Addis Ababa University

School of Graduate Studies

Addis Ababa Institute of Technology

Understanding Metrological Aspects of Starting and Cessation of Rainfall on Upper Blue Nile Basin, Ethiopia

A thesis submitted and presented to the school of graduate studies of Addis Ababa University in partial fulfillment of the degree of Masters of Science in Civil Engineering (Major Hydraulic Engineering)

By

Rebuma Wakesa

Addis Ababa University

September, 2018

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Approval by Board of Examiners

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Advisor Signature

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Internal Examiner Signature

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External Examiner Signature

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Chairman (Department of Graduate Committee) Signature

ABSTRACT

Ethiopian agriculture is mostly rain fed, whereas rainfall in the country is erratic, unreliable, and highly variable with space and time. Due to this rainfall variability frequent drought, high floods and famine have been occurring in many parts of the country. Therefore, Understanding of climate variability through study of spatial and temporal rainfall distribution is required.

This study was designed to assess changes in the start, end and length of the growing season using historical daily rainfall data derived from the selected meteorological stations located in upper Blue Nile basin. In addition, the study investigates the trends of onset, cessation and length of growing period in study area and dry spell analysis. The analysis is done based on 29 years (1986 – 2014) daily rainfall of 33 stations spatially distributed on the basin and using INSTAT software, Excel 2010, TREND and ArcGIS. Rainfall onset identification was based on rainfall accumulation while cessation was based on dry spell analysis. The length of growing period was obtained from the difference between the onset and cessation. Trend of rainfall onset, rainfall cessation and length of growing period is calculated using Mann-Kendall's trend test. The result indicate that rainfall onset is more variable than rainfall cessation and also the studied trend of rainfall onset, cessation and LGP and annual number of wet days does not show clear significant trend change throughout the basin. Also Result from dry spell analysis show that the probability of getting dry spells of 7, 10, 15 and 21 days during rainy season (JJAS) is less than 5% except the stations on the eastern part of the basin.

The rainfall onset and cession for Upper blue-Nile can be used as the base for different rainfed based production analysis and system development.

Key words: Rainfall, Onset, Cessation, Length of growing period, Dry spell, Trend,

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List of Acronyms and Abbreviations

AEZ	Agro-ecological zones
ANRS	Amhara National Regional State
CV	Coefficient of Variation
CSA	Central Statistics Agency
DOY	Day of Year
ENSO	El Niño Southern Oscillation
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
INSTAT	Interactive Statistical Processing Package
ITCZ	Inter Tropical Convergence Zone
JJAS	June, July, September, August
LGP	Length of growing period
masl	Meter above sea level
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
NMA	National Meteorology Agency
NMSA	National Meteorology Service Agency
NRD	Number of rainy days
SD	Standard Deviation
UBN	Upper Blue Nile

1. Introduction

1.1. Background

In Ethiopia agriculture serve as the back bone of economy as well as the main source of food production and income for about 80% of labour force and 47.68% of the gross domestic product (GDP) (Kebede et al, 2016). Moreover, Ethiopian agriculture is mainly dependent on rainfed agriculture. However, the rainfall in the country is erratic, unreliable, and highly variable with space and time (Messay, 2006).

It has been also noted that the rainfall is highly variable in amount, distribution and becomes unpredictable across regions and seasons (Tesfaye and walker, 2004; Tilahun, 1999; Mersha, 1999). In addition the Ethiopian climatic condition, being part of Sub-Saharan Africa, and has been experiencing a series of climatic vagaries with many episodes of cyclic droughts and flood that claimed the lives of thousands of people and slashed economic development. (Haile, 1988; Gissila, et al., 2004; NMA, 2007).

Also climate change and variability has direct influence on the agricultural system of the country, its threat is greater in Ethiopia because of the country's less adaptive capacity and deepened poverty (Michael, 2006).

Agriculture would be seriously affected by increased variability and trends in the seasonal characteristics of rainfall in an environment where one of the major limiting factors of agricultural production is the amount of water available through rainfall. Due to this variation, frequent drought has been occurring in various parts of Ethiopia affecting crop production, food market prices and ultimately, the cost of living (NMA, 1996a; Ghosh, 1999). The seasonal climate variability of Ethiopia particularly rainfall is influenced by weather systems of various scales; from mesoscales to the large scale mainly El Nino -Southern Oscillation (ENSO) related phenomena (NMSA (National Meteorology Service Agency), 1996).The summer rainfall that accounts for the major part (approx. 65–95%) of total annual rainfall over Ethiopia is governed by the El Niño-Southern Oscillation (ENSO) and further enhanced by local climatic forcing (Korecha and Barnston 2007). Main rainy season droughts in Ethiopia are likely associated with warm ENSO episodes (Seleshi and Demarée 1995, Tsegay 1998, Seleshi and Zanke 2004).

Different researches had been conducted to assess the spatial and temporal patterns of rainfall in different parts of the country. Wing et al, (2008) found significant decline in June to September rainfall (that is, Kiremt) were recorded in watersheds located in the southwestern and central parts of Ethiopia. Hadgu et al, (2013) also identified rainfall events such as onset, cessation, dry spell, wet spell and numbers of rainy days are more important than annual and seasonal totals. For the agricultural sector, it is crucial to know how rainfall characteristics that affect planting dates and the crop growth cycle (Dennett 1987, Ati et al. 2002, Usman etal. 2005). The main concern of an agriculturist is the start, end and length of the rainy season, the distribution of rainfall amounts throughout the year and the risk of dry spells.

A farmer who practices agriculture in a rain-dependent environment has to be contended just with the amount and distribution of rainfall received annually but also with the problem of variability in onset, duration and termination of the rainy season. This information helps the farmers in planning operations such as planting, irrigating and harvesting of their crops.

Therefore, assessing the onset, cessation, of rainfall, the LGP and trends in rainfall characteristics based on the past records is essential for developing suitable farming strategies (Hadgu et al. 2013).

This study tries to investigate the characteristics and trends of rainfall in upper Blue Nile river basin. It focus on the onset, cessation, length of growing period and dry spell analysis which is crucial for effective rain fed crop production.

1.2. Problem statement

Rainfall variability is a treat to Ethiopian economy since the country crop production mainly depend on rainfed agriculture. The irregularity of the rainfall in amount and timing can cause a shortage of water, commonly known as droughts or dry spells (Savenije, 1998; Rockstrom, 2003; Enfors and Gordon, 2007). Particularly, the onset and cession of rainfall affects the production system.

Crop yields are often reduced significantly due to the late start and early cessation of the growing season. This is further complicated by the occurrence of long dry spells during the summer (JJAS) or kiremt season when most crops are in their vegetative and reproductive growth stages. Also there is a strong relationship among start, end and length of growing season, and planning of farming activities (Mugalavai et al., 2008). All most the all farmers in Ethiopia starts planting when the rain comes no matter it is early or late. And, this will result in failure of crops, low yields and famine. Determination of the onset, cessation, LGP and dry spell of the rains of is important for agricultural applications as well as to enhance our understanding on the inter-annual variability of the rains of the season.

Therefore, knowing on the time variability of rainfall start, end and length of the growing season and the pattern of dry spells during the season is useful for the planning of land preparation and planting activities. However, there are limited researches conducted in analyzing such characteristics of rainfall onset, cessation, LGP and dry spell.

This study was designed to assess whether there has been any changes in the start, end and length of growing season and the pattern in the upper Blue Nile river basin.

1.3. Objective of the study

1.3.1. General objective

This study aimed to assess the rainfall pattern of upper Blue Nile River Basin in relation with the start, end, length of growing season and dry spell.

1.3.2. Specific objective

The following are specific objectives of the study:

- Determination of rainfall onset, rainfall cessation and LGP over the basin
- To analyze trend and variation of rainfall onset, rainfall cessation and LGP
- To determine probability (risk) of longest dry spell on crop growing stage

1.4. Significance of the study

In Ethiopia the social-economic activities is largely determined by the amount, distribution and reliability of rainfall. The yields of crops, which are mainly grown in the rainy season, depend on the timing of the onset, end of the seasonal rains and its distribution.

Therefore, there is need to determine accurately the onset, cessation and hence distribution of the rainfall season for any given place.

The farmers need to be educated on how to fully utilize the seasonal rains. This will help in improving the economy of the country as well as enhancing food production that will lead to food security for the increasing population in the country.

Therefore, this study will add knowledge on the determination of the starting of rainfall, cessation of rainfall, length of growing periods and dry spell analysis in the basin crop production system.

1.5. Outline of the study

This study presents the understanding metrological aspects of starting and cessation of rainfall in upper Blue Nile basin. This thesis work consists five chapters. The first chapter consist general introduction about rainfall variability, problem statement, objective of study and significance of the study. Chapter two is a literature review part. In this chapter, different literatures related to this study are discussed. The third chapter discusses about methods and materials used during study. In chapter four. results and discussions are presented. Chapter five contains brief conclusion and recommendation.

2. Literature review

2.1. General

In a highly agrarian community like Ethiopia, where the livelihood of the population and the gross domestic product of the country are almost entirely dependent upon rain-fed agricultural production, analysis of precipitation patterns has great importance to cope with impacts on crop yields, animal breeding, power production and ecosystem management.

Most parts of Ethiopia have experienced severe drought conditions and poor agricultural output due to extreme climatic conditions. Virtually all food crop agriculture in Ethiopia depends on rainfall that is frequently erratic and unpredictable.

Rainfall in much of the country is often erratic and unreliable; rainfall variability and associated droughts have historically been major causes of food shortages and famines (Wood, 1977; Pankhurst and Johnson, 1988). According to Von Braun (1991), for instance, a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in the country's food production. It was further noted that in a study conducted in Oromiya region at Debre Zeit and Kulumsa areas (Ethiopia), using wheat as a model crop, a 24 to 33% crop yield reduction was observed due to rainfall and temperature variation (MoWR, 2001).

Various authors have reported several approaches for assessing trends of rainfall characteristics and their application to agriculture. Examples includes; determination of start, end and dry spells of the growing season in semi-arid areas of southern Zimbabwe (Mupangwa et al. 2011) and in Zambia (Hachigonta et al. 2008) using rainfall data; analysis of onset, cessation and length of growing season for western Kenya using rainfall and soil water balance (Mugalavai et al. 2008); determination of onset and cessation date using rainfall and soil water balance respectively, analyzing trends and variability of rainfall in Tigray region, Northern Ethiopia (Hadgu et al. 2013)…etc.

From all these studies, it is imperative to use an approach that will be relevant for the end users, in this case, the farmers.

The key characteristics of rainfall include amount, intensity, distribution, onset, cessation and length of growing period (LGP) (Ezenekwe et al. 2013).

To a smallholder subsistence farmer, having prior knowledge about onset dates of the rainy season is very useful for planning the timely preparation of fields. This also helps farmers to decide a less risky planting date or planting method, or sowing of less risky types/cultivars of crops. Furthermore, it minimizes the risks involved in planting too early or too late (Omotosho et al. 2000).

Knowledge of the early phases of previous rainy seasons can be applied to advise farmers on the use, type, rates and timing of fertilizer additions and on adapting sowing densities/patterns and, later in the season, on plant densities by thinning (Ezenekwe et al. 2013).

Knowing cessation dates during a particular season is important as it helps farmers to assess the possible length of the growing season. It also provides information for the optimal harvesting and subsequent storage of crops since unexpected late rains can cause these to spoil (Hachigonta et al. 2008). This information can also help with the year-to-year selection of crop cultivars adapted to the variability in the length of the rainy season (Hachigonta et al. 2008).

LGP determines the growing season and selection of cultivars of various crops and is critical for planning farming activities before and during the growing season (Mugalavai et al. 2008), rather than merely seasonal rainfall totals (Hachigonta et al. 2008).

Generally, prediction of the onset, cessation and duration of rainfall season is very important to determine whether the use of irrigation in agricultural production is feasible or not. If the duration of rainfall season is less than the growing period of the crops commonly grown in the area, obviously, the farmers need supplemental irrigation for an optimal production.

High spatial and temporal rainfall variability during the season increases the risk of intra seasonal dry spells and droughts in semi-arid areas (Rockströmand Falkenmark, 2000).

Assessing long-term trends of onset, cessation and length of growing period can help to formulate farming strategies to efficiently use the available water.

The presence of a relationship between onset, cessation dates and LGP is relevant for planning agronomic activities in the season (Mugalavai et al. 2008). Thus, reliable estimation of onset and cessation of the rain could help optimize rainwater use in semi-arid areas (Raes et al. 2004, Mugalavai et al. 2008). Therefore, assessing trends in rainfall characteristics based on the past records is essential for developing suitable farming strategies (Hadgu et al. 2013) in different areas.

2.2. Agro-climatic zones and seasons in Ethiopia

In Ethiopia, there are three major climatic zones, which have been known since ancient times due to varied topography are Dega, Weina Dega and the Kolla. The Dega (also known as the cool zone) occurs in the central sections of the western and eastern parts of the north- western plateau. The elevation of this region is above 2400m, and daily temperature ranges from near freezing to 16^0c while the Weina Dega (the temperate zone) ranges from between 1500m and 2400m in elevation, and consists of parts of the central plateau. The kola or hot zone generally comprises areas lower than 1500m in elevation, the Denakil depression and the Blue Nile valley (NMSA, 1996; Cheung et al.2008).

According to NMSA (1996), there are three distinct seasons locally known as Bega (October to January), Belg (February to May) and Kiremt (June to September) are observed in Ethiopia. Of these three seasons, Kiremt is the main rainy season, in which about 85% to 95% of the food crops of the country are produced (Degefu, 1987; NMSA, 1996; Mesay, 2006). In Kiremt season magnitude of rainfall is higher as compared to the other seasons for many parts of the country (NMSA; 1996, Messay, 2006).

While Rainfall distribution and amount during Belg season is highly variable in time and space and maximum temperature value is common (NMSA, 1996; Mesay, 2006).The western half of the country, with one dry and one wet season in a year, receives the highest amount of rainfall in Kiremt, which is generally decreasing from 10 months in the south west to only 2 months in the northwest (NMSA, 1996; Mesay, 2006; Viste et al., 2012). The central and southeastern high lands and the adjoining lowlands experience all the three seasons and receives..0 about 60% of the total annual rainfall during the Kiremt (NMSA, 1996). The southern and southeastern low lands of the country have a bi-modal rainfall pattern with main rainy season occurring from March-May and the second short rains from September-October.

On the other hand, the northeastern part of the country receives very small amount of Kiremt rainfall in a year (Mesay, 2006; NMSA, 1996; Viste et al., 2012).

According to Seleshi and Zanke, 2004 seasonal rainfall in Ethiopia is driven mainly by the migration of the tropical rain belt, the Inter-Tropical Convergence Zone (ITCZ). Major rain-producing systems during Kiremt are: the northward migration of the ITCZ; development and persistence of the Arabian and the Sudan thermal lows along 20°N latitude; development of quasi-permanent high-pressure systems over the South Atlantic and south Indian Oceans; development of the tropical easterly jet and its persistence; and the generation of the low-level 'Somali jet', which enhances low level southwesterly flow. Major systems during the Belg are the development of a thermal low (cyclone) over the south of Sudan, and winds from the Gulf of Aden and the Indian Ocean highs that are drawn towards this center and blow across central and southern Ethiopia. These moist, easterly and southeasterly winds produce the main rains in southern and southeastern Ethiopia and the Belg rains to the east-central part of the northwestern highlands.

2.3. Start of rainy seasons

The start of the rainy seasons is important because it determine the time of the sowing and planting of crops. Yemenu and Edossa (2010) reported that the assessment of beginning and end of rainy season is a key issue in countries, which rely on rain-fed agriculture for better explanation of growing season of a given area and maximizing crop yield per unit of water. Start of rainfall is complex in agronomical aspects since rain does not start in a particular time. Further, it is argued that the first precipitation is not the start of rain (Mazandarani et al. 2013).

Different researcher gives different definition for start of the rainfall; among them, According to FAO (1978) the start of the rainy season both for belg (the shorter) and kiremt(the main growing season) can be identified based on simple soil water balance model. It is suggested that using Penman equation for calculating evapo-transpiration, a start of growing period can be obtained when a dekadal (ten-day) rainfall amount is equal or greater than half of the reference evapotranspiration (ETo) during the beginning of the rainy season. The first attempt of producing onset and cessation of the small season of Ethiopia were made by Tesfaye Haile in 1989.

(Sahu, 2002) defines onset of monsoon as follows; the daily rainfall events of a particular month e.g. June are arranged in rows and years in columns. The date from which there was rainfall in more number of years is considered as most likely date of onset of monsoon and he suggests that, the rain during planting time should be 50-100 mm depending on soil type and onset of monsoon.

Kowal and Knabe (1972) used the rainfall and evapo-transpiration to calculate the date of onset. They defined it as the dekad in which the rainfall is greater than 25mm and where subsequent dekad of rainfall are greater than 0.5 potential evapotranspiration. Benoit (1977) used the daily data to define the onset as the date when accumulated rainfall exceeds and remain greater than 0.5 potential evapo-transpiration for the remainder of the growing season provided that no spell longer than five days occurs immediately after this date (Edoga,2007).

Camberlin and okoola (2003) undertook a study on the onset and cessation of long rains in eastern Africa and their inter-annual variability. The accumulated the principal component (PCA) scores to determine the onset and cessation dates. The study found out that on average over the years 1958-1987, onset occurs on March 25th and the cessation on 21st May (for the long rains) which gave duration of no more than 57 days. They also found out that over the years 1958 to 1987, there was a small trend toward a delayed onset of the rains. The study considered only long rains season.

Stern et al. (1982) defined onset of a season as the date when the rainfall accumulated over 2 days is at least 20 mm and when no dry spell (exceeding 10 days) occurs within the following 30 days. Whereas, Tesfaye and Walker (2004) defined onset as the date in which 20mm or more rainfall accumulated over three consecutive rainy days after a specified date with no dry spell greater than 7 days in the next 30 days.

For Belg onset as indicated in Mesay (2006), rainfall total of 10 mm or more in consecutive three days or more with no dry spell length of 9 days or more in the next 30 days should occur with an earliest starting day first of February.

The study conducted in western Amhara Region of Ethiopia revealed variability in the onset of Kiremt rain among stations (Taye et al. (2013). According to Taye et al. (2013) on average the Kiremt rain at BahirDar, Motta, Debre Markos and Dangla stations begins on 153th,151th, 144th and 132th day of the years (DOY), respectively.

Given that there are several ways of defining the onset of a growing period in literature selecting the best method is difficult. This is because these definitions exist at different scales and estimation is always subjective.

2.4. End of rainy season

End of rainy season marks withdrawal of rainy season. Its definition should be in complete relationship with the definition of the start of rainfall. Like rainfall onset, different authors also define end of rainy season differently. For instance, Mesay (2006) used to determine end of Belg rain with an earliest possible day of May 1, the capacities of soils to persist precipitation with a water balance equal to zero. Whereas Tesfaye and Walker (2004) defined end of rainy season (for Kiremt) as the date when the available soil water content drops to 10 mm/m of the available water after September 11.

Hadgu et al. (2013) and Kassie et al. (2014) used the same definition to determine end of rainy season. In another study, Stern et al. (1982), Mamo (2005), Mesay (2006) and Taye et al. (2013), defined as any date when water balance reaches zero after the first date of September (for Kiremt). According to Zargina (1987), the minimum daily rainfall threshold of 25mm can indicate the termination of the growing season.

FAO (1978) defined end of growing period when precipitation amount is below half of the reference evapo-transpiration. For the regions except southwestern Ethiopia, Segele and Lamb (2005) defined end of rainy season for Kiremt as the first day of a dry-spell of at least 20 days duration that occurred after onset. For southwestern Ethiopia Segele and Lamb (2005) defined Kiremt cessation as the first day of a dry-spell of at least 15 days that occurred after onset. If no such dry-spell occurred by the end of November, then the first day of a post-November 1 dry-spell of at least five days was taken as the cessation date.

According to Ilesanmi (1972), end of growing period is taken as the time when an accumulated 90% of the annual rainfall totals is obtained. Odekunle (2004) used the same method to determine cessation of growing period. In another study, Admassu et al,

(2014) used the definition proposed by Panigrahi and Panda (2002) to determine end of rainy season. According to the authors, end of rainy season is determined using backward summation of weekly rainfall starting from 48^{th} week until 20mm of the rainfall is accumulated.

Also, end of rainy season is obtained when a dekadal rainfall amount is less than half of the corresponding reference evapotranspiration (ETo) at the end of rainy season.

To determine the end of the growing season or rainy season, the stored soil water and its availability to the crop after the rain stops was a very useful criterion (Stern et. al, 2006).

The study done by (Taye et al., 2013) revealed that Kiremt rain ends on 302^{th}, 304^{th}, 292^{th}, 302^{th} and 317^{th} DOY at Bahir Dar, Motta, Yetmen, Debre Markos and Dangla, respectively.

Onset identification was based on rainfall accumulation while cessation was based on daily analysis of the ratio of actual to reference crop evapo-transpiration.

2.5. Length of Growing period (LGP)

The length of growing period is the difference between the onset and end of rainy season and adding the time for soil moisture capacity (FAO, 1978).

Length of the growing period (LGP) may be defined by counting the number of days between the start and the end of the growing period plus the period required to evapotranspire the 100mm moisture stored in the soil reserve during the rainy season.

Length of rainy season is the duration in days between onset date and cessation date (Ayoade, 1974; Adefolalu, 1983; Madeoye, 1985; Zargina, 1987; Odekunle, 2004; Segele and Lamb 2005; Hadgu et al., 2013; Hadgu et al., 2014; Kassie et al., 2014). According to Stewart (1988) and Borrell et al. (2003), length of growing season analysis is very important to advice farmers in selecting suitable crop variety that can be produced in specific area. Accordingly, Taye et al. (2013) reported that on average the Kiremt rainy season has length of 149,153,142,158 and 185 days at Bahir Dar, Motta, Yetmen, Debre Markos and Dangla stations, respectively in the north west of Ethiopia. In another study, Hadgu et al. (2013) reported that the average length of growing period in northern Ethiopia varies from 66 to 85 days depending on the location of the study area. At

Mekelle, Alamata and Edagahamus, Hadgu et al. (2013) observed length of growing season of 85, 79 and 66 days, respectively.

