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Analysis of Seasonal Rainfall Variability for Agricultural Water Resource Management in Southern Region, Ethiopia

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ABSTRACT
The livelihood of over 80% of the people of Southern region of Ethiopia is dependent on agriculture. However, the region is known by its food insecurity problem due to increasing population growth and alarmingly increasing natural resource degradation as well as unpredictability of rainfall. Therefore, it needs to assess the seasonal rainfall variability in selected areas of the region. Instat software version 3.36 was used to analyze and estimate the onset and end of the growing season, and the Length of Growing Period (LGP). Trend analysis for 17 rainfall stations' data was also made by Mann-Kendall, Spearman test and Ordinary Least Square (OLS) methods. The Pattern of variability (coherent rainfall variability areas) was also identified by using Principal Component Analysis. The result shows that, the annual rainfall in the region varied from slightly over 780 mm in Billate station to more than 2110 mm in Gerese station with mean, SD and CV as 1200 mm, 197 mm and 25% respectively and that of kiremt varied from 157 mm in Konso to 844 mm in Welkite with mean, SD and CV as 506 mm, 202 mm and 39% respectively. Belg seasonal rain varied from 863 mm in Gerese to 246mm in Bue with mean, SD and CV of 409mm, 121mm and 30% respectively. CV of 15%-64% for kiremt, 17%-52% for March April May (MAM) and 12%-46% for annual were observed. For Kiremt season, CV greater than 30% was observed in 18 stations; between 20-30% in 10 stations and below 20% for 5 stations. The mean onset, end and LGP of the main growing season was found to be at Days of year (DOY) 92, DOY 286, and 193 days for Hosaina area; at DOY 117, DOY 290 and 169 days for Welkite area; and at DOY 84, DOY 146 and 62days for Gato area respectively. OLS apparently showed a non significant decreasing linear trend for rainfall amount in 10 stations out of 17 while significant decreasing trend at Sawla; p= 0.04(-9.15 mm/yr) and Chida; p= 0.05(-16.08 mm/yr). However, for the start of MAM, March was unreliable in Hosaina and Welkite while reliable in Gato area. In addition, two homogenous areas of coherent rainfall variability, in terms of both seasons were obtained. This classification could be used for regional water management and rainfall prediction. Therefore, time of planting crops and other soil and water conservation activities should be performed accounting these variability parameters.
Key words: Variability, Seasonal rainfall, rainfall trend, DOY (days of the year), Onset, End date, LGP, Homogenous rainfall areas.

LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro ecological Zone
BoPED	Bureau of Population and Economic Development
CRDA	Christian Relief and Development Association
CV	Coefficient of Variation
DOY	Days of the Year (DOY1=Jan 1 up to DOY 336=December 31)
DPPC	Disaster Prevention and Preparedness Commission
ETo	Reference evapotranspiration
IBID	the same author just referred above
ITCZ	Inter tropical Convergence Zone
JJAS	Jun-July-August-September season
LGP	Length of Growing Period
MAM	March-April-May season
NMA	National Meteorological Agency
PC	Principal Component
PCA	Principal Component Analysis
RRC	Relief and Rehabilitation Commission
SNNPR	Southern Nations Nationalities and People Region
SON	September-October-November season
SPSS	Statistical package for social studies

1.INTRODUCTION

Rainfed farming is the main form of crop production in Ethiopia; like for many of neighbouring regions in Africa. However, it is highly variable in most parts of the country both in terms of length of the rainy season and amount of rainfall (Messay, 2006). 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). This uncertainty regarding agricultural production as well as investments in agricultural improvements has caused concerns in both local authorities and world bodies alike. In order to optimize the use of available rainfall, the specific areas of high variability, the amount of probable rainfall in the area and rainfall reliability with respect to meeting crop water requirements should be known. This is also the input for analysis of crop water requirements for the different representative crops to be planted depending on their suitability for a particular area. It is, therefore, necessary to give adequate attention to rainfed agriculture as a key element in food security in Ethiopia (NMA, 1996b). The coefficient of variability (CV) of rainfall in Ethiopia varies from 10% to 70%, of which, areas with CV above 30% are vulnerable to drought (NMA, 1996b).

