize crop starts on the decade 10, 11and 12 while the end of growing season was observed on decade 22, 23 for Maize, and 25 and 26 for Sorghum.

The occurrence of drought in the study area was analyzed using DrinC software to explain the spatial and temporal variations of drought, its frequency, magnitude and intensity. The drought indices (SPI) of two rainy seasons (*Belg* and *Kiremt*) for the short time scale (1-and 3-months

SPI) revealed that there was high frequency of dry and wet periods, but with increasing time scales its occurrences decrease in the area during the study period.

From this study, it could be noted that planning of agricultural activities is simple and less risky in and around the study area during the long rainy season (*Kiremt*) due to the stability of the onset dates and occurrences of the sufficient wet spell whereas the variability of LGP of *Belg* explicated more by variability of onset and *Kiremt* season was influenced more by cessation. Moreover, the shorter rainy season (*Belg*) is characterized by frequent dry decades and its impacts on rainfed crop production in this particular season need a due consideration and monitoring of crops grown in the area. Therefore, *Kiremt* season is more advisable to plan for the regular rainfed crop production planning in the area.

Maize and Sorghum production over the study area is relatively risky of water stress around Alaba Kulito and less in Hosanna area for the last 30 years (1987-2016) as both crops need more water at Alaba Kulito than Hosanna, which necessities supplementing the crops with irrigation to cope up with the water stress problem of the crops during the sensitive growth stages and to avoid the crops reaching critical stages at times when there are high probability of dry spells.

Generally, analyzing intra-seasonal rainfall characteristics in terms of the rainfall amount, distribution, start and end of the season and intervening dry spell are indispensable for altering the crop production system depending on the length of growing period of the crop and its water requirement. Therefore, for the crops planted at the end of the season and short rainfall to satisfy the crop water demand under changing climate depending on the crop type and growth stage, supplementary irrigation is vital for the crops to maximize the production.

5.2. Recommendations

Based on the result obtained in this work the following recommendations are forwarded:

- ✓ Characterization of growing periods in the study area was probabilistic. Thus, the onset and cessation of rainfall and LGP of the crops should be determined by validating for the local area conditions and specific crop varieties using local observations.

- ✓ Sowing time for maize and sorghum should be performed after the end of March and planting crops before first decade of April is risky, and even short cycle rainfed crops could be exposed to water stress at any time during their life cycle, indicating the need to develop drought resistant crops/varieties.
- ✓ *Kiremt* season is more advisable to plan for the regular rainfed crop production planning in and around the study area.
- ✓ Supplement by irrigation, use of drought resistant and early maturing crop variety should be performed to minimize the risk due to persistent drought, delayed onset and early cessation of rainfall during the growing season.
- ✓ NMA as well as agriculture sectors should help farmers with the necessary climatic and agronomic information which enable them to plan cropping season, land management, and soil and water conservation activities.
- ✓ Finally, further studies focusing on the characteristics of onset and cessation of rainfall and soil-crop-climate must be carried out to find long term solution in the study area and tremendously helpful for decision making in agricultural planning, particularly rainfed crop production and related activities at a local area level.

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7. APPENDICES

Appendix Table 1. Standard meteorological decade (SMD)

Decade	Month	Date	Decade	Month	Date
1	January	1-10	19	July	1-10
2		11-20	20		11-20
3		21-31	21		21-31
4	February	1-10	22	August	1-10
5		11-20	23		11-20
6		21-29	24		21-31
7	March	1-10	25	September	1-10
8		11-20	26		11-20
9		21-31	27		21-30
10	April	1-10	28	October	1-10
11		11-20	29		11-20
12		21-30	30		21-31
13	May	1-10	31	November	1-10
14		11-20	32		11-20
15		21-31	33		21-30
16	June	1-10	34	December	1-10
17		11-20	35		11-20
18		21-30	36		21-31

Appendix Table 2. Monthly rainfall distribution of Alaba Kulito station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	5.4	40.9	117.4	0.0	250.5	62.4	21.2	98.2	29.8	71.3	11.9	6.1
1988	20.3	43.0	47.3	133.5	108.0	72.0	208.4	127.4	81.4	105.9	0.0	11.4
1989	7.1	6.3	27.9	137.3	122.8	94.3	241.7	83.1	203.3	80.1	11.3	18.2
1990	0.9	9.3	28.9	171.0	78.1	74.8	75.0	31.1	23.5	22.1	23.7	9.4
1991	31.3	72.4	86.1	57.6	87.8	98.9	74.9	125.4	56.3	32.5	0.0	42.2
1992	24.2	110.5	73.9	141.7	94.6	66.7	75.2	82.6	111.4	117.2	94.2	24.0
1993	89.5	69.2	11.7	135.2	211.9	82.4	43.8	41.5	59.4	98.9	9.7	2.9
1994	0.0	19.9	46.9	179.2	46.6	96.8	256.6	25.7	36.3	57.3	39.6	35.0
1995	0.0	46.0	75.8	116.9	88.4	19.7	84.2	45.8	65.5	65.9	0.4	41.6
1996	115.8	0.0	97.8	126.5	106.0	235.4	135.0	118.5	64.1	38.8	18.7	25.4
1997	72.9	0.0	73.9	131.8	130.5	98.8	106.1	87.8	106.6	174.0	194.9	16.2

1998	71.1	44.8	154.8	154.9	152.7	98.3	194.7	169.5	75.7	96.1	27.5	0.0
1999	107.4	37.5	79.3	153.7	56.0	100.0	61.0	110.0	68.9	49.6	93.9	122.7
2000	48.2	0.0	0.0	77.3	231.7	73.2	123.0	79.8	64.2	153.9	43.4	20.5
2001	8.5	8.0	107.0	57.7	137.6	39.8	179.7	102.5	91.2	111.8	18.0	2.8
2002	29.4	61.8	76.4	91.0	35.9	68.3	63.8	144.7	32.9	65.5	3.4	25.5
2003	141.7	10.0	108.9	120.9	150.3	58.3	73.3	63.0	188.0	45.8	9.7	83.1
2004	119.4	53.3	24.2	166.5	97.8	44.6	56.9	138.4	155.2	121.9	0.0	14.4
2005	9.7	29.3	73.8	91.2	233.7	52.8	41.3	125.0	100.3	57.8	52.4	1.2
2006	2.9	4.9	87.8	141.2	111.3	74.2	113.9	131.5	57.4	66.8	42.9	39.0
2007	0.0	20.0	0.0	105.0	32.4	170.7	99.4	160.0	60.0	153.8	129.0	170.4
2008	0.7	0.6	0.4	60.3	114.9	113.7	105.8	112.1	165.6	63.4	211.2	0.0
2009	3.0	46.9	66.0	67.7	83.2	9.4	105.5	24.1	114.1	138.4	60.7	125.2
2010	97.9	227.5	96.4	448.7	359.5	106.0	67.7	126.9	155.2	105.0	1.4	13.1
2011	14.4	11.4	47.7	40.5	77.3	176.0	161.1	194.8	120.9	37.6	45.0	39.5
2012	31.9	37.2	5.3	0.0	21.8	108.2	120.1	188.7	62.3	5.9	7.4	79.0
2013	94.9	46.3	10.4	10.5	160.9	153.1	132.7	159.9	176.6	118.8	481.2	101.0
2014	100.1	17.6	24.2	44.2	169.9	111.9	100.6	207.9	42.8	144.1	0.2	64.1
2015	0.0	17.9	0.7	110.2	46.2	56.2	86.3	118.1	67.4	8.1	32.2	80.9
2016	73.9	79.2	140.0	60.7	144.9	86.5	95.0	83.0	32.5	80.9	79.2	120.0

Appendix Table 3. Monthly rainfall distribution of Fonko station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	0.0	99.4	286.3	147.9	272.0	82.2	65.9	254.2	114.3	76.2	2.5	1.7
1988	10.8	51.9	21.5	158.3	69.2	151.2	166.0	197.7	165.5	122.9	0.0	0.0
1989	0.0	80.1	182.5	322.3	38.5	106.8	172.8	174.6	147.0	54.5	0.0	115.4
1990	0.0	124.8	123.6	125.3	119.8	37.0	110.4	131.7	181.3	79.6	2.9	0.0
1991	9.1	82.3	135.3	46.8	87.7	140.0	171.1	163.2	106.9	16.6	0.0	58.9
1992	49.5	42.9	132.3	219.4	203.0	160.4	229.1	231.2	124.0	122.8	46.3	0.0
1993	61.0	110.5	0.0	317.4	253.8	66.3	137.5	183.1	125.8	255.6	0.0	0.0
1994	0.0	0.0	84.0	89.7	134.8	125.6	157.7	122.8	148.4	0.0	7.9	0.0
1995	0.0	23.0	61.6	217.4	118.6	66.4	128.3	156.5	119.6	0.0	0.0	54.7
1996	95.4	0.0	265.4	210.0	159.5	140.4	201.0	175.4	116.8	1.4	10.1	0.0
1997	32.6	21.0	19.1	143.6	129.2	199.1	132.4	176.4	187.6	373.4	250.5	0.0
1998	0.0	117.4	234.0	87.0	201.7	73.2	135.4	174.5	141.3	178.7	45.9	0.0
1999	0.0	0.0	101.3	31.5	54.5	112.1	246.6	149.8	163.3	294.4	0.0	0.0
2000	0.0	0.0	0.0	140.3	239.1	61.7	189.4	161.2	176.7	128.6	26.4	56.8
2001	2.4	61.7	128.5	211.6	189.5	162.4	137.6	206.9	236.8	72.0	10.4	1.2
2002	94.7	35.3	127.4	83.0	116.1	174.2	134.9	200.9	188.0	91.3	0.0	80.1
2003	80.2	69.9	113.3	135.3	272.2	95.4	233.2	215.0	157.7	144.4	8.2	55.7
2004	13.6	101.4	73.1	146.5	75.8	72.9	104.5	269.0	105.4	195.2	0.0	6.0
2005	40.4	17.4	105.7	39.2	271.4	99.8	172.2	167.2	158.0	138.7	0.0	58.8

2006	18.3	241.0	111.7	139.7	157.8	241.8	141.0	47.7	48.2	10.8	10.8	9.2
2007	19.9	88.7	47.7	167.2	94.1	163.7	155.4	183.7	298.0	71.2	1.0	0.0
2008	0.0	7.8	7.8	66.9	158.8	103.0	255.8	206.7	168.6	90.2	203.9	0.0
2009	0.0	58.3	7.0	54.0	56.7	83.2	116.8	269.3	129.6	141.7	39.7	36.5
2010	55.7	205.4	139.3	85.2	46.7	55.7	136.5	189.3	222.6	128.1	50.0	61.7
2011	12.8	15.3	40.9	174.8	87.9	225.1	115.0	178.7	91.9	107.4	18.6	8.8
2012	0.0	0.0	16.2	88.5	116.4	115.8	174.7	173.6	273.5	92.6	14.5	17.0
2013	83.8	90.5	7.9	54.7	0.0	220.8	114.0	136.2	177.0	116.7	0.0	49.8
2014	121.4	133.9	102.4	212.1	42.4	26.7	48.5	152.4	189.6	157.4	0.0	16.4
2015	0.0	0.0	0.0	74.5	225.4	205.8	119.7	159.4	130.5	148.4	66.1	0.0
2016	84.5	96.7	138.1	0.6	106.1	84.9	132.5	111.9	231.1	57.2	13.1	101.2

Appendix Table 4. Monthly rainfall distribution of Hosanna station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	8.5	49.0	9.3	106.7	295.2	312.2	357.8	303.4	176.7	72.6	14.8	13.6
1988	11.5	40.0	54.9	117.8	100.9	249.5	260.2	382.2	376.9	111.1	0.3	7.4
1989	69.4	71.3	151.1	119.6	155.3	379.9	329.3	303.8	208.9	134.6	12.7	57.7
1990	5.1	28.8	76.0	66.3	188.9	221.7	467.7	485.7	65.5	2.2	29.8	7.7
1991	10.9	54.0	24.2	104.3	91.0	326.6	237.9	423.2	396.3	73.2	3.9	28.3
1992	54.0	90.1	98.4	44.6	107.8	268.3	184.6	483.3	264.8	20.1	72.0	21.9
1993	0.9	82.8	57.0	340.2	95.8	248.2	310.9	256.2	294.3	48.0	1.0	0.4
1994	0.6	15.7	182.4	62.5	34.8	174.2	284.4	287.5	249.4	21.8	0.1	6.8
1995	19.7	87.7	62.9	113.1	170.4	198.7	296.5	255.4	128.8	99.2	34.3	22.5
1996	29.1	74.7	3.5	147.0	166.9	257.2	228.4	236.3	323.4	312.1	0.0	0.0
1997	0.0	0.5	59.7	110.6	143.6	227.9	327.2	179.3	221.4	14.1	8.5	0.0
1998	4.3	16.4	18.5	143.9	148.4	113.8	182.1	149.2	273.9	42.1	8.2	4.7
1999	59.3	18.4	41.6	207.3	261.7	265.9	201.2	284.8	284.0	214.0	0.1	9.9
2000	29.9	0.0	124.8	292.5	107.0	201.9	268.2	392.3	191.8	271.5	40.7	0.1
2001	49.0	44.7	52.5	159.5	233.5	220.1	275.1	196.9	275.8	287.0	0.1	0.1
2002	21.9	4.5	73.8	69.2	142.8	217.0	268.8	280.7	242.4	208.7	0.7	4.4
2003	26.4	24.7	45.9	200.3	53.1	227.8	240.7	239.0	333.8	36.8	22.6	55.0
2004	2.9	17.5	144.1	88.6	164.0	228.6	285.3	266.9	147.0	14.3	13.4	4.4
2005	28.7	1.5	115.6	52.5	63.4	232.0	133.1	195.8	114.0	12.0	3.2	13.1
2006	5.9	4.0	12.2	182.5	20.8	170.5	165.3	213.4	179.7	8.3	13.3	16.8
2007	45.0	2.5	41.9	232.8	34.5	193.4	223.6	231.5	201.1	62.4	4.8	1.9
2008	21.1	9.3	23.1	220.7	284.3	104.5	186.3	176.6	223.9	46.3	1.8	0.0
2009	0.8	4.3	52.8	162.6	63.2	197.9	231.5	251.6	197.2	111.5	1.1	0.6
2010	9.8	17.7	30.9	106.9	154.5	289.3	165.5	141.7	313.7	42.3	2.6	0.0
2011	5.8	4.5	99.6	33.5	172.2	128.3	364.5	366.5	395.1	4.7	43.8	5.9
2012	3.7	0.1	69.2	148.9	119.3	297.5	393.1	446.0	311.1	15.1	3.6	0.6
2013	13.1	8.5	75.5	124.6	177.5	268.9	250.1	206.1	273.5	170.3	76.4	7.9

2014	5.5	4.4	137.6	38.0	281.9	235.3	245.6	288.8	215.0	7.8	28.7	6.1
2015	6.1	0.2	52.0	275.0	113.3	240.7	255.1	379.5	275.4	20.7	3.5	0.3
2016	12.3	3.1	89.4	177.8	126.9	378.2	242.7	203.1	228.9	34.2	86.3	13.0