2.6. Number of rainy days

Based on the definition of National Meteorological Service Agency of Ethiopia, a day is considered as a rainy day if it accumulates 1 mm or more rainfall (NMSA, 2001). The number of rainy days was, therefore counted starting from the first day of June to September 30 (kiremt season) in each year. Moreover, maximum number of consecutive dry days (a day that accumulate rainfall <1 mm) were counted to determine dry spell length in kiremt season.

Based on this definition, in the Tigray region of northern Ethiopia, Hadgu et al. (2013) counted number of rainy days for Kiremt season (starting from the first day of June to September 31 following the traditional classification of JJAS as Kiremt and found 50 days at Adigudum, 66 days at Alamata and 61 days at Mekelle. In a similar region, Seleshi and Zanke (2004) observed no-significant change in number of rainy days at Mekele for the period 1965-2002. As Ayalew et al. (2012) indicated, by the years of 2080s the number of rainy days will decrease in the ANRS of Ethiopia.

2.7. Dry spell length

Dry spell can be defined as a sequence of dry days including days with less than a 1mm value of rainfall. According to NMSA (2001), a day is said to be dry if it accumulate rainfall less than1 mm (<1mm) and dry spell length is the maximum number of consecutive dry days with rainfall less than 1mm per day exceeding 5, 7, 10, and 15 (Tesfaye and Walker, 2004). The same definition was used by Mesay (2006) to determine the dry days in rainy season.

Mesay (2006) found mean dry spell length of up to 28 days in the north western, northern and eastern parts of Ethiopia during Belg season. Hadgu et al. (2013) found dry spells of 21 days at Mekele, 26 days at Alemata and Edamame during the Kiremt season. In another study, Seleshi and Camberlin (2006) reported dry spell length of 20.3 days at Mekele in the northern Ethiopia and 16.2 days at Jijiga in the eastern Ethiopia.

2.8. Trends and variability of rainfall in Ethiopia

The amount and distribution of annual and seasonal total rainfall, timing of onset and end dates, and length of growing seasons (LGS) are critical rainfall features that indicate useful information on temporal and spatial rainfall variability over an area.

Various studies have been conducted on the past decades to examine rainfall trends in Ethiopia (NMSA, 2001; Osman and Sauer born, 2002; Bewket and Conway, 2007; Seleshi and Camberlin, 2008; Viste *et al*., 2012; Hadgu *et al.*, 2013 and Muluneh, 2015). NMSA (2001) reported significant reduction in annual rainfall in the north and southwest part and conversely an increasing trend in the central part of the country. However, Bewket and Conway (2007) observed inconsistent trends in the annual, *Kiremt* and *Belg* rainfall among different stations in the country.

According to Bewket and Conway (2007) for the period of 1975 to 2003, *Kiremt* and annual rainfall showed significant increasing trend at Dessie and Labella and conversely significant decreasing trend at Debre Tabor. Seleshi and Camberlin (2006) and Cheung *et al*. (2008) did not find any significant trend over the northern and northeastern part of the country.

Hadgu *et al*. (2013) also showed a declining trend in annual and seasonal rainfall amounts in northern Ethiopia, but the trends were non-significant at most of the stations he studied. As indicate by Hadgu *et al*. (2013), start date of growing season showed increasing trend whereas, end date and length of growing season declining trend in the northern Ethiopia.

Taye and Zewdu, 2012 also found that the statistically increasing significant trends in annual and kiremt rainfall in some selected stations of Amhara region.

The rainfall is highly variable in both amount and distribution across regions and seasons (Tesfaye, 2003, Mersha, 1999). The spatial variation of the rainfall is influenced by the changes in the intensity, position, and direction of movement of these rain-producing systems over the country (Temesgen, 2000). Moreover, the spatial distribution of rainfall in Ethiopia is significantly influenced by topography that also has many unexpected changes in the Rift Valley.

2.9. Effects of el-nino on Ethiopian rainfall variability

June to September (JJAS) is normally the major rainy season over Ethiopia. JJAS seasonal rainfall, except the south and southeast other portions of the nation benefited, particularly for the southwest, west, north, central and east regions of Ethiopia. However, the onset, cessation and the spatial and temporal distribution of Kiremt rainfall varies from place to place (Segele and Lamb, 2005). The intra-seasonal rainfall variability also shows significant differences, with relatively highly variation across the lowlands and Rift Valley regions.

Kiremt rainfall contributes for 50 to 90% of the annual rainfall over major rainfall area of the country and responsible for 85% to 95% of the production of food crops of the country (Krauer, 1988 and Gebremichael, 2014). It is relatively stable when compared to the belg however; irregularity and deficiency of the rainfall of this season affects the food production of the country (NMA,1996a).

Most Ethiopian rainfall variation, with the exception of the south and southeastern parts of the country, is caused by the ITCZ (Kassahun, 1999; and Romilly and Gebremichael, 2010). It oscillates seasonally within the tropics but its surface position is influenced by topography and local eddies. It is this variation in rainfall distribution over space and time that creates serious hydrological extremes, such as floods and droughts (NMA, 1996).

El Niño–Southern Oscillation (ENSO)have 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 (Mason and Goddard, 2001). The El Niño-Southern Oscillation (ENSO) phenomenon is a global event arising from large-scale interactions between the ocean and the atmosphere in the tropical Pacific Ocean.

The onset, cessation, and variability of the kiremt rains fall under the influence of the ENSO phenomenon and tropical depression over the Indian Ocean (Block et al; 2007).

There is significant connection between JJAS rainfall in Ethiopia and ENSO according to different researchers. The correlation showing that rainfall could be below average through El Niño episode furthermore high drought probabilities during strong El Niño years.

According to (Fikadu K., 2015) El Nino is associated with below-normal JJAS rainfall in most of Ethiopia (exception: the southeast lowlands), while La Nina linked with above normal.

While forecasting the intensity of an El Niño episode is difficult, in Ethiopia there is general agreement that an El Niño episode has a high probability to cause:

- Above-normal rainfall from October to March in the south and south east areas; typically associated with supporting pastoralist areas due to good pasture but can also cause flooding and outbreaks of human and livestock diseases.
- Above-normal belg rains with an early onset as early as January or February. At the same time, harvesting the main season cereal crops between October and November may be disrupted due to off-season rains.
- Below-normal kiremt (JJAS) rains which are also typically late, erratic and shorter than usual

3. Materials and Methods

3.1. Description of the study area (Upper Blue Nile Basin)

3.1.1. Location

The upper Blue Nile is the major tributary of the Nile and is located within the western and central part of Ethiopia between latitudes 7^0 45’ and 12^0 45’ N, and longitudes of 34^0 05’ and 39^0 45’ E. The upper Blue Nile consists of the major part of the Abay basin of Ethiopia and covers an area of 157,000 km2. It includes all sub-basins of the Abay except Rahad and Dinder, which do not drain to Sudan through the main river system of the Abay (Michael, M.G., 2012)

The upper Blue Nile drains towards Sudan on its western border and shares common boundaries with the Tekeze and Dinder basins to the north, the Omo Gibe basin to the south, the Awash basin to the east and south-east and the Baro-Akobo to the south-west. The basin is located within the Amhara, Oromiya and Benishangul-Gumuz regions of Ethiopia.

In this study, 33 stations were used for the analysis. The distribution of the stations within the basin is good at the central, eastern and southern part of the basin. Whereas, western and northwestern part of the basin does not have sufficient stations.

Generally, the distributions of the stations used in this study is shown in figure below.

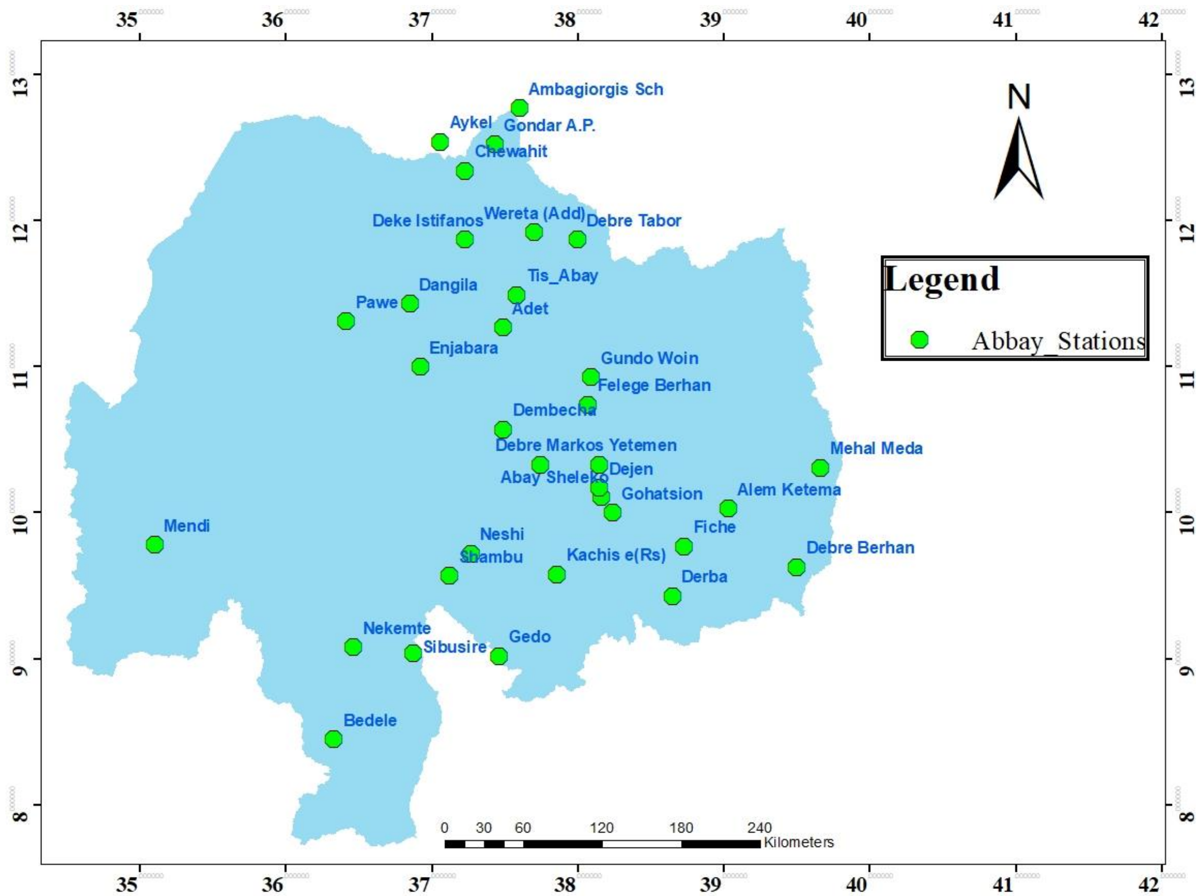

Figure 1: Upper Blue Nile basin

3.1.2. Climate

The climate of the upper Blue Nile basin is predominantly influenced by altitude and its proximity to the equatorial monsoonal systems (Michael, M.G., 2012). Climate of the basin ranges from hot and semi-arid to high altitude cool alpine climates (MWR, 1998b).

The basin has three main seasons: a main rainy season which occurs between June and September locally known as Kirmet, a dry season from October to January locally known as Bega and the short rain period which may occur between February and May locally known as Belg (MWR, 1998b).

About 70% of annual precipitation is concentrated on Kiremt. The annual precipitation has an increasing trend from northeast to southwest. Mean annual rainfall of the basin varies from 800 - 2,200 mm (Mellander P.E., et al 2013).

In most parts of the basin the rainfall is unimodal. However, the eastern part of the basin gets a substantial amount of rainfall during the short rainy period (MWR, 1998b). The headwater of the Abay and the Didesa basin receives high rainfall, which is usually greater than 2000 mm/yr. Western and Southwestern part of the basin receives a high rainfall with rainfall starting early April and ends after September.

Generally, temperature is cool and moderate in the highlands and it is warm and hot in the western lowlands. The average minimum and maximum temperatures are 11°C and 26°C, respectively (Mellander P.E., et al 2013).

The annual potential evapo-transpiration is 1,100 mm with a seasonal variation of less than 20 mm (Gamachu 1977; Kim et al. 2008).

Annual average humidity in the upper Blue Nile basin varies between 47-88%. The humidity level is lower in the highlands as compared to the lowlands. In the highlands most of the months have humidity levels ranging from 45 to 65 %. The humidity increases to around 80% during the main rainy season (MWR, 1998b).

3.1.3. Topography

The upper Blue Nile basin has diverse landforms, which include high mountains, rolling ridges, flat grassland areas and valleys. The elevation range is from about 490 masl, where the Abay crosses the Sudan border to 4620 masl in the eastern highlands. About 62% of Upper Blue Nile basin is above 1500 msl.

Three major relief units can be identified in the basin:

- **i.** the plateau highlands in the central Ethiopian highlands with elevations ranging between2,000–2,700 masl;
- **ii.** the plateau valleys in the eastern part of the basin which descend to the Abay canyon and contain the main tributaries of the Abay; and
- **iii.** the lower plains and hill lands in the western part of the basin close to the Sudanese border

The head waters of the Abay, which are located in the western Ethiopian highlands and are situated between 2,000 to 3,000 masl, sloping downwards in westerly direction to the escarpment above the lowland plains and the valley of the Nile River (Figure 2) (MWR, 1998a, Michael, M.G., 2012).

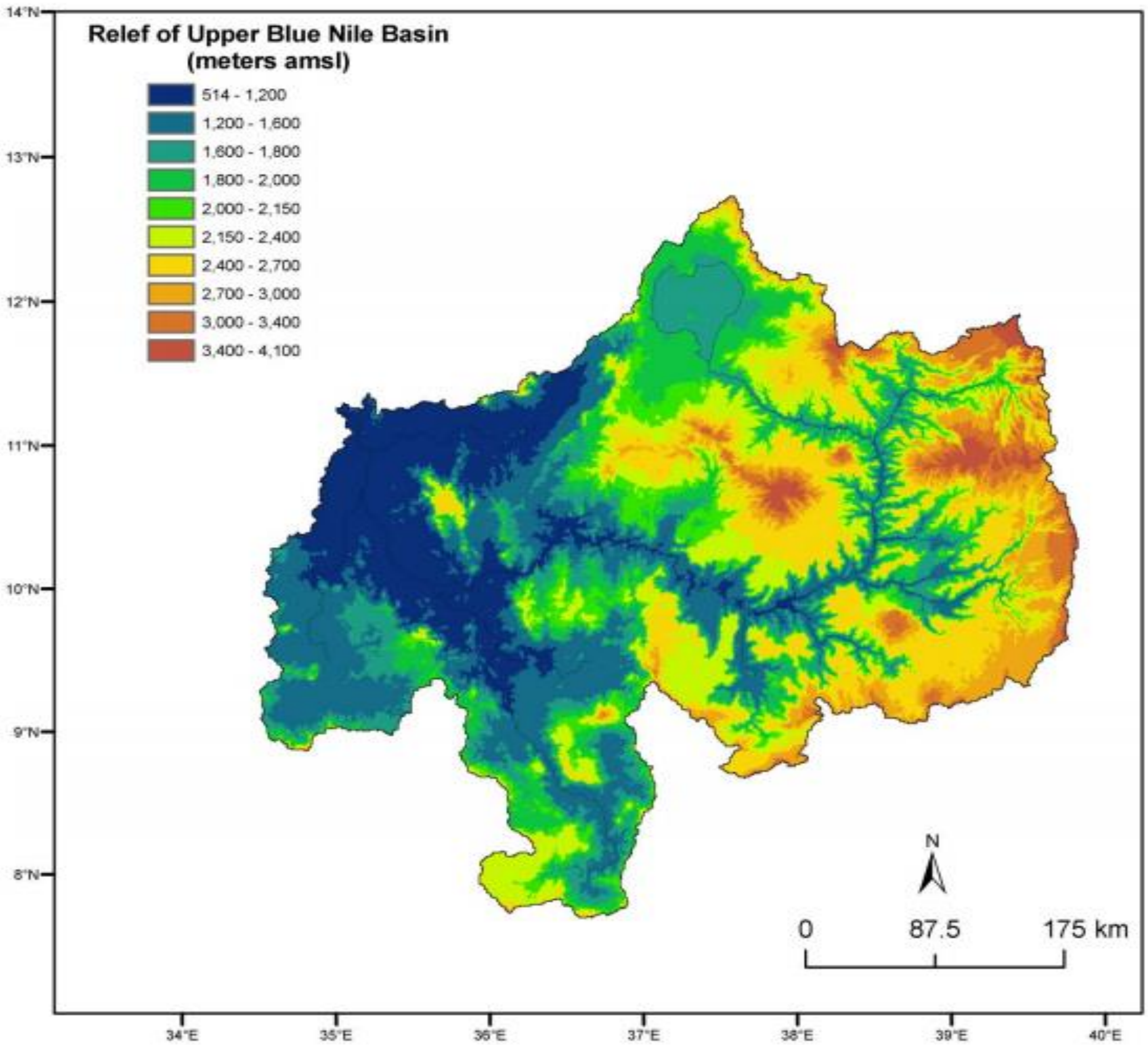

Figure 2: Relief of upper Blue Nile basin

3.2. Data source and selection

Precipitation data of daily rainfall record for the selected stations (Table 1) from the period 1986-2014 were obtained from Ethiopian National Meteorological Agency (NMA), Addis Ababa. The stations are selected based on data availability, quality and relative length of time and geographic location considering fair distribution of stations throughout the basin. Data were captured into Microsoft Excel 2010 spreadsheet following the days of year (DOY) entry format. Data were carefully inspected for its quality and completeness.

Table 1: Geographic information of the selected stations for this study

Station name	Elevation	Longitude(E)	Latitude(N)	Years of observation	%ge of Missing
Abay Sheleko	1823	38.16	10.11	1986-2014	8.01
Felege Berhan	2710	38.07	10.74	1986-2014	2.03
Gundo Woin	2052	38.09	10.93	1986-2014	6.39
Yetemen	2418	38.15	10.33	1986-2014	5.25
Dejen	2448	38.15	10.17	1986-2014	1.16
Debre Markos	2446	37.74	10.33	1986-2014	1.48
Adet	2179	37.49	11.27	1986-2014	5.75
Tis_Abay	2642	37.58	11.49	1986-2014	10.51
Deke Istifanos	1815	37.23	11.87	1986-2014	10.42
Dembecha	2117	37.49	10.57	1986-2014	3.68
Enjabara	2568	36.92	11.00	1986-2014	4.19
Dangila	2116	36.85	11.43	1986-2014	7.29
Chewahit	1925	37.23	12.34	1986-2014	6.84
Gondar A.P.	1973	37.43	12.52	1986-2014	6.67
Aykel	2254	37.06	12.54	1986-2014	4.58
Debre Tabor	2612	38.00	11.87	1986-2014	15.05
Ambagiorgis	2900	37.60	12.77	1986-2014	9.55
Wereta	1819	37.70	11.92	1986-2014	6.35
Nekemte	2080	36.46	9.08	1986-2014	3.27
Neshi	2060	37.27	9.72	1986-2014	9.37
Shambu	2460	37.12	9.57	1986-2014	6.24
Sibusire	1826	36.87	9.04	1986-2014	7.40
Mendi	1650	35.1	9.78	1986-2014	26.00
Debre Berhan	2750	39.50	9.63	1986-2014	1.69

Alem Ketema	2280	39.03	10.03	1986-2014	6.46
Fiche	2784	38.73	9.77	1986-2014	0.63
Derba	2385	38.65	9.43	1986-2014	13.76
Mehal Meda	3084	39.66	10.31	1986-2014	9.19
Gohatsion	2507	38.24	10.00	1986-2014	4.04
Gedo	2520	37.46	9.02	1986-2014	8.45
Kachise	2520	37.86	9.58	1986-2014	9.19
Pawe	1119	36.41	11.31	1986-2014	5.98
Bedele	2011	36.33	8.45	1986-2014	11.63

3.3. Data quality control

Data quality analysis was carried out to ensure that the data used in the study were of good quality. In this study, data quality control involves estimation of missing data and consistent test.

Prior to analysis, the observed rainfall data of all station were plotted against time (DOY format) and subjected to visual examination for the presence of missing and special codes. Special codes were removed and typing errors treated case-by-case using information from the day before and after the event and by reference to nearby stations.

3.3.1. Filling missing data

Failure of any rain gauge or absence of observations from a station causes a short break in the record of rainfall at the station. These gaps can be filled using data from the surrounding gauging stations located within the basin on the assumption that the group of stations has a metrological similarity (Patra, 2002).

Different methods are available for estimation of missing data as recommended by WMO (1966), such as arithmetic mean methods, normal ratio methods, correlation methods, regression method and inverse distance method. Arithmetic mean is used for stations having coefficient of variation less than 10% and serving as base station for the regression equation for similar regions and regression method for all other conditions.

The observed rainfall data were captured into Microsoft Excel 2010 spreadsheet following the days of year (DOY) entry format and percentage of missing of all stations are calculated.

The stations are grouped in to five relative homogenous regions based on their rainfall characteristics and relative closeness. From each groups the station with minimum missing data (less than 10%) is selected and used as the base station to fill missing data's in the other neighboring stations and to check the consistency of the data.

Then the stations having minimum missing data are selected and filled with arithmetic mean method. Those stations with minimum missing data are taken as base stations so the other neighboring stations are filled from base stations using multiple linear regressions.

The station having missing data is placed on first column and the other complete stations are placed next to it. Then, relation between the station with missing data and the complete stations are determined in excel using regression tool and the equation is formulated. Using this equation, the missing data of incomplete station is calculated.

$$\boldsymbol{P_x = b_o + b_1 p_1 + b_2 p_2 + \cdots + b_n p_n} \text{...} \textbf{(1)}$$

P_x is the missing precipitation value for stations X for certain time period
$P_1, P_2, \dots, P_n$, are precipitation values at neighboring stations for the same period
$b_o, \dots, b_n$, are coefficient calculated by least-squares methods
n is number or nearby gages

This method is suitable when there is large number of days when observations are available for all gages.