In SNNPR, almost above 80% of people depend on rainfed agricultural activity (CSA, 2007). However, according to survey report of Southern Agricultural Research Institute (SARI, 2008) in SNNPR, the dry lands with shortage of water for crop production comprise 65% of the total area under water shortage during the dry season affected the successful establishment of seedlings while erratic and heavy flooding during rainy season coming from mountainous areas severely attacked farmlands. The performance of rains in the region is very variable due to undulating topographical setting. The onset of the rains is late by two to four weeks in most of the zones and special woredas, except in Dawro and Gamo Gofa zones, and Konso and Alaba, special woredas. There had been three to six weeks of dry spells during the first half of belg onset season (February and March) which creates serious moisture stress on the planted belg crops in many areas of the region, particularly on maize and sorghum crops. Similarly, excessive rains and flooding during belg cause serious damage like overflow of the Woito River, resulting in destruction of some belg crops and a canal (Aklilu and Alebachew, 2009). As a consequence, the performance of the agricultural sector, since the last three decades, has been declining and at times on the negative side. Some 33 woredas of the region are identified as drought prone and largely food insecure. North Omo is the largest zone with many woredas most affected by drought (Aregay, 1999).

In recognition of the guarantee and hazards associated with rainfed agriculture in the region, evaluating the seasonal variability, dependable rainfall and frequency of occurrence of drought is now very important to be prepared and cope up with. According to Taddesse (2000), rainfall analysis is important hydrologic tool, which bridges the gap between the design need and the availability of design information especially in planning and design of water resource projects. Therefore, area specific knowledge of dependable rainfall amount and year to year rainfall variability as well as its distribution pattern is important for planning and sustaining rainfed agriculture and for the design of drainage structures and irrigation scheme. Girma (2005) also justified that, for the rainfed-based farming to be productive and profitable, the relationship between the two had to be decisively subjected to detail examination. This shows the necessity of the study of the variability in various rainfall properties, including onset date, duration, end of the season and rainfall amount. Although different studies were performed in rainfall variability at national level (Mersha, 2003; Tesfaye, 2004; Girma, 2005 and Messay, 2006), regional based detail information is still not available for operational farm management decisions.

On the other hand, different attempts were also made for harvesting of water and its efficient uses, however, much of water harvesting structures in the region were unable to tap the rain at a place and on time due to temporal fluctuation of onset and recession of rainfall and absence of proper analysis of dependable rainfall amount prior to designing. Individual farmer-based soil and water conservation efforts in the region tended to be ineffective as they are destroyed by unexpected and concentrated floods from upstream farms (Eyasu, 2002).

Furthermore, having more than 120 weather observatory stations in the region with limited records, the scientific advances in making use of this resource in agricultural application as well as in the regional development strategy is rather limited. The farmers in the region who are adopting modern agricultural inputs are distressed by unreliable weather situation which is also the concern of extension workers advising them (Eyasu, 2002). Generally, the analyses of sensitivity thresholds that, if exceeded, could lead to a catastrophic effect have not been done in any detail and/or for any specific location. This general problem is the driving force for the inception of the idea of this research work in the region and it is, therefore, assumed that the study would at least pinpoint in reducing the above gaps.

Therefore, anticipating that, institutions and individuals in the area of the management of agricultural water resource and related activities would use the findings; this research presents a detail account of the rainfall variability statistics results for possible application to cropping system management with a view to achieving the following specific objectives:

1. To analyze the variability and the trend of seasonal rainfall in the growing periods
2. To know the frequencies of seasonal rainfall events
3. To develop homogenous seasonal rainfall variability pattern in the region