Appendix Table 5. Decadal rainfall distribution of Alaba Kulito station

Year	1	2	3	4	5	6	7	8	9	10	11	12
1987	1.2	0.0	4.2	0.0	19.3	21.6	32.9	72.3	12.2	0.0	0.0	0.0
1988	6.5	12.7	1.1	0.7	16.7	25.6	19.2	3.0	25.1	11.9	54.5	67.1
1989	0.0	6.7	0.4	5.9	0.5	0.1	0.6	16.1	20.2	26.6	14.1	108
1990	0.1	0.1	0.0	3.8	4.3	1.5	17.6	4.1	21.4	73.9	49.9	38.3
1991	1.5	0.1	2.3	2.5	1.9	34.4	0.0	0.1	40.9	64.6	64.8	0.6
1992	10.4	13.8	12.0	34.1	32.1	47.9	11.9	7.7	55.6	24.8	13.3	97.7
1993	16.6	42.1	29.1	62.4	6.4	0.4	4.9	0.0	21.6	51.9	37.8	40.4
1994	0.0	0.0	0.0	1.5	13.0	6.8	17.5	15.7	37.8	37.2	92.6	30.2
1995	0.0	0.0	0.0	10.1	0.9	41.8	14.2	28.9	23.9	60.2	42.8	12.1
1996	14.6	50.7	1.3	0.0	0.0	0.8	59.7	30.1	27.1	57.4	37.0	20.6
1997	0.0	27.1	45.8	0.0	0.0	8.8	0.0	29.3	56.0	65.0	26.8	75.4
1998	39.9	31.2	4.0	5.6	30.1	38.4	111.4	8.0	2.1	40.6	51.7	92.2
1999	18.2	86.1	5.2	26.4	9.0	61.0	2.7	11.2	36.7	52.3	69.1	6.2
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.0	25.3	109
2001	0.0	8.5	0.0	8.0	0.0	4.5	26.8	112.2	51.2	19.4	3.5	67.0
2002	26.9	2.5	0.0	0.0	61.8	0.0	68.7	7.5	4.9	18.1	66.0	2.2
2003	2.0	42.3	0.0	0.0	0.0	62.1	0.0	38.9	71.8	1.0	53.7	84.8
2004	0.0	117	32.9	22.3	0.0	0.0	0.0	24.2	15.2	99.2	52.1	32.3
2005	0.0	9.7	29.3	0.0	0.0	7.7	9.7	45.4	0.0	0.0	92.9	144
2006	2.9	0.0	2.0	0.0	13.2	27.4	7.1	66.4	63.8	42.0	29.9	49.6
2007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	73.0	19.5	1.2
2008	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.0	27.9	5.9	27.6	20.2
2009	0.7	0.0	9.6	37.3	0.0	66.0	0.0	1.6	31.5	22.2	12.4	0.0
2010	22.5	114	56.1	70.2	104.9	2.1	30.2	20.7	52.3	254.7	258	230
2011	0.0	7.2	1.6	0.0	21.0	0.0	11.9	36.5	0.0	23.3	12.1	44.1
2012	31.9	2.6	2.7	31.9	2.6	2.7	0.0	0.0	0.0	0.0	0.0	0.0
2013	46.4	127	3.4	8.2	0.0	2.2	8.2	0.0	2.2	1.5	65.0	44.5
2014	4.5	16.6	1.7	2.0	0.0	4.0	20.2	28.8	9.0	2.4	88.2	17.9
2015	0.0	7.7	10.2	0.0	0.0	0.0	0.0	45.4	8.0	57.5	1.5	34.0
2016	61.0	2.4	12.0	64.8	177.5	75.6	179.0	26.5	38.5	10.7	29.6	36.7
	13	14	15	16	17	18	19	20	21	22	23	24
1987	50.7	75.9	123.9	47.50	3.20	13.30	4.90	2.50	12.60	3.40	53.4	41.9
1988	21.1	84.1	5.90	30.10	2.20	36.60	32.70	111.3	72.40	51.40	64.4	3.60
1989	16.4	59.2	31.29	52.91	30.20	7.47	38.51	132.0	70.49	25.45	24.9	63.5
1990	9.57	62.0	1.20	27.50	47.20	0.10	19.80	44.60	12.10	21.70	7.90	3.90

1991	3.62	1.75	48.69	25.51	50.88	102.7	116.9	147.1	46.23	40.63	53.2	117
1992	41.7	23.0	18.20	23.10	19.00	25.40	28.60	11.00	49.20	31.30	7.80	27.8
1993	68.3	95.2	39.90	78.40	2.80	4.50	19.30	18.80	1.20	15.50	15.8	10.2
1994	23.9	12.5	7.80	22.30	22.40	98.60	125.8	58.10	23.70	14.90	9.50	0.00
1995	6.30	30.1	49.90	0.00	9.60	39.70	33.30	10.80	11.40	13.50	0.80	41.6
1996	38.7	34.3	68.30	155.5	37.00	4.60	58.00	10.90	77.60	13.50	76.1	20.8
1997	18.5	38.4	26.60	7.40	82.80	10.80	43.70	10.10	41.50	74.70	1.50	28.6
1998	65.8	32.5	25.10	39.90	37.30	63.00	47.50	85.00	66.70	27.80	84.0	16.1
1999	0.00	0.00	0.00	0.00	0.00	0.00	2.10	4.00	0.00	0.00	0.00	0.00
2000	107	3.20	30.20	21.00	29.00	22.80	71.70	35.20	26.00	38.40	13.1	13.6
2001	24.3	38.3	36.00	11.60	16.60	89.70	43.00	43.60	34.90	13.80	25.2	85.8
2002	21.2	1.70	34.30	27.80	19.20	31.10	4.70	28.00	38.40	45.50	53.8	10.0
2003	7.60	55.9	12.00	29.20	19.10	25.20	22.80	25.30	18.90	18.60	25.5	124
2004	65.5	0.00	10.70	16.90	17.00	0.60	15.30	36.50	54.20	49.60	22.4	40.4
2005	38.9	48.2	7.20	32.30	13.30	10.50	12.20	18.60	64.10	35.10	25.8	10.0
2006	23.4	20.4	6.2	41.40	55.10	17.00	61.70	20.40	53.30	47.60	16.9	27.2
2007	0.00	64.8	20.30	54.00	62.80	0.00	17.70	90.60	53.20	42.50	60.1	11.0
2008	70.6	23.0	21.60	91.20	7.20	20.70	50.70	28.10	28.60	52.00	33.6	54.6
2009	68.7	14.5	8.40	1.00	1.00	33.10	1.20	70.30	7.20	10.50	20.6	60.3
2010	0.10	29.3	0.00	13.10	64.50	19.40	47.50	29.20	54.90	16.90	69.4	67.7
2011	17.6	50.9	54.30	34.20	42.40	78.80	76.10	38.00	100.4	52.40	29.3	84.3
2012	21.8	0.00	36.20	54.30	35.70	54.00	28.90	59.60	101.6	38.00	23.1	47.9
2013	58.0	13.4	60.90	78.80	0.20	53.30	16.50	105.3	47.30	63.90	48.0	16.0
2014	44.4	28.6	40.80	23.40	90.50	26.20	19.80	10.70	52.20	150.5	1.10	1.50
2015	10.0	19.4	36.00	1.50	32.60	36.60	17.10	39.80	46.00	32.30	28.9	32.9
2016	42.2	45.3	41.40	34.90	7.40	40.70	48.20	32.30	43.10	7.60	7.60	24.6
	25	26	27	28	29	30	31	32	33	34	35	36
1987	2.10	15.2	12.00	29.80	2.00	39.10	1.50	0.00	10.40	4.20	0.00	1.90
1988	29.2	4.80	47.40	37.60	51.60	16.70	0.00	0.00	0.00	10.00	1.40	0.00
1989	98.9	29.8	47.71	15.10	55.43	5.89	3.95	4.31	2.44	12.78	2.50	3.94
1990	4.10	9.00	7.10	13.10	8.40	0.00	17.88	0.00	7.40	7.78	0.00	0.20
1991	97.1	122	81.53	79.73	2.80	0.00	0.00	0.00	1.11	0.15	0.01	0.04
1992	42.5	24.4	44.90	41.30	68.00	16.80	58.30	4.50	22.10	5.60	9.50	10
1993	8.60	2.30	55.30	16.90	52.00	23.20	0.00	9.70	0.00	2.90	0.00	0.00
1994	13.2	10.4	15.40	34.30	0.00	20.30	35.50	4.10	35.00	0.00	0.00	0.00
1995	9.30	12.2	45.10	21.60	16.70	15.50	0.00	0.20	0.20	3.40	12.9	74.5
1996	23.8	31.2	31.50	8.40	0.00	0.00	0.00	18.70	0.00	9.90	15.5	0.00
1997	1.60	54.9	49.90	32.40	98.60	49.70	10.50	68.20	102.7	0.00	0.00	6.20
1998	16.8	20.1	49.60	35.30	29.10	23.76	2.80	16.60	0.00	0.00	0.00	0.00
1999	45.0	23.9	3.00	0.00	46.60	24.50	37.50	30.20	57.70	17.20	39.3	58.4
2000	17.7	18.9	67.40	73.30	5.60	27.70	36.00	7.40	0.00	5.00	15.5	0.00

2001	13.8	25.2	82.00	22.60	7.20	18.00	0.00	0.00	0.00	2.80	0.00	0.00
2002	2.50	27.4	58.00	6.00	0.00	4.90	0.00	0.00	0.00	0.00	17.0	105
2003	25.6	37.6	36.30	0.00	9.50	0.00	9.70	0.00	39.10	44.00	0.00	0.00
2004	53.2	78.3	46.70	34.90	40.30	0.00	0.00	0.00	14.40	0.00	0.00	0.00
2005	45.5	44.8	26.00	29.00	2.80	5.40	0.00	48.20	0.00	0.00	0.00	0.00
2006	20.0	10.2	29.30	31.40	6.10	42.90	0.00	11.50	0.00	27.50	0.00	0.00
2007	39.2	5.10	97.00	41.00	15.80	40.20	55.90	44.40	98.60	24.40	36.6	0.00
2008	55.3	87.4	24.90	4.70	0.00	136.9	74.30	0.00	0.00	0.00	0.00	2.30
2009	11.3	45.4	22.40	40.40	83.50	11.60	19.70	4.30	33.80	55.80	42.1	5.40
2010	43.0	21.7	54.90	29.40	0.10	0.00	0.00	1.40	11.40	0.00	1.70	10.2
2011	5.30	24.0	24.40	0.60	0.00	0.00	45.00	0.00	39.50	0.00	0.00	0.00
2012	0.00	1.50	2.70	1.70	0.00	7.30	0.10	2.50	4.80	50.50	46.6	30.3
2013	109	9.90	0.00	303.0	299.3	297.7	0.00	0.00	0.20	174.3	52.3	67.1
2014	40.6	103	16.70	24.32	0.00	0.00	0.00	0.20	64.10	0.00	0.00	0.00
2015	5.60	0.20	0.00	7.60	7.60	24.60	0.30	0.00	19.90	61.00	2.40	10.5
2016	0.30	0.00	19.90	61.00	2.30	10.60	66.30	177.5	68.50	179.0	26.5	38.5

Appendix Table 6. Decadal rainfall distribution of Fonko station

Year	1	2	3	4	5	6	7	8	9	10	11	12
1987	0.00	0.00	0.00	0.00	56.30	37.10	114.4	74.40	89.90	107.3	21.1	0.00
1988	0.20	10.6	0.30	10.10	20.00	15.50	12.40	0.00	0.50	30.50	61.3	70.4
1989	0.00	0.00	0.00	80.10	0.00	0.00	11.90	54.70	85.90	62.10	135	104
1990	0.00	0.00	4.00	42.90	43.00	34.90	66.50	1.20	57.60	35.80	29.0	60.9
1991	5.70	3.40	0.00	24.40	48.80	9.10	113.2	2.90	30.10	1.10	34.8	5.00
1992	8.31	4.73	14.88	0.33	0.00	0.10	32.97	44.69	47.39	29.14	91.1	1.56
1993	0.18	0.62	11.78	23.51	47.58	46.72	0.13	3.63	120.0	18.53	198	3.89
1994	0.00	0.21	2.51	8.12	5.14	6.39	81.69	60.10	66.69	0.03	14.9	29.1
1995	0.00	0.00	0.00	19.00	4.00	0.00	41.60	20.00	80.20	55.00	82.2	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	106.5	108.1	72.70	86.20	94.2	20.0
1997	4.80	2.70	46.10	0.00	0.00	0.00	0.00	11.40	60.30	69.40	10.9	55.4
1998	0.06	0.01	8.30	7.82	2.68	5.11	7.47	3.50	27.06	53.19	63.6	9.76
1999	6.27	0.24	0.40	0.10	3.27	4.30	35.26	17.78	36.34	3.50	23.7	15.6
2000	13.4	10.1	0.00	0.00	0.00	0.01	4.04	75.19	166.6	4.23	167	0.20
2001	38.3	0.01	14.96	26.13	3.56	34.56	1.66	16.29	8.30	58.27	84.9	135
2002	20.4	0.00	0.00	4.01	1.62	32.93	16.25	22.03	2.65	7.53	53.4	20.3
2003	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00	37.98	41.59	92.0	206
2004	2.67	0.09	7.37	10.16	0.00	32.14	75.39	23.33	12.45	0.00	85.7	48.0
2005	13.6	0.00	0.00	1.45	0.96	99.91	13.91	0.72	3.96	46.33	2.32	18.7
2006	0.54	0.38	0.00	0.26	3.76	0.00	5.40	6.77	0.00	82.08	100	13.3
2007	37.5	7.39	2.49	0.00	0.22	0.04	10.20	4.70	78.52	144.4	36.5	22.3
2008	18.7	2.19	0.14	0.00	9.30	20.18	2.79	0.10	0.00	42.94	168	173

2009	0.79	0.00	0.00	1.07	3.20	2.12	4.40	19.19	106.1	14.59	68.9	26.8
2010	0.05	3.04	23.48	0.50	0.37	0.00	13.46	17.48	7.35	99.07	0.45	14.6
2011	0.60	0.00	3.46	0.00	0.01	0.00	0.00	0.28	13.80	10.76	5.62	47.2
2012	0.29	42.4	0.42	2.23	0.01	0.00	0.02	5.02	168.7	7.74	0.27	0.03
2013	4.52	0.10	37.91	139.6	100.7	70.37	28.05	70.29	88.33	136.1	116	132
2014	0.21	5.28	0.06	4.31	0.00	47.43	53.20	0.00	5.81	3.96	28.2	32.0
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.30	12.60	41.60	32.9	131
2016	14.0	10.7	49.60	26.80	90.10	43.50	0.00	0.00	0.00	0.60	0.00	16.8
	13	14	15	16	17	18	19	20	21	22	23	24
1987	80.0	94.1	97.90	38.20	27.40	16.60	30.00	8.00	29.20	30.30	130	127
1988	24.9	30.9	4.50	61.50	20.30	69.40	99.60	17.80	50.70	84.50	63.8	47.3
1989	0.00	34.2	4.60	32.04	36.00	49.80	92.80	49.90	24.20	47.50	31.7	99.9
1990	23.3	32.2	40.20	9.80	20.40	19.50	36.10	37.40	27.80	52.80	38.4	71.8
1991	57.1	12.0	21.90	44.40	49.50	67.10	55.80	37.70	65.10	69.40	29.3	69.7
1992	21.4	28.8	83.21	66.24	40.89	51.97	109.2	154.7	69.54	56.77	51.7	158
1993	15.3	76.0	85.38	67.02	96.33	125.8	137.0	31.79	62.68	98.09	89.8	122
1994	1.93	3.74	32.98	79.53	61.72	74.68	84.08	107.0	113.4	61.97	119	112
1995	55.9	15.3	63.30	46.80	3.70	23.80	81.20	13.30	52.30	43.30	49.8	76.8
1996	93.8	30.7	74.10	69.50	19.50	15.10	61.80	53.00	104.2	30.70	56.5	67.7
1997	2.00	24.9	71.20	66.30	99.20	65.90	34.90	16.40	65.80	52.80	63.4	57.6
1998	57.6	67.5	13.91	57.41	55.88	72.42	46.75	48.73	31.31	40.10	77.3	154
1999	132	47.1	109.2	115.0	76.43	52.50	101.7	146.2	115.8	86.03	61.9	89.1
2000	47.5	48.0	58.60	33.08	83.41	117.0	48.87	115.7	149.2	63.43	181	75.9
2001	90.9	6.85	54.19	66.15	100.5	70.36	72.59	121.7	99.37	31.66	68.0	98.4
2002	9.98	95.4	72.89	70.16	73.90	56.38	88.89	113.9	144.1	41.17	90.0	47.8
2003	59.8	15.5	51.58	60.06	57.40	55.02	71.56	54.77	74.33	53.21	131	130
2004	45.4	49.7	77.38	74.03	91.94	116.6	96.51	74.10	59.44	81.60	103	106
2005	25.0	19.6	26.43	134.1	71.49	21.60	98.38	12.17	69.38	52.73	69.0	50.7
2006	7.45	0.00	17.48	76.49	76.49	48.72	41.80	51.10	71.79	76.81	74.0	87.8
2007	8.81	3.08	47.35	65.41	80.81	92.65	42.24	76.45	75.64	101.7	66.2	76.5
2008	70.0	50.2	16.03	38.99	45.56	52.86	30.81	40.51	95.79	77.22	67.3	73.8
2009	3.49	27.3	58.36	53.30	91.68	118.2	41.27	71.31	105.8	55.01	79.9	86.5
2010	28.5	71.8	81.27	121.8	125.6	87.21	19.90	45.05	49.64	70.10	26.3	112
2011	17.2	4.40	84.68	51.13	29.08	56.51	76.33	36.15	53.42	65.04	25.1	91.1
2012	56.2	8.79	9.76	7.02	45.36	41.52	104.9	48.52	87.10	84.83	19.9	73.2
2013	142	90.0	75.49	63.06	53.81	93.95	46.36	87.30	71.34	81.66	130	124
2014	92.5	150	94.88	78.07	69.13	109.9	158.4	170.5	163.4	190.5	128	210
2015	48.8	47.5	153.8	16.70	43.60	29.70	26.30	93.90	55.30	15.70	52.8	31.8
2016	89.3	47.6	37.30	0.00	0.00	0.00	128.4	17.10	16.50	61.50	207	39.6
	25	26	27	28	29	30	31	32	33	34	35	36
1987	15.1	34.2	38.40	43.90	0.00	23.90	0.00	0.00	2.50	1.70	0.00	0.00