3.3.2. Consistency check

Rainfall data reported from a station may not always be consistent. A consistent record is one where the characteristics of the record have not changed with time.

An inconsistent record may result from any one of a number of events; such as shifting of rainguage stations in to new location, the neghberiod of the station undergoing a marked change, occurrence of observational error from a certain date and natural causes such as heavy forest fire, earth quick and land slide (Subramanya, 2008).

Data consistency check is done by using double mass curve analysis. Double-mass curve analysis is a graph plotted for cumulative precipitation of stations under consideration on Y-axis against cumulative of average group neighboring station on X-axis in reversed chronological order (i.e. the latest record as first entry and the oldest record as the last entry on the list).

3.4. Definitions of intra-seasonal rainfall indices

At each of the selected stations intra seasonal rainfall were analyzed in terms of Onset of rainy season; end of rainy season; annual total rainfall (mm); length of rainy season; length of dry spell and coefficient of variation.

3.4.1. Onset of rainy season

The onset of rainy season was determined as in Tesfaye and Walker (2004) and Mesay (2006):-

- A date when 20 mm or more rainfall accumulated over three consecutive rainy days
- Should occur after a starting date 1st of April
- No dry spell length greater than 7 days in the next 30 days
- A threshold value of 1 mm (a rainy day is a day with 1mm or more rainfall)

First of April was selected because most farmers in the basin begin to practice land preparation for the coming main cropping season.

The condition of having no dry spells of more than 7 days after start of rainy season eliminates the possibility of a false start of the season. A period of 30 days is the average length for the initial growth stage of most crops (Allen et al., 1998).

Given the above definitions, INSTAT statistical programme (version 3.37) is used to compute start date of growing season for each studied stations.

3.4.2. Cessation of rainy season

The end of the rainy season was defined as the first day of a dry-spell of at least 20 days that occurred after onset. Segale and Lamb 2005 use the same definition. INSTAT 3.37 software is used to compute end date of growing season for each studied stations.

3.4.3. Length of growing period (LGP)

Length of growing season was determined as the difference between the end and onset of rainy season (Mamo, 2005; Mesay, 2006; Feyera, 2013; Hadgu et al., 2013; Hadgu et al., 2014; Feyera et al., 2015). Also in this study the same procedures as above scholars is followed to calculate length of growing period.

3.4.4. Number of rainy and dry days

Even though there is small recorded amount of rainfall which is less than 1 mm, a threshold value of 1mm was used to define days as wet or dry because rainfall value of less than 1mm almost has no effect on growth of crops (Robel et al.,2013). Thus, in the current study, number of rainy and dry days were determined by counting all days with rainfall $\geq$1.0mm as rainy and those days with $<$ 1.0mm as dry days respectively as outlined by (NMSA, 2001). Different researchers used the same definition (Segele and Lamb, 2005; Mesay, 2006; Hadgu et al., 2013).

3.4.5. Rainfall totals

Annual and seasonal rainfall totals were determined as sum of rainfall of each day with greater or equal to 1 mm (NMSA, 2001; Segele and Lamb, 2005; Mesay, 2006; Hadgu et al., 2013) for the specified period.

3.4.6. Dry spell probability analysis

This information is very important to farmers in the region in deciding on crop types to be cultivated and on planning sowing dates as a function of observed from the onset dates. Information on dry-spell lengths could be used in decision making with respect to selecting dry spell resistance crop and field operations within the farming system.

The dry spell effects on crop growth are related to water requirement of the crop and soil water holding capacity. Thus, whether soil has high or low water holding capacity information is extremely useful for planning and design applications for agriculture crop production.

The occurrence of higher probability dry spell lengths at critical stages of crop growth are damaging specially at flowering and grain filling stages.

Moreover, these types of dry spell analysis could provide an overview of each days of the year with varying probabilities of dry spells that could help farmers to adjust farm management practices in a given cropping year.

The dry spell probabilities were determined as consecutive number of days with rainfall less than 1 mm per day exceeding 5, 7, 10 15 and 21 consecutive days. The risk of dry spells for varying number of days following the planting period is computed using Markov chain modeling in which case analysis has to be done from the very beginning with the daily long year's raw data.

Dry spell length was analyzed by Markov Chain analysis (Stern et al., 2006; Sreenivas et al., 2008; Stern and Cooper, 2011) using INSTAT v3.37 programme.

The onset of rainfall and dry spell risk are very crucial to farmers as it answers the vital question "when to plant? Moreover, what will be frequency of dry spell expectation for the forthcoming season?

3.5. Variability analysis

Variability of rainfall can be expressed by statistical parameters such as mean, standard deviation (SD), Skewness, Kurtosis, maximum, minimum and the coefficient of variability (CV). According to Hare (1983), CV is used to classify the degree of variability of rainfall events as less, moderate and high. When CV < 20% it is less variable, CV from 20% to 30% is moderately variable, and CV > 30% is highly variable. Areas with CV > 30 % are said to be vulnerable to drought (Abiy et al 2014).

Where CV can be computed as:

$$\mathbf{CV} = \frac{SD}{\bar{X}} * \mathbf{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

Where, $\bar{X}$ and SD are the average and standard deviation of rainfall, respectively over the given period.

On the other hand, standard deviation is computed as the square root of variance. Using the classification of Reddy (1990), the stability of rainfall is examined as follows: when standard deviation <10 as very high stability, 10-20 as high stability, and 20-40 as moderate stability and >40 as less stability.

Where SD can be computed as:

$$\mathbf{SD}=\sqrt{\left[\sum_{i=1}^{n}\frac{(X_i-\bar{X})^2}{n}\right]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3)}$$

Rainfall anomaly

Rainfall anomaly was used to examine the nature of rainfall over the period of observation and to determine dry and wet years in the record.

Rainfall anomaly (Z) was calculated as:

$$\mathbf{Z}=\frac{(X-\bar{X})}{SD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \mathbf{(4)}$$

Where, x is the seasonal total rainfall of a particular year; $\bar{X}$ is mean of the observation and SD is the standard deviation of the observation. Based on Z values, drought severity classes are given as extreme drought ($Z < -1.65$), severe drought ($-1.28 > Z > -1.65$), moderate drought ($-0.84 > Z > -1.28$), and no drought ($Z > -0.84$) (McKee, 1993). Ayalew et al. (2012) and Hadgu et al. (2013) to identify dry and wet years in their study used the same method.

3.6. Trend analysis

Most of hydrological time series are characterized by a high variability and large scale random variation about the mean value and in spite of that, sometimes monotonic change in a mean value defined as trend is observed in such series (Duggal, and Soni, 2000). The subject of trend detection in hydrologic data has received a great deal of attention lately, especially in connection with the anticipated changes in global climate.

Trends are one type of systematic changes in rainfall series. Inconsistency (systematic error) and non-homogeneity (changes in nature by humans or by natural disruptive, evolutive or sudden process) are mainly responsible for the over year trends.

Analysis of rainfall for agricultural purpose must include information concerning the gradual change (trend), the start, end and length of rainy season, the distribution of rainfall amounts through the year, etc.

There are parametric and non-parametric test for trends detection. Parametric tests assume that the time series data and the errors (deviations from the trend) follow a particular distribution (usually normal distribution). Parametric tests are useful as they also quantify the change in the data (e.g., magnitude of change in the mean or gradient of the trend). Parametric tests are generally more powerful that non-parametric tests. Parametric test includes Linear Regression test, Cumulative Deviation test, Worsley Likelihood Ratio test and Student's t test.

Non-parametric tests are generally distribution-free. They detect trend/change, but do not quantify the size of the trend/change. They are very useful because most hydrologic time series data are not normally distributed. The most commonly used non-parametric tests for detecting monotonic trend in a time series are Mann-Kendall (MK) and Spearman's rho (SR) test.

In this particular study, TREND statistic software (which is designed to facilitate statistical testing for trend, change and randomness in hydrological and other time series data) used and Mann-Kendall's trend tests were assessed at 0.05 level of significance.

3.6.1. **Mann-Kendal (MK)**

Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear (Partal and Kahya, 2006; Yenigun et al., 2008, Hadgu et al., 2013).

The Mann-Kendall's test statistic is given as:

$$S=\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} sgn(X_j - X_i) \quad \text{.......................................} \quad (5)$$

Where S is the Mann-Kendal's test statistics; Xi and Xj are the sequential data values of the time series in the years i and j (j > i) and N is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series.

The sign function is given as;

$$Sgn(X_j - X_i) = \begin{cases} +1 \; if \; (X_j - X_i) > 0 \\ 0 \; if \; (X_j - X_i) = 0 \\ -1 \; if \; (X_j - X_i) < 0 \end{cases} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(6)}$$

The variance of S, for the situation where there may be ties (i.e., equal values) in the X values, is given by

$$\mathrm{Var}(S) = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{i=1}^{m} t_i\,(t_i - 1)(2t_i - 1)\right] \dots\dots\dots \text{(7)}$$

Where, m is the number of tied groups in the data set and t_i is the number of data points in the i^{th} tied group. For n larger than 10, Z_{MK} approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun et al., 2008) and computed as follows.

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \; if \; S < 0 \end{cases} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(8)}$$

The presence of a statistically significant trend is evaluated using the Z_{MK} value. In a two-sided test for trend, the null hypothesis Ho should be accepted if $|Z_{MK}| < Z_{1-\alpha/2}$ at a given level of significance. $Z_{1-\alpha/2}$ is the critical value of Z_{MK} from the standard normal table. E.g. for 5% significance level, the value of $Z_{1-\alpha/2}$ is 1.96.

3.7. About INSTAT + 3.37 software

INSTATT is a statistical package Produced by the Statistical Services Centre at the University of Reading, UK.

Instat is a simple general-purpose statistics package. It is designed to support the teaching of statistics, while being powerful enough to assist research in any discipline that requires the statistical analysis of data.

The analyses use Instat, a simple general statistics package that also includes a range of special facilities to simplify the processing of climatic data. It is designed to support the analysis of climatic data.

4. Result and Discussion

4.1. Rainfall data analysis

The daily rainfall data of 33 gauging stations, which distributed in the basin processed and analyzed including gap and consistency testing for their correct data set arrangement. Missing daily rainfall values were filled-in using multiple correlations of daily data with neighboring stations. The sample results are presented in appendix 1 for double mass curve analysis.

4.2. Rainfall onset of stations

This section presents results of the analysis of onset of the rainy season in the upper Blue Nile basin during the period of analysis, which is important for the planning of agricultural water management.

Based on definition of rainfall onset the following result has been found and discussed and below.

Results of the analysis show that the mean onsets of rainy season for stations in Upper Blue Nile basin ranges from April to June.

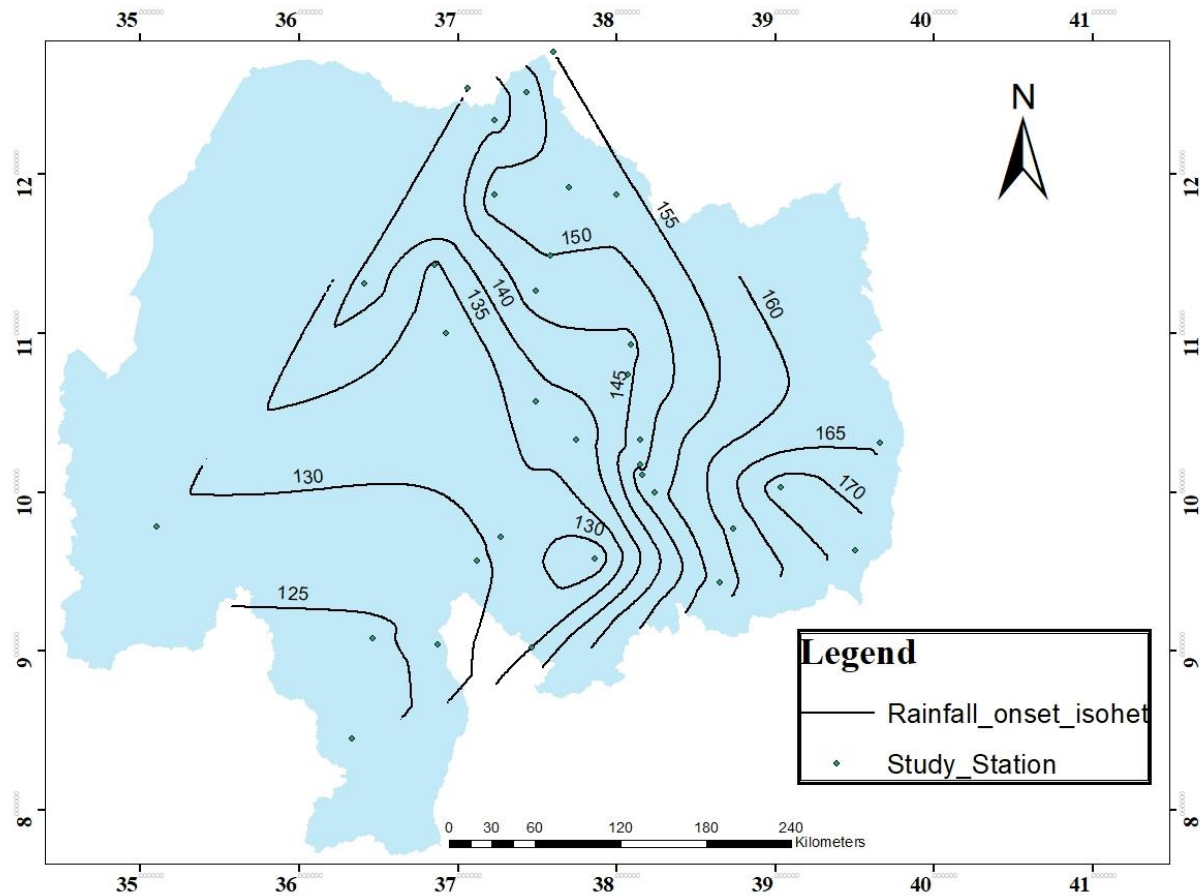

Figure 3: Mean rainfall onset dates across the basin

Table 2: Date number of day of the year

Day of the month	**Day of the year (DOY)**	**Day of the month**	**Day of the year (DOY)**
1-Jan	1	1-Jul	183
15-Jan	15	15-Jul	197
1-Feb	32	1-Aug	214
15-Feb	46	15-Aug	228
1-Mar	61	1-Sep	244
15-Mar	75	15-Sep	258
1-Apr	92	1-Oct	276
15-Apr	106	15-Oct	290
1-May	122	1-Nov	306
15-May	136	15-Nov	320
1-Jun	153	1-Dec	337
15-Jun	167	15-Dec	351

In Southwestern part of the basin, the rainfall starts at the end of April and first decade of May. On average the mean onset date of Nekemte, Bedele and Mendi are 3-May, 29-April and 7-May respectively.

Table 3: Rainfall onset date and it's variation for south-west stations

Station name	Rainfall onset date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Nekemte	124	3-May	16.7	13.47
Bedele	120	29-Apr	14.7	12.25
Mendi	128	7-May	21.3	16.64

In Northern, part of the basin rainfall enters at 19-May, 26-May and 22-May at Akel, Gonder and Chewahit respectively.

Table 4: Rainfall onset date and it's variation for northern stations

Station name	Rainfall onset date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Aykel	140	19-May	19.4	13.86
Gondar	147	26-May	17.6	11.97
Chewahit	143	22-May	20.9	14.62

At Eastern part of the basin, the rainfall enters at 12-June at Mehal Meda and 173 both at Debre Berhan and at Alem Ketema.

Table 5: Rainfall onset date and it's variation for eastern stations

Station name	Rainfall onset date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Mehal Meda	164	12-Jun	34.9	21.28
Debre Berhan	173	21-Jun	26.6	15.38
Alem Ketema	173	21-Jun	22.9	13.24

At Central part of the basin, the rainfall starts 15-May at Debre Markos, 17-May at Dembecha and 23-May at Felege Berhan.

Table 6: Rainfall onset date and it's variation for central stations

Station name	Rainfall onset date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Debre Markos	136	15-May	26.6	19.56
Dembecha	138	17-May	27.5	19.93
Felege Berhan	144	23-May	27.6	19.17

Lowest variability in the onset of the wet season rainfall is observed at Pawe station, with the CV of 9.09, while the highest variability is observed at Mehal Meda stations with the CV of 21.28.

Across the basin, the delayed onset date is observed at Mehal Meda in 2014 with value of 22-July and the earliest onset date of rainfall is observed before April first in some of South Western Stations, however since onset criteria is starting from April first it has been omitted.

Generally, the result shows that there is high variability in the onset of the rainy season and there exist spatial variability over entire the basin. In addition, the mean rainfall onset dates of the stations in this basin range between ends of April to end of June. The Onset of rainfall gradually advances northeastward from southwestern regions of basin starting in April. The onset of rainfall is moderately variable, with standard deviation across the basin ranging from 13 to 35 and coefficient variation 9.1 to 19.9.

4.3. Rainfall cessation of stations

This section presents results of the analysis of cessation of the rainy season in the upper Blue Nile basin during the period of analysis.

Based on definition of rainfall cessation, the following result has been found. The result is discussed and tabulated below on different parts of the basin.

The rainfall tends to cease starting from October in Eastern and Northern part of the basin to November in Southwestern part of the basin.

The Kiremt rains leave from northeastern and central regions early in the third dekad of October and cease over southwestern regions by late November.

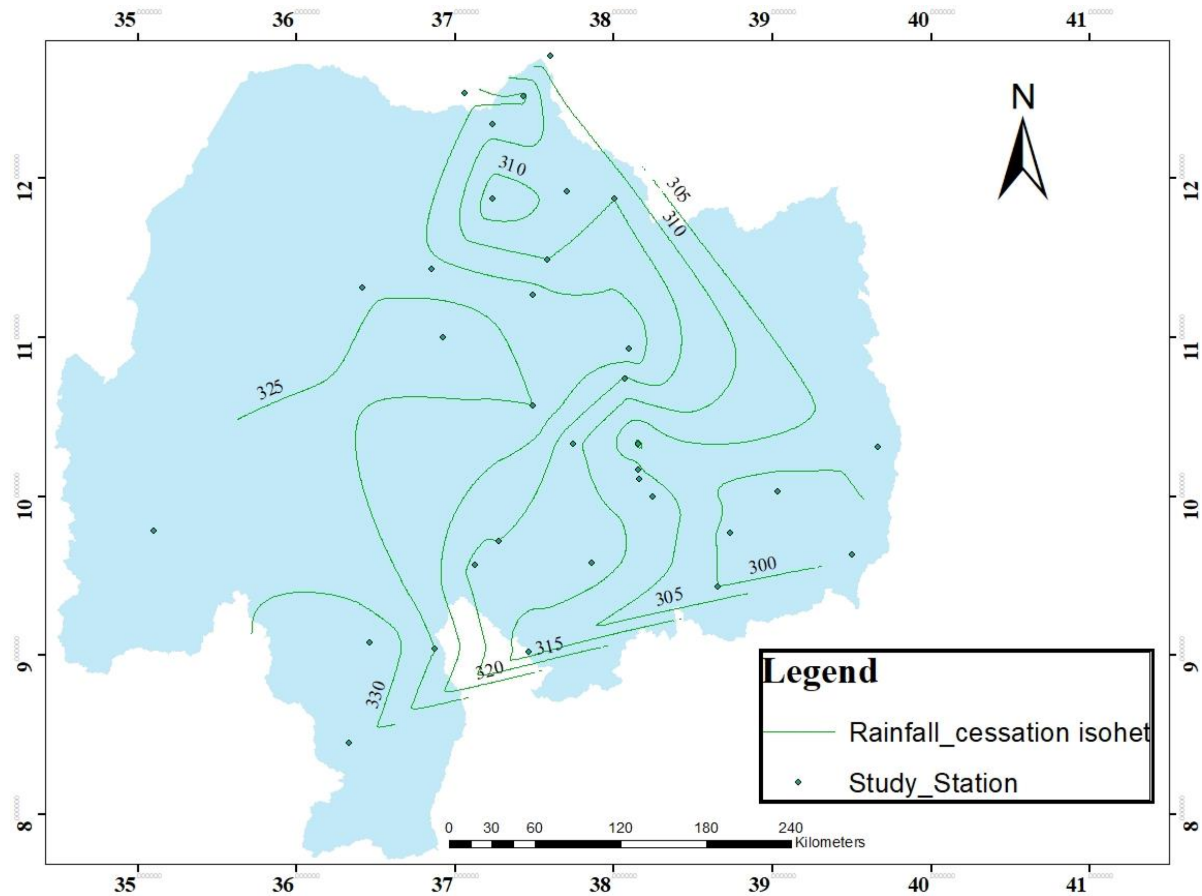

Figure 4: Mean rainfall cessation dates across the basin

In Southwestern part of the basin, the rainfall cessation starts at the end of November. On average, the mean cessation dates of Nekemte, Bedele and Mendi are 30-November, 29-November and 21- November respectively.

Table 7: Rainfall cessation date and it's variation for south-western stations

Station name	Cessation date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Nekemte	335	30-Nov	8.87	2.65
Bedele	334	29-Nov	16.3	4.88
Mendi	326	21-Nov	11.6	3.56

In Northern part of the basin rainfall start to cease 17- November, 16- November and 12-November at Akel, Gonder and Chewahit respectively.

Table 8: Rainfall cessation date and it's variation for northern stations

Station name	Cessation date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Aykel	322	17-Nov	14.29	4.44
Gondar	321	16-Nov	13.9	4.33
Chewahit	317	12-Nov	15.37	4.85

In Eastern part of the basin the rainfall start to cease 28-October at Mehal Meda, 24-October at Debre Berhan and 23-October at Alem Ketema.

Table 9: Rainfall cessation date and it's variation for eastern stations

Station name	Cessation date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Mehal Meda	302	28-Oct	13.15	4.35
Debre Berhan	298	24-Oct	9.64	3.23
Alem Ketema	297	23-Oct	11.96	4.03

At Central part of the basin, the rainfall starts to cease 6-November at Debre Markos, 20-November at Dembecha and 9-November at Felege Berhan.