2. LITRATURE REVIEW

2.1. Seasons and Agro Climatic Zones of Ethiopia

Ethiopia is characterized by three distinct seasons. These are locally known as *Bega* (October to January), *Belg* (February to May) and *Kiremt* (June to September). The rainfall pattern is also named according to their rainfall distribution as Region A, Region B, Region C and Region D. These classifications don't encompass the southern and south-eastern lowlands of the country, which have a bimodal rainfall with long rainfall periods from March to May and short rains from September to October. The south-western part of the country also doesn't follow the three-season pattern, because there it occurs from February to November (NMA, 1996). Three major climatic zones, which have been known since ancient times in Ethiopia due to varied topography are dega, weina dega, and the kolla. The dega (also known as the cool zone) occupies the central sections of the western and eastern parts of the north-western plateau. The elevation of this region is mostly above 2400 m, and daily temperatures range from near freezing to 16 ^{0}C while the weina dega or the temperate zone ranges between 1500 m and 2400 m in elevation, and consists of parts of the central plateau. The kolla or hot zone generally comprises areas lower than 1500 m in elevation, the Denakil depression, and the tropical valleys of the Blue Nile (Cheung *et al*. 2008)

As the climate is rather complex, it has been the topic for the societal and scientific debates and several classification systems have been applied to the Ethiopian situation. The Ethiopian traditional system uses altitude and mean daily temperature to divide the country into 5 climate zones (Gemechu, 1977). Both the Köppen and the Thornthwaite classification systems have also been applied (NMA, 1996a). Another broad classification can be made using the rainfall distribution though the year giving the distinction between the uni-modal and the bi-modal and a diffuse rainfall region (Haile and Yarotskaya, 1987).

However, the most useful for agricultural purposes is the agro climatic zones which uses the water balance concept, the length of the growing season (including onset dates) at certain probability levels (NMA, 1996a). In this way three distinct zones can be identified namely the area without a significant growing period, areas with a single growing period and area with a double growing period. This information should be able to form the basis on which to build the seasonal forecasts with particular emphasis on the specific crop choices in each region (NMA, 1996a).

2.2. Regional weather systems producing rainfall over Ethiopia

Ethiopia lies in the eastern horn of Africa approximately at 3^0-15^0N latitude and 33^0-48^0E longitude which has an implication on atmospheric circulation. The country's topography is composed of massive highland complex of mountains and dissected plateaus divided by Great Rift Valley running generally southwest to northeast (Mersha, 1999) The seasonal and annual rainfall variations are the results of the macro-scale pressure systems and monsoon flows which are related to the changes in the pressure systems (Haile, 1986; Beltrando and Camberlin, 1993 and NMA, 1996).

The most important weather systems that cause rain over Ethiopia include Sub-Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and Somalia Jet (NMA, 1996b). The tropical easterly jet (TEJ) and the Tibetan anticyclone are the two important upper-level atmospheric features. The strength and position of these atmospheric systems vary from year to year and, so, also the rainfall activity. Regional and global weather systems affecting Kiremt (JJAS) season include the (ITCZ), the Maskaran High Pressure in the Southern Indian Ocean, the Helena High Pressure Zone in the Atlantic, the Congo air Boundary, the Monsoon depression and Monsoon trough, the Monsoon Clusters and the Tropical Easterly Jet (Kassahun, 1999).

2.3. Rainfall variability and agriculture in Ethiopia

Rain-fed crop production is the basis of all subsistence farming in most parts of the country and accounts for more than 95% for the land area cultivated annually. However, rainfall in much of the country is erratic and unreliable so that its variability and associated droughts have historically been major causes of food shortages and famines (Taddesse, 2000). There is a significant relation between climate and agricultural production in terms of the timing, variability, and quantity of seasonal and annual rainfall in Ethiopia. As a result, farmers during unexpected break in rainfall in early growing season may be able to recover and resume production despite the loss of some of their crops (Cheung *et al.* 2008). According to von (1991), a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in the country's food production. Verdin *et al*., (2005) explained that, short cycle crops (e.g. wheat, teff, barley) that are cultivated during the belg and kiremt seasons constitute 5 – 10% and 40 – 45% of national crop production, respectively while long cycle crops, such as maize and sorghum, growing during the entire belg and kiremt seasons, constitute for 50% of national production. Abebe (1989) as cited in Tesfaye, (2003), mentioned that, on an average the south-western part of the country gets the highest mean annual rainfall (1581.7 mm) with coefficient of variation (CV) as 7.8% while the northern part receives the minimum mean annual rainfall (562.9 mm) with CV as 63%.