1988	46.3	68.6	52.30	4.60	116.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	52.6	24.0	70.00	0.00	45.00	0.00	0.00	0.00	0.00	75.40	17.3	22.7
1990	20.9	61.5	100.5	39.70	0.00	0.00	2.90	0.00	0.00	0.00	0.00	0.00
1991	56.3	27.7	3.30	14.20	0.00	0.00	0.00	0.00	31.00	18.70	9.20	0.00
1992	79.9	66.0	30.80	35.10	25.93	0.63	0.04	1.26	0.11	0.46	2.11	0.24
1993	98.5	84.8	47.14	0.84	0.00	0.44	0.57	0.00	0.05	0.35	0.00	2.45
1994	71.1	76.8	21.15	0.00	0.67	0.00	0.00	0.05	4.87	0.07	1.83	1.08
1995	52.3	11.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.20	0.00	120
1996	41.6	58.9	5.10	0.00	0.00	0.00	2.30	7.80	0.00	0.00	0.00	0.00
1997	46.5	81.1	47.80	88.70	185.4	236.7	6.00	50.50	12.80	0.00	0.00	0.00
1998	68.1	65.4	0.44	37.92	3.71	4.01	3.35	0.86	0.00	4.07	0.43	14.0
1999	107	137	102.8	0.68	0.42	0.40	6.18	20.63	1.89	0.29	3.08	6.31
2000	52.1	86.0	27.69	84.00	146.8	15.23	32.84	5.56	0.02	0.00	0.09	0.60
2001	88.2	97.2	101.9	98.58	86.44	0.01	0.12	0.00	0.00	0.07	0.00	1.40
2002	117	91.6	116.9	143.6	47.45	1.39	0.01	0.00	0.64	0.32	3.47	0.00
2003	100	76.7	91.51	62.98	16.76	3.73	0.93	0.00	0.00	1.08	0.00	0.14
2004	57.4	7.76	6.51	8.90	1.42	0.00	13.38	0.00	1.94	0.30	1.89	15.3
2005	56.2	12.6	0.02	7.56	4.37	0.09	0.00	3.09	0.00	2.01	11.0	5.41
2006	68.2	38.1	7.15	1.13	0.00	3.44	9.82	0.00	16.74	0.00	0.02	0.00
2007	38.8	84.1	12.40	51.12	0.60	0.43	0.00	4.37	0.50	0.09	0.05	1.25
2008	118	34.5	34.36	11.85	0.03	0.01	1.81	0.00	0.00	0.00	0.00	0.00
2009	91.8	30.2	68.72	9.83	32.96	0.10	0.00	1.00	0.46	0.00	0.12	0.06
2010	89.9	120	40.56	1.75	0.00	2.62	0.00	0.00	0.00	0.00	0.00	0.00
2011	84.1	41.7	1.33	1.01	47.43	95.19	0.00	0.00	0.05	0.00	0.00	0.07
2012	29.6	55.8	60.72	74.20	17.17	5.37	0.00	0.00	0.19	42.49	16.6	13.5
2013	109	71.6	20.81	17.45	0.90	0.00	0.03	1.06	0.00	18.78	1.31	4.17
2014	136	81.3	7.64	0.16	0.00	19.04	2.06	7.61	6.11	0.00	0.00	0.00
2015	60.5	53.0	50.00	44.10	39.80	27.60	0.00	0.00	0.00	0.00	0.00	67.6
2016	0.00	30.8	6.30	0.00	30.80	6.30	0.60	0.00	18.80	61.50	207	51.9

Appendix Table 7. Decadal rainfall distribution of Hosanna station

Year	1	2	3	4	5	6	7	8	9	10	11	12
1987	0.66	1.64	6.21	13.73	46.00	79.22	70.45	121.0	14.03	74.99	10.4	0.33
1988	0.07	11.2	0.21	16.61	15.90	7.51	36.97	0.27	7.63	49.94	149	107
1989	0.07	56.3	2.93	60.11	1.03	0.20	10.70	130.2	104.4	97.63	59.8	133
1990	1.37	3.60	0.12	49.51	55.51	123.8	89.05	26.90	62.67	142.6	31.6	151
1991	3.67	1.90	5.30	13.55	29.62	10.79	79.72	34.81	145.1	23.80	4.44	57.4
1992	5.99	30.5	64.04	46.77	12.79	30.50	13.42	24.19	20.76	78.63	5.29	60.6
1993	0.09	0.74	0.06	15.08	22.34	45.40	46.77	1.68	25.52	112.6	16.5	167
1994	0.34	0.00	0.23	2.63	10.76	2.32	17.93	85.19	109.0	17.76	0.03	14.9
1995	19.1	0.00	0.53	41.87	42.36	3.43	15.93	18.48	24.82	74.79	88.0	140

1996	0.12	15.2	13.76	63.71	7.46	3.63	0.67	2.53	0.27	7.26	81.7	58.0
1997	0.00	0.00	0.00	0.00	0.49	0.00	12.40	7.65	39.64	0.45	50.7	59.4
1998	4.33	0.00	0.01	12.46	3.67	0.28	9.12	6.40	2.95	28.61	55.6	60.8
1999	10.5	38.8	0.00	0.00	8.59	2.65	74.52	25.78	41.34	17.24	51.8	118
2000	7.23	12.6	10.10	0.00	0.00	0.00	0.09	4.02	120.7	111.2	26.3	145
2001	0.62	48.3	0.01	15.82	28.76	0.07	34.68	1.58	16.25	13.47	65.3	80.8
2002	2.92	18.9	0.00	0.00	4.01	0.48	35.38	14.94	23.87	0.81	8.90	62.8
2003	16.2	3.75	6.44	0.01	2.50	22.15	0.15	32.12	13.53	1.17	164	114
2004	0.20	2.61	0.09	15.46	2.07	0.00	63.18	37.78	33.18	2.51	0.65	77.4
2005	15.1	13.5	0.00	0.00	1.45	0.00	102.7	12.35	0.56	14.84	36.5	1.13
2006	4.95	0.68	0.24	0.00	0.27	3.75	0.00	5.90	6.27	0.00	96.3	86.2
2007	0.00	37.5	7.41	2.44	0.00	0.05	0.04	10.29	33.47	72.16	155	2.99
2008	0.00	20.2	0.81	0.00	0.00	10.55	20.18	2.79	0.10	0.00	47.6	173
2009	0.45	0.34	0.00	0.00	2.28	1.99	3.08	3.69	53.31	71.77	20.3	63.1
2010	0.06	0.08	9.64	16.85	0.84	0.03	0.00	22.89	8.05	8.96	97.4	0.45
2011	0.07	1.44	4.27	0.20	4.29	0.00	50.86	38.77	0.00	8.86	9.51	17.4
2012	0.00	3.70	0.00	0.00	0.03	0.07	1.65	0.08	47.43	110.5	11.7	26.6
2013	10.4	1.50	1.14	6.80	0.23	1.50	1.84	10.48	63.15	8.06	87.4	113
2014	0.00	2.12	3.37	0.06	4.31	0.00	37.44	60.19	0.00	5.81	5.55	28.5
2015	0.00	6.13	0.00	0.00	0.18	0.00	2.14	0.09	74.24	286.1	40.5	23.7
2016	8.08	1.26	2.98	2.53	0.11	0.45	0.73	24.29	144.3	23.20	99.8	134
	13	14	15	16	17	18	19	20	21	22	23	24
1987	128	85.3	192.4	169.0	93.1	131.7	148.5	73.3	127.9	68.9	104	134
1988	27.2	44.2	29.5	131.8	72.2	145.5	249.3	173.2	227.7	115.8	131	134
1989	10.1	74.0	69.9	178.7	87.0	89.3	157.5	244.0	209.6	152.7	96.8	160
1990	1.5	74.5	121.8	190.9	138.5	196.9	244.4	229.1	94.9	200.9	192	197
1991	72.4	12.3	6.7	148.4	159.3	133.0	156.2	142.4	257.0	209.3	179	231
1992	42.3	21.6	43.9	125.9	158.2	184.2	168.1	152.9	253.6	163.7	177	142
1993	0.0	18.9	73.6	88.4	80.1	85.8	129.9	141.8	35.8	70.5	88.2	103
1994	29.5	1.6	3.7	42.9	71.6	67.5	74.9	78.4	139.5	83.6	74.5	123
1995	27.0	102	142.0	18.2	154.8	139.4	165.0	116.4	103.4	57.0	126	166
1996	19.4	43.8	103.7	73.2	127.9	56.1	67.7	96.6	64.0	89.4	55.3	91.7
1997	29.9	111	4.5	103.9	81.2	51.7	68.8	113.3	140.4	70.8	48.0	63.9
1998	8.5	65.4	73.5	0.6	60.5	58.2	68.5	59.0	50.2	17.6	39.3	92.0
1999	66.0	56.7	239.0	120.0	191.1	154.8	164.2	172.7	234.3	248.0	91.4	232
2000	0.2	54.1	52.7	50.7	40.5	100.7	83.9	54.9	129.4	126.7	77.8	187
2001	140	88.2	18.0	45.8	69.6	96.8	75.7	67.6	142.8	73.6	34.4	82.0
2002	16.6	19.2	120.9	57.5	77.8	64.9	59.3	91.2	129.4	127.0	37.2	111
2003	31.4	19.8	1.8	109.9	146.7	151.8	128.3	126.1	190.8	96.8	152	204
2004	55.0	40.6	68.4	67.4	68.3	93.0	116.7	103.7	64.9	60.1	85.9	120
2005	18.8	32.8	12.7	28.8	136.3	73.8	14.8	99.6	16.8	65.6	64.5	71.0

2006	13.3	7.5	0.0	30.0	71.1	69.4	49.3	45.2	77.1	50.5	71.0	97.5
2007	22.1	8.8	4.4	63.0	83.7	46.7	91.7	53.1	91.9	74.5	90.9	56.2
2008	171	76.4	36.0	20.1	38.6	45.7	48.9	31.6	105.7	40.5	67.6	68.5
2009	26.9	3.5	38.5	57.5	56.4	84.6	117.8	46.6	60.9	105.8	61.5	98.0
2010	16.2	27.0	118.2	35.8	129.7	127.3	80.9	16.0	63.7	34.7	70.5	39.7
2011	19.3	95.1	159.1	106.2	122.1	199.6	151.7	246.5	232.8	194.3	258	221
2012	81.5	3.2	14.6	70.7	72.5	154.3	252.9	185.9	254.3	152.8	202	290
2013	84.6	26.7	53.5	94.8	136.3	100.9	214.5	231.9	202.6	107.1	194	132
2014	36.2	102	151.2	86.1	75.3	82.1	99.9	157.6	183.7	158.7	194	128
2015	100	9.1	3.5	49.0	85.0	122.0	168.9	100.1	215.8	136.8	139	173
2016	157	23.4	46.3	75.2	234.6	68.4	147.6	191.2	203.9	112.2	96.7	94.2

	25	26	27	28	29	30	31	32	33	34	35	36
1987	138	134	98.76	149.8	43.90	74.96	2.73	3.51	8.10	13.63	0.00	0.01
1988	160	169	246	104.7	102.7	3.48	0.00	0.31	0.00	6.66	0.07	0.70
1989	166	168	125.2	33.50	76.52	7.97	3.97	1.32	7.26	29.64	3.72	24.3
1990	149	187	118.4	87.23	3.19	0.25	28.26	1.19	0.07	4.52	0.05	3.14
1991	204	140	130.5	58.69	0.34	5.39	0.29	0.35	5.58	18.84	3.42	3.72
1992	177	191	94.91	130.7	86.54	2.78	52.54	2.67	16.75	0.69	2.31	18.9
1993	109	114	61.07	47.16	0.82	0.00	0.70	0.31	0.00	0.17	0.23	2.11
1994	100	72.	66.57	20.99	0.00	0.67	0.00	0.00	0.28	4.68	0.71	1.15
1995	240	147	133.6	9.27	66.09	22.13	3.21	19.46	2.08	2.08	13.9	6.39
1996	71.0	119	133.0	125.3	10.16	176.5	0.00	0.00	0.00	0.00	0.00	0.01
1997	81.9	96.2	33.93	0.01	13.97	0.11	6.40	0.10	1.93	0.03	0.00	0.00
1998	142	81.0	48.78	0.57	37.76	3.89	3.77	3.88	0.33	0.00	4.08	0.86
1999	85.8	228	169.4	157.4	202.9	53.70	0.00	0.07	0.00	3.20	6.66	0.00
2000	53.9	65.1	72.77	28.55	94.57	148.4	2.27	32.84	5.56	0.02	0.05	0.04
2001	90.8	86.5	93.89	110.5	97.15	74.57	0.13	0.00	0.00	0.00	0.07	0.00
2002	28.8	136	87.08	112.8	164.5	15.31	0.17	0.01	0.00	0.64	1.61	2.18
2003	75.1	131	112.7	14.93	6.65	0.08	20.44	0.06	2.31	54.04	0.72	0.00
2004	81.0	55.6	10.26	7.18	6.08	1.07	0.00	13.38	0.00	1.94	0.30	2.20
2005	34.0	56.3	12.61	0.02	7.56	4.44	0.02	0.00	3.09	0.00	3.31	10.1
2006	62.0	67.9	40.61	4.37	1.08	0.00	13.26	0.00	0.01	16.73	0.02	0.00
2007	72.9	46.4	77.88	43.72	17.65	0.60	0.43	2.21	2.16	0.59	0.00	1.30
2008	80.0	111	32.42	43.91	2.33	0.01	0.00	1.81	0.00	0.00	0.00	0.00
2009	65.2	94.6	23.93	75.02	3.08	33.03	0.03	0.00	1.00	0.46	0.00	0.12
2010	107	92.9	109.4	35.49	1.75	0.00	2.62	0.00	0.00	0.00	0.00	0.00
2011	248	167	67.93	3.57	0.14	0.07	31.11	0.00	15.16	3.38	0.00	0.00
2012	200	127	83.47	1.42	0.00	13.69	2.83	0.28	0.47	0.38	0.21	0.03
2013	190	195	68.03	106.2	43.19	10.83	11.39	60.60	1.56	0.00	0.00	10.0
2014	198	132	83.23	2.86	0.14	0.00	20.07	1.03	9.87	3.85	0.00	0.00
2015	128	128	71.06	2.86	0.07	11.04	0.51	1.91	0.63	0.04	0.27	0.00