Table 10: Rainfall cessation date and it's variation for central stations

Station name	Cessation date and it's variation			
	Date number	Day of the year (DOY)	SD	CV
Debre Markos	311	6-Nov	12.51	4.02
Dembecha	325	20-Nov	16.75	5.14
Felege Berhan	314	9-Nov	14.4	4.58

Lowest variability in the cessation of the Kiremt season rainfall is observed at Nekemte station, with the CV of 2.65, while the highest variability is observed at Gohatsion stations with the CV of 7.07. The coefficient of variation (CV) of the end of the rainy season is less than 10 % for all stations and CV of onset rainy season is less than 20 % for all stations except Mehal meda, which is 21.28 %.

Throughout the basin, the delayed cessation date is observed at Bedele in 2006 with value of 28-Dec and the earliest cessation date of rainfall is observed at Aykel, Amba Gyorgis and Deke Istifanos with value of 20-September in 1992, 2010 and 1991 respectively.

Generally, the result indicated that rainfall has ceased early in the eastern part of the basin as compared to the western parts and the variability of rainfall cessation of the rainy season is small as compared to onset variability. In addition, the mean rainfall cessation dates of the stations in this basin range between ends of October to end of November. The cessation of rainfall is shows low variability, with standard deviation across the basin ranging from 8.87 to 21.86 and coefficient variation 2.65 to 7.07.

4.4. LGP with values and with agro climatic classification

Knowledge of duration of rainy season is important for best planning of agriculture activities. The duration as well as the mean duration had been determined using Instat software programme. Prediction of the onset, cessation and duration of rainfall season is very important to determine whether the use of irrigation in agricultural production is feasible or not. If the duration of rainfall season is less than the growing period of the crops commonly grown in the area, obviously, the farmers need supplemental irrigation for an optimal production.

4.4.1. LGP with values

Length of growing period is the time between the onset of rainfall and cessation of rainfall. The summary of the mean length of rainy season and its variation is discussed below over different parts of the upper Blue Nile basin.

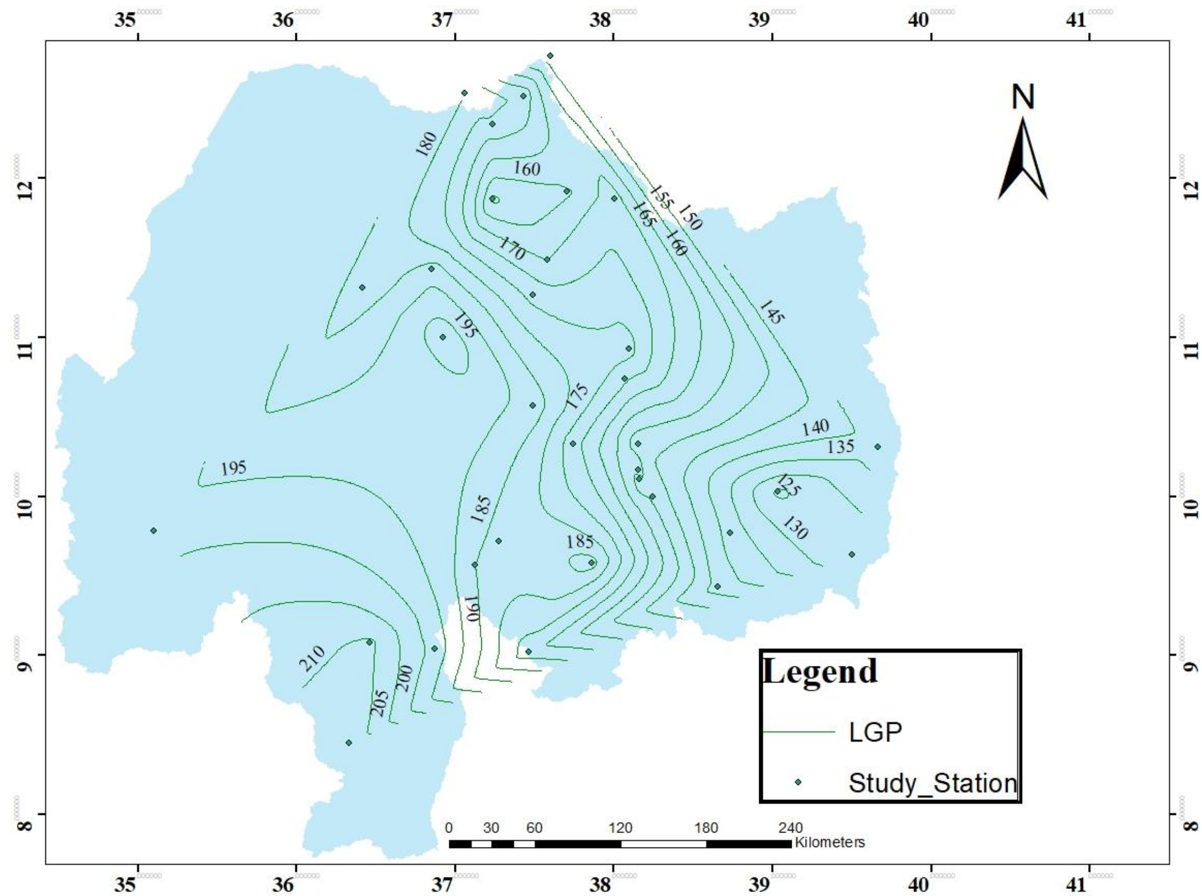

Figure 5: Mean LGP across the basin

Length of growing period in the study basin varies from 124 days at Alem Ketema to 214 days at Bedele depending on the location of the station. The length of growing season increased from North and Eastern to Western and Southern part of the stations in the basin.

In Southwestern part of the basin the mean length of growing period of selected stations like Nekemte, Bedele and Mendi are 211, 214 and 198 days respectively. This part of the basin is characterized by long LGP.

Table 11: LGP and it's variation for south-western stations

Station name	LGP and it's variation		
	Day length	SD	CV
Nekemte	211	19.83	9.4
Bedele	214	21.53	10.06
Mendi	198	24.88	12.55

In Northern, part of the basin the mean length of growing period is 180 days for Aykel and 174 days for Gondar and Chewahit respectively.

Table 12: LGP and it's variation for northern stations

Station name	LGP and it's variation		
	Day length	SD	CV
Aykel	180	27.43	15.25
Gondar	174	23.08	13.27
Chewahit	174	31.66	18.24

In Eastern part of the basin the mean length of growing period for selected stations like Mehal Meda, Debre Berhan and Alem Ketema are 138, 125 and 124 days respectively. This part of the basin is characterized by short LGP.

Table 13: LGP and it's variation for eastern stations

Station name	LGP and it's variation		
	Day length	SD	CV
Mehal Meda	138	35.72	25.93
Debre Berhan	125	25.93	20.72
Alem Ketema	124	26.22	21.1

In Central part of the basin the mean length of growing period for selected stations like Debre Markos, Dembecha and Felege Berhan are 172, 171 and 188 days respectively.

Table 14: LGP and it's variation for central stations

Station name	LGP and it's variation		
	Day length	SD	CV
Debre Markos	172	25.95	14.9
Dembecha	188	30.54	16.27
Felege Berhan	171	33.87	19.85

Lowest variability in the length of growing period is observed at Nekemte station with the CV of 9.4 %, while the highest variability is observed at Mehal meda stations with the CV of 25.93 %.

The longest growing season recorded across this region was 260 days at Bedele in 2006 and the shortest growing season observed was 84 days recorded at Debre Berhan in 1987.

The Western and southern part of the basin is characterized by long LGP so that the length of growing period could not be problem to any crop in this region and hence, what could be the challenge is the occurrence of different dry spell lengths. Whereas the Eastern and Northern part of the basin is characterized as short LGP, so it would be useful to design appropriate decision support systems and strategies accordingly.

Generally, the number of LGP is advancing to South -Western part starting from North and eastern part and there is high variability in the LGP across the basin. In addition, the eastern region of the basin has the largest variation shown by the highest standard deviation in both onset and duration.

4.4.2. LGP with agro climatic condition

There are different ways of classifying the climatic systems of Ethiopia, including the traditional, the Köppen's, the Throthwaite's, the rainfall regimes, and the agro-climatic zone classification systems (Yohannes, 2003). The most commonly used classification systems are the traditional and the agro-ecological zones (AEZs). According to the traditional classification system, which mainly relies on altitude and temperature, Ethiopia has five climatic zones (Wurcha, Dega, Weyna dega, Kola and Berha).

The AEZ classification method on the other hand is based on combining growing periods with temperature and moisture regimes. These AEZ's are grouped under seven categories, which is described table below;

Table 15: AEZ classification system

S No.	Standard name	LGP in days
1	Arid(A)	<45
2	Semi-Arid(SA)	46-60
3	Sub-Moist(SM)	61-120
4	Moist(M)	121-180
5	Sub-Moist(SH)	181-240
6	Humid(H)	241-300
7	Per-Humid(SH)	>300

Source: Agro-ecological zones of Ethiopia. National resources management and regulation department of MOA, March 1988, Addis Ababa

Table 16: Agro-climatic classification of UBNB based on LGP

Station name	Eleation	X-cord.	Y-cord.	LGP	Agro-climate classification based on LGP
Abay Sheleko	1823	38.16	10.11	122	Moist(M)
Felege Berhan	2710	38.07	10.74	141	Moist(M)
Gundo Woin	2052	38.09	10.93	140	Moist(M)
Dejen	2448	38.15	10.17	132	Moist(M)
Debre Markos	2446	37.74	10.33	146	Moist(M)
Adet	2179	37.49	11.27	148	Moist(M)
Tis_Abay	2642	37.58	11.49	151	Moist(M)
Deke Istifanos	1815	37.23	11.87	138	Moist(M)
Dembecha	2117	37.49	10.57	151	Moist(M)
Enjabara	2568	36.92	11.00	177	Moist(M)
Dangila	2116	36.85	11.43	165	Moist(M)
Chewahit	1925	37.23	12.34	135	Moist(M)
Gondar	1973	37.43	12.52	153	Moist(M)
Aykel	2254	37.06	12.54	163	Moist(M)
Debre Tabor	2612	38.00	11.87	133	Moist(M)
Wereta	1819	37.70	11.92	134	Moist(M)
Nekemte	2080	36.46	9.08	195	Sub-Humid(SH)
Bedele	2011	36.33	8.45	195	Sub-Humid(SH)
Neshi	2060	37.27	9.72	161	Moist(M)
Shambu	2460	37.12	9.57	160	Moist(M)
Sibusire	1826	36.87	9.04	178	Moist(M)
Mendi	1650	35.1	9.78	180	Moist(M)
Ambagiorgis	2900	37.60	12.77	127	Sub-Moist(SM)
Yetemen	2418	38.15	10.33	120	Sub-Moist(SM)
Debre Berhan	2750	39.50	9.63	105	Sub-Moist(SM)
Alem Ketema	2280	39.03	10.03	102	Sub-Moist(SM)
Fiche	2784	38.73	9.77	110	Sub-Moist(SM)

Derba	2385	38.65	9.43	118	Sub-Moist(SM)
Mehal Meda	3084	39.66	10.31	108	Sub-Moist(SM)
Gohatsion	2507	38.24	10.00	124	Moist(M)
Gedo	2520	37.46	9.02	147	Moist(M)
Kachise	2520	37.86	9.58	165	Moist(M)
Pawe	1119	36.41	11.31	165	Moist(M)

Based on the above classification the study stations in the Upper Blue Nile basin is grouped in to three agro climatic conditions; namely Moist (M), Sub-Moist (SM) and Sub-Humid (SH).

In southwestern part of the basin stations like Nekemte and Bedele are grouped under Sub-Humid (SH) agro climatic conditions.

Also in eastern part of the basin the stations like Fiche, Debre Berhan, mehal meda, Derba and Alem Ketema are classified under Sub-Moist (SM) agro climatic conditions.

Generally, except the stations found around eastern part of the basin (which is Sub-Moist (SM)) and southwestern part of the basin (which is Sub-Humid (SH)) most of the stations in Upper Blue Nile basin is categorized under Moist (M) agro climatic conditions.

4.5. Trend analysis

4.5.1. Trends in long term characteristics of rainfall Onset, cessation and LGP

During the study period (1986-2014), increasing and deceasing trends on onset date of rainfall, on cessation date of rainfall and on the length of growing period were observed at different studied stations. Although there is increasing and decreasing trend in rainfall onset, rainfall cessation and length of growing period, the observed trends were not statistically significant at most of the studied stations. The positive signs are indications of a tendency of late rainfall onset, late rainfall cessation and increasing length of growing period and the negative signs are indication of early onset of rainfall, early cessation and decreasing length of growing period. The trend test was done at 5% significance level.

In Southwestern part of the basin, some of the selected stations shows decreasing trend in rainfall onset. However, only one significant decreasing trend at Nekemte was observed. In this area, rainfall cessation shows decreasing trend at Bedele and Mendi and increasing trend at Nekemte of which none of stations show statically significant trend. Trend of LGP shows increasing at three of the stations but significant increasing trend is observed only at Nekemte station. Generally, there is a trend change although it is not significant at most of the station.

Table 17: Trend test of rainfall onset, cessation and LGP of southwestern stations

Station name	Test statics (S) using Mann-kendal test					
	Onset	Result	Cessation	Result	LGP	Result
Nekemte	-2.045	S(5%)	0.9	NS	2.364	S(5%)
Bedele	-0.957	NS	-0.957	NS	0.482	NS
Mendi	-0.769	NS	-0.975	NS	0.506	NS

NS = not significant trend, S(5%) = statically significant trend at 5%

In Northern part of the basin some of the selected stations like Aykel, Gondar and Chewahit shows decreasing trend in rainfall onset of which none of them shows statically significant decreasing trend.

In this area, rainfall cessation shows decreasing trend at Aykel, Gondar and Chewahit but none of the stations show statically significant decreasing trend. Also trend of LGP shows increasing trend at Aykel and chewahit and decreasing trend at Gondar stations but none of the stations show significant increasing or decreasing trend. Generally, there is an indication of trend change although it is not significant at most of the station.

Table 18: Trend test of rainfall onset, cessation and LGP of northern stations

Station name	Test statics(S) using Mann-kendal					
	Onset	Result	Cessation	Result	LGP	Result
Aykel	-0.975	NS	-0.3	NS	0.9	NS
Gondar	-1.125	NS	-1.838	NS	-0.431	NS
Chewahit	-0.75	NS	-0.338	NS	0.375	NS

NS = not significant trend

In Eastern, part of the basin there is decreasing trend in rainfall onset at Debre Berhan and Alem Ketema and increasing trend at Mehal meda, but none of this stations shows significant trend change. Also cessation of rainfall shows increasing trend at Debre Berhan and Mehal meda and decreasing trend at Alem ketema of which none of this stations show significant trend change.

In this area, trend of LGP shows increasing trend at Debre Berhan and Alem Ketema and decreasing trend at Mehal meda, but none of this indicate significant trend change.

Table 19: Trend test of rainfall onset, cessation and LGP of southwestern stations

Station name	Test statics(S) using Mann-kendal					
	Onset	Result	Cessation	Result	LGP	Result
Debre Berhan	-0.882	NS	0.675	NS	1.069	NS
Alem Ketema	-1.032	NS	-0.525	NS	0.506	NS
Mehal Meda	1.088	NS	0.038	NS	-1.463	NS

NS = not significant trend

In Central part of the basin, there is increase in rainfall onset at Dembecha and Debre Markos and decreasing trend at Felege Berhan even though any of these stations show significant trend change (increasing/decreasing). In addition, cessation of rainfall in this specific area shows decreasing trend at Felege Berhan and Debre Markos and increasing trend at Dembecha although there is no significant trend change.

In this area trend of LGP shows, decreasing trend at Dembecha and Felege Berhan and increasing trend at Debre Markos but none of this indicate significant trend change.

Table 20: Trend test of rainfall onset, cessation and LGP of central stations

Station name	Test statics(S) using Mann-kendal					
	Onset	Result	Cessation	Result	LGP	Result
Dembecha	0.675	NS	0.281	NS	-0.15	NS
Felege Berhan	-0.281	NS	-1.013	NS	-0.375	NS
Debre Markos	60.413	NS	-1.182	NS	0.225	NS

NS = not significant trend

Generally, the trend of rainfall onset, cessation and LGP does not show a clear significant trend change (increasing/decreasing) over the Upper Blue Nile basin. Even though there is significant trend change at few stations, this does not represent the whole basin condition. Also from the different areas discussed above, there is no parts, which shows clear trend as whole in the basin.

4.5.2. Annual number of wet days and its variation and trend

Trends in the duration of the rain and dry spells within the rainy season have also important environmental implications, especially for agriculture and ecosystems. For instance, long dry spells may cause drying of the soil, implying that need for supplement irrigation is needed, whereas longer rain spells may increase flooding risk that indicate the need for drainage system.

The number of annual rainy days, its variation and its trend in the basin at different parts of the basin are discussed below;

In southwestern part of the basin, the observed number of average annual rainy days varies from 139 at Mendi, 165 days at Nekemte to 155 days at Bedele.

The observed CV values also showed more variability at Mendi and less variability at Nekemte and Bedele in the number of rainy days during the study period 1986 -2014.

During the study period, decreasing trends in number of rainy days (NRD) were observed at Bedele, Nekemte and Mendi in the study area. There is no significant trend change observed in this region.

Table 21: Number of rainy days, its variation and trend for southwestern stations

Station name	Statics					Mannkendal trend test	
	Avg.	**ST. DEV.**	**CV**	**Max**	**Min**	**Test statics(S)**	**Result**
Bedele	155	13	8	179	133	-0.263	NS
Nekemte	165	14	9	200	127	-0.75	NS
Mendi	139	35	25	213	77	-0.431	NS

NS = not significant trend

In Northern part of the basin, the observed number of average annual rainy days varies from 120 at Aykel, 115 days at Gondar to 111 days at Chewahit.

The observed CV values also showed less variability at Aykel, Gondar and Chewahit in the number of rainy days during the study period 1986 -2014.

During the study period, decreasing trends in number of rainy days (NRD) were observed at Aykel, Gondar and Chewahit in the study area. There is no significant trend change observed in this region.

Table 22: Number of rainy days, its variation and trend for northern stations

Station name	Statics					Mannkendal trend test	
	Avg.	**ST. DEV.**	**CV**	**Max**	**Min**	**Test statics(S)**	**Result**
Aykel	120	15	13	154	101	-1.801	NS
Gondar	115	9	8	138	91	-0.188	NS
Chewahit	111	12	11	137	92	-0.188	NS

NS = not significant trend

In Eastern part of the basin, the observed number of average annual rainy days is 98 at Debre Berhan and Mehal Meda and 99 at Alem Ketema.

The observed CV values also showed less variability at those stations in the number of rainy days during the study period 1986 -2014.

Also during the study period, decreasing trends in number of rainy days (NRD) were observed at Alem Ketema and Mehal Meda and increasing trend in number of rainy days at Debre Berhan in the in the study area. There is no significant trend change observed in this region.

Table 23: Number of rainy days, its variation and trend for eastern stations

Station name	Statics					Mannkendal trend test	
	Avg.	**ST. D.**	**CV**	**Max**	**Min**	**Test statics(S)**	**Result**
Debre Berhan	98	8	8	117	85	0.807	NS
Alem Ketema	99	8	8	114	75	-0.263	NS
Mehal Meda	98	7	7	108	78	-0.075	NS

NS = not significant trend

In Central part of the basin, the observed number of average annual rainy days is 136 at Dembecha, 141 at Debre Markos and 129 at Felege Berhan.

The observed CV values also showed less variability at those stations in the number of rainy days during the study period 1986 -2014.

Also during the study period, increasing trends in number of rainy days (NRD) were observed at Dembecha, Debre Markos and Felege Berhan. Off this stations there is significant trend change observed at Dembecha.

Table 24: Number of rainy days, its variation and trend for central stations

Station name	Statics					Mannkendal trend test	
	Avg.	**ST. DEV.**	**CV**	**Max**	**Min**	**Test statics(S)**	**Result**
Dembecha	136	20	15	172	92	2.457	S(5%)
Debre markos	141	12	8	157	110	0.225	NS
Felege Berhan	129	13	10	155	94	0.431	NS

NS = not significant trend, S (5%) = statically significant trend at 5%

Generally, there is no region that indicates statically significant trend change (increasing/decreasing) consistently, even though there a few stations in those regions that show significant trend change.

4.6. Dry spell analysis

Estimation of risk of dry spells over the growing period can help for adjusting planting time so that the sensitive period of the crop could be synchronized with the water availability period. These give insight into the risk related to dry spell lengths during the entire growing season. In addition, the reason behind including the dry spell length conditions into the later month of the growing season is to provide a complete picture of how the dry spell length of various magnitudes are distributed during the entire growing season and to examine the associated risk at the site.

Also dry spell analysis are important for on farm level agricultural decisions like choice of crop or variety (short, medium or long maturing, drought tolerant or susceptible) and crop management practices (supplemental irrigation, fertilizer and insecticide application).

The overall risk of dry spells from the beginning of April (DOY 92) to end of September (DOY 275) in UBN basin over the 29 years period considering chance of occurrence exceeding 5, 7, 10, 15 or 21 days are showed in figures developed below.

The peak rainfall period during the growing season occurs between June and August in the upper Blue Nile basin. The possibility of getting 5, 7, 10, 15 and 21-day dry spells during any time of the year in each region is discussed below. More than 5 continuous days of no rain are common over most parts of the basin. This study focuses on analysis of dry spell from planting time to end.

In southwestern part of the basin, some of selected station like Nekemte, Bedele and Mendi shows probability of dry spell occurrence of 5 days length was above 80% in all stations at the beginning of April (DOY 92). On the other hand, the observed probability of dry spell occurrence greater than 7 days length was 40% at Nekemte, 65% at Bedele and 85% at Mendi at the beginning of April.

Whereas, the probability of dry spell occurrence greater than 10 days length were observed being 10% at Nekemte and Bedele and 50% at Mendi at the start of April. In addition, the probability of dry spell occurrence greater than 15 and 21 days length were less than 5% at the beginning of April for Nekemte, Bedele and Mendi stations.