Most Ethiopian rainfall variation, with the exception of the south and south-eastern 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, 1996b).

The amount, duration and intensity of rainfall in SNNPR vary considerably. It generally decreases from west and northwest to south-eastwards in the region. The livelihood of over 93 % of the people of the region dependent on it, however, agricultural system in the region is at subsistence level and food insecurity problem is increasing at alarming rate. Moreover, rapid natural resource degradation is prevalent (Aklilu and Alebachew, 2009). The lowest is experienced in parts of Debub Omo Zone such as Selamago, Benatsemay, kuraz and Hamer Woredas, and in Bench Maji zone such as Surma, Bero & Maji woredas. On the other hand highest values are recorded in Masha woreda of Sheka zone. Generally, in the western part of the region the rain occurs all the year round while it is bimodal in the eastern and southern part of the region (BoPED, 2010). Relying on the reliability of rainfall for crop production and duration of growing periods, the seasonal pattern of rainfall in the region experienced belg (March ,April, May), the amount of rainfall received is relatively lower than the kiremt (Jun, July, August and September) rainfall. However, in each of the seasons the rain may begin earlier/later and lasts before the usual time. This imposes unpredictability of rainfall distribution and growing period (BoPED, 2010). According to NMA (1996), lowlands of southern part of the country is characterized by high rainfall variability (CV>30%).

2.3.1. Belg rainfall variability

Belg rainfall is more important for long duration crops like maize and sorghum (NMA,1996a). It mainly concentrates over the highlands of central, south-western and southern parts, and generally decreases northwards. The beginning of the *belg* rain is also the period when the ITCZ begins to reach south and southwest Ethiopia in its south-north movement (Kassahun, 1999). As described by Amare (no date), at the beginning of the *belg* season, the ITCZ reaches the maximum southward position. Then, the systems including the ITCZ gradually move northwards. At the end of March and beginning of April ITCZ is already in the southern and south-western Ethiopia.

The two sub-tropical anticyclones (the Mascarene and the St. Helena) resume migrating northwards. In the northern hemisphere the sub-tropical anticyclones (the Sahara and Arabian) bring dry air to Ethiopia at the beginning of the season. At the middle and end of the *belg* season the deep penetration of extra-tropical low-pressure systems to the Middle East and the formation and propagation of the Mediterranean depression forces the Arabian anticyclone to shift to the Arabian Sea. These low-pressure systems (extra-tropical and Mediterranean) occasionally interact with tropical air masses. During *belg* season the southern part of the western region and some parts of central highlands receive the highest rainfall (500-600mm) while the rest of the regions get lesser amount (Messay, 2006).

2.3.2. Kiremt rainfall variability

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). 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).

Between June and September, the ITCZ is located north of Ethiopia and pronounced cyclonic cells along the ITCZ are over North Africa and the Arabian Peninsula. The rest of the country comes under the influence of the Atlantic equatorial westerlies and southerly winds from the equatorial Indian Ocean. The south-west equatorial westerlies ascend over the south-western highlands and produce the main rainy season over most parts of highland Ethiopia. The southerly winds from the Indian Ocean, despite the fact that they lose their moisture over the East African highlands, are blowing over the eastern lowlands of Ethiopia where their influence on rainfall is minimized due to the effect (Kassahun 1999). During kiremt season the maximum rainfall occurs over the central and southwestern highlands (600-1200mm) while the rest of the regions get lesser amount (Messay, 2006).