2016	134	164	30.04	181.9	46.32	5.98	11.86	74.30	0.16	0.00	0.00	13.0

Appendix Table 8. Estimated ETo of Alaba Kulito station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	167.6	158.1	190.9	200.1	172.1	135.4	132.7	132.8	155.6	164.9	167.9	168.4
1988	173.3	173.2	217.0	191.4	192.4	147.2	113.5	129.4	142.3	147.5	165.8	163.6
1989	161.3	160.9	188.9	165.2	187.2	144.7	119.4	135.5	132.6	153.9	166.3	128.9
1990	117.7	112.8	141.0	150.9	178.7	169.5	176.3	185.5	192.9	192.3	147.8	139.3
1991	106.0	98.5	139.5	131.1	181.7	166.2	176.0	167.7	181.2	157.4	145.3	134.5
1992	113.7	104.9	140.6	150.4	184.0	160.5	165.7	170.7	166.4	170.4	150.6	129.8
1993	117.8	107.6	144.1	157.3	192.2	180.5	186.3	182.1	187.7	170.9	161.8	155.6
1994	116.6	113.0	143.0	173.4	201.6	172.3	170.8	179.5	179.3	187.0	159.6	147.0
1995	121.4	100.3	130.1	151.0	182.9	177.0	171.5	166.6	188.3	179.7	144.1	123.2
1996	115.3	105.7	145.1	156.6	181.0	182.1	185.6	203.3	188.7	185.3	141.0	131.4
1997	101.0	97.3	139.3	171.1	195.4	178.2	185.4	175.2	180.4	184.3	148.3	147.0
1998	112.6	112.4	138.7	155.5	186.2	170.4	175.2	196.7	187.9	170.7	142.1	107.0
1999	100.7	93.6	129.9	138.5	171.9	160.9	172.6	163.3	179.4	154.8	136.6	137.3
2000	122.4	111.4	142.3	158.7	148.4	146.9	163.9	155.1	152.3	166.0	136.3	131.5
2001	113.3	100.4	127.5	135.3	152.2	170.4	164.3	124.5	141.7	134.0	132.1	148.0
2002	157.5	163.4	185.4	167.9	165.3	152.4	153.6	176.2	174.1	176.0	136.1	134.4
2003	116.1	114.5	131.9	130.4	149.3	155.5	161.7	174.1	168.8	143.8	138.5	124.1
2004	116.9	107.0	131.9	145.3	158.2	163.7	162.4	168.3	167.5	162.6	143.8	136.8
2005	134.0	122.7	138.9	139.8	155.4	164.0	167.7	159.7	163.6	176.2	143.4	130.8
2006	147.1	114.3	136.7	152.3	188.1	165.6	160.7	159.4	140.7	120.7	125.1	130.2
2007	146.3	144.4	176.4	174.6	191.9	174.1	151.9	151.9	127.5	121.5	116.9	120.8
2008	150.5	137.2	172.6	179.9	185.6	158.1	158.8	155.7	133.7	111.5	116.6	135.0
2009	143.6	146.0	169.6	171.4	173.4	166.9	175.6	180.0	161.2	148.6	109.5	115.0
2010	117.4	126.6	168.4	181.7	192.5	187.9	177.9	158.4	141.6	126.7	122.8	133.9
2011	145.5	140.2	175.5	174.4	183.8	164.6	183.1	186.9	190.2	169.0	140.4	122.7
2012	133.9	145.6	146.0	53.3	153.5	145.0	174.2	171.5	147.8	172.2	157.3	120.3
2013	129.6	155.8	178.3	177.7	193.2	179.1	178.4	161.9	139.7	126.7	115.1	135.1
2014	153.4	141.5	172.8	180.0	176.9	179.3	184.3	188.3	156.1	130.7	120.5	128.2
2015	156.1	159.8	177.7	135.5	141.3	177.1	183.4	169.4	164.8	152.3	118.3	136.0
2016	134.9	44.3	161.8	152.4	179.1	173.5	157.9	169.2	152.2	109.8	116.0	118.9

Appendix Table 9. Estimated ETo of Fonko station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	138.8	138.9	143.4	156.1	142.5	114.2	109.2	108.5	128.2	137.3	140.2	139.2
1988	141.4	138.8	172.2	153.8	165.7	129.4	86.7	104.9	117.2	126.8	136.9	135.7
1989	139.6	133.7	157.4	133.4	158.5	122.5	144.1	155.2	127.8	147.2	129.7	85.1
1990	81.6	83.1	110.2	132.5	161.3	152.3	154.3	163.3	172.4	157.4	137.5	119.2

1991	73.8	67.6	100.4	109.8	159.2	154.9	154.5	149.6	158.8	132.3	126.7	107.6
1992	80.5	74.7	105.2	128.8	161.9	142.3	141.9	142.6	138.3	152.2	131.5	102.2
1993	79.6	78.6	107.8	133.5	161.7	153.8	165.6	156.6	165.4	148.2	139.6	123.0
1994	82.3	78.7	111.8	143.8	173.1	150.6	149.4	149.8	152.9	164.3	144.0	118.1
1995	85.1	65.7	93.5	132.8	160.6	156.8	148.2	137.9	168.8	162.2	128.6	91.5
1996	77.0	76.8	104.6	121.2	148.3	162.6	169.7	179.7	169.0	157.6	128.4	103.1
1997	69.6	72.1	104.0	149.9	163.9	160.8	171.0	155.1	160.1	164.0	134.4	125.0
1998	78.2	83.5	107.6	141.6	164.7	153.5	149.4	173.8	166.9	143.3	126.6	81.0
1999	71.0	64.6	96.6	118.5	156.8	145.7	152.7	158.1	179.3	132.5	134.4	119.0
2000	79.8	79.6	116.8	137.8	131.3	139.1	147.4	152.6	147.1	163.8	119.5	122.4
2001	77.2	62.7	94.2	104.4	138.1	159.0	167.8	178.8	165.2	171.8	143.9	112.7
2002	87.4	74.9	106.6	114.5	146.6	155.5	173.7	186.0	189.1	184.7	120.5	124.2
2003	92.1	84.3	103.3	126.7	153.8	158.2	154.9	166.8	162.4	160.2	142.9	116.6
2004	93.0	77.2	114.9	146.8	170.9	161.4	155.6	182.4	159.2	168.1	152.9	132.7
2005	107.0	100.0	131.3	151.8	179.8	169.6	150.9	175.0	186.9	170.4	148.4	149.7
2006	94.4	87.7	113.8	145.2	178.4	163.2	168.0	159.9	186.0	153.5	156.4	133.6
2007	102.5	87.2	124.1	136.9	175.3	164.9	171.2	168.3	174.2	176.6	113.3	123.0
2008	92.0	84.1	102.5	137.5	176.2	156.3	175.0	176.7	153.4	152.6	148.0	129.6
2009	89.9	77.0	113.0	136.4	154.8	154.1	166.5	158.6	187.2	156.7	149.0	115.2
2010	80.9	84.7	105.8	129.0	162.6	166.6	173.5	178.3	187.7	171.5	133.0	122.7
2011	101.3	78.7	115.1	146.5	147.9	159.5	174.4	151.3	180.2	153.6	151.3	132.5
2012	103.5	89.1	125.8	128.8	156.5	152.2	128.9	145.1	137.8	131.6	102.9	102.4
2013	84.6	75.2	94.2	129.8	164.3	148.9	156.1	168.6	171.2	176.5	153.5	102.2
2014	95.5	78.4	96.0	131.6	160.0	153.4	169.3	184.2	183.6	161.4	138.3	129.3
2015	87.5	71.2	101.1	134.1	159.5	162.5	165.3	173.5	182.4	156.6	121.1	110.1
2016	84.1	72.7	101.4	117.9	151.9	148.1	155.7	159.3	155.1	150.6	132.4	119.4

Appendix Table 10. Estimated ETo of Hosanna station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	140.2	134.9	147.2	157.0	139.1	101.7	102.8	107.9	122.9	139.8	141.6	143.0
1988	149.2	137.0	185.7	157.9	163.2	119.8	85.4	100.9	110.0	126.3	146.9	140.0
1989	141.6	137.0	152.3	132.5	158.5	114.9	134.8	148.0	122.2	114.6	109.5	100.3
1990	96.1	94.6	118.5	124.8	136.2	140.8	144.6	142.9	140.6	133.0	108.9	104.7
1991	80.1	76.6	106.6	109.0	121.5	122.9	125.8	124.0	124.3	108.4	108.1	95.7
1992	85.2	88.6	119.8	116.0	129.0	126.5	129.8	133.4	125.9	120.0	111.0	97.9
1993	93.8	85.0	111.4	115.8	134.4	136.8	145.0	141.7	128.7	131.2	112.2	95.3
1994	86.8	86.7	110.6	122.4	137.5	124.3	133.4	124.6	134.0	127.0	106.9	98.0
1995	87.0	71.4	88.2	126.4	153.4	156.8	155.7	135.5	162.2	166.6	129.0	95.2
1996	80.1	70.8	102.8	116.7	144.1	158.5	169.8	181.6	170.2	160.9	127.3	113.8
1997	72.6	67.1	104.1	137.1	160.2	156.8	171.8	158.2	158.6	167.4	115.3	107.5
1998	89.1	87.3	115.7	131.9	143.6	141.4	133.6	145.5	133.1	123.0	107.0	92.8

1999	91.2	83.5	112.2	122.9	141.1	133.7	141.4	138.0	153.1	126.6	114.7	110.5
2000	89.5	91.3	120.3	125.6	118.5	119.5	133.5	138.4	125.7	135.8	108.5	108.0
2001	94.7	83.0	100.9	116.2	118.6	123.8	138.1	142.7	141.3	135.9	126.7	125.9
2002	110.6	91.9	101.7	112.7	118.1	127.8	133.5	142.6	139.8	149.0	138.9	112.0
2003	117.6	88.2	100.1	111.9	120.7	124.9	123.2	123.6	130.8	124.3	113.8	96.9
2004	96.9	86.5	115.6	124.7	132.7	133.6	129.8	134.4	126.1	131.9	113.8	109.9
2005	104.1	93.0	117.6	127.8	136.8	138.3	152.1	131.8	142.2	137.9	112.6	122.3
2006	93.4	86.6	105.1	118.8	139.0	128.5	141.9	126.8	136.7	133.3	116.1	113.1
2007	96.8	92.2	115.2	119.6	133.1	131.0	134.9	132.0	144.7	138.5	106.8	107.5
2008	96.9	92.4	118.7	133.4	137.6	126.7	122.0	140.7	132.0	133.5	112.6	113.9
2009	103.5	94.2	100.9	117.0	135.1	128.6	137.1	133.0	131.5	136.7	128.2	115.9
2010	112.4	91.9	109.7	112.9	116.5	121.2	131.3	127.5	112.1	94.5	95.3	98.7
2011	108.2	110.5	144.1	150.5	150.9	150.8	140.9	133.2	140.9	152.4	123.7	109.7
2012	101.1	102.2	140.8	130.6	130.4	120.3	136.5	129.2	136.0	122.0	104.8	115.8
2013	122.6	121.3	151.3	149.3	109.0	103.5	108.6	110.5	124.1	147.2	139.9	129.9
2014	114.1	119.4	121.0	130.1	141.2	135.9	113.7	146.8	144.3	128.6	114.3	101.0
2015	109.1	118.3	142.5	130.7	119.0	134.2	133.0	138.5	126.4	135.5	112.6	100.4
2016	108.7	104.4	146.7	153.9	154.1	144.7	130.0	128.8	117.9	120.4	124.5	124.3

Appendix Table 11. Half ETo of the growing season at Alaba Kulito station

Year	1	2	3	4	5	6	7	8	9	10	11	12
1987	27.93	27.93	27.92	26.36	26.36	26.45	31.81	31.81	31.72	33.35	33.35	33.35
1988	28.89	28.89	28.88	28.87	28.87	28.96	36.16	36.16	36.05	31.89	31.89	31.89
1989	26.88	26.88	26.87	26.81	26.81	26.90	31.49	31.49	31.40	27.54	27.54	27.54
1990	19.61	19.61	19.61	18.80	18.80	18.86	23.50	23.50	23.43	25.15	25.15	25.15
1991	17.67	17.67	17.67	16.41	16.41	16.47	23.25	23.25	23.18	21.85	21.85	21.85
1992	18.96	18.96	18.95	17.49	17.49	17.55	23.43	23.43	23.36	25.06	25.06	25.06
1993	19.63	19.63	19.62	17.93	17.93	17.99	24.02	24.02	23.95	26.22	26.22	26.22
1994	19.43	19.43	19.42	18.83	18.83	18.90	23.83	23.83	23.76	28.89	28.89	28.89
1995	20.23	20.23	20.22	16.71	16.71	16.77	21.68	21.68	21.62	25.17	25.17	25.17
1996	19.22	19.22	19.21	17.62	17.62	17.68	24.18	24.18	24.11	26.10	26.10	26.10
1997	16.83	16.83	16.83	16.21	16.21	16.27	23.21	23.21	23.14	28.51	28.51	28.51
1998	18.76	18.76	18.76	18.73	18.73	18.79	23.12	23.12	23.05	25.91	25.91	25.91
1999	16.78	16.78	16.78	15.60	15.60	15.65	21.64	21.64	21.58	23.09	23.09	23.09
2000	20.40	20.40	20.39	18.56	18.56	18.62	23.72	23.72	23.65	26.44	26.44	26.44
2001	18.88	18.88	18.87	16.73	16.73	16.78	21.25	21.25	21.18	22.56	22.56	22.56
2002	26.25	26.25	26.24	27.23	27.23	27.33	30.90	30.90	30.80	27.98	27.98	27.98
2003	19.35	19.35	19.34	19.09	19.09	19.15	21.98	21.98	21.91	21.74	21.74	21.74
2004	19.49	19.49	19.48	17.83	17.83	17.89	21.99	21.99	21.92	24.22	24.22	24.22
2005	22.34	22.34	22.33	20.44	20.44	20.51	23.15	23.15	23.08	23.30	23.30	23.30
2006	24.52	24.52	24.51	19.05	19.05	19.11	22.78	22.78	22.71	25.39	25.39	25.39

2007	24.38	24.38	24.37	24.06	24.06	24.15	29.40	29.40	29.32	29.11	29.11	29.11
2008	25.08	25.08	25.08	22.87	22.87	22.95	28.76	28.76	28.68	29.98	29.98	29.98
2009	23.93	23.93	23.92	24.33	24.33	24.41	28.27	28.27	28.18	28.57	28.57	28.57
2010	19.56	19.56	19.55	21.11	21.11	21.18	28.07	28.07	27.98	30.28	30.28	30.28
2011	24.26	24.26	24.25	23.37	23.37	23.45	29.25	29.25	29.16	29.07	29.07	29.07
2012	22.32	22.32	22.31	24.26	24.26	24.34	24.34	24.34	24.27	8.89	8.89	8.89
2013	21.60	21.60	21.59	25.97	25.97	26.05	29.71	29.71	29.62	29.61	29.61	29.61
2014	25.57	25.57	25.56	23.59	23.59	23.67	28.80	28.80	28.71	30.01	30.01	30.01
2015	26.01	26.01	26.00	26.63	26.63	26.72	29.61	29.61	29.52	22.58	22.58	22.58
2016	22.48	22.48	22.47	7.39	7.39	7.42	26.96	26.96	26.88	25.40	25.40	25.40
	13	14	15	16	17	18	19	20	21	22	23	24
1987	28.68	28.68	28.59	22.57	22.57	22.57	22.12	22.12	22.05	22.13	22.13	22.07
1988	32.07	32.07	31.97	24.54	24.54	24.54	18.92	18.92	18.86	21.57	21.57	21.51
1989	31.21	31.21	31.11	24.11	24.11	24.11	19.9	19.9	19.84	22.58	22.58	22.51
1990	29.79	29.79	29.6	28.25	28.25	28.25	29.38	29.38	29.29	30.91	30.91	30.82
1991	30.28	30.28	30.18	27.7	27.7	27.7	29.33	29.33	29.25	27.95	27.95	27.87
1992	30.67	30.67	30.57	26.74	26.74	26.74	27.62	27.62	27.53	28.45	28.45	28.37
1993	32.04	32.04	31.92	30.08	30.08	30.08	31.05	31.05	30.95	30.35	30.35	30.26
1994	33.6	33.6	33.5	28.72	28.72	28.72	28.47	28.47	28.38	29.91	29.91	29.82
1995	30.49	30.49	30.39	29.49	29.49	29.49	28.58	28.58	28.5	27.76	27.76	27.68
1996	30.17	30.17	30.07	30.35	30.35	30.35	30.94	30.94	30.85	33.88	33.88	33.78
1997	32.56	32.56	32.46	29.69	29.69	29.69	30.91	30.91	30.81	29.2	29.2	29.12
1998	31.03	31.03	30.93	28.39	28.39	28.39	29.2	29.2	29.11	32.78	32.78	32.68
1999	28.65	28.65	28.56	26.81	26.81	26.81	28.77	28.77	28.69	27.22	27.22	27.14
2000	24.74	24.74	24.66	24.49	24.49	24.49	27.31	27.31	27.23	25.85	25.85	25.77
2001	25.37	25.37	25.29	28.4	28.4	28.4	27.39	27.39	27.31	20.76	20.76	20.7
2002	27.55	27.55	27.47	25.4	25.4	25.4	25.59	25.59	25.52	29.37	29.37	29.29
2003	24.89	24.89	24.81	25.92	25.92	25.92	26.95	26.95	26.87	29.02	29.02	28.93
2004	26.37	26.37	26.29	27.28	27.28	27.28	27.07	27.07	26.99	28.05	28.05	27.96
2005	25.9	25.9	25.82	27.33	27.33	27.33	27.96	27.96	27.87	26.61	26.61	26.53
2006	31.34	31.34	31.25	27.6	27.6	27.6	26.79	26.79	26.71	26.56	26.56	26.48
2007	31.99	31.99	31.89	29.02	29.02	29.02	25.31	25.31	25.24	25.32	25.32	25.24
2008	30.94	30.94	30.84	26.34	26.34	26.34	26.47	26.47	26.39	25.94	25.94	25.86
2009	28.9	28.9	28.81	27.82	27.82	27.82	29.27	29.27	29.18	30.00	30.00	29.91
2010	32.09	32.09	31.99	31.32	31.32	31.32	29.65	29.65	29.56	26.4	26.4	26.33
2011	30.63	30.63	30.53	27.43	27.43	27.43	30.51	30.51	30.42	31.15	31.15	31.06
2012	25.58	25.58	25.5	24.16	24.16	24.16	29.03	29.03	28.95	28.59	28.59	28.5
2013	32.2	32.2	32.1	29.86	29.86	29.86	29.74	29.74	29.65	26.99	26.99	26.91
2014	29.48	29.48	29.38	29.89	29.89	29.89	30.71	30.71	30.62	31.39	31.39	31.29
2015	23.55	23.55	23.48	29.52	29.52	29.52	30.56	30.56	30.47	28.23	28.23	28.14
2016	29.85	29.85	29.76	28.92	28.92	28.92	26.31	26.31	26.23	28.21	28.21	28.12