The probability of dry spell length start to decrease before April up to end of May and attains less than 5% for all for all spell lengths studied. The probability of dry spell length starting from beginning of June (DOY 153) up to beginning of September (DOY 245) were at 0% for Bedele and Nekemte and less than 5% for Mendi for all spell lengths analyzed.

The probability of dry spells decreased gradually beginning from start of April until the end of August and begins rising starting from start of September. The probability of occurrence of short dry spell days is higher than the prolonged dry spells. At this region, prolonged period of dry spell is not common during summer season. From this region, dry spell risk analysis of Nekemte and Mendi is shown in figure below.

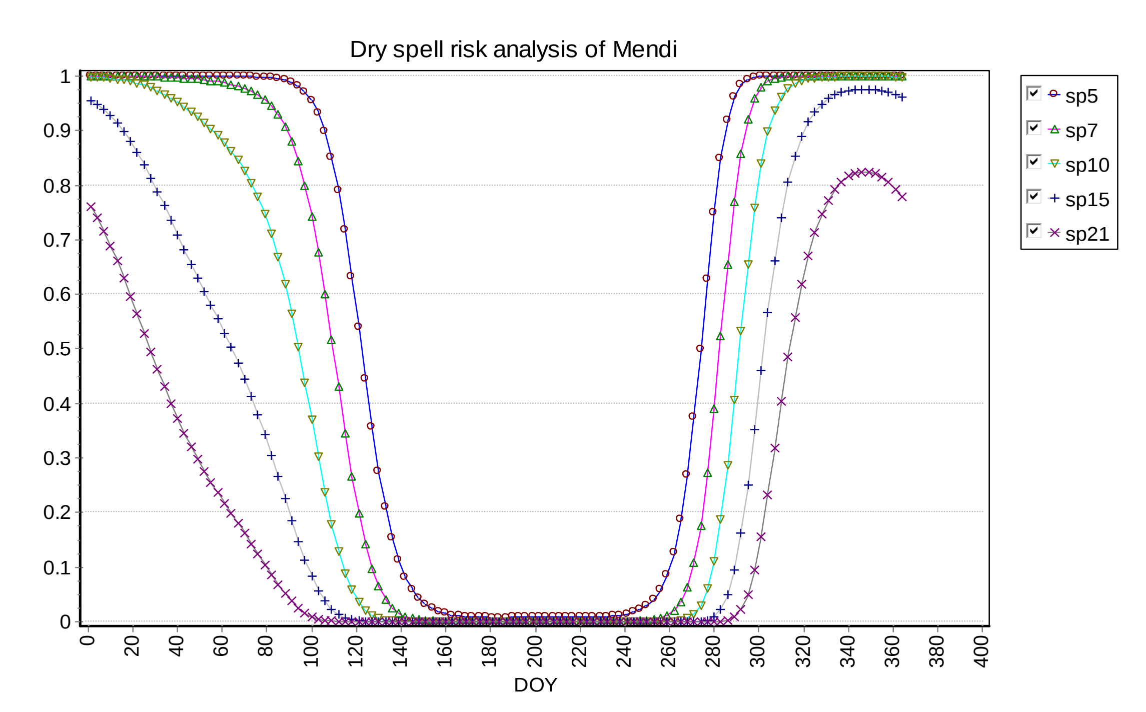

Figure 6: Dry spell risk analysis of Mendi

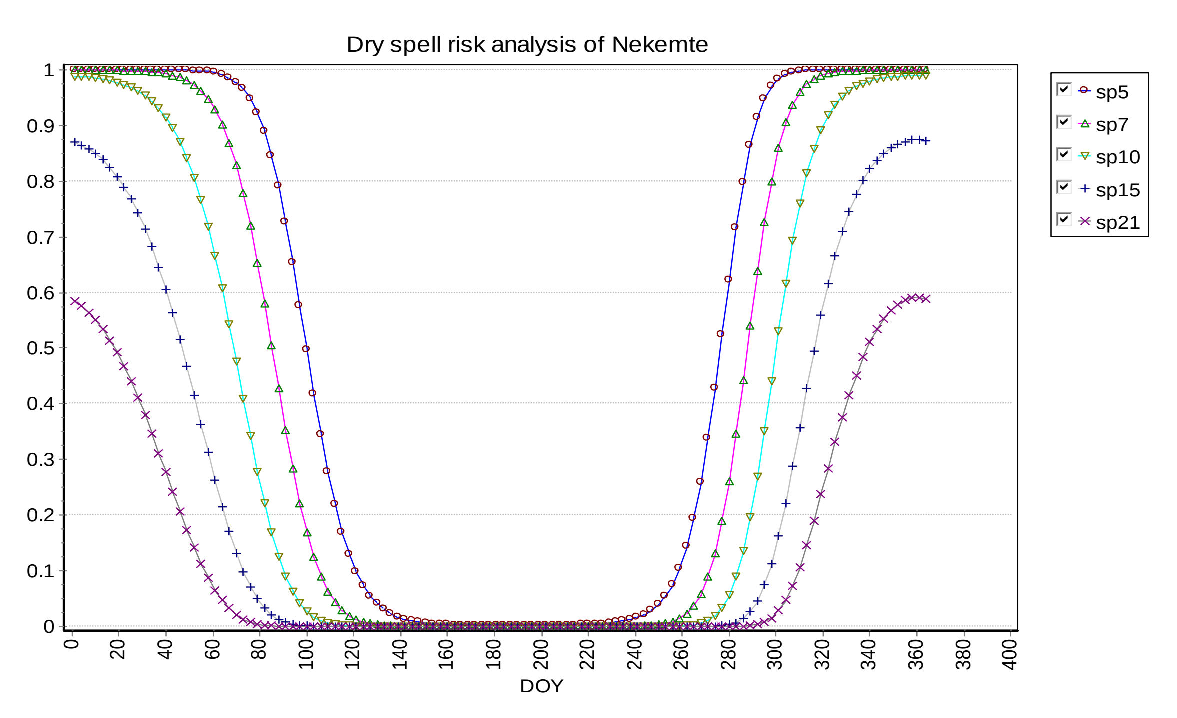

Figure 7: Dry spell risk analysis of Nekemte

In northern part of the basin, some of selected station like Aykel, Gondar and Chewahit shows probability of dry spell occurrence of 5 days length was above 95% in all stations at the beginning of April (DOY 92).

On the other hand, the observed probability of dry spell occurrence greater than 7 days length was 90%, 95% and 100% at Chewahit, Gondar and Aykel respectively at the beginning of April. Whereas, the probability of dry spell occurrence greater than 10 days length were observed being 80% at Aykel, 70% at Gondar and 60% at Chewahit at the start of April.

Also the probability of dry spell occurrence greater than 15 day is 40% at Aykel, 30% at Gondar and 20% at Chewahit at the start of April. The probability of dry spell length of 21 days in this region is less than 10% at the beginning of April.

The probabilities of dry spell length start to decrease beginning at April up to end of mid-June for all for all spell lengths studied. The probability of dry spell length starting from mid-June up to beginning of August (DOY 214) were at 0% for all spell lengths analyzed at all stations.

The probability of dry spells begins to rise starting from August onwards. From this region, dry spell risk analysis of Gondar and Aykel is shown in figure below.

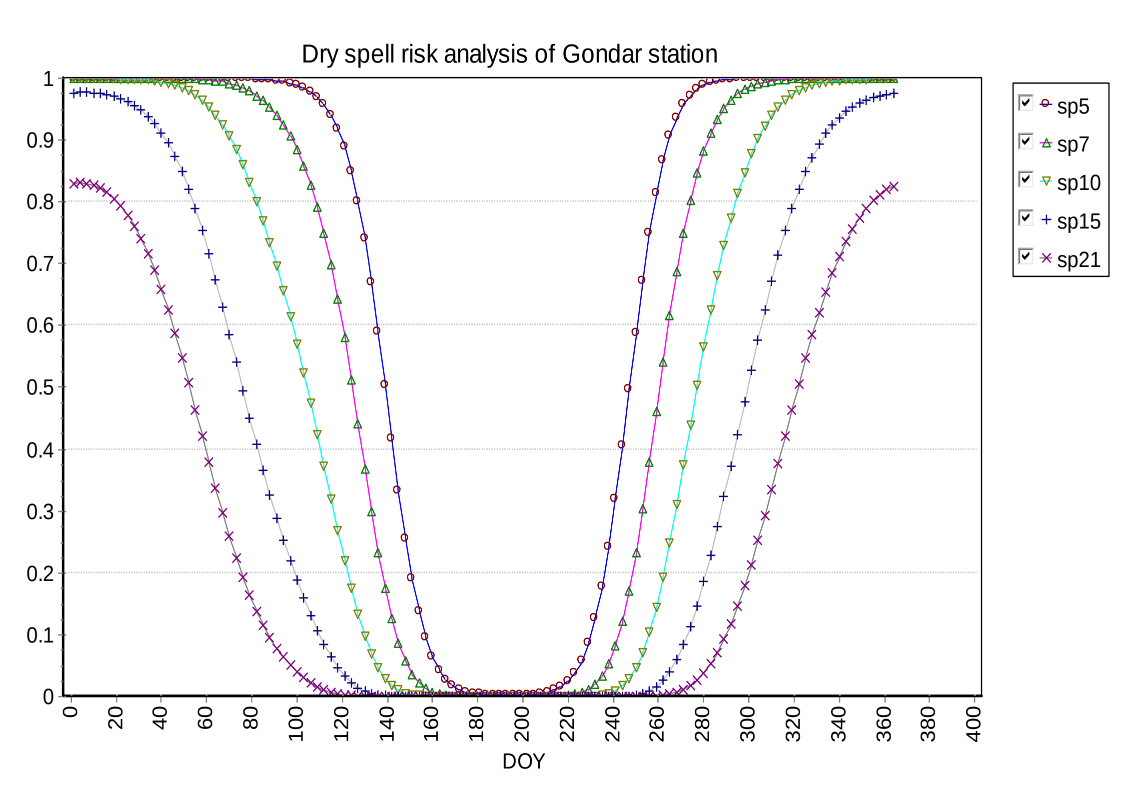

Figure 8: Dry spell risk analysis of Gondar

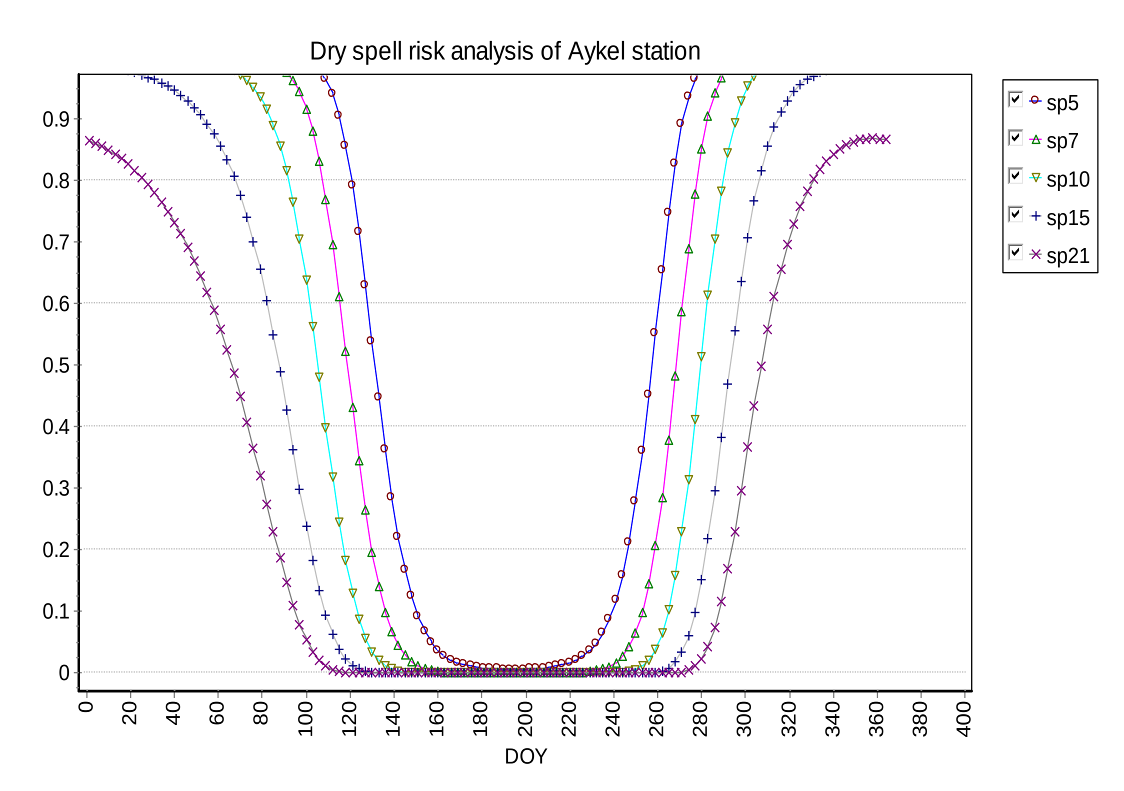

Figure 9: Dry spell risk analysis of Aykel

In the eastern part of the basin, some of selected station like Debre Berhan, Alem Ketema and Mehal Meda shows probability of dry spell occurrence of 5 days length was above 95% at the beginning of April (DOY 92).

On the other hand, the observed probability of dry spell occurrence greater than 7 days length was 75% at Alem Ketema, 80% at Debre Berhan and Mehal Meda at the beginning of April. The probability of dry spell occurrence greater than 10 day is 35% at Alem Ketema and 40% Debre Berhan and Mehal Meda.

Whereas, the probability of dry spell occurrence greater than 15 days length were observed being 10% in Alem Ketema, Debre Berhan and Mehal Meda at the beginning of April. In addition, probability of dry spell occurrence greater than 21 day is 0% at all stations at the beginning of April.

Dry spell probability is decreased from May 1st (DOY 122) to July (DOY 183) and stays less than 5% starting from July 1stto end of July. The probabilities of dry spell begin to rise starting from August 1st on wards. From this region, dry spell risk analysis of Debre Berhan and Alem Ketema is shown in figure below.

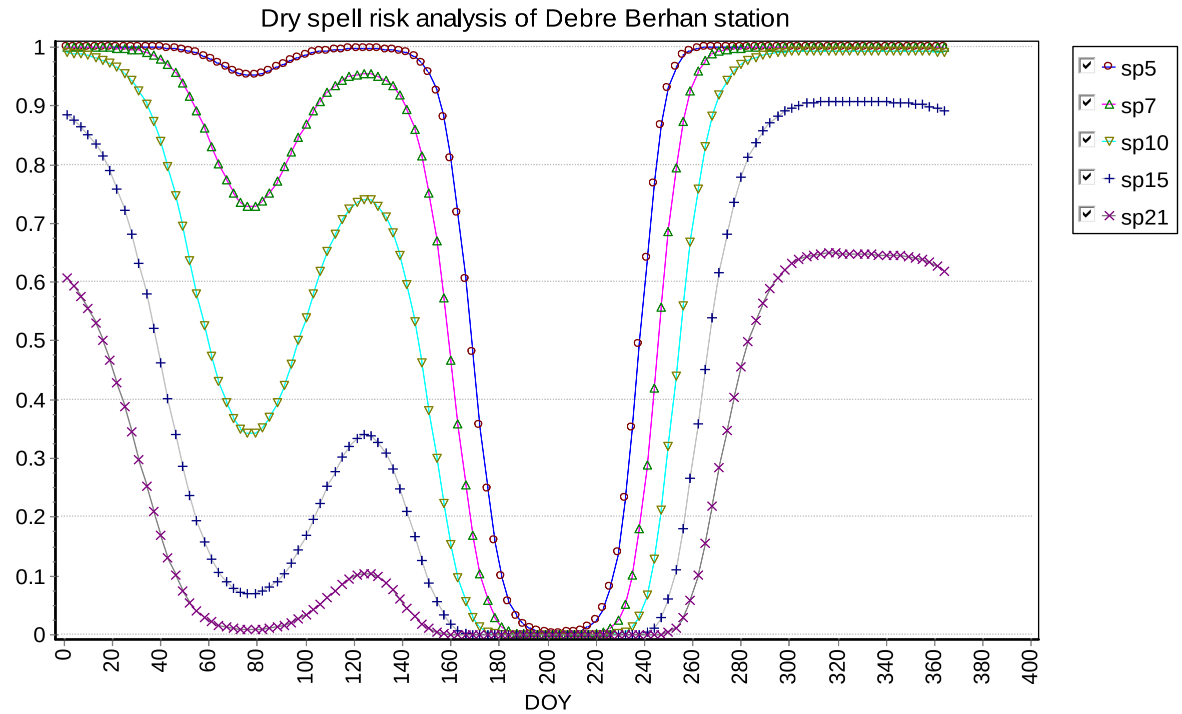

Figure 10: Dry spell risk analysis of Debre Berhan

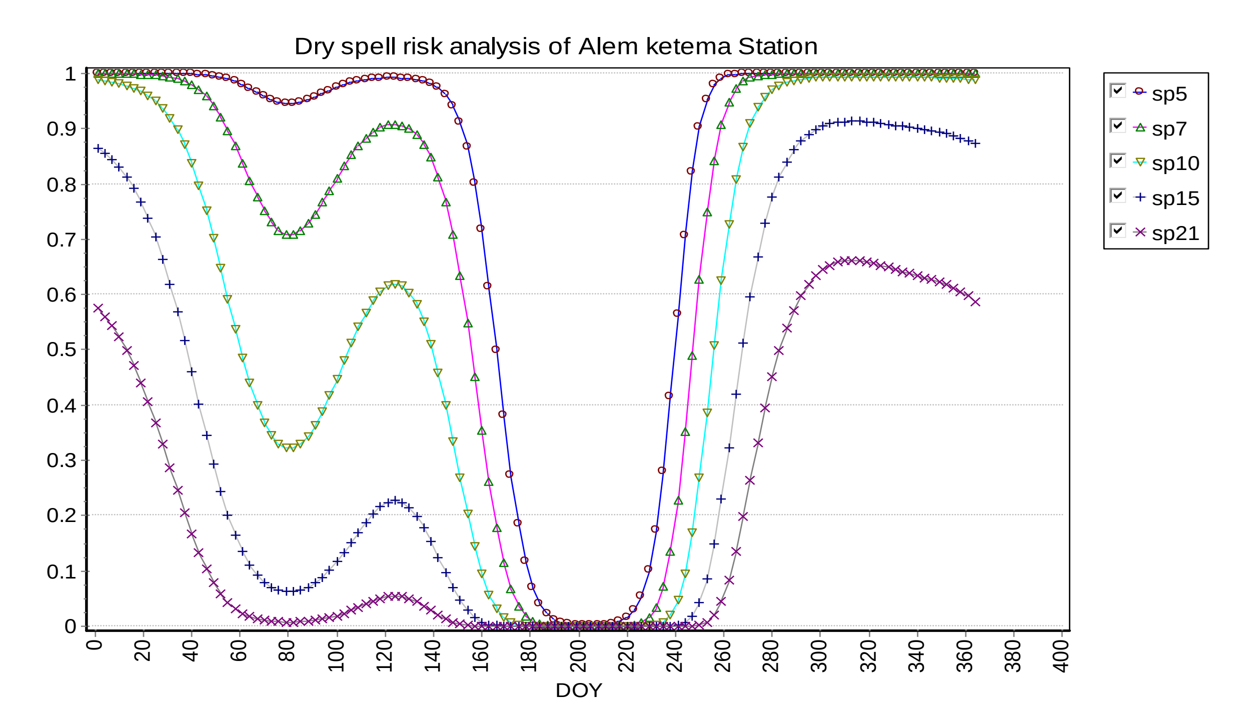

Figure 11: Dry spell risk analysis of Alem Ketema

Generally dry spell in this region increases from March 2nd week to May 1st and from August 1st onwards.

In Central part of the basin, some of selected station like Felege Berhan, Dembecha and Debre Markos shows the probability of dry spell occurrence of 5 days length was above 95% at the beginning of April (DOY 92).

On the other hand, the observed probability of dry spell occurrence greater than 7 days length was 75% at Felege Berhan, 80% at Dembecha and 50% at Debre Markos at the beginning of April. Whereas, the probability of dry spell occurrence greater than 10 days length were observed being 45% at Dembecha, 25% at Felege Berhan, 15% at Debre Markos at the start of April.

In addition, the probability of dry spell occurrence greater than 15 day is 10% at Dembecha, 5% at Felege Berhan, 0% at Debre Markos at the start of April.

In addition, probability of dry spell occurrence greater than 21 day is 5% at all stations at the beginning of April.

The probabilities of dry spell length start to decrease beginning at April up to end of mid-June for all for all spell lengths studied. The probability of dry spell length starting from mid-June up to beginning of August (DOY 214) were at 0% for all spell lengths analyzed at all stations. The probability of dry spells begins to rise starting from August onwards. From this region, dry spell risk analysis of Dembecha and Felege Berhan is shown in figure below.