2.3.3. Start and end of rainy season and length of growing period

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. Similarly, 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. Then after, the 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. Evidence from the study indicated that annual crops which grow during the rainy season can utilize stored moisture in the range of 75 – 125 mm by the time of maturity (FAO 1978 and Mersha, 2003 cited in Fitsume, 2009) so that average 100mm of soil moisture capacity is added after end of rainy season to calculate

length of growing period.
Kowal and Knabe (1972) used the rainfall and evapotranspiration 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 evapotranspiration for the remainder of the growing season provided that no spell longer than five days occurs immediately after this date (Edoga, 2007) However, determination of rainfall onset and end was made by different researchers without evaporation data input by setting different criteria that can affect the rainfall onset and end.
Peiris, (1989) defined the start of the rainy season, in a given year as the earliest possible day after the 1st of April with more than 100 mm and less than 600 mm of rain totaled over 20 days. In addition at least 10 days should be rainy days and there should not be a dry spell of length 10 days or more in the next 20 days. Similarly, the date for the end of the rain season was defined as the first day of at least 15 consecutive dry days after first of June. The end of the rains was taken as the first day of at least 25 consecutive dry days after first of January. (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.
According to Zargina (1987), the minimum daily rainfall threshold of 25mm can indicate the termination of the growing season. Other who estimated the start and end of rainy season without ETo input data include (Raman, 1974 cited in Stern *et. al,* 2006; Sivakumar, 1992; Girma, 2005; Messay, 2006; Ndomba, 2006; Edoga 2007 and Tadros *et al*, 2009). They applied different criteria in setting an onset date and end date for rainy season for different crops exhibiting in different maturity, drought tolerance levels and soil types. Raman (1974) adopted 20 mm of total rainfall received over three consecutive days that were not followed by greater than 10 days of dry spell length within 30 days from planting day. A period of 30 days is the average length for the initial growth stage of most crops and these criteria are useful particularly in mitigating the seedling establishment related rainfall risk (Allen *et al.,* 1998). The same type of definition but using 25mm total rainfall amount was used by Tadros *et al*, (2009). For the definition of cessation, he used 3 consecutive dekad of less than 20 mm each, occurring after assumed month at end of season. 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).

2.4. Principal Component Analysis (PCA), theory and technical details

Although there is much to say about principal component analysis, here only those conceptual aspects of the methodology which are relevant to this study; such as, Eigenvalues, Eigenvectors, the PC loadings, PC scores, selection of PCs and their rotation will be described. Principal Components Analysis is a covariance analysis between different factors (Smith, 2002). Covariance is always measured between two factors. So with three factors, covariance is measured between factor *x* and *y*; *y* and *z,* and *x* and *z*. When more than two factors are involved, covariance values can be placed into a matrix. This is where PCA becomes useful. PCA or variable reduction method will find Eigenvectors and eigenvalues relevant to the data using a covariance matrix. Eigenvectors can be thought of as "preferential directions" of a data set, or in other words, main patterns in the data (Ehrendorfer, 1987).
In PCA, there cannot be more components than there are conditions in the data. Eigenvalues can be thought of as quantitative assessment of how much a component represents the data. The higher the eigenvalues of a component, the more representative it is of the data. Eigenvalues can also be representative of the level of explained variance as a percentage of total variance. The percent of variance explained is dependent on how well all the components summarize the data. In theory, the sum of all components explains 100% variability in the data (Ehrendorfer, 1987). The PCs (principal components) are the eigenvectors of the dispersion matrices (correlation or covariance matrices) which are symmetric and positive definite. These eigenvectors represent the orthogonal and the optimal modes (i.e. explaining maximum variance) of variability when the elements of the matrix represent correlations/covariances between time series at 2 grid points or stations. The resultant eigenvectors or PCs can be displayed in space. This analysis procedure is called spatial (S-mode) PCA and is commonly employed in climate research (Singh, 1996). When an element of the eigenvector is multiplied by the square root of its eigenvalue, we obtain a quantity called loading, which represents the correlation between the time series of the original variable observed at the corresponding location and the corresponding PC scores. Rotation of scores tends to orient the loadings such that they are higher over smaller and more coherent regions and lower (near zero values) over the remaining parts of the area. A good number of rotation procedures, orthogonal, have been suggested, but orthogonal varimax- rotation (Smith, 2002) has been more commonly used and has provided satisfactory results in most climatic studies. An orthogonal solution is one in which the components remain uncorrelated (orthogonal means "uncorrelated"). Ehrendorfer (1987) and Singh (1996) used PCA for developing homogenous regions of rainfall variability in Australia and India respectively. Similar work