	25	26	27	28	29	30	31	32	33	34	35	36
1987	25.94	25.94	25.94	27.49	27.49	27.48	27.98	27.98	27.98	28.06	28.06	28.05
1988	23.71	23.71	23.71	24.58	24.58	24.57	27.63	27.63	27.63	27.26	27.26	27.25
1989	22.1	22.1	22.1	25.64	25.64	25.63	27.72	27.72	27.72	21.48	21.48	21.48
1990	32.14	32.14	32.14	32.05	32.05	32.04	24.64	24.64	24.64	23.22	23.22	23.21
1991	30.2	30.2	30.2	26.24	26.24	26.23	24.22	24.22	24.22	22.41	22.41	22.41
1992	27.73	27.73	27.73	28.4	28.4	28.39	25.1	25.1	25.1	21.63	21.63	21.62
1993	31.29	31.29	31.29	28.49	28.49	28.48	26.96	26.96	26.96	25.94	25.94	25.93
1994	29.88	29.88	29.88	31.16	31.16	31.15	26.6	26.6	26.6	24.5	24.5	24.49
1995	31.38	31.38	31.38	29.95	29.95	29.94	24.01	24.01	24.01	20.54	20.54	20.53
1996	31.45	31.45	31.45	30.88	30.88	30.87	23.5	23.5	23.5	21.9	21.9	21.9
1997	30.07	30.07	30.07	30.72	30.72	30.71	24.72	24.72	24.72	24.5	24.5	24.5
1998	31.31	31.31	31.31	28.45	28.45	28.44	23.68	23.68	23.68	17.84	17.84	17.83
1999	29.9	29.9	29.9	25.8	25.8	25.79	22.77	22.77	22.77	22.89	22.89	22.88
2000	25.39	25.39	25.39	27.67	27.67	27.66	22.71	22.71	22.71	21.92	21.92	21.91
2001	23.62	23.62	23.62	22.33	22.33	22.32	22.01	22.01	22.01	24.67	24.67	24.66
2002	29.02	29.02	29.02	29.34	29.34	29.33	22.68	22.68	22.68	22.41	22.41	22.4
2003	28.14	28.14	28.14	23.96	23.96	23.95	23.08	23.08	23.08	20.68	20.68	20.67
2004	27.92	27.92	27.92	27.1	27.1	27.09	23.96	23.96	23.96	22.8	22.8	22.79
2005	27.26	27.26	27.26	29.37	29.37	29.36	23.9	23.9	23.9	21.8	21.8	21.79
2006	23.45	23.45	23.45	20.12	20.12	20.11	20.85	20.85	20.85	21.69	21.69	21.69
2007	21.25	21.25	21.25	20.25	20.25	20.24	19.48	19.48	19.48	20.14	20.14	20.13
2008	22.28	22.28	22.28	18.58	18.58	18.58	19.43	19.43	19.43	22.51	22.51	22.5
2009	26.86	26.86	26.86	24.77	24.77	24.76	18.26	18.26	18.26	19.17	19.17	19.16
2010	23.6	23.6	23.6	21.11	21.11	21.1	20.47	20.47	20.47	22.32	22.32	22.32
2011	31.7	31.7	31.7	28.16	28.16	28.15	23.4	23.4	23.4	20.45	20.45	20.45
2012	24.63	24.63	24.63	28.7	28.7	28.69	26.21	26.21	26.21	20.04	20.04	20.04
2013	23.29	23.29	23.29	21.12	21.12	21.11	19.19	19.19	19.19	22.52	22.52	22.52
2014	26.02	26.02	26.02	21.79	21.79	21.78	20.08	20.08	20.08	21.37	21.37	21.36
2015	27.47	27.47	27.47	25.39	25.39	25.38	19.72	19.72	19.72	22.67	22.67	22.66
2016	25.37	25.37	25.37	18.3	18.3	18.29	19.33	19.33	19.33	19.82	19.82	19.81

Appendix Table 12. Half ETo of the growing season at Fonko station

Year	1	2	3	4	5	6	7	8	9	10	11	12
1987	23.13	23.13	23.06	23.15	23.15	23.16	23.90	23.90	23.82	26.02	26.02	26.02
1988	23.57	23.57	23.50	23.13	23.13	23.14	28.69	28.69	28.61	25.63	25.63	25.63
1989	23.27	23.27	23.20	22.29	22.29	22.29	26.23	26.23	26.15	22.23	22.23	22.23
1990	13.61	13.61	13.56	13.86	13.86	13.86	18.36	18.36	18.31	22.08	22.08	22.08
1991	12.30	12.30	12.27	11.26	11.26	11.27	16.74	16.74	16.69	18.30	18.30	18.30
1992	13.41	13.41	13.37	12.45	12.45	12.46	17.53	17.53	17.48	21.47	21.47	21.47
1993	13.26	13.26	13.22	13.10	13.10	13.10	17.96	17.96	17.91	22.24	22.24	22.24

1994	13.72	13.72	13.68	13.12	13.12	13.12	18.63	18.63	18.57	23.97	23.97	23.97
1995	14.18	14.18	14.14	10.96	10.96	10.96	15.58	15.58	15.53	22.14	22.14	22.14
1996	12.84	12.84	12.80	12.80	12.80	12.80	17.43	17.43	17.37	20.20	20.20	20.20
1997	11.60	11.60	11.56	12.02	12.02	12.03	17.33	17.33	17.28	24.99	24.99	24.99
1998	13.03	13.03	12.99	13.92	13.92	13.93	17.94	17.94	17.88	23.60	23.60	23.60
1999	11.84	11.84	11.80	10.77	10.77	10.78	16.10	16.10	16.05	19.75	19.75	19.75
2000	13.30	13.30	13.26	13.26	13.26	13.26	19.47	19.47	19.41	22.96	22.96	22.96
2001	12.87	12.87	12.83	10.45	10.45	10.46	15.69	15.69	15.65	17.41	17.41	17.41
2002	14.57	14.57	14.52	12.48	12.48	12.48	17.76	17.76	17.71	19.08	19.08	19.08
2003	15.34	15.34	15.30	14.04	14.04	14.05	17.22	17.22	17.17	21.11	21.11	21.11
2004	15.50	15.50	15.45	12.86	12.86	12.87	19.15	19.15	19.10	24.46	24.46	24.46
2005	17.83	17.83	17.78	16.67	16.67	16.68	21.89	21.89	21.82	25.30	25.30	25.30
2006	15.73	15.73	15.68	14.62	14.62	14.62	18.96	18.96	18.90	24.19	24.19	24.19
2007	17.08	17.08	17.03	14.53	14.53	14.54	20.68	20.68	20.62	22.82	22.82	22.82
2008	15.34	15.34	15.29	14.02	14.02	14.02	17.09	17.09	17.04	22.92	22.92	22.92
2009	14.98	14.98	14.93	12.84	12.84	12.84	18.83	18.83	18.77	22.74	22.74	22.74
2010	13.49	13.49	13.45	14.12	14.12	14.13	17.63	17.63	17.58	21.50	21.50	21.50
2011	16.88	16.88	16.83	13.12	13.12	13.12	19.19	19.19	19.13	24.42	24.42	24.42
2012	17.25	17.25	17.19	14.85	14.85	14.86	20.97	20.97	20.90	21.47	21.47	21.47
2013	14.10	14.10	14.06	12.54	12.54	12.54	15.70	15.70	15.65	21.63	21.63	21.63
2014	15.92	15.92	15.88	13.07	13.07	13.07	16.01	16.01	15.96	21.93	21.93	21.93
2015	14.58	14.58	14.54	11.87	11.87	11.88	16.85	16.85	16.80	22.35	22.35	22.35
2016	14.02	14.02	13.98	12.12	12.12	12.12	16.90	16.90	16.85	19.64	19.64	19.64
	13	14	15	16	17	18	19	20	21	22	23	24
1987	23.76	23.76	23.69	19.03	19.03	19.03	18.21	18.21	18.15	18.09	18.09	18.04
1988	27.62	27.62	27.54	21.57	21.57	21.57	14.46	14.46	14.41	17.49	17.49	17.44
1989	26.42	26.42	26.34	20.41	20.41	20.41	24.02	24.02	23.95	25.87	25.87	25.80
1990	26.88	26.88	26.80	25.38	25.38	25.38	25.71	25.71	25.64	27.22	27.22	27.14
1991	26.54	26.54	26.46	25.81	25.81	25.81	25.75	25.75	25.67	24.93	24.93	24.85
1992	26.98	26.98	26.90	23.71	23.71	23.71	23.64	23.64	23.57	23.77	23.77	23.70
1993	26.95	26.95	26.87	25.64	25.64	25.64	27.60	27.60	27.51	26.10	26.10	26.02
1994	28.86	28.86	28.77	25.09	25.09	25.09	24.90	24.90	24.82	24.97	24.97	24.90
1995	26.77	26.77	26.69	26.14	26.14	26.14	24.71	24.71	24.63	22.98	22.98	22.91
1996	24.71	24.71	24.64	27.10	27.10	27.10	28.28	28.28	28.20	29.95	29.95	29.86
1997	27.31	27.31	27.23	26.79	26.79	26.79	28.49	28.49	28.41	25.84	25.84	25.77
1998	27.45	27.45	27.36	25.58	25.58	25.58	24.89	24.89	24.82	28.97	28.97	28.89
1999	26.14	26.14	26.06	24.28	24.28	24.28	25.45	25.45	25.37	26.35	26.35	26.27
2000	21.89	21.89	21.82	23.18	23.18	23.18	24.57	24.57	24.49	25.44	25.44	25.36
2001	23.01	23.01	22.94	26.49	26.49	26.49	27.97	27.97	27.88	29.80	29.80	29.71
2002	24.44	24.44	24.36	25.92	25.92	25.92	28.96	28.96	28.87	31.00	31.00	30.90
2003	25.64	25.64	25.56	26.37	26.37	26.37	25.82	25.82	25.74	27.80	27.80	27.71

2004	28.48	28.48	28.39	26.91	26.91	26.91	25.93	25.93	25.85	30.40	30.40	30.31
2005	29.97	29.97	29.88	28.26	28.26	28.26	25.15	25.15	25.07	29.17	29.17	29.08
2006	29.73	29.73	29.64	27.21	27.21	27.21	28.01	28.01	27.92	26.64	26.64	26.56
2007	29.21	29.21	29.13	27.49	27.49	27.49	28.53	28.53	28.45	28.05	28.05	27.97
2008	29.36	29.36	29.27	26.05	26.05	26.05	29.17	29.17	29.08	29.45	29.45	29.37
2009	25.81	25.81	25.73	25.68	25.68	25.68	27.74	27.74	27.66	26.43	26.43	26.35
2010	27.10	27.10	27.01	27.77	27.77	27.77	28.92	28.92	28.84	29.71	29.71	29.62
2011	24.65	24.65	24.58	26.59	26.59	26.59	29.07	29.07	28.98	25.22	25.22	25.15
2012	26.09	26.09	26.01	25.36	25.36	25.36	21.48	21.48	21.42	24.19	24.19	24.11
2013	27.38	27.38	27.29	24.81	24.81	24.81	26.02	26.02	25.95	28.10	28.10	28.02
2014	26.66	26.66	26.58	25.56	25.56	25.56	28.21	28.21	28.13	30.70	30.70	30.61
2015	26.58	26.58	26.50	27.08	27.08	27.08	27.54	27.54	27.46	28.91	28.91	28.82
2016	25.31	25.31	25.24	24.68	24.68	24.68	25.95	25.95	25.87	26.54	26.54	26.46
	25	26	27	28	29	30	31	32	33	34	35	36
1987	21.36	21.36	21.36	22.89	22.89	22.82	23.36	23.36	23.36	23.20	23.20	23.13
1988	19.54	19.54	19.54	21.13	21.13	21.06	22.82	22.82	22.82	22.61	22.61	22.54
1989	21.30	21.30	21.30	24.53	24.53	24.46	21.62	21.62	21.62	14.19	14.19	14.14
1990	28.73	28.73	28.73	26.23	26.23	26.15	22.92	22.92	22.92	19.87	19.87	19.81
1991	26.47	26.47	26.47	22.05	22.05	21.98	21.12	21.12	21.12	17.94	17.94	17.89
1992	23.05	23.05	23.05	25.37	25.37	25.29	21.91	21.91	21.91	17.03	17.03	16.98
1993	27.57	27.57	27.57	24.71	24.71	24.63	23.27	23.27	23.27	20.49	20.49	20.43
1994	25.49	25.49	25.49	27.38	27.38	27.29	24.00	24.00	24.00	19.68	19.68	19.62
1995	28.14	28.14	28.14	27.03	27.03	26.95	21.43	21.43	21.43	15.25	15.25	15.21
1996	28.16	28.16	28.16	26.26	26.26	26.18	21.40	21.40	21.40	17.19	17.19	17.13
1997	26.68	26.68	26.68	27.34	27.34	27.26	22.40	22.40	22.40	20.84	20.84	20.78
1998	27.82	27.82	27.82	23.89	23.89	23.81	21.10	21.10	21.10	13.51	13.51	13.47
1999	29.88	29.88	29.88	22.08	22.08	22.02	22.40	22.40	22.40	19.83	19.83	19.78
2000	24.52	24.52	24.52	27.30	27.30	27.22	19.91	19.91	19.91	20.40	20.40	20.34
2001	27.53	27.53	27.53	28.63	28.63	28.55	23.98	23.98	23.98	18.79	18.79	18.73
2002	31.52	31.52	31.52	30.78	30.78	30.69	20.08	20.08	20.08	20.71	20.71	20.65
2003	27.06	27.06	27.06	26.70	26.70	26.62	23.81	23.81	23.81	19.43	19.43	19.37
2004	26.54	26.54	26.54	28.02	28.02	27.93	25.48	25.48	25.48	22.11	22.11	22.04
2005	31.15	31.15	31.15	28.41	28.41	28.32	24.73	24.73	24.73	24.96	24.96	24.88
2006	31.01	31.01	31.01	25.58	25.58	25.51	26.06	26.06	26.06	22.27	22.27	22.20
2007	29.03	29.03	29.03	29.43	29.43	29.34	18.89	18.89	18.89	20.50	20.50	20.43
2008	25.57	25.57	25.57	25.44	25.44	25.36	24.67	24.67	24.67	21.60	21.60	21.53
2009	31.20	31.20	31.20	26.11	26.11	26.03	24.83	24.83	24.83	19.19	19.19	19.14
2010	31.28	31.28	31.28	28.58	28.58	28.49	22.17	22.17	22.17	20.45	20.45	20.39
2011	30.03	30.03	30.03	25.59	25.59	25.52	25.22	25.22	25.22	22.09	22.09	22.02
2012	22.96	22.96	22.96	21.93	21.93	21.87	17.15	17.15	17.15	17.07	17.07	17.02
2013	28.54	28.54	28.54	29.41	29.41	29.32	25.59	25.59	25.59	17.03	17.03	16.98

2014	30.60	30.60	30.60	26.90	26.90	26.82	23.04	23.04	23.04	21.55	21.55	21.48
2015	30.40	30.40	30.40	26.10	26.10	26.02	20.18	20.18	20.18	18.34	18.34	18.29
2016	25.85	25.85	25.85	25.11	25.11	25.03	22.07	22.07	22.07	19.90	19.90	19.84