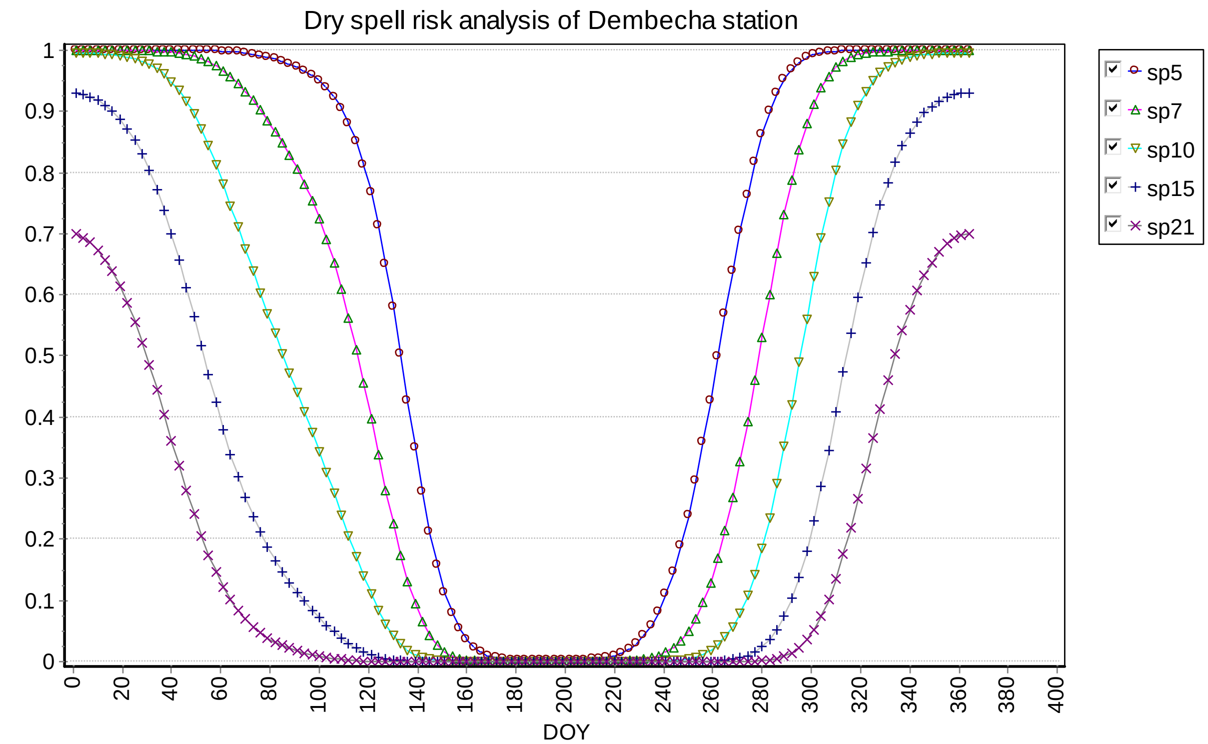

Figure 12: Dry spell risk analysis of Dembecha

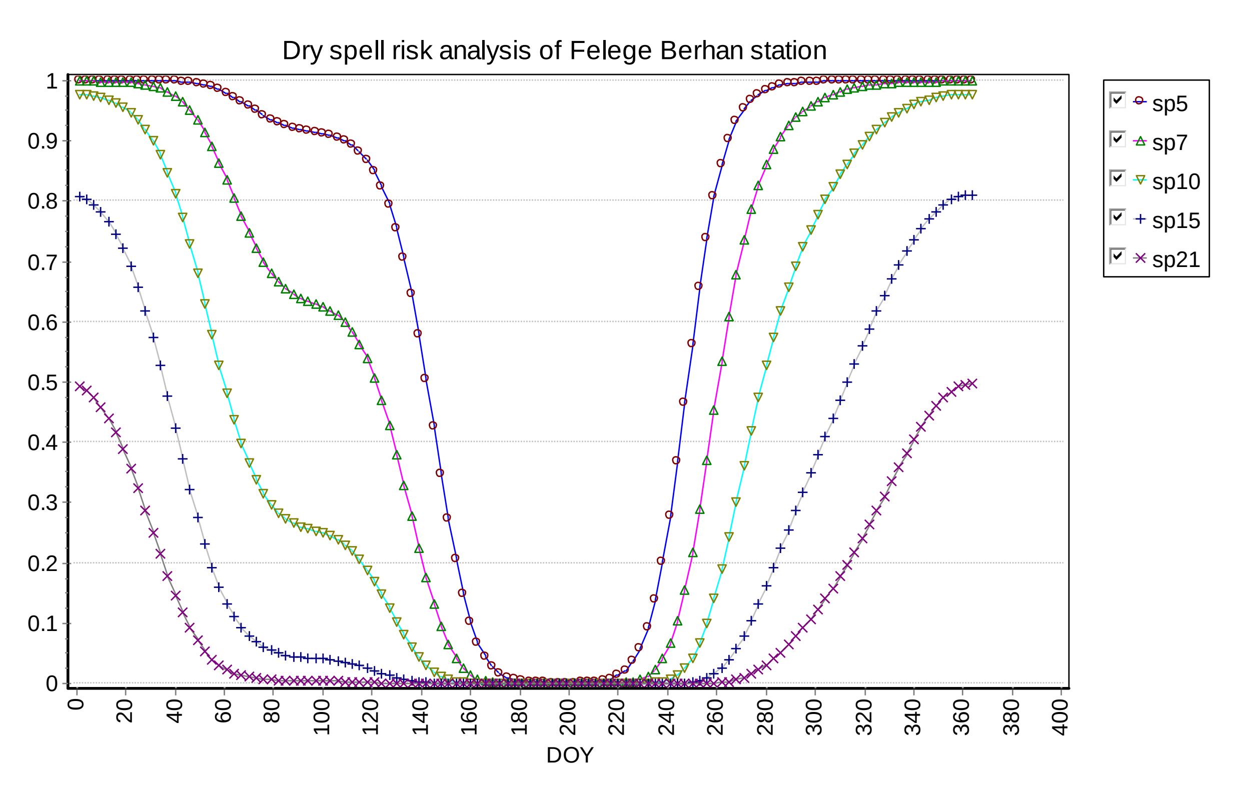

Figure 13: Dry spell risk analysis of Felege Berhan

Generally, more than 5 continuous days of no rain are common over most parts of the basin.

5. Conclusion and Recommendations

5.1. Conclusion

Due to seasonal rainfall variability in Ethiopia, analysis of intra seasonal rainfall variability and its trend were found to be crucial for agricultural planning and water management practices. In response to this, the present study aimed at determining intra-seasonal rainfall variability such as; rainfall onset, cessation, LGP, dry spell analysis and examine its trend in the Upper Blue Nile basin.

The onset and cessation dates were identified for 33 stations spatially distributed in Upper Blue Nile basin.

This information is very important to farmers in the region in deciding on crop types to be cultivated and on planning sowing dates as a function of observed onset dates.

The onset of rainfall is moderately variable, with standard deviation across the basin ranging from 13 to 35 and coefficient variation 9.1 to 19.9. The cessation of rainfall has low variation having coefficient of variation range from 2.65 to 7.07. The LGP shows high variation in the basin having coefficient of variation 9.4 to 25.93. In addition, LGP value is higher in the Southwestern part of basin when related to North and Eastern part of the basin.

Also the basin is classified using Agro-climatic classification based on LGP. According to this classification most of stations in the Upper Blue Nile basin grouped under Moist (M) agro-climatic conditions with the exception of stations in southwestern part of the basin (e.g. Nekemte and Bedele) which is Sub-Humid (SH) and the stations in the eastern part of the basin (e.g. Debre Berhan, Alem Ketema and Mehal Meda) which is Sub-Moist (SM).

The trend of rainfall onset, cessation, LGP and number of rainy day does not show a clear significant trend change (increasing/decreasing) over the Upper Blue Nile basin. Also Result from dry spell analysis show that the probability of getting dry spells of 7, 10, and 15 and 21 days during rainy season (JJAS) is less than 5% except the stations in the in the eastern part of the basin.

5.2. Recommendations

Information of onset of rain, cessation of the rain and LGP and there trend is important for appropriate agricultural decision making so that reduction in yield of the crops is avoided by taking appropriate action.

Since the study is situated in the upper Nile River basin, the findings of this study can contribute much to the future planning and management of water resources of the basin.

Depending on the result obtained in this work, the following useful points are recommended;

1. This research project may serve as a guiding tool for decision makers in providing the time of onset, cessation and LGP of the region so as to select the suitable crop varieties in the basin.
2. The rainfall onset-cession can be used as the base for different rainfed based production analysis and system development.
3. The crop production in the regions better to plan according to the onset and cessation and LGP.
4. In the eastern part of the basin, the LGP is short when related to other part of the basin so it would be useful to design appropriate decision support systems and strategies accordingly.
5. Further study on onset, cessation and LGP has to be done considering ENSO, long years of record and more number of stations.

In general, for sustainable management of agricultural water (through proper planning of rain-fed agriculture) in the area and in order to reduce impacts related to droughts, future research directions should be geared to investigating impacts of climate change on future characteristics of rainy season in the area.

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Appendix

Appendix 1 Double mass curve analysis to check data consistency

Table 25: Double mass curve analysis of Debre Berhan

Year	Annual Rf. Of Debre B.	Comm. Rf. Of Debre B.	Avg. Rf. Of 6 stations	Comm. Rf. Of 6 stations
2014	908.7	908.7	1415.6	1415.6
2013	884.9	1793.6	1166.4	2582.0
2012	1050.9	2844.5	1234.2	3816.2
2011	1060.3	3904.8	1195.9	5012.1
2010	1057.6	4962.4	1013.4	6025.5
2009	906.3	5868.7	1148.4	7174.0
2008	946.7	6815.4	1232.6	8406.5
2007	1083.5	7898.9	1386.9	9793.4
2006	980.3	8879.2	1366.6	11160.0
2005	932.4	9811.6	1190.0	12350.0
2004	1023.2	10834.8	1114.3	13464.3
2003	1006.5	11841.3	1180.4	14644.7
2002	830.1	12671.4	1033.3	15678.0
2001	931.9	13603.3	1160.6	16838.6
2000	985.3	14588.6	1244.7	18083.3
1999	937.0	15525.6	1195.4	19278.7
1998	859.1	16384.7	1202.0	20480.7
1997	948.4	17333.1	1183.6	21664.3
1996	984.0	18317.1	1385.7	23050.0
1995	652.3	18969.4	1144.5	24194.5
1994	885.3	19854.8	1081.3	25275.8
1993	959.1	20813.9	1473.3	26749.1
1992	901.5	21715.4	1330.6	28079.7
1991	882.0	22597.3	1214.9	29294.6
1990	852.4	23449.7	1294.3	30588.8
1989	731.4	24181.1	1321.2	31910.1
1988	940.0	25121.1	1356.0	33266.1
1987	698.5	25819.6	1432.7	34698.8
1986	1068.3	26887.9	1333.6	36032.4

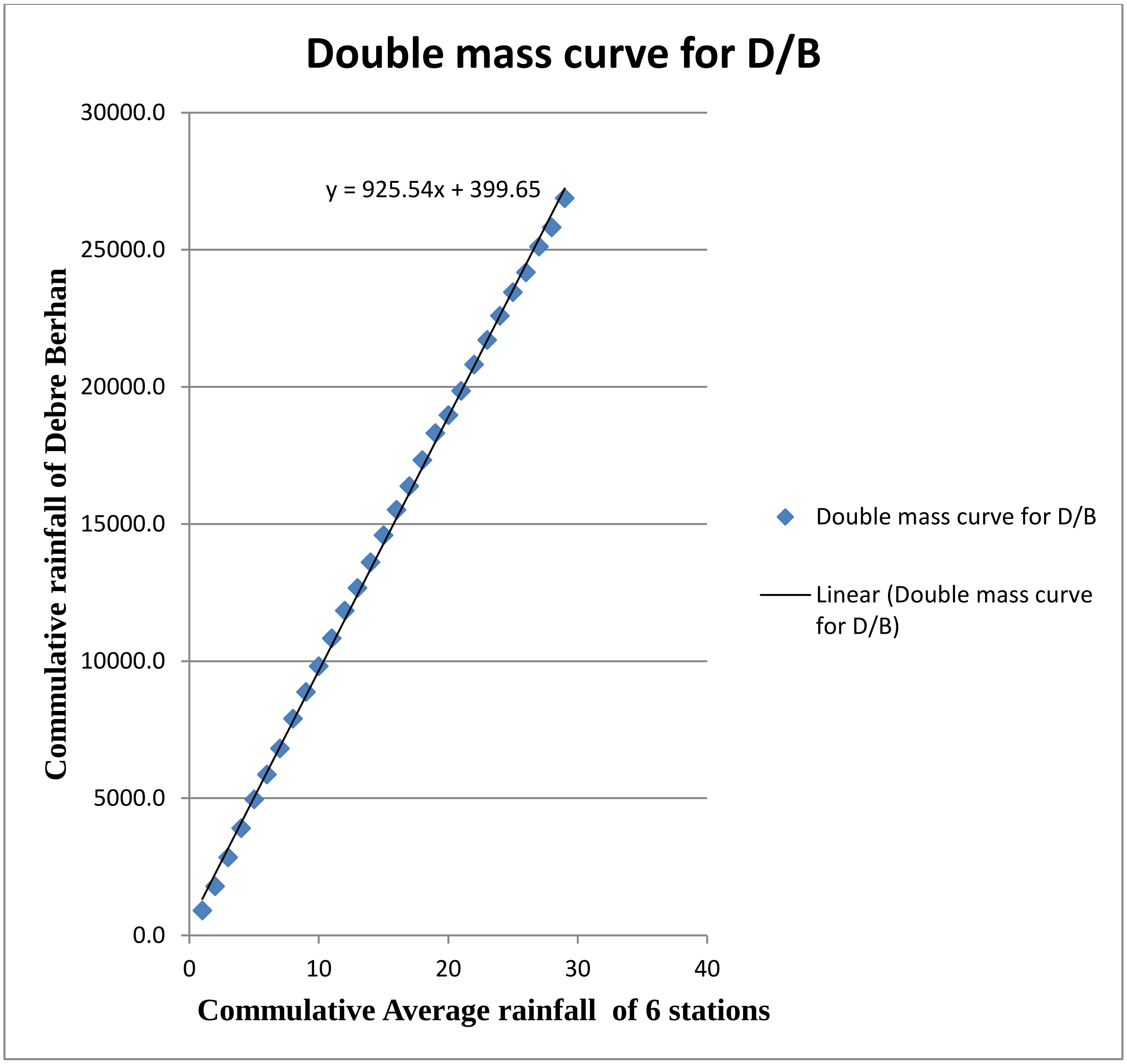

Figure A.1 Double mass curve analysis of Debre Berhan

Appendix 2: Display of daily data

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day												
1	1	32	61	92	122	153	183	214	244	276	306	337
2	2	33	62	93	123	154	184	215	245	277	307	338
3	3	34	63	94	124	155	185	216	246	278	308	339
4	4	35	64	95	125	156	186	217	247	279	309	340
5	5	36	65	96	126	157	187	218	248	280	310	341
6	6	37	66	97	127	158	188	219	249	281	311	342
7	7	38	67	98	128	159	189	220	250	282	312	343
8	8	39	68	99	129	160	190	221	251	283	313	344
9	9	40	69	100	130	161	191	222	252	284	314	345
10	10	41	70	101	131	162	192	223	253	285	315	346
11	11	42	71	102	132	163	193	224	254	286	316	347
12	12	43	72	103	133	164	194	225	255	287	317	348
13	13	44	73	104	134	165	195	226	256	288	318	349
14	14	45	74	105	135	166	196	227	257	289	319	350
15	15	46	75	106	136	167	197	228	258	290	320	351
16	16	47	76	107	137	168	198	229	259	291	321	352
17	17	48	77	108	138	169	199	230	260	292	322	353
18	18	49	78	109	139	170	200	231	261	293	323	354
19	19	50	79	110	140	171	201	232	262	294	324	355
20	20	51	80	111	141	172	202	233	263	295	325	356
21	21	52	81	112	142	173	203	234	264	296	326	357
22	22	53	82	113	143	174	204	235	265	297	327	358
23	23	54	83	114	144	175	205	236	266	298	328	359
24	24	55	84	115	145	176	206	237	267	299	329	360
25	25	56	85	116	146	177	207	238	268	300	330	361
26	26	57	86	117	147	178	208	239	269	301	331	362
27	27	58	87	118	148	179	209	240	270	302	332	363
28	28	59	88	119	149	180	210	241	271	303	333	364
29	29	60	89	120	150	181	211	242	272	304	334	365
30	30		90	121	151	182	212	243	273	305	335	366
31	31		91		152		213		274		336	

Appendix 3 Rainfall onset of different regions of UBNB

Table 26: Rainfall onset of southwestern stations

Year	Nekemte		Sibu Sire		Shambu		Neshi		Gedo		Bedele		Mendi	
1986	149	28-May	159	7-Jun	155	3-Jun	171	19-Jun	160	8-Jun	148	27-May	145	24-May
1987	136	15-May	108	17-Apr	130	9-May	129	8-May	131	10-May	141	20-May	130	9-May
1988	128	7-May	123	2-May	123	2-May	141	20-May	156	4-Jun	122	1-May	134	13-May
1989	131	10-May	134	13-May	135	14-May	161	9-Jun	130	9-May	138	17-May	131	10-May
1990	154	2-Jun	113	22-Apr	162	10-Jun	113	22-Apr	92	1-Apr	107	16-Apr	161	9-Jun
1991	128	7-May	164	12-Jun	161	9-Jun	154	2-Jun	155	3-Jun	110	19-Apr	153	1-Jun
1992	119	28-Apr	110	19-Apr	115	24-Apr	110	19-Apr	157	5-Jun	107	16-Apr	103	12-Apr
1993	128	7-May	92	1-Apr	92	1-Apr	142	21-May	93	2-Apr	128	7-May	127	6-May
1994	110	19-Apr	118	27-Apr	117	26-Apr	94	3-Apr	107	16-Apr	118	27-Apr	112	21-Apr
1995	110	19-Apr	110	19-Apr	114	23-Apr	116	25-Apr	125	4-May	108	17-Apr	94	3-Apr
1996	114	23-Apr	118	27-Apr	119	28-Apr	117	26-Apr	131	10-May	104	13-Apr	92	1-Apr
1997	96	5-Apr	96	5-Apr	112	21-Apr	126	5-May	150	29-May	98	7-Apr	98	7-Apr
1998	148	27-May	152	31-May	152	31-May	152	31-May	114	23-Apr	121	30-Apr	148	27-May
1999	117	26-Apr	117	26-Apr	122	1-May	118	27-Apr	118	27-Apr	103	12-Apr	113	22-Apr
2000	129	8-May	128	7-May	113	22-Apr	114	23-Apr	136	15-May	131	10-May	136	15-May
2001	130	9-May	131	10-May	130	9-May	132	11-May	130	9-May	130	9-May	157	5-Jun
2002	152	31-May	152	31-May	138	17-May	150	29-May	136	15-May	135	14-May	154	2-Jun
2003	142	21-May	156	4-Jun	154	2-Jun	153	1-Jun	154	2-Jun	138	17-May	154	2-Jun
2004	117	26-Apr	146	25-May	143	22-May	145	24-May	157	5-Jun	114	23-Apr	166	14-Jun
2005	143	22-May	144	23-May	143	22-May	143	22-May	144	23-May	142	21-May	124	3-May
2006	125	4-May	123	2-May	92	1-Apr	124	3-May	101	10-Apr	103	12-Apr	143	22-May
2007	118	27-Apr	120	29-Apr	117	26-Apr	97	6-Apr	128	7-May	116	25-Apr	118	27-Apr
2008	93	2-Apr	121	30-Apr	123	2-May	123	2-May	123	2-May	111	20-Apr	101	10-Apr
2009	100	9-Apr	158	6-Jun	155	3-Jun	168	16-Jun	151	30-May	99	8-Apr	101	10-Apr
2010	124	3-May	123	2-May	121	30-Apr	124	3-May	143	22-May	123	2-May	126	5-May
2011	112	21-Apr	112	21-Apr	122	1-May	122	1-May	191	9-Jul	122	1-May	122	1-May
2012	128	7-May	128	7-May	128	7-May	156	4-Jun	176	24-Jun	127	6-May	128	7-May
2013	124	3-May	131	10-May	124	3-May	124	3-May	141	20-May	126	5-May	112	21-Apr
2014	96	5-Apr	94	3-Apr	97	6-Apr	117	26-Apr	94	3-Apr	96	5-Apr	127	6-May
Average	124	3-May	127	5-May	128	6-May	132	11-May	135	14-May	120	28-Apr	128	6-May
Stad. Dev.	16.68		20.01		19.34		20.27		24.36		14.66		21.30	
Cv	13.43		15.76		15.12		15.33		18.00		12.27		16.65	
Max	154		164		162		171		191		148		166	
Min	93		92		92		94		92		96		92	