Appendix Table 13. Half ETo of the growing season at Hosanna station

Year	1	2	3	4	5	6	7	8	9	10	11	12
1987	23.37	23.37	23.30	22.49	22.49	22.50	24.54	24.54	24.47	26.16	26.16	26.16
1988	24.86	24.86	24.78	22.84	22.84	22.84	30.95	30.95	30.85	26.32	26.32	26.32
1989	23.59	23.59	23.52	22.84	22.84	22.84	25.38	25.38	25.30	22.08	22.08	22.08
1990	16.02	16.02	15.97	15.77	15.77	15.78	19.75	19.75	19.69	20.80	20.80	20.80
1991	13.36	13.36	13.32	12.77	12.77	12.77	17.77	17.77	17.72	18.17	18.17	18.17
1992	14.20	14.20	14.15	14.77	14.77	14.78	19.97	19.97	19.91	19.33	19.33	19.33
1993	15.63	15.63	15.59	14.17	14.17	14.17	18.57	18.57	18.51	19.30	19.30	19.30
1994	14.47	14.47	14.43	14.44	14.44	14.45	18.43	18.43	18.38	20.40	20.40	20.40
1995	14.51	14.51	14.46	11.90	11.90	11.91	14.70	14.70	14.65	21.07	21.07	21.07
1996	13.35	13.35	13.31	11.80	11.80	11.80	17.14	17.14	17.09	19.45	19.45	19.45
1997	12.10	12.10	12.06	11.18	11.18	11.18	17.35	17.35	17.30	22.85	22.85	22.85
1998	14.85	14.85	14.81	14.56	14.56	14.56	19.28	19.28	19.22	21.98	21.98	21.98
1999	15.21	15.21	15.16	13.92	13.92	13.92	18.69	18.69	18.64	20.49	20.49	20.49
2000	14.91	14.91	14.87	15.22	15.22	15.23	20.04	20.04	19.98	20.94	20.94	20.94
2001	15.78	15.78	15.73	13.83	13.83	13.83	16.82	16.82	16.77	19.36	19.36	19.36
2002	18.43	18.43	18.38	15.31	15.31	15.31	16.96	16.96	16.91	18.79	18.79	18.79
2003	19.60	19.60	19.54	14.70	14.70	14.70	16.68	16.68	16.63	18.66	18.66	18.66
2004	16.16	16.16	16.11	14.42	14.42	14.43	19.26	19.26	19.21	20.79	20.79	20.79
2005	17.35	17.35	17.29	15.51	15.51	15.51	19.61	19.61	19.55	21.30	21.30	21.30
2006	15.57	15.57	15.52	14.44	14.44	14.44	17.52	17.52	17.46	19.79	19.79	19.79
2007	16.14	16.14	16.09	15.36	15.36	15.36	19.21	19.21	19.15	19.93	19.93	19.93
2008	16.16	16.16	16.11	15.40	15.40	15.41	19.78	19.78	19.72	22.24	22.24	22.24
2009	17.26	17.26	17.21	15.71	15.71	15.71	16.82	16.82	16.77	19.50	19.50	19.50
2010	18.73	18.73	18.67	15.32	15.32	15.32	18.28	18.28	18.22	18.81	18.81	18.81
2011	18.03	18.03	17.97	18.41	18.41	18.42	24.02	24.02	23.95	25.08	25.08	25.08
2012	16.86	16.86	16.81	17.03	17.03	17.04	23.46	23.46	23.39	21.77	21.77	21.77
2013	20.43	20.43	20.36	20.22	20.22	20.23	25.21	25.21	25.14	24.88	24.88	24.88
2014	19.02	19.02	18.96	19.90	19.90	19.91	20.16	20.16	20.10	21.69	21.69	21.69
2015	18.18	18.18	18.13	19.71	19.71	19.72	23.76	23.76	23.69	21.78	21.78	21.78
2016	18.12	18.12	18.07	17.40	17.40	17.41	24.45	24.45	24.37	25.64	25.64	25.64
	13	14	15	16	17	18	19	20	21	22	23	24
1987	23.19	23.19	23.12	16.94	16.94	16.94	17.13	17.13	17.08	17.98	17.98	17.92
1988	27.20	27.20	27.12	19.97	19.97	19.97	14.24	14.24	14.20	16.82	16.82	16.77
1989	26.42	26.42	26.34	19.16	19.16	19.16	22.47	22.47	22.41	24.67	24.67	24.60
1990	22.70	22.70	22.63	23.47	23.47	23.47	24.09	24.09	24.02	23.81	23.81	23.74

1991	20.25	20.25	20.19	20.48	20.48	20.48	20.96	20.96	20.90	20.66	20.66	20.60
1992	21.51	21.51	21.44	21.08	21.08	21.08	21.64	21.64	21.58	22.23	22.23	22.16
1993	22.40	22.40	22.33	22.80	22.80	22.80	24.17	24.17	24.09	23.61	23.61	23.54
1994	22.92	22.92	22.85	20.72	20.72	20.72	22.24	22.24	22.17	20.76	20.76	20.70
1995	25.56	25.56	25.49	26.14	26.14	26.14	25.96	25.96	25.88	22.59	22.59	22.52
1996	24.02	24.02	23.95	26.42	26.42	26.42	28.30	28.30	28.21	30.27	30.27	30.18
1997	26.70	26.70	26.62	26.14	26.14	26.14	28.64	28.64	28.55	26.37	26.37	26.29
1998	23.93	23.93	23.86	23.57	23.57	23.57	22.26	22.26	22.19	24.26	24.26	24.18
1999	23.51	23.51	23.44	22.28	22.28	22.28	23.56	23.56	23.49	23.01	23.01	22.94
2000	19.75	19.75	19.69	19.92	19.92	19.92	22.26	22.26	22.19	23.07	23.07	23.00
2001	19.77	19.77	19.71	20.64	20.64	20.64	23.02	23.02	22.95	23.78	23.78	23.71
2002	19.68	19.68	19.62	21.30	21.30	21.30	22.25	22.25	22.18	23.77	23.77	23.70
2003	20.11	20.11	20.05	20.82	20.82	20.82	20.53	20.53	20.47	20.60	20.60	20.53
2004	22.12	22.12	22.05	22.26	22.26	22.26	21.64	21.64	21.57	22.41	22.41	22.34
2005	22.79	22.79	22.73	23.04	23.04	23.04	25.34	25.34	25.27	21.97	21.97	21.91
2006	23.17	23.17	23.10	21.42	21.42	21.42	23.65	23.65	23.58	21.13	21.13	21.06
2007	22.19	22.19	22.12	21.83	21.83	21.83	22.49	22.49	22.42	21.99	21.99	21.93
2008	22.94	22.94	22.87	21.12	21.12	21.12	20.34	20.34	20.28	23.45	23.45	23.38
2009	22.51	22.51	22.45	21.43	21.43	21.43	22.85	22.85	22.78	22.16	22.16	22.10
2010	19.41	19.41	19.35	20.19	20.19	20.19	21.88	21.88	21.82	21.25	21.25	21.18
2011	25.14	25.14	25.07	25.13	25.13	25.13	23.48	23.48	23.41	22.21	22.21	22.14
2012	21.73	21.73	21.67	20.05	20.05	20.05	22.76	22.76	22.69	21.53	21.53	21.47
2013	18.16	18.16	18.11	17.25	17.25	17.25	18.10	18.10	18.05	18.42	18.42	18.37
2014	23.53	23.53	23.46	22.64	22.64	22.64	18.95	18.95	18.90	24.47	24.47	24.39
2015	19.84	19.84	19.78	22.36	22.36	22.36	22.16	22.16	22.10	23.08	23.08	23.01
2016	25.68	25.68	25.61	24.12	24.12	24.12	21.66	21.66	21.60	21.47	21.47	21.41
	25	26	27	28	29	30	31	32	33	34	35	36
1987	20.49	20.49	20.49	23.31	23.31	23.24	23.59	23.59	23.59	23.83	11.92	23.76
1988	18.34	18.34	18.34	21.04	21.04	20.98	24.49	24.49	24.49	23.33	11.67	23.26
1989	20.36	20.36	20.36	19.09	19.09	19.03	18.25	18.25	18.25	16.72	8.36	16.67
1990	23.43	23.43	23.43	22.16	22.16	22.09	18.14	18.14	18.14	17.45	8.72	17.39
1991	20.72	20.72	20.72	18.07	18.07	18.02	18.01	18.01	18.01	15.95	7.98	15.90
1992	20.99	20.99	20.99	20.01	20.01	19.95	18.49	18.49	18.49	16.32	8.16	16.27
1993	21.44	21.44	21.44	21.87	21.87	21.80	18.70	18.70	18.70	15.88	7.94	15.83
1994	22.33	22.33	22.33	21.16	21.16	21.10	17.82	17.82	17.82	16.33	8.17	16.29
1995	27.03	27.03	27.03	27.76	27.76	27.68	21.50	21.50	21.50	15.86	7.93	15.81
1996	28.36	28.36	28.36	26.82	26.82	26.74	21.22	21.22	21.22	18.96	9.48	18.90
1997	26.43	26.43	26.43	27.91	27.91	27.82	19.21	19.21	19.21	17.92	8.96	17.87
1998	22.19	22.19	22.19	20.50	20.50	20.44	17.83	17.83	17.83	15.47	7.73	15.42
1999	25.51	25.51	25.51	21.10	21.10	21.04	19.11	19.11	19.11	18.42	9.21	18.37
2000	20.96	20.96	20.96	22.63	22.63	22.57	18.09	18.09	18.09	18.01	9.00	17.95

2001	23.56	23.56	23.56	22.65	22.65	22.58	21.11	21.11	21.11	20.98	10.49	20.92
2002	23.29	23.29	23.29	24.83	24.83	24.75	23.15	23.15	23.15	18.67	9.34	18.62
2003	21.80	21.80	21.80	20.71	20.71	20.65	18.97	18.97	18.97	16.14	8.07	16.10
2004	21.02	21.02	21.02	21.98	21.98	21.91	18.97	18.97	18.97	18.31	9.16	18.26
2005	23.69	23.69	23.69	22.99	22.99	22.92	18.76	18.76	18.76	20.39	10.20	20.33
2006	22.78	22.78	22.78	22.22	22.22	22.16	19.35	19.35	19.35	18.85	9.43	18.79
2007	24.11	24.11	24.11	23.08	23.08	23.02	17.80	17.80	17.80	17.92	8.96	17.86
2008	22.00	22.00	22.00	22.25	22.25	22.18	18.77	18.77	18.77	18.98	9.49	18.92
2009	21.91	21.91	21.91	22.79	22.79	22.72	21.36	21.36	21.36	19.32	9.66	19.26
2010	18.68	18.68	18.68	15.75	15.75	15.70	15.89	15.89	15.89	16.44	8.22	16.39
2011	23.48	23.48	23.48	25.39	25.39	25.32	20.62	20.62	20.62	18.29	9.14	18.23
2012	22.67	22.67	22.67	20.33	20.33	20.27	17.46	17.46	17.46	19.30	9.65	19.25
2013	20.69	20.69	20.69	24.53	24.53	24.46	23.31	23.31	23.31	21.65	10.83	21.59
2014	24.06	24.06	24.06	21.43	21.43	21.37	19.04	19.04	19.04	16.84	8.42	16.79
2015	21.06	21.06	21.06	22.58	22.58	22.51	18.76	18.76	18.76	16.73	8.36	16.68
2016	19.66	19.66	19.66	20.07	20.07	20.01	20.74	20.74	20.74	20.72	10.36	20.66

Appendix Table 14. Occurrences of drought events based on 1-month time scale at Alaba Kulito station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	-0.65	0.39	0.82	-1.50	1.41	-0.38	-1.90	-0.01	-1.49	-0.10	-0.38	-0.86
1988	-0.13	0.43	0.01	0.46	0.04	-0.15	1.40	0.49	0.03	0.42	-1.28	-0.61
1989	-0.57	-0.66	-0.34	0.50	0.22	0.31	1.72	-0.30	1.92	0.05	-0.40	-0.38
1990	-0.98	-0.53	-0.32	0.89	-0.40	-0.09	-0.36	-1.52	-1.79	-1.33	-0.07	-0.69
1991	0.12	0.96	0.52	-0.70	-0.25	0.39	-0.36	0.46	-0.58	-0.96	-1.28	0.14
1992	-0.03	1.49	0.38	0.56	-0.15	-0.28	-0.36	-0.31	0.61	0.57	0.81	-0.22
1993	0.94	0.91	-0.80	0.48	1.11	0.07	-1.08	-1.26	-0.50	0.33	-0.45	-1.08
1994	-1.11	-0.15	0.01	0.98	-1.01	0.35	1.85	-1.64	-1.23	-0.36	0.21	0.01
1995	-1.11	0.49	0.40	0.24	-0.24	-1.61	-0.19	-1.15	-0.34	-0.19	-1.11	0.13
1996	1.20	-0.97	0.64	0.37	0.01	2.28	0.58	0.35	-0.38	-0.79	-0.18	-0.19
1997	0.75	-0.97	0.38	0.44	0.31	0.39	0.17	-0.20	0.52	1.19	1.50	-0.44
1998	0.73	0.47	1.13	0.71	0.55	0.38	1.27	1.09	-0.10	0.29	0.00	-1.50
1999	1.12	0.31	0.44	0.70	-2.77	-1.83	-3.02	-1.83	-0.26	-0.52	0.81	1.07
2000	0.41	-0.97	-1.50	-0.35	1.27	-0.13	0.42	-0.36	-0.37	0.99	0.26	-0.31
2001	-0.51	-0.59	1.30	-0.70	0.39	-0.99	1.11	0.07	0.23	0.50	-0.20	-1.09
2002	0.08	0.79	0.41	-0.13	-1.29	-0.24	-0.59	0.75	-1.36	-0.20	-0.77	-0.19
2003	1.43	-0.97	0.75	0.30	0.53	-0.48	-0.40	-0.73	1.73	-0.61	-0.45	0.69
2004	1.23	0.64	-0.43	0.84	-0.10	-0.85	-0.75	0.66	1.29	0.63	-1.28	-0.50
2005	-0.46	0.11	0.38	-0.13	1.28	-0.62	-1.16	0.45	0.40	-0.35	0.38	-1.26
2006	-0.81	-0.73	0.53	0.55	0.08	-0.10	0.29	0.55	-0.55	-0.18	0.25	0.09
2007	-1.11	-0.97	-1.50	0.08	-1.39	1.51	0.06	0.96	-0.48	0.99	1.09	1.45

2008	-1.00	-0.94	-1.45	-0.65	0.12	0.66	0.16	0.24	1.44	-0.24	1.59	-1.50
2009	-0.80	0.51	0.28	-0.52	-0.32	-1.80	0.16	-1.67	0.65	0.82	0.48	1.10
2010	1.03	2.65	0.62	3.06	2.15	0.52	-0.51	0.48	1.29	0.41	-0.95	-0.54
2011	-0.30	-0.45	0.02	-1.03	-0.41	1.58	0.90	1.41	0.77	-0.82	0.28	0.09
2012	0.13	0.30	-1.08	-1.50	-1.77	0.56	0.37	1.34	-0.42	-2.34	-0.55	0.64
2013	1.82	0.50	-0.85	-1.48	0.64	1.27	0.55	0.96	1.58	2.95	2.71	1.65
2014	1.05	-0.23	-0.43	-0.96	0.73	0.63	0.08	1.57	-1.00	0.88	-1.17	0.46
2015	-1.11	-0.22	-1.42	0.15	-1.02	-0.53	-0.15	0.34	-0.29	-2.12	0.09	0.67
2016	0.76	1.07	2.65	-0.64	0.47	0.15	-0.01	-0.30	-1.38	0.06	0.68	2.86

Appendix Table 15. Occurrence of drought events based on 3-, 6-month time scale and annual at Alaba Kulito station

	3-month time scale					6-month time scale			
Year	1	2	3	4	Year	1	2	Year	Annual
1987	0.81	0.31	0.05	-1.53	1987	-0.41	-0.88	1987	-0.89
1988	0.51	-0.13	0.06	1.00	1988	-0.57	0.65	1988	-0.01
1989	0.59	-0.98	0.40	1.72	1989	-1.14	1.35	1989	0.24
1990	1.30	-1.02	0.15	-1.82	1990	-1.72	-0.94	1990	-1.64
1991	1.00	0.49	-0.59	-0.30	1991	-0.34	-0.63	1991	-0.70
1992	0.40	0.61	-0.03	-0.18	1992	0.53	-0.20	1992	0.18
1993	0.57	0.36	0.96	-1.60	1993	-0.24	-0.19	1993	-0.36
1994	0.37	-0.61	0.14	0.25	1994	-0.77	0.19	1994	-0.42
1995	0.60	-0.03	-0.80	-0.94	1995	-0.56	-1.17	1995	-1.17
1996	0.89	0.64	1.22	0.24	1996	-0.16	0.91	1996	0.39
1997	1.19	0.18	0.45	0.10	1997	0.87	0.29	1997	0.72
1998	0.45	0.97	0.79	1.16	1998	0.32	1.19	1998	0.85
1999	0.59	0.71	-1.59	-2.84	1999	0.72	-2.78	1999	-0.85
2000	0.29	-0.87	0.61	-0.20	2000	-0.33	0.23	2000	-0.15
2001	0.36	0.52	-0.69	0.68	2001	0.00	0.01	2001	-0.08
2002	0.75	0.34	-1.14	-0.45	2002	-0.36	-1.06	2002	-0.96
2003	0.31	0.86	0.19	0.30	2003	0.29	0.25	2003	0.27
2004	0.33	0.54	0.02	0.51	2004	0.03	0.28	2004	0.11
2005	0.57	-0.11	0.58	-0.21	2005	-0.59	0.20	2005	-0.31
2006	0.22	-0.28	0.17	0.12	2006	-0.46	0.12	2006	-0.30
2007	1.48	-1.83	0.01	0.26	2007	0.57	0.11	2007	0.38
2008	0.63	-1.82	-0.16	0.76	2008	-0.27	0.35	2008	-0.04
2009	0.90	-0.08	-1.58	-0.43	2009	0.52	-1.29	2009	-0.40
2010	0.49	1.67	3.59	0.50	2010	0.91	2.82	2010	2.24
2011	0.46	-0.52	-0.12	1.40	2011	-0.79	0.84	2011	0.02
2012	0.78	-0.51	-2.03	0.67	2012	-1.01	-0.63	2012	-1.09
2013	3.44	0.87	0.15	1.35	2013	3.06	0.95	2013	2.95

2014	0.23	0.14	0.16	0.52	2014	0.11	0.38	2014	0.22
2015	0.47	-1.43	-0.93	-0.16	2015	-1.24	-0.74	2015	-1.28
2016	2.03	2.30	-0.13	-0.77	2016	2.72	-0.62	2016	2.00

Appendix Table 16. Occurrence of drought events based on 1-month time scale at Fonko station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	-0.25	0.69	1.75	0.39	1.55	-0.58	-2.11	1.44	-0.85	-0.20	-0.15	-0.20
1988	-0.05	-0.02	-0.82	0.49	-0.88	0.62	0.40	0.48	0.20	0.32	-0.34	-0.25
1989	-0.25	0.43	1.07	1.62	-1.48	-0.10	0.52	0.04	-0.15	-0.51	-0.34	1.73
1990	-0.25	1.01	0.58	0.17	-0.07	-1.85	-0.80	-0.90	0.47	-0.16	-0.13	-0.25
1991	-0.09	0.46	0.69	-0.92	-0.56	0.45	0.49	-0.19	-1.02	-1.22	-0.34	1.01
1992	0.74	-0.18	0.66	0.97	0.91	0.75	1.47	1.07	-0.63	0.32	0.82	-0.25
1993	0.93	0.83	-1.28	1.59	1.39	-0.95	-0.17	0.21	-0.59	1.34	-0.34	-0.25
1994	-0.25	-0.84	0.16	-0.24	0.13	0.23	0.24	-1.12	-0.12	-1.50	0.06	-0.25
1995	-0.25	-0.55	-0.12	0.96	-0.09	-0.95	-0.38	-0.33	-0.73	-1.50	-0.34	0.94
1996	1.44	-0.84	1.62	0.90	0.44	0.46	1.02	0.06	-0.79	-1.49	0.12	-0.25
1997	0.42	-0.59	-0.87	0.35	0.06	1.25	-0.28	0.08	0.58	2.00	2.55	-0.25
1998	-0.25	0.92	1.43	-0.27	0.90	-0.79	-0.22	0.04	-0.26	0.81	0.81	-0.25
1999	-0.25	-0.84	0.36	-1.29	-1.17	0.00	1.73	-0.48	0.16	1.58	-0.34	-0.25
2000	-0.25	-0.84	-1.28	0.32	1.26	-1.07	0.82	-0.23	0.40	0.38	0.50	0.98
2001	-0.22	0.14	0.62	0.91	0.77	0.78	-0.17	0.65	1.34	-0.26	0.13	-0.22
2002	1.43	-0.32	0.61	-0.32	-0.12	0.93	-0.23	0.54	0.59	-0.02	-0.34	1.31
2003	1.23	0.27	0.48	0.27	1.55	-0.31	1.53	0.79	0.05	0.52	0.07	0.96
2004	0.01	0.72	0.03	0.38	-0.76	-0.79	-0.95	1.67	-1.06	0.93	-0.34	-0.07
2005	0.57	-0.65	0.40	-1.09	1.54	-0.23	0.51	-0.11	0.06	0.47	-0.34	1.01
2006	0.11	2.12	0.46	0.32	0.42	1.73	-0.10	-3.69	-2.87	-1.34	0.14	0.02
2007	0.15	0.55	-0.33	0.56	-0.45	0.79	0.19	0.22	2.15	-0.27	-0.24	-0.25
2008	-0.25	-0.79	-1.13	-0.56	0.43	-0.16	1.86	0.65	0.25	-0.03	2.25	-0.25
2009	-0.25	0.09	-1.15	-0.78	-1.12	-0.56	-0.64	1.67	-0.51	0.50	0.72	0.63
2010	0.84	1.82	0.72	-0.30	-1.32	-1.24	-0.20	0.33	1.13	0.37	0.87	1.05
2011	-0.01	-0.68	-0.44	0.63	-0.55	1.55	-0.69	0.12	-1.41	0.16	0.34	0.01
2012	-0.25	-0.84	-0.93	-0.25	-0.12	0.06	0.56	0.02	1.84	0.00	0.24	0.22
2013	1.28	0.57	-1.13	-0.77	-1.83	1.50	-0.71	-0.79	0.40	0.26	-0.34	0.86
2014	1.76	1.11	0.37	0.92	-1.41	-2.29	-2.80	-0.42	0.61	0.63	-0.34	0.20
2015	-0.25	-0.84	-1.28	-0.45	1.13	1.33	-0.57	-0.27	-0.49	0.56	1.08	-0.25
2016	1.29	0.66	0.71	-3.70	-0.27	-0.52	-0.28	-1.41	1.26	-0.47	0.21	1.57

Appendix Table 17. Occurrence of drought events based on 3-, 6-month time scale and annual at Fonko station

	3-month time scale					6-month time scale			
Year	1	2	3	4	Year	1	2	Year	Annual
1987	-0.66	1.30	0.89	-0.56	1987	0.78	0.44	1987	0.85
1988	-0.17	-0.68	0.01	0.49	1988	-1.02	0.24	1988	-0.61
1989	0.25	0.67	0.66	0.12	1989	0.59	0.60	1989	0.82
1990	-0.63	0.59	-0.83	-0.69	1990	-0.04	-1.26	1990	-1.05
1991	-0.73	0.46	-0.90	-0.48	1991	-0.24	-1.18	1991	-1.16
1992	0.24	0.45	1.40	1.04	1992	0.36	1.87	1992	1.58
1993	0.84	0.08	1.71	-0.42	1993	0.56	1.38	1993	1.35
1994	-2.57	-0.68	-0.22	-0.63	1994	-2.43	-0.69	1994	-2.07
1995	-1.05	-0.67	0.19	-0.93	1995	-1.75	-0.48	1995	-1.59
1996	-2.32	1.18	0.94	0.10	1996	0.23	0.87	1996	0.72
1997	2.50	-0.80	0.69	0.14	1997	1.87	0.65	1997	2.03
1998	0.64	1.14	-0.12	-0.37	1998	1.33	-0.43	1998	0.79
1999	1.07	-0.51	-1.73	0.80	1999	0.37	-0.85	1999	-0.40
2000	0.56	-1.50	0.48	0.47	2000	-0.98	0.65	2000	-0.26
2001	-0.62	0.23	1.28	1.01	2001	-0.44	1.74	2001	0.94
2002	0.26	0.64	-0.03	0.43	2002	0.57	0.17	2002	0.48
2003	0.53	0.68	0.90	1.25	2003	0.81	1.53	2003	1.66
2004	0.48	0.20	-0.70	-0.05	2004	0.34	-0.72	2004	-0.35
2005	0.46	0.03	0.25	0.15	2005	0.16	0.24	2005	0.20
2006	-1.57	1.23	1.13	-3.40	2006	0.41	-0.71	2006	-0.27
2007	-0.77	-0.03	0.36	1.54	2007	-0.83	1.24	2007	0.31
2008	1.07	-1.44	-0.40	1.48	2008	-0.19	0.59	2008	0.20
2009	0.60	-0.89	-1.79	0.34	2009	-0.38	-1.23	2009	-1.31
2010	0.74	1.36	-1.86	0.68	2010	1.63	-1.02	2010	0.73
2011	-0.06	-0.84	0.80	-1.16	2011	-1.05	0.00	2011	-0.82
2012	-0.16	-1.43	-0.47	1.40	2012	-1.74	0.48	2012	-0.79
2013	0.22	0.16	-0.89	-0.65	2013	0.08	-1.29	2013	-0.97
2014	0.28	1.17	-0.83	-1.10	2014	1.12	-1.54	2014	-0.14
2015	0.58	-1.50	0.92	-0.86	2015	-0.95	0.29	2015	-0.53
2016	0.26	0.98	-1.81	-0.09	2016	0.91	-1.58	2016	-0.38

Appendix Table 18. Occurrence of drought events based on 1-month time scale at Hosanna station

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.

1987	-0.31	1.75	1.33	-0.66	1.91	1.07	-0.04	-0.20	0.40	1.23	0.36	0.67
1988	-0.10	0.53	-0.41	1.15	-0.46	0.60	1.38	0.33	1.60	0.93	-1.15	0.28
1989	1.75	0.99	1.63	1.16	0.17	0.84	1.25	0.46	1.23	0.46	0.26	2.04
1990	-0.63	2.30	1.06	1.44	0.49	1.79	1.00	1.41	0.98	0.21	0.85	0.30
1991	-0.14	0.76	2.10	-0.69	-0.60	1.17	0.87	1.58	1.16	-0.07	-0.34	1.27
1992	2.32	1.21	0.25	-0.22	-0.37	1.45	1.07	0.90	0.97	0.97	1.70	1.04
1993	-1.37	1.13	-0.37	1.29	-0.53	-0.29	-0.32	-0.55	-0.22	-0.39	-0.83	-0.83
1994	-1.48	-0.04	1.11	-1.35	-1.72	-1.11	-0.50	-0.31	-0.61	-0.89	-1.48	0.23
1995	0.33	1.18	-0.27	1.12	1.13	0.18	0.18	0.16	1.34	0.18	0.97	1.06
1996	0.70	1.04	-2.49	-0.20	0.29	-0.20	-0.90	-0.72	0.01	1.40	-1.83	-1.36
1997	-1.83	-1.25	-0.32	-0.61	0.05	-0.49	-0.22	-1.25	-0.88	-1.13	0.03	-1.27
1998	-0.72	-0.02	-1.39	-0.23	0.10	-1.99	-1.30	-1.58	-0.39	-0.48	0.01	0.04
1999	1.53	0.04	0.74	0.36	1.72	1.43	1.14	1.40	1.09	1.79	-1.43	0.45
2000	0.73	-1.83	0.56	0.99	-0.38	-0.78	-0.61	0.39	-1.19	1.22	1.12	-1.09
2001	1.29	0.61	-0.46	-0.07	0.86	-0.57	-0.56	-1.08	-0.38	1.29	-1.33	-1.16
2002	0.43	-0.61	-0.09	-1.23	0.04	-0.61	-0.60	-0.36	-0.68	1.38	-0.94	0.01
2003	0.61	0.21	-0.59	1.04	-1.26	1.18	0.41	0.66	0.09	-0.57	0.64	1.98
2004	-0.92	0.01	0.76	-0.92	0.26	-0.48	-0.49	-0.47	-1.73	-1.12	0.29	0.01
2005	0.69	-0.98	0.46	-1.56	-1.05	-0.45	-1.80	-1.09	-2.21	-1.21	-0.42	0.64
2006	-0.54	-0.65	-1.70	0.15	-2.21	-1.15	-1.46	-0.92	-1.32	-1.39	0.29	0.82
2007	1.18	-0.82	-0.68	0.56	-1.73	-0.87	-0.94	-0.76	-1.09	-0.20	-0.25	-0.36
2008	0.39	-0.30	-1.21	0.47	1.23	-2.15	-1.26	-1.28	-0.85	-0.41	-0.64	-1.50
2009	-1.40	-0.63	-0.45	-0.04	-1.06	-0.82	-0.88	-0.59	-1.13	0.28	-0.81	-0.74
2010	-0.22	0.02	-0.96	-0.66	0.16	0.10	-1.46	-1.67	-0.07	-0.47	-0.50	-1.50
2011	-0.55	-0.60	0.27	-2.04	1.14	1.18	1.39	1.77	1.15	-1.65	1.19	0.16
2012	-0.80	-1.53	-0.16	-0.18	-0.22	0.17	1.50	1.68	0.63	-1.09	-0.38	-0.72
2013	-0.01	-0.34	-0.06	0.50	0.39	0.75	1.34	0.47	1.02	0.69	1.77	0.31
2014	-0.58	-0.62	0.70	-1.91	1.21	-0.41	0.43	0.93	0.66	-1.42	0.83	0.17
2015	-0.52	-1.44	-0.47	1.49	-0.30	-0.36	0.48	0.88	0.39	-0.92	-0.39	-0.89
2016	-0.05	-0.74	1.17	0.89	0.81	0.82	0.89	-0.20	0.05	1.04	1.92	0.63

Appendix Table 19. Occurrence of drought events based on 3-, 6-month time scale and annual at Hosanna station

	3-month time scale					6-month time scale			
Year	1	2	3	4	Year	1	2	Year	Annual
1987	1.19	1.71	1.29	0.02	1987	1.58	0.48	1987	0.86
1988	0.76	-0.31	0.69	1.20	1988	0.32	1.10	1988	0.97
1989	0.67	1.85	1.05	1.06	1989	1.36	1.11	1989	1.28
1990	0.22	1.94	1.88	1.20	1990	1.21	1.50	1990	1.54
1991	-0.07	1.83	0.02	1.27	1991	1.01	0.95	1991	1.04
1992	1.25	1.25	0.48	1.04	1992	1.38	0.92	1992	1.13

1993	-0.76	0.08	0.32	-0.42	1993	-0.43	-0.19	1993	-0.30
1994	-1.17	0.60	-2.23	-0.53	1994	-0.20	-1.10	1994	-1.00
1995	0.35	0.36	1.16	0.56	1995	0.33	0.79	1995	0.71
1996	1.25	-0.30	-0.24	-0.62	1996	0.73	-0.54	1996	-0.24
1997	-1.34	-1.00	-0.73	-0.80	1997	-1.39	-0.84	1997	-1.05
1998	-0.67	-1.45	-1.21	-1.19	1998	-1.25	-1.29	1998	-1.42
1999	1.72	0.76	1.73	1.29	1999	1.50	1.51	1999	1.64
2000	1.25	0.21	-0.08	-0.44	2000	0.91	-0.36	2000	-0.03
2001	1.13	0.13	-0.02	-0.74	2001	0.78	-0.54	2001	-0.22
2002	1.25	-0.39	-1.06	-0.61	2002	0.71	-0.82	2002	-0.46
2003	0.01	-0.43	0.75	0.42	2003	-0.29	0.54	2003	0.36
2004	-1.09	0.31	-0.74	-0.88	2004	-0.39	-0.91	2004	-0.90
2005	-1.18	0.13	-1.61	-1.81	2005	-0.55	-1.87	2005	-1.73
2006	-0.96	-1.99	-1.43	-1.35	2006	-1.70	-1.49	2006	-1.66
2007	-0.47	-0.53	-0.86	-1.02	2007	-0.66	-1.05	2007	-1.08
2008	-0.78	-1.13	-0.04	-1.25	2008	-1.17	-0.87	2008	-1.04
2009	0.00	-1.04	-1.09	-0.94	2009	-0.57	-1.08	2009	-1.08
2010	-0.83	-1.03	-0.35	-1.14	2010	-1.15	-0.93	2010	-1.08
2011	-0.68	-0.27	0.54	1.55	2011	-0.62	1.33	2011	0.98
2012	-1.44	-0.78	-0.27	1.43	2012	-1.28	1.00	2012	0.61
2013	0.96	-0.43	0.70	1.04	2013	0.44	0.98	2013	0.90
2014	-0.87	0.14	-0.32	0.70	2014	-0.43	0.40	2014	0.21
2015	-1.28	-1.04	0.52	0.62	2015	-1.39	0.61	2015	0.24
2016	1.34	0.65	1.16	0.33	2016	1.17	0.64	2016	0.84

Appendix Table 20. Time series of length of growing periods at Alaba Kulito for long rainy season (Kiremt)

Year	Onset (decade)	Cessation (decade)	Average daily ETo	100mm evapotranspired (days)	LGP (days)
1987	16	27	5.3	19.0	139
1988	16	27	5.3	19.0	139
1989	16	26	5.0	20.0	130
1990	17	27	5.2	19.0	129
1991	16	26	4.9	20.0	130
1992	18	27	4.9	20.0	120
1993	16	27	5.3	19.0	139
1994	18	27	5.3	19.0	119