Table 27: Rainfall onset of northern stations

Year	Aykel		Gondar		Chewahit		Amba Gyorgis		Deke Istifanos		Debre Tabor		Wereta	
1986	155	3-Jun	162	10-Jun	172	20-Jun	163	11-Jun	192	10-Jul	162	10-Jun	170	18-Jun
1987	130	9-May	134	13-May	129	8-May	126	5-May	129	8-May	130	9-May	131	10-May
1988	124	3-May	154	2-Jun	128	7-May	165	13-Jun	154	2-Jun	154	2-Jun	154	2-Jun
1989	125	4-May	144	23-May	165	13-Jun	166	14-Jun	155	3-Jun	162	10-Jun	162	10-Jun
1990	169	17-Jun	181	29-Jun	171	19-Jun	169	17-Jun	171	19-Jun	181	29-Jun	165	13-Jun
1991	160	8-Jun	181	29-Jun	125	4-May	137	16-May	183	1-Jul	120	29-Apr	107	16-Apr
1992	160	8-Jun	160	8-Jun	154	2-Jun	109	18-Apr	149	28-May	115	24-Apr	173	21-Jun
1993	143	22-May	150	29-May	119	28-Apr	128	7-May	145	24-May	92	1-Apr	141	20-May
1994	155	3-Jun	145	24-May	158	6-Jun	161	9-Jun	162	10-Jun	156	4-Jun	164	12-Jun
1995	147	26-May	113	22-Apr	151	30-May	177	25-Jun	128	7-May	180	28-Jun	168	16-Jun
1996	141	20-May	116	25-Apr	120	29-Apr	130	9-May	115	24-Apr	131	10-May	120	29-Apr
1997	133	12-May	135	14-May	110	19-Apr	97	6-Apr	128	7-May	138	17-May	140	19-May
1998	153	1-Jun	162	10-Jun	148	27-May	162	10-Jun	170	18-Jun	176	24-Jun	170	18-Jun
1999	118	27-Apr	135	14-May	114	23-Apr	173	21-Jun	174	22-Jun	173	21-Jun	130	9-May
2000	160	8-Jun	153	1-Jun	155	3-Jun	161	9-Jun	174	22-Jun	108	17-Apr	173	21-Jun
2001	138	17-May	144	23-May	153	1-Jun	164	12-Jun	157	5-Jun	131	10-May	159	7-Jun
2002	148	27-May	165	13-Jun	166	14-Jun	149	28-May	161	9-Jun	167	15-Jun	166	14-Jun
2003	175	23-Jun	149	28-May	173	21-Jun	166	14-Jun	163	11-Jun	180	28-Jun	154	2-Jun
2004	156	4-Jun	162	10-Jun	169	17-Jun	167	15-Jun	158	6-Jun	163	11-Jun	172	20-Jun
2005	162	10-Jun	164	12-Jun	144	23-May	174	22-Jun	165	13-Jun	164	12-Jun	164	12-Jun
2006	128	7-May	139	18-May	139	18-May	163	11-Jun	152	31-May	125	4-May	141	20-May
2007	125	4-May	148	27-May	116	25-Apr	146	25-May	153	1-Jun	117	26-Apr	153	1-Jun
2008	98	7-Apr	122	1-May	123	2-May	155	3-Jun	124	3-May	121	30-Apr	125	4-May
2009	144	23-May	155	3-Jun	172	20-Jun	171	19-Jun	157	5-Jun	179	27-Jun	179	27-Jun
2010	142	21-May	149	28-May	121	30-Apr	154	2-Jun	168	16-Jun	163	11-Jun	163	11-Jun
2011	131	10-May	131	10-May	131	10-May	142	21-May	138	17-May	136	15-May	137	16-May
2012	129	8-May	162	10-Jun	159	7-Jun	176	24-Jun	157	5-Jun	170	18-Jun	170	18-Jun
2013	165	13-Jun	134	13-May	145	24-May	139	18-May	174	22-Jun	164	12-Jun	164	12-Jun
2014	101	10-Apr	119	28-Apr	118	27-Apr	173	21-Jun	119	28-Apr	102	11-Apr	118	27-Apr
Average	142	20-May	147	26-May	143	22-May	154	1-Jun	154	2-Jun	147	25-May	153	31-May
Stad. Dev.	19.14		17.58		20.85		20.45		19.43		26.63		19.61	
Cv	13.49		11.95		14.58		13.29		12.59		18.13		12.83	
Max	175		181		173		177		192		181		179	
Min	98		113		110		97		115		92		107	

Table 28: Rainfall onset of eastern stations

Year	Fiche		Debre Berhan		Alem Ketema		Mehal Meda		Derba	
1986	92	1-Apr	154	2-Jun	173	21-Jun	173	21-Jun	109	18-Apr
1987	141	20-May	218	5-Aug	187	5-Jul	159	7-Jun	130	9-May
1988	186	4-Jul	192	10-Jul	186	4-Jul	98	7-Apr	159	7-Jun
1989	160	8-Jun	190	8-Jul	188	6-Jul	92	1-Apr	160	8-Jun
1990	185	3-Jul	184	2-Jul	185	3-Jul	185	3-Jul	176	24-Jun
1991	175	23-Jun	173	21-Jun	178	26-Jun	178	26-Jun	160	8-Jun
1992	180	28-Jun	192	10-Jul	181	29-Jun	197	15-Jul	179	27-Jun
1993	104	13-Apr	185	3-Jul	132	11-May	188	6-Jul	134	13-May
1994	177	25-Jun	176	24-Jun	177	25-Jun	187	5-Jul	161	9-Jun
1995	182	30-Jun	189	7-Jul	189	7-Jul	95	4-Apr	183	1-Jul
1996	133	12-May	157	5-Jun	157	5-Jun	135	14-May	133	12-May
1997	173	21-Jun	152	31-May	176	24-Jun	182	30-Jun	172	20-Jun
1998	176	24-Jun	106	15-Apr	178	26-Jun	184	2-Jul	116	25-Apr
1999	180	28-Jun	180	28-Jun	181	29-Jun	180	28-Jun	151	30-May
2000	182	30-Jun	177	25-Jun	180	28-Jun	180	28-Jun	189	7-Jul
2001	168	16-Jun	185	3-Jul	175	23-Jun	112	21-Apr	169	17-Jun
2002	192	10-Jul	195	13-Jul	193	11-Jul	193	11-Jul	168	16-Jun
2003	173	21-Jun	173	21-Jun	174	22-Jun	174	22-Jun	175	23-Jun
2004	171	19-Jun	170	18-Jun	177	25-Jun	177	25-Jun	178	26-Jun
2005	181	29-Jun	108	17-Apr	109	18-Apr	116	25-Apr	117	26-Apr
2006	165	13-Jun	187	5-Jul	175	23-Jun	186	4-Jul	186	4-Jul
2007	172	20-Jun	176	24-Jun	168	16-Jun	178	26-Jun	148	27-May
2008	189	7-Jul	188	6-Jul	187	5-Jul	188	6-Jul	172	20-Jun
2009	186	4-Jul	184	2-Jul	190	8-Jul	182	30-Jun	188	6-Jul
2010	99	8-Apr	104	13-Apr	189	7-Jul	98	7-Apr	172	20-Jun
2011	180	28-Jun	187	5-Jul	188	6-Jul	195	13-Jul	146	25-May
2012	96	5-Apr	172	20-Jun	96	5-Apr	179	27-Jun	173	21-Jun
2013	166	14-Jun	185	3-Jul	166	14-Jun	167	15-Jun	170	18-Jun
2014	96	5-Apr	187	5-Jul	174	22-Jun	204	22-Jul	96	5-Apr
Average	161	8-Jun	173	21-Jun	173	20-Jun	164	12-Jun	158	5-Jun
Stad. Dev.	32.01		26.65		22.89		34.93		25.27	
Cv	19.92		15.38		13.25		21.27		16.04	
Max	192		218		193		204		189	
Min	92		104		96		92		96	

Table 29: Rainfall onset of central stations

Year	Dembecha		Gundo Wein		Felege Berhan		Dejen		Abay Sheleko		Gohatsion		Yetemen		Debre Markos	
1986	94	3-Apr	166	14-Jun	163	11-Jun	177	25-Jun	163	11-Jun	163	11-Jun	147	26-May	162	10-Jun
1987	132	11-May	130	9-May	127	6-May	132	11-May	138	17-May	141	20-May	142	21-May	131	10-May
1988	139	18-May	154	2-Jun	154	2-Jun	179	27-Jun	179	27-Jun	158	6-Jun	184	2-Jul	154	2-Jun
1989	207	25-Jul	163	11-Jun	164	12-Jun	161	9-Jun	187	5-Jul	177	25-Jun	161	9-Jun	164	12-Jun
1990	155	3-Jun	179	27-Jun	166	14-Jun	155	3-Jun	180	28-Jun	183	1-Jul	120	29-Apr	155	3-Jun
1991	149	28-May	174	22-Jun	178	26-Jun	165	13-Jun	128	7-May	166	14-Jun	166	14-Jun	128	7-May
1992	117	26-Apr	160	8-Jun	115	24-Apr	159	7-Jun	156	4-Jun	179	27-Jun	181	29-Jun	160	8-Jun
1993	134	13-May	138	17-May	92	1-Apr	135	14-May	134	13-May	100	9-Apr	128	7-May	96	5-Apr
1994	124	3-May	132	11-May	161	9-Jun	155	3-Jun	182	30-Jun	177	25-Jun	160	8-Jun	132	11-May
1995	100	9-Apr	111	20-Apr	112	21-Apr	115	24-Apr	116	25-Apr	115	24-Apr	107	16-Apr	112	21-Apr
1996	112	21-Apr	157	5-Jun	96	5-Apr	129	8-May	129	8-May	157	5-Jun	131	10-May	96	5-Apr
1997	101	10-Apr	98	7-Apr	98	7-Apr	142	21-May	139	18-May	150	29-May	138	17-May	119	28-Apr
1998	161	9-Jun	176	24-Jun	151	30-May	153	1-Jun	177	25-Jun	153	1-Jun	165	13-Jun	153	1-Jun
1999	149	28-May	115	24-Apr	155	3-Jun	123	2-May	177	25-Jun	166	14-Jun	154	2-Jun	151	30-May
2000	155	3-Jun	160	8-Jun	176	24-Jun	161	9-Jun	179	27-Jun	161	9-Jun	176	24-Jun	164	12-Jun
2001	131	10-May	149	28-May	148	27-May	153	1-Jun	153	1-Jun	153	1-Jun	147	26-May	137	16-May
2002	156	4-Jun	151	30-May	173	21-Jun	171	19-Jun	172	20-Jun	173	21-Jun	165	13-Jun	165	13-Jun
2003	157	5-Jun	167	15-Jun	174	22-Jun	175	23-Jun	166	14-Jun	168	16-Jun	174	22-Jun	168	16-Jun
2004	167	15-Jun	168	16-Jun	167	15-Jun	173	21-Jun	173	21-Jun	96	5-Apr	170	18-Jun	164	12-Jun
2005	170	18-Jun	166	14-Jun	167	15-Jun	105	14-Apr	177	25-Jun	166	14-Jun	117	26-Apr	172	20-Jun
2006	124	3-May	151	30-May	92	1-Apr	98	7-Apr	92	1-Apr	151	30-May	134	13-May	100	9-Apr
2007	134	13-May	97	6-Apr	146	25-May	136	15-May	135	14-May	169	17-Jun	137	16-May	130	9-May
2008	96	5-Apr	125	4-May	122	1-May	181	29-Jun	125	4-May	151	30-May	153	1-Jun	122	1-May
2009	169	17-Jun	174	22-Jun	182	30-Jun	168	16-Jun	183	1-Jul	170	18-Jun	194	12-Jul	155	3-Jun
2010	143	22-May	94	3-Apr	122	1-May	102	11-Apr	125	4-May	126	5-May	114	23-Apr	96	5-Apr
2011	114	23-Apr	164	12-Jun	138	17-May	116	25-Apr	172	20-Jun	138	17-May	115	24-Apr	137	16-May
2012	170	18-Jun	156	4-Jun	148	27-May	173	21-Jun	173	21-Jun	173	21-Jun	173	21-Jun	175	23-Jun
2013	144	23-May	137	16-May	137	16-May	125	4-May	167	15-Jun	125	4-May	156	4-Jun	134	13-May
2014	97	6-Apr	122	1-May	145	24-May	144	23-May	119	28-Apr	173	21-Jun	97	6-Apr	96	5-Apr
Average	138	16-May	146	25-May	144	22-May	147	25-May	155	3-Jun	154	2-Jun	148	27-May	139	17-May
Stad. Dev.	27.45		25.24		27.58		24.91		25.84		22.95		25.23		25.71	
Cv	19.90		17.29		19.18		16.95		16.67		14.87		16.99		18.51	
Max	207		179		182		181		187		183		194		175	
Min	94		94		92		98		92		96		97		96	

Appendix 4 Rainfall cessations of different regions of UBNB

Table 30: Rainfall cessation of southwestern stations

Year	Nekemte		Bedele		Sibu Sire		Mendi		Shambu		Neshi		Gedo	
1986	325	20-Nov	344	9-Dec	327	22-Nov	324	19-Nov	313	8-Nov	314	9-Nov	296	22-Oct
1987	342	7-Dec	336	1-Dec	339	4-Dec	325	20-Nov	334	29-Nov	322	17-Nov	325	20-Nov
1988	340	5-Dec	329	24-Nov	329	24-Nov	327	22-Nov	311	6-Nov	314	9-Nov	316	11-Nov
1989	327	22-Nov	325	20-Nov	312	7-Nov	330	25-Nov	325	20-Nov	296	22-Oct	289	15-Oct
1990	338	3-Dec	337	2-Dec	312	7-Nov	316	11-Nov	301	27-Oct	303	29-Oct	296	22-Oct
1991	334	29-Nov	307	2-Nov	306	1-Nov	317	12-Nov	298	24-Oct	290	16-Oct	299	25-Oct
1992	338	3-Dec	356	21-Dec	330	25-Nov	334	29-Nov	355	20-Dec	327	22-Nov	307	2-Nov
1993	322	17-Nov	330	25-Nov	322	17-Nov	333	28-Nov	327	22-Nov	320	15-Nov	297	23-Oct
1994	325	20-Nov	350	15-Dec	303	29-Oct	328	23-Nov	288	14-Oct	294	20-Oct	288	14-Oct
1995	327	22-Nov	339	4-Dec	309	4-Nov	327	22-Nov	327	22-Nov	321	16-Nov	327	22-Nov
1996	345	10-Dec	349	14-Dec	301	27-Oct	323	18-Nov	300	26-Oct	315	10-Nov	291	17-Oct
1997	353	18-Dec	346	11-Dec	348	13-Dec	335	30-Nov	313	8-Nov	340	5-Dec	351	16-Dec
1998	336	1-Dec	338	3-Dec	337	2-Dec	329	24-Nov	321	16-Nov	337	2-Dec	332	27-Nov
1999	326	21-Nov	326	21-Nov	340	5-Dec	324	19-Nov	326	21-Nov	314	9-Nov	339	4-Dec
2000	346	11-Dec	340	5-Dec	341	6-Dec	335	30-Nov	346	11-Dec	335	30-Nov	314	9-Nov
2001	327	22-Nov	325	20-Nov	342	7-Dec	323	18-Nov	320	15-Nov	339	4-Dec	322	17-Nov
2002	325	20-Nov	323	18-Nov	324	19-Nov	361	26-Dec	298	24-Oct	311	6-Nov	291	17-Oct
2003	337	2-Dec	358	23-Dec	307	2-Nov	346	11-Dec	295	21-Oct	294	20-Oct	294	20-Oct
2004	328	23-Nov	307	2-Nov	327	22-Nov	294	20-Oct	306	1-Nov	308	3-Nov	306	1-Nov
2005	345	10-Dec	346	11-Dec	345	10-Dec	325	20-Nov	304	30-Oct	305	31-Oct	293	19-Oct
2006	337	2-Dec	363	28-Dec	325	20-Nov	324	19-Nov	323	18-Nov	323	18-Nov	323	18-Nov
2007	334	29-Nov	339	4-Dec	325	20-Nov	334	29-Nov	312	7-Nov	312	7-Nov	309	4-Nov
2008	333	28-Nov	333	28-Nov	340	5-Dec	318	13-Nov	295	21-Oct	335	30-Nov	294	20-Oct
2009	323	18-Nov	319	14-Nov	321	16-Nov	322	17-Nov	313	8-Nov	320	15-Nov	320	15-Nov
2010	352	17-Dec	312	7-Nov	303	29-Oct	321	16-Nov	312	7-Nov	312	7-Nov	290	16-Oct
2011	338	3-Dec	339	4-Dec	336	1-Dec	334	29-Nov	297	23-Oct	296	22-Oct	291	17-Oct
2012	330	25-Nov	295	21-Oct	330	25-Nov	324	19-Nov	298	24-Oct	331	26-Nov	306	1-Nov
2013	340	5-Dec	347	12-Dec	347	12-Dec	319	14-Nov	317	12-Nov	315	10-Nov	301	27-Oct
2014	348	13-Dec	317	12-Nov	309	4-Nov	307	2-Nov	305	31-Oct	308	3-Nov	304	30-Oct
Average	335	30-Nov	334	28-Nov	325	20-Nov	326	21-Nov	313	8-Nov	316	10-Nov	307	2-Nov
Stad. Dev.	8.87		16.30		14.69		11.67		15.75		14.25		16.71	
Cv	2.65		4.89		4.51		3.58		5.03		4.51		5.44	
Max	353		363		348		361		355		340		351	
Min	322		295		301		294		288		290		288	

Table 31: Rainfall cessation of northern stations

Year	Aykel		Gondar		Chewahit		Amba Gyorgis		Deke Istifanos		Debre Tabor		Wereta	
1986	323	18-Nov	334	29-Nov	293	19-Oct	325	20-Nov	308	3-Nov	333	28-Nov	297	23-Oct
1987	326	21-Nov	338	3-Dec	337	2-Dec	330	25-Nov	298	24-Oct	330	25-Nov	327	22-Nov
1988	330	25-Nov	340	5-Dec	331	26-Nov	330	25-Nov	312	7-Nov	340	5-Dec	312	7-Nov
1989	328	23-Nov	322	17-Nov	322	17-Nov	318	13-Nov	291	17-Oct	326	21-Nov	326	21-Nov
1990	313	8-Nov	300	26-Oct	299	25-Oct	300	26-Oct	306	1-Nov	314	9-Nov	297	23-Oct
1991	335	30-Nov	326	21-Nov	319	14-Nov	335	30-Nov	264	20-Sep	308	3-Nov	326	21-Nov
1992	264	20-Sep	334	29-Nov	328	23-Nov	308	3-Nov	320	15-Nov	337	2-Dec	327	22-Nov
1993	314	9-Nov	342	7-Dec	330	25-Nov	318	13-Nov	321	16-Nov	322	17-Nov	321	16-Nov
1994	335	30-Nov	340	5-Dec	287	13-Oct	286	12-Oct	288	14-Oct	287	13-Oct	294	20-Oct
1995	326	21-Nov	310	5-Nov	311	6-Nov	275	1-Oct	271	27-Sep	286	12-Oct	284	10-Oct
1996	314	9-Nov	314	9-Nov	312	7-Nov	287	13-Oct	312	7-Nov	313	8-Nov	314	9-Nov
1997	335	30-Nov	337	2-Dec	338	3-Dec	307	2-Nov	306	1-Nov	324	19-Nov	326	21-Nov
1998	318	13-Nov	315	10-Nov	313	8-Nov	280	6-Oct	321	16-Nov	315	10-Nov	320	15-Nov
1999	322	17-Nov	324	19-Nov	322	17-Nov	322	17-Nov	323	18-Nov	314	9-Nov	313	8-Nov
2000	336	1-Dec	323	18-Nov	337	2-Dec	321	16-Nov	314	9-Nov	343	8-Dec	333	28-Nov
2001	324	19-Nov	317	12-Nov	323	18-Nov	319	14-Nov	309	4-Nov	320	15-Nov	326	21-Nov
2002	324	19-Nov	291	17-Oct	286	12-Oct	307	2-Nov	301	27-Oct	293	19-Oct	319	14-Nov
2003	315	10-Nov	315	10-Nov	308	3-Nov	293	19-Oct	306	1-Nov	301	27-Oct	306	1-Nov
2004	307	2-Nov	307	2-Nov	308	3-Nov	328	23-Nov	308	3-Nov	306	1-Nov	306	1-Nov
2005	325	20-Nov	329	24-Nov	330	25-Nov	306	1-Nov	303	29-Oct	303	29-Oct	308	3-Nov
2006	323	18-Nov	323	18-Nov	321	16-Nov	323	18-Nov	333	28-Nov	323	18-Nov	323	18-Nov
2007	334	29-Nov	324	19-Nov	329	24-Nov	275	1-Oct	332	27-Nov	298	24-Oct	291	17-Oct
2008	334	29-Nov	294	20-Oct	294	20-Oct	285	11-Oct	326	21-Nov	326	21-Nov	274	30-Sep
2009	323	18-Nov	323	18-Nov	318	13-Nov	309	4-Nov	319	14-Nov	319	14-Nov	320	15-Nov
2010	320	15-Nov	312	7-Nov	319	14-Nov	264	20-Sep	311	6-Nov	303	29-Oct	303	29-Oct
2011	340	5-Dec	337	2-Dec	335	30-Nov	287	13-Oct	298	24-Oct	335	30-Nov	333	28-Nov
2012	306	1-Nov	304	30-Oct	294	20-Oct	334	29-Nov	318	13-Nov	294	20-Oct	294	20-Oct
2013	311	6-Nov	312	7-Nov	312	7-Nov	300	26-Oct	317	12-Nov	317	12-Nov	312	7-Nov
2014	325	20-Nov	325	20-Nov	325	20-Nov	299	25-Oct	306	1-Nov	305	31-Oct	298	24-Oct
Average	322	16-Nov	321	16-Nov	317	11-Nov	306	31-Oct	308	3-Nov	315	10-Nov	311	6-Nov
Stad. Dev.	14.29		13.90		15.37		19.89		15.69		15.68		15.38	
Cv	4.44		4.33		4.86		6.50		5.09		4.98		4.94	
Max	340		342		338		335		333		343		333	
Min	264		291		286		264		264		286		274	

Table 32: Rainfall cessation of eastern stations

Year	Fiche		Debre Berhan		Alem Ketema		Mehal Meda		Derba	
1986	299	25-Oct	298	24-Oct	299	25-Oct	299	25-Oct	298	24-Oct
1987	288	14-Oct	302	28-Oct	289	15-Oct	301	27-Oct	287	13-Oct
1988	311	6-Nov	292	18-Oct	313	8-Nov	312	7-Nov	310	5-Nov
1989	291	17-Oct	293	19-Oct	291	17-Oct	291	17-Oct	292	18-Oct
1990	295	21-Oct	294	20-Oct	296	22-Oct	296	22-Oct	294	20-Oct
1991	300	26-Oct	299	25-Oct	300	26-Oct	300	26-Oct	297	23-Oct
1992	304	30-Oct	304	30-Oct	310	5-Nov	305	31-Oct	336	1-Dec
1993	296	22-Oct	322	17-Nov	299	25-Oct	300	26-Oct	321	16-Nov
1994	286	12-Oct	286	12-Oct	286	12-Oct	287	13-Oct	286	12-Oct
1995	284	10-Oct	287	13-Oct	284	10-Oct	286	12-Oct	293	19-Oct
1996	295	21-Oct	274	30-Sep	286	12-Oct	295	21-Oct	295	21-Oct
1997	290	16-Oct	293	19-Oct	285	11-Oct	350	15-Dec	290	16-Oct
1998	317	12-Nov	305	31-Oct	317	12-Nov	305	31-Oct	336	1-Dec
1999	313	8-Nov	314	9-Nov	325	20-Nov	321	16-Nov	314	9-Nov
2000	303	29-Oct	302	28-Oct	311	6-Nov	300	26-Oct	338	3-Dec
2001	296	22-Oct	301	27-Oct	282	8-Oct	310	5-Nov	283	9-Oct
2002	280	6-Oct	300	26-Oct	285	11-Oct	301	27-Oct	288	14-Oct
2003	295	21-Oct	301	27-Oct	295	21-Oct	294	20-Oct	294	20-Oct
2004	319	14-Nov	300	26-Oct	319	14-Nov	300	26-Oct	288	14-Oct
2005	335	30-Nov	291	17-Oct	304	30-Oct	305	31-Oct	304	30-Oct
2006	292	18-Oct	296	22-Oct	293	19-Oct	320	15-Nov	287	13-Oct
2007	309	4-Nov	310	5-Nov	297	23-Oct	279	5-Oct	309	4-Nov
2008	297	23-Oct	303	29-Oct	297	23-Oct	295	21-Oct	288	14-Oct
2009	271	27-Sep	312	7-Nov	281	7-Oct	312	7-Nov	306	1-Nov
2010	298	24-Oct	287	13-Oct	284	10-Oct	297	23-Oct	295	21-Oct
2011	290	16-Oct	290	16-Oct	290	16-Oct	299	25-Oct	292	18-Oct
2012	295	21-Oct	293	19-Oct	289	15-Oct	289	15-Oct	294	20-Oct
2013	302	28-Oct	304	30-Oct	301	27-Oct	304	30-Oct	302	28-Oct
2014	302	28-Oct	303	29-Oct	304	30-Oct	303	29-Oct	299	25-Oct
Average	298	24-Oct	298	24-Oct	297	22-Oct	302	27-Oct	301	26-Oct
Stad. Dev.	12.72		9.64		11.96		13.15		15.36	
Cv	4.26		3.23		4.03		4.36		5.11	
Max	335		322		325		350		338	
Min	271		274		281		279		283	

Table 33: Rainfall cessation of central stations

Year	Dembecha		Gundo Wein		Felege Berhan		Dejen		Abay Sheleko		Gohatsion		Yetemen		Debre Markos	
1986	334	29-Nov	297	23-Oct	309	4-Nov	294	20-Oct	298	24-Oct	294	20-Oct	297	23-Oct	316	11-Nov
1987	330	25-Nov	336	1-Dec	336	1-Dec	351	16-Dec	303	29-Oct	306	1-Nov	286	12-Oct	328	23-Nov
1988	313	8-Nov	361	26-Dec	321	16-Nov	311	6-Nov	311	6-Nov	311	6-Nov	283	9-Oct	311	6-Nov
1989	327	22-Nov	325	20-Nov	315	10-Nov	314	9-Nov	277	3-Oct	311	6-Nov	325	20-Nov	292	18-Oct
1990	333	28-Nov	331	26-Nov	312	7-Nov	302	28-Oct	301	27-Oct	291	17-Oct	296	22-Oct	301	27-Oct
1991	333	28-Nov	313	8-Nov	297	23-Oct	299	25-Oct	299	25-Oct	299	25-Oct	299	25-Oct	304	30-Oct
1992	335	30-Nov	335	30-Nov	312	7-Nov	331	26-Nov	312	7-Nov	352	17-Dec	286	12-Oct	334	29-Nov
1993	342	7-Dec	331	26-Nov	331	26-Nov	322	17-Nov	318	13-Nov	319	14-Nov	320	15-Nov	312	7-Nov
1994	290	16-Oct	341	6-Dec	287	13-Oct	288	14-Oct	293	19-Oct	287	13-Oct	287	13-Oct	298	24-Oct
1995	309	4-Nov	327	22-Nov	309	4-Nov	310	5-Nov	311	6-Nov	288	14-Oct	294	20-Oct	327	22-Nov
1996	284	10-Oct	315	10-Nov	311	6-Nov	302	28-Oct	302	28-Oct	298	24-Oct	295	21-Oct	301	27-Oct
1997	325	20-Nov	324	19-Nov	353	18-Dec	292	18-Oct	292	18-Oct	353	18-Dec	290	16-Oct	313	8-Nov
1998	332	27-Nov	338	3-Dec	321	16-Nov	318	13-Nov	317	12-Nov	365	30-Dec	317	12-Nov	317	12-Nov
1999	314	9-Nov	321	16-Nov	313	8-Nov	324	19-Nov	314	9-Nov	321	16-Nov	324	19-Nov	326	21-Nov
2000	347	12-Dec	335	30-Nov	335	30-Nov	312	7-Nov	312	7-Nov	354	19-Dec	312	7-Nov	344	9-Dec
2001	320	15-Nov	327	22-Nov	321	16-Nov	320	15-Nov	315	10-Nov	316	11-Nov	311	6-Nov	319	14-Nov
2002	314	9-Nov	315	10-Nov	323	18-Nov	292	18-Oct	285	11-Oct	287	13-Oct	284	10-Oct	299	25-Oct
2003	311	6-Nov	307	2-Nov	315	10-Nov	294	20-Oct	289	15-Oct	292	18-Oct	289	15-Oct	306	1-Nov
2004	327	22-Nov	307	2-Nov	307	2-Nov	307	2-Nov	307	2-Nov	308	3-Nov	306	1-Nov	305	31-Oct
2005	346	11-Dec	328	23-Nov	306	1-Nov	304	30-Oct	313	8-Nov	306	1-Nov	299	25-Oct	317	12-Nov
2006	362	27-Dec	323	18-Nov	323	18-Nov	293	19-Oct	305	31-Oct	322	17-Nov	267	23-Sep	301	27-Oct
2007	312	7-Nov	326	21-Nov	326	21-Nov	295	21-Oct	311	6-Nov	296	22-Oct	311	6-Nov	312	7-Nov
2008	332	27-Nov	301	27-Oct	294	20-Oct	294	20-Oct	294	20-Oct	290	16-Oct	294	20-Oct	295	21-Oct
2009	324	19-Nov	321	16-Nov	321	16-Nov	314	9-Nov	314	9-Nov	313	8-Nov	314	9-Nov	313	8-Nov
2010	325	20-Nov	312	7-Nov	301	27-Oct	295	21-Oct	318	13-Nov	297	23-Oct	318	13-Nov	301	27-Oct
2011	335	30-Nov	292	18-Oct	294	20-Oct	289	15-Oct	290	16-Oct	291	17-Oct	291	17-Oct	303	29-Oct
2012	314	9-Nov	294	20-Oct	294	20-Oct	294	20-Oct	295	21-Oct	294	20-Oct	284	10-Oct	294	20-Oct
2013	351	16-Dec	340	5-Dec	315	10-Nov	317	12-Nov	318	13-Nov	299	25-Oct	297	23-Oct	312	7-Nov
2014	322	17-Nov	357	22-Dec	314	9-Nov	333	28-Nov	323	18-Nov	297	23-Oct	307	2-Nov	305	31-Oct
Average	326	20-Nov	323	18-Nov	314	9-Nov	307	2-Nov	305	30-Oct	309	3-Nov	299	25-Oct	311	5-Nov
Stad. Dev.	16.75		16.82		14.40		15.42		11.68		21.86		14.34		12.51	
Cv	5.14		5.20		4.58		5.02		3.83		7.08		4.79		4.03	
Max	362		361		353		351		323		365		325		344	
Min	284		292		287		288		277		287		267		292	

Appendix 5 LGP of different regions of UBNB

Table 34: LGP of southwestern stations

Year	Nekemte	Sibu Sire	Shambu	Neshi	Gedo	Bedele	Kachise	Mendi
1986	176	168	158	143	136	196	198	179
1987	206	231	204	193	194	195	191	195
1988	212	206	188	173	160	207	175	193
1989	196	178	190	135	159	187	155	199
1990	184	199	139	190	204	230	147	155
1991	206	142	137	136	144	197	133	164
1992	219	220	240	217	150	249	222	231
1993	194	230	235	178	204	202	233	206
1994	215	185	171	200	181	232	168	216
1995	217	199	213	205	202	231	180	233
1996	231	183	181	198	160	245	184	231
1997	257	252	201	214	201	248	216	237
1998	188	185	169	185	218	217	214	181
1999	209	223	204	196	221	223	190	211
2000	217	213	233	221	178	209	235	199
2001	197	211	190	207	192	195	207	166
2002	173	172	160	161	155	188	149	207
2003	195	151	141	141	140	220	197	192
2004	211	181	163	163	149	193	212	128
2005	202	201	161	162	149	204	183	201
2006	212	202	231	199	222	260	220	181
2007	216	205	195	215	181	223	178	216
2008	240	219	172	212	171	222	169	217
2009	223	163	158	152	169	220	165	221
2010	228	180	191	188	147	189	206	195
2011	226	224	175	174	100	217	190	212
2012	202	202	170	175	130	168	138	196
2013	216	216	193	191	160	221	190	207
2014	252	215	208	191	210	221	183	180
Average	211	198	185	183	172	214	187	198
Stad. Dev.	19.83	25.45	28.63	25.47	30.74	21.53	27.27	24.88
Cv	9.40	12.82	15.46	13.90	17.87	10.06	14.57	12.55
Max	257	252	240	221	222	260	235	237
Min	173	142	137	135	100	168	133	128

Table 35: LGP of northern stations

Year	Aykel	Gondar	Chewahi t	Amba Gyorgis	Deke Istifanos	Debre Tabor	Wereta
1986	168	172	121	162	116	171	127
1987	196	204	208	204	169	200	196
1988	206	186	203	165	158	186	158
1989	203	178	157	152	136	164	164
1990	144	119	128	131	135	133	132
1991	175	145	194	198	81	188	219
1992	104	174	174	199	171	222	154
1993	171	192	211	190	176	230	180
1994	180	195	129	125	126	131	130
1995	179	197	160	98	143	106	116
1996	173	198	192	157	197	182	194
1997	202	202	228	210	178	186	186
1998	165	153	165	118	151	139	150
1999	204	189	208	149	149	141	183
2000	176	170	182	160	140	235	160
2001	186	173	170	155	152	189	167
2002	176	126	120	158	140	126	153
2003	140	166	135	127	143	121	152
2004	151	145	139	161	150	143	134
2005	163	165	186	132	138	139	144
2006	195	184	182	160	181	198	182
2007	209	176	213	129	179	181	138
2008	236	172	171	130	202	205	149
2009	179	168	146	138	162	140	141
2010	178	163	198	110	143	140	140
2011	209	206	204	145	160	199	196
2012	177	142	135	158	161	124	124
2013	146	178	167	161	143	153	148
2014	224	206	207	126	187	203	180
Average	180	174	174	152	154	168	159
Stad. Dev.	27.43	23.08	31.66	28.33	25.19	35.75	25.65
Cv	15.25	13.27	18.24	18.64	16.35	21.27	16.18
Max	236	206	228	210	202	235	219
Min	104	119	120	98	81	106	116

Table 36: LGP of eastern stations

Year	Fiche	Debre Berhan	Alem Ketema	Mehal Meda	Derba
1986	207	144	126	126	189
1987	147	84	102	142	157
1988	125	100	127	214	151
1989	131	103	103	199	132
1990	110	110	111	111	118
1991	125	126	122	122	137
1992	124	112	129	108	157
1993	192	137	167	112	187
1994	109	110	109	100	125
1995	102	98	95	191	110
1996	162	117	129	160	162
1997	117	141	109	168	118
1998	141	199	139	121	220
1999	133	134	144	141	163
2000	121	125	131	120	149
2001	128	116	107	198	114
2002	88	105	92	108	120
2003	122	128	121	120	119
2004	148	130	142	123	110
2005	154	183	195	189	187
2006	127	109	118	134	101
2007	137	134	129	101	161
2008	108	115	110	107	116
2009	85	128	91	130	118
2010	199	183	95	199	123
2011	110	103	102	104	146
2012	199	121	193	110	121
2013	136	119	135	137	132
2014	206	116	130	99	203
Average	138	125	124	138	143
Stad. Dev.	34.07	25.93	26.22	35.72	31.10
Cv	24.74	20.72	21.10	25.93	21.75
Max	207	199	195	214	220
Min	85	84	91	99	101

Table 37: LGP of central stations

Year	Dembecha	Gundo Wein	Felege Berhan	Dejen	Abay Sheleko	Gohatsion	Yetemen	Debre Markos
1986	240	131	146	117	135	131	150	154
1987	198	206	209	219	165	165	144	197
1988	174	207	167	132	132	153	99	157
1989	120	162	151	153	90	134	164	128
1990	178	152	146	147	121	108	176	146
1991	184	139	119	134	171	133	133	176
1992	218	175	197	172	156	173	105	174
1993	208	193	239	187	184	219	192	216
1994	166	209	126	133	111	110	127	166
1995	209	216	197	195	195	173	187	215
1996	172	158	215	173	173	141	164	205
1997	224	226	255	150	153	203	152	194
1998	171	162	170	165	140	212	152	164
1999	165	206	158	201	137	155	170	175
2000	192	175	159	151	133	193	136	180
2001	189	178	173	167	162	163	164	182
2002	158	164	150	121	113	114	119	134
2003	154	140	141	119	123	124	115	138
2004	160	139	140	134	134	212	136	141
2005	176	162	139	199	136	140	182	145
2006	238	172	231	195	213	171	133	201
2007	178	229	180	159	176	127	174	182
2008	236	176	172	113	169	139	141	173
2009	155	147	139	146	131	143	120	158
2010	182	218	179	193	193	171	204	205
2011	221	128	156	173	118	153	176	166
2012	144	138	146	121	122	121	111	119
2013	207	203	178	192	151	174	141	178
2014	225	235	169	189	204	124	210	209
Average	188	177	171	160	150	154	151	172
Stad. Dev.	30.54	32.33	33.87	30.24	30.54	31.69	29.58	26.86
Cv	16.27	18.22	19.85	18.86	20.40	20.52	19.60	15.65
Max	240	235	255	219	213	219	210	216
Min	120	128	119	113	90	108	99	119

Appendix 6 Annual rainfall variation of Study stations

Table 38: Annual rainfall variation of study stations

Station name	Mean annual RF.	SD	CV
Abay Sheleko	1175.4	261.9	22.3
Felege Berhan	1317.7	162.3	12.3
Gundo Woin	1574.7	215.2	13.7
Yetemen	1456.7	453.8	31.2
Dejen	1385.9	283.9	20.5
Debre Markos	1338.6	144.3	10.8
Adet	1254.4	195.4	15.6
Tis_Abay	1225.8	250.6	20.4
Deke Istifanos	1533.2	234.1	15.3
Dembecha	1390.4	248.4	17.9
Enjabara	2386.4	286.9	12.0
Dangila	1654.0	215.5	13.0
Chewahit	1037.8	138.3	13.3
Gondar A.P.	1111.3	118.9	10.7
Aykel	1182.3	134.7	11.4
Debre Tabor	1511.4	196.9	13.0
Ambagiorgis Sch	1138.5	217.3	19.1
Wereta (Add)	1342.0	255.0	19.0
Nekemte	2107.4	267.0	12.7
Neshi	1735.9	491.0	28.3
Shambu	1573.5	161.3	10.2
Sibusire	1368.3	191.6	14.0
Mendi	2110.5	467.4	22.1
Debre Berhan	927.2	106.0	11.4
Alem Ketema	1091.9	208.8	19.1
Fiche	1153.2	112.5	9.8
Derba	1185.7	235.5	19.9
Mehal Meda	904.5	104.8	11.6
Gohatsion	1202.2	181.0	15.1
Gedo	1018.3	305.2	30.0
Kachis e(Rs)	1825.5	284.1	15.6
Pawe	1593.1	220.5	13.8
Bedele	1877.0	237.4	12.6

Appendix 7 Rainfall onset, cessation and LGP variation

Table 39: Rainfall onset, cessation and LGP variation

Station name	Onset date				Cessation date				LGP		
	Date no.	Date of year(DOY)	SD	CV	Date no.	Date of year(DOY)	SD	CV	Day length	SD	CV
Abay Sheleko	155	3-Jun	25.8	16.65	305	31-Oct	11.68	3.83	150	30.54	20.4
Felege Berhan	144	23-May	27.6	19.17	314	9-Nov	14.4	4.58	171	33.87	19.85
Gundo Woin	144	23-May	26	18.06	324	19-Nov	18.6	5.74	177	35.05	19.67
Yetemen	148	27-May	25.2	17.03	299	25-Oct	14.36	4.80	151	29.58	19.6
Dejen	147	26-May	24.9	16.94	307	2-Nov	15.42	5.02	160	30.24	18.86
Debre Markos	136	15-May	26.6	19.56	311	6-Nov	12.51	4.02	172	25.95	14.9
Adet	148	27-May	23.2	15.68	322	17-Nov	8.97	2.79	173	26.38	15.24
Tis_Abay	150	29-May	19.8	13.20	315	10-Nov	11.87	3.77	165	20.07	12.17
Deke Istifanos	154	2-Jun	19.4	12.60	306	1-Nov	14.65	4.79	154	25.18	16.39
Dembecha	138	17-May	27.5	19.93	325	20-Nov	16.75	5.14	188	30.54	16.27
Enjabara	130	9-May	17.2	13.23	329	24-Nov	12.55	3.81	199	22.72	11.41
Dangila	134	13-May	18.3	13.66	322	17-Nov	10.01	3.11	188	23.74	12.63
Chewahit	143	22-May	20.9	14.62	317	12-Nov	15.37	4.85	174	31.66	18.24
Gondar A.P.	147	26-May	17.6	11.97	321	16-Nov	13.9	4.33	174	23.08	13.27
Aykel	140	19-May	19.4	13.86	322	17-Nov	14.29	4.44	180	27.43	15.25
Debre Tabor	153	1-Jun	19.89	13.00	315	10-Nov	15.68	4.98	168	35.75	21.27
Ambagiorgis	155	3-Jun	21.8	14.06	306	1-Nov	19.89	6.50	152	28.33	18.64
Wereta	153	1-Jun	19.6	12.81	311	6-Nov	15.38	4.95	159	25.65	16.18
Nekemte	124	3-May	16.7	13.47	335	30-Nov	8.87	2.65	211	19.83	9.4
Neshi	133	12-May	23.2	17.44	315	10-Nov	14.31	4.54	183	25.47	13.9
Shambu	128	7-May	19.3	15.08	313	8-Nov	15.75	5.03	185	28.63	15.46
Sibusire	127	6-May	20	15.75	325	20-Nov	14.69	4.52	198	28.63	15.43
Mendi	128	7-May	21.3	16.64	326	21-Nov	11.6	3.56	198	24.88	12.55
Debre Berhan	173	21-Jun	26.6	15.38	298	24-Oct	9.64	3.23	125	25.93	20.72
Alem Ketema	173	21-Jun	22.9	13.24	297	23-Oct	11.96	4.03	124	26.22	21.1
Fiche	161	9-Jun	32	19.88	298	24-Oct	12.72	4.27	138	34.07	24.74
Derba	158	6-Jun	25.3	16.01	300	26-Oct	15.36	5.12	143	31.07	21.73
Mehal Meda	164	12-Jun	34.9	21.28	302	28-Oct	13.15	4.35	138	35.72	25.93
Gohatsion	154	2-Jun	23	14.94	309	4-Nov	21.86	7.07	154	31.69	20.52
Gedo	135	14-May	24.4	18.07	307	2-Nov	16.71	5.44	172	30.74	17.84
Kachis e(Rs)	126	5-May	22.5	17.86	313	8-Nov	19.43	6.21	187	27.27	14.57
Pawe	143	22-May	13	9.09	324	19-Nov	10.03	3.10	181	18.09	9.97
Bedele	120	29-Apr	14.7	12.25	334	29-Nov	16.3	4.88	214	21.53	10.06

Appendix 8 Agro-climatic classification of the study stations based on LGP

Table 40: Agro-climatic classification of the study stations based on LGP

S.No	Station Name	Elevation	X-cord.	Y-cord.	LGP	Agro-climate zone based on LGP
1	Nekemte	2080	36.46	9.08	195	Sub-Humid(SH)
2	Bedele	2011	36.33	8.45	195	Sub-Humid(SH)
3	Neshi	2060	37.27	9.72	161	Moist(M)
4	Shambu	2460	37.12	9.57	160	Moist(M)
5	Sibusire	1826	36.87	9.04	178	Moist(M)
6	Mendi	1650	35.1	9.78	180	Moist(M)
7	Gedo	2520	37.46	9.02	147	Moist(M)
8	Kachise	2520	37.86	9.58	165	Moist(M)
9	Enjabara	2568	36.92	11.00	177	Moist(M)
10	Dangila	2116	36.85	11.43	165	Moist(M)
11	Pawe	1119	36.41	11.31	165	Moist(M)
12	Felege Berhan	2710	38.07	10.74	141	Moist(M)
13	Gundo Woin	2052	38.09	10.93	140	Moist(M)
14	Dembecha	2117	37.49	10.57	151	Moist(M)
15	Chewahit	1925	37.23	12.34	135	Moist(M)
16	Gondar A.P.	1973	37.43	12.52	153	Moist(M)
17	Aykel	2254	37.06	12.54	163	Moist(M)
18	Ambagiorgis	2900	37.60	12.77	127	Sub-Moist(SM)
19	Abay Sheleko	1823	38.16	10.11	122	Moist(M)
20	Yetemen	2418	38.15	10.33	120	Sub-Moist(SM)
21	Dejen	2448	38.15	10.17	132	Moist(M)
22	Debre Markos	2446	37.74	10.33	146	Moist(M)
23	Adet	2179	37.49	11.27	148	Moist(M)
24	Tis_Abay	2642	37.58	11.49	151	Moist(M)
25	Deke Istifanos	1815	37.23	11.87	138	Moist(M)
26	Debre Tabor	2612	38.00	11.87	133	Moist(M)
27	Wereta (Add)	1819	37.70	11.92	134	Moist(M)
28	Gohatsion	2507	38.24	10.00	124	Moist(M)
29	Debre Berhan	2750	39.50	9.63	105	Sub-Moist(SM)
30	Alem Ketema	2280	39.03	10.03	102	Sub-Moist(SM)
31	Fiche	2784	38.73	9.77	110	Sub-Moist(SM)
32	Derba	2385	38.65	9.43	118	Sub-Moist(SM)
33	Mehal Meda	3084	39.66	10.31	108	Sub-Moist(SM)