1995	19	27	5.0	20.0	110
1996	16	27	5.2	19.0	139
1997	17	28	5.2	19.0	139
1998	16	27	5.1	20.0	140
1999	18	27	4.8	21.0	121
2000	17	27	4.7	21.0	131
2001	18	27	4.5	22.0	122
2002	16	27	5.3	19.0	139
2003	16	29	4.7	21.0	161
2004	17	26	4.8	21.0	121
2005	16	27	4.9	20.0	140
2006	18	27	4.8	21.0	121
2007	16	27	4.9	20.0	140
2008	16	26	4.9	20.0	130
2009	18	27	5.1	18.0	118
2010	17	27	5.0	20.0	130
2011	17	28	5.4	18.0	138
2012	16	27	4.7	21.0	141
2013	16	28	5.1	19.0	149
2014	17	29	5.2	19.0	149
2015	17	27	5.1	20.0	130
2016	16	27	4.6	22.0	142
Mean	16	26			133
SD	0.9	0.7			11

Appendix Table 21. Time series of length of growing periods at Fonko for long rainy season (Kiremt)

Year	Onset (decade)	Cessation (decade)	Average daily ETo	100mm evapotranspired (days)	LGP (days)
1987	17	29	4.4	23.0	153
1988	16	26	4.4	23.0	133
1989	17	29	4.5	22.0	152

1990	19	27	4.4	22.0	112
1991	17	28	4.1	24.0	144
1992	16	29	4.1	24.0	164
1993	17	29	4.4	22.0	152
1994	16	29	4.4	22.0	162
1995	16	28	4.2	24.0	154
1996	16	28	4.4	22.0	152
1997	16	27	4.5	22.0	142
1998	16	29	4.3	23.0	163
1999	16	26	4.2	24.0	134
2000	17	26	4.2	24.0	124
2001	16	27	4.3	23.0	143
2002	16	28	4.5	22.0	152
2003	16	27	4.4	22.0	142
2004	16	28	4.7	21.0	151
2005	16	27	5.0	20.0	140
2006	16	29	4.8	21.0	161
2007	16	27	4.7	21.0	141
2008	18	29	4.6	21.0	141
2009	17	26	4.5	22.0	122
2010	16	29	4.6	21.0	161
2011	17	28	4.6	21.0	141
2012	17	26	4.1	24.0	124
2013	17	29	4.4	22.0	152
2014	16	29	4.6	21.0	161
2015	16	29	4.4	22.0	162
2016	18	28	4.2	23.0	133
Mean	17	27			145
SD	0.77	1.12			14

Appendix Table 22. Time series of length of growing periods at Hosanna for long rainy season (Kiremt)

Year	Onset (decade)	Cessation (decade)	Average daily ETo	100mm evapotranspired (days)	LGP (days)
1987	16	33	4.31	23	203
1988	16	32	4.43	22	192
1989	16	32	4.28	23	193
1990	16	31	4.06	25	185
1991	16	31	3.56	28	188
1992	16	33	3.78	26	206
1993	16	30	3.91	25	175
1994	17	30	3.80	26	166
1995	17	32	4.17	24	184
1996	17	33	4.36	23	193
1997	16	29	4.31	23	163
1998	17	30	3.95	25	165
1999	16	33	4.01	25	205
2000	16	34	3.87	26	216
2001	16	32	3.96	25	195
2002	16	32	4.04	25	195
2003	16	30	3.76	27	177
2004	16	29	3.92	25	165
2005	17	29	4.14	24	154
2006	17	29	3.93	25	155
2007	16	31	3.97	25	185
2008	18	28	3.99	25	135
2009	17	31	3.99	25	175
2010	17	30	3.62	27	167
2011	16	30	4.41	22	172
2012	16	30	4.02	25	175
2013	16	31	4.15	24	184

2014	16	30	4.13	24	174
2015	17	30	4.10	24	164
2016	16	32	4.26	23	193
Mean	17	29			180
SD	0.7	1.5			18

Appendix Table 23. Onset, cessation and length of growing periods of maize crop at Alaba Kulito station

Year	Onset	Cessation	LGP (days)
1987	93	214	121
1988	92	214	122
1989	92	214	122
1990	95	215	120
1991	97	214	117
1992	94	211	117
1993	99	216	117
1994	100	211	111
1995	92	214	122
1996	92	213	121
1997	92	218	126
1998	93	218	125
1999	92	214	122
2000	103	214	111
2001	92	220	128
2002	92	214	122
2003	92	214	122
2004	94	217	123
2005	92	221	129

2006	92	215	123
2007	92	214	122
2008	95	214	119
2009	100	215	115
2010	92	222	130
2011	96	214	118
2012	92	219	127
2013	92	213	121
2014	93	214	121
2015	92	215	123
2016	101	214	113
Mean	93	215	122
SD	3.25	2.6	4.7

Appendix Table 24. Onset, cessation and length of growing periods of maize crop at Fonko station

Year	Onset	Cessation	LGP (days)
1987	127	225	98
1988	103	225	122
1989	94	225	131
1990	111	225	114
1991	111	230	119
1992	92	228	136
1993	109	225	116
1994	102	225	123
1995	125	230	105
1996	98	228	130
1997	102	225	123
1998	99	232	133
1999	92	225	133

2000	103	225	122
2001	93	228	135
2002	108	225	117
2003	100	229	129
2004	104	225	121
2005	95	225	130
2006	96	230	134
2007	93	225	132
2008	99	230	131
2009	105	225	120
2010	108	225	117
2011	117	225	108
2012	127	233	106
2013	93	225	132
2014	115	235	120
2015	99	225	126
2016	127	225	98
Mean	105	226	122
SD	11	3	11

Appendix Table 25. Onset, cessation and length of growing periods of maize crop at Hosanna station

Year	Onset	Cessation	LGP (days)
1987	126	225	99
1988	98	225	127
1989	96	226	130
1990	92	225	133
1991	114	230	116
1992	93	225	132
1993	92	225	133
1994	101	225	124
1995	97	230	133

1996	104	228	124
1997	108	225	117
1998	99	232	133
1999	109	225	116
2000	92	225	133
2001	102	225	123
2002	115	225	110
2003	102	229	127
2004	113	225	112
2005	114	228	114
2006	105	225	120
2007	95	225	130
2008	108	230	122
2009	92	225	133
2010	117	225	108
2011	116	225	109
2012	92	233	141
2013	107	225	118
2014	124	235	111
2015	92	225	133
2016	108	225	117
Mean	104	227	123
SD	10	2.85	10

Appendix Table 26. Onset, cessation and length of growing periods of sorghum crop at Alaba Kulito station

Year	Onset	Cessation	LGP (days)
1987	130	245	115
1988	112	242	130
1989	113	245	132
1990	119	245	126
1991	119	245	126

1992	115	245	130
1993	116	245	129
1994	112	247	135
1995	111	242	131
1996	126	245	119
1997	112	245	133
1998	112	242	130
1999	113	245	132
2000	113	245	132
2001	121	248	127
2002	115	245	130
2003	114	245	131
2004	110	245	135
2005	113	243	130
2006	118	245	127
2007	119	245	126
2008	122	245	123
2009	110	243	133
2010	115	241	126
2011	122	245	123
2012	111	242	131
2013	116	245	129
2014	126	245	119
2015	119	238	119
2016	114	245	131
Mean	112	244	128
SD	5	2	5

Appendix Table 27. Onset, cessation and length of growing periods of sorghum crop at Fonko station

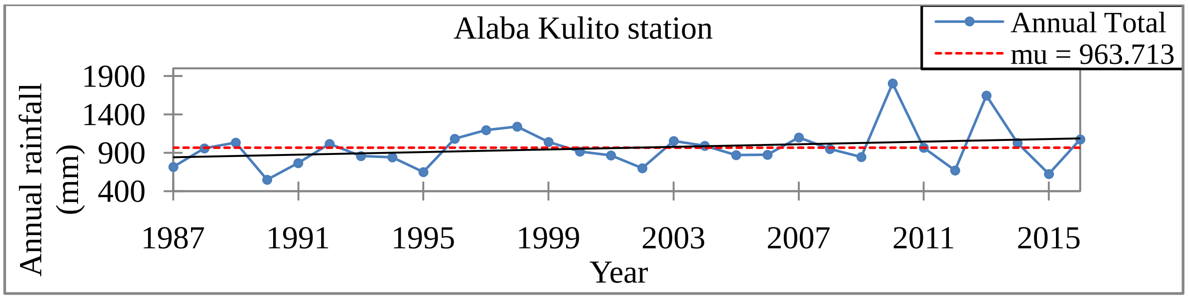
Year	Onset	Cessation	LGP (days)
1987	127	255	128

1988	104	248	144
1989	107	255	148
1990	111	255	144
1991	102	255	153
1992	119	260	141
1993	109	255	146
1994	102	255	153
1995	112	255	143
1996	102	255	153
1997	102	249	147
1998	102	255	153
1999	112	255	143
2000	103	255	152
2001	103	246	143
2002	103	255	152
2003	102	255	153
2004	104	255	151
2005	105	255	150
2006	104	242	138
2007	102	255	153
2008	102	255	153
2009	105	255	150
2010	108	255	147
2011	104	245	141
2012	111	255	144
2013	102	255	153
2014	109	245	136
2015	102	255	153
2016	117	255	138
Mean	106	253	146
SD	6	4	6.5

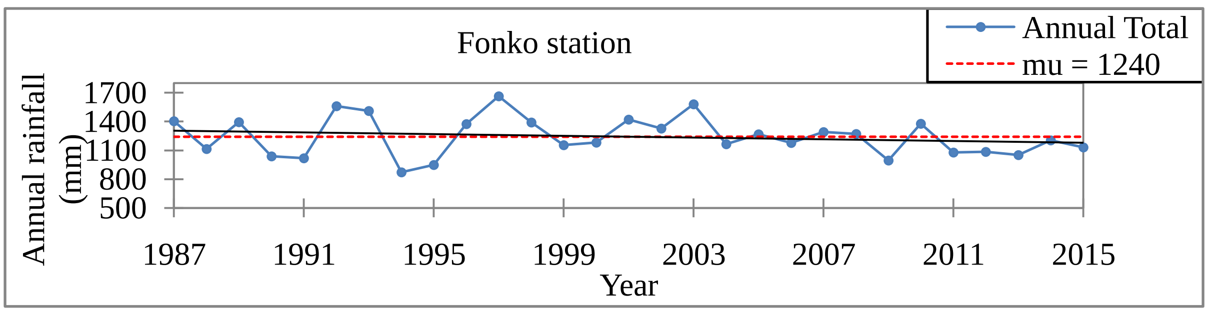
Appendix Table 28. Onset, cessation and length of growing periods of sorghum crop at Hosanna station

Year	Onset	Cessation	LGP (days)
1987	126	260	134
1988	102	255	153
1989	102	255	153
1990	109	255	146
1991	114	249	135
1992	118	255	137
1993	108	255	147
1994	102	255	153
1995	107	248	141
1996	104	255	151
1997	109	255	146
1998	108	255	147
1999	109	256	147
2000	109	255	146
2001	102	256	154
2002	106	257	151
2003	102	255	153
2004	113	247	134
2005	104	255	151
2006	103	246	143
2007	106	255	149
2008	109	247	138
2009	104	255	151
2010	107	255	148
2011	106	258	152
2012	109	255	146
2013	107	257	150
2014	108	249	141

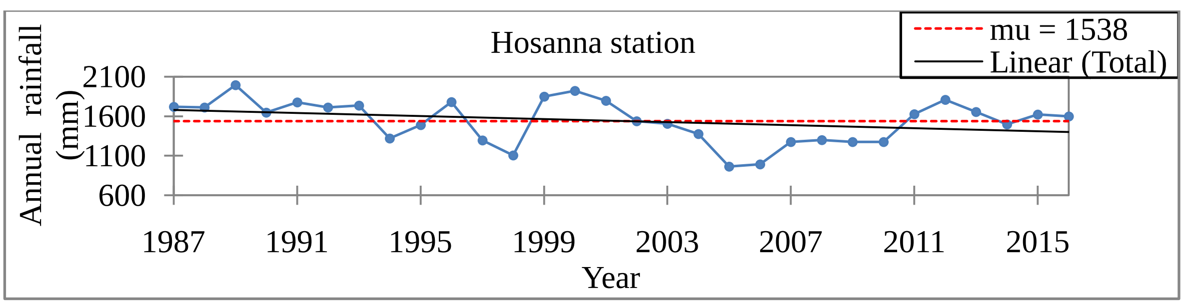
2015	102	255	153
2016	108	255	147
Mean	107	254	146
SD	5	3.5	6



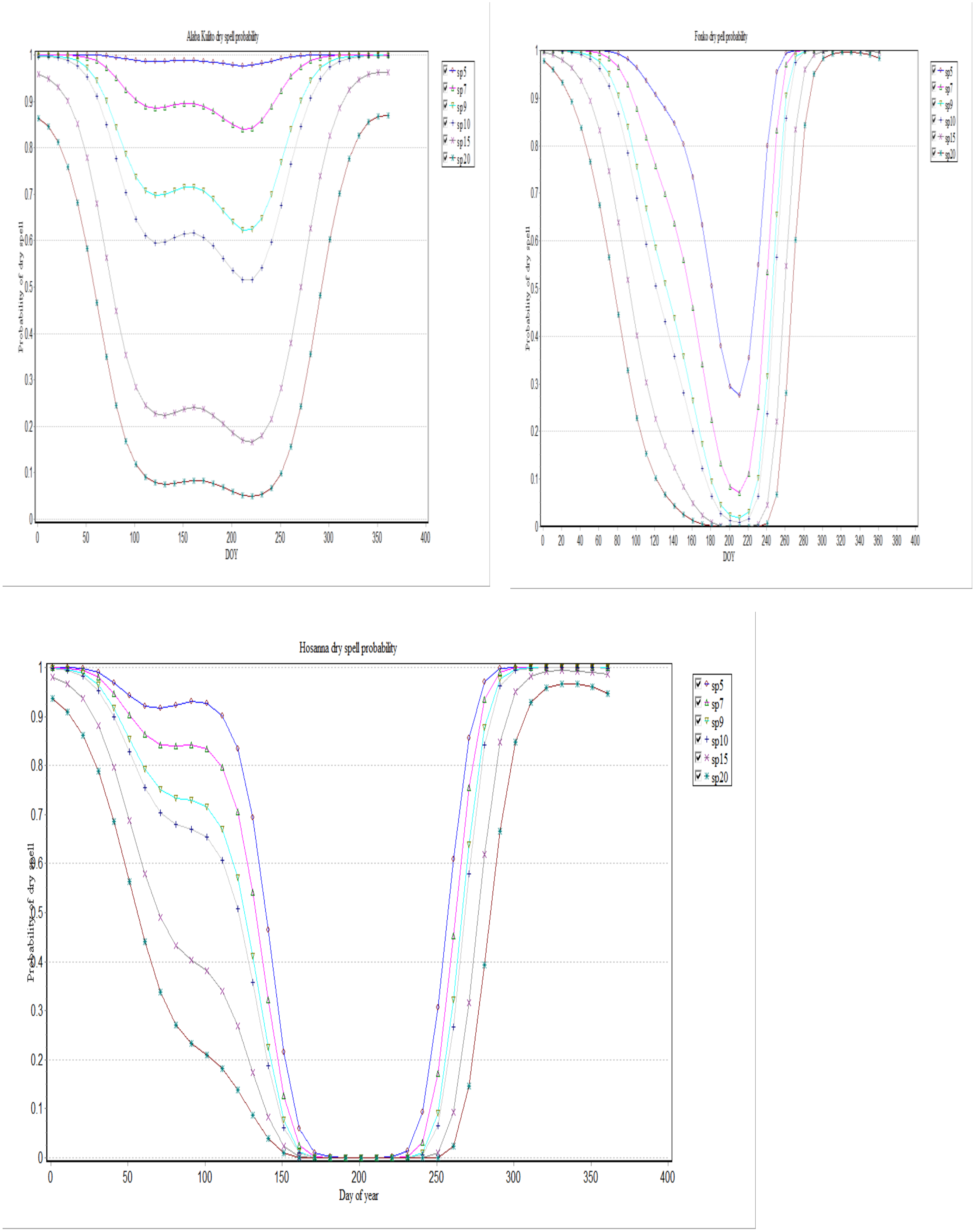
Appendix Figure 1. Homogeneity test for Alaba Kulito station



Appendix Figure 2. Homogeneity test for Fonko station



Appendix Figure 3. Homogeneity test for Hosanna station



Appendix Figure 4. The Probability of dry spell lengths of the selected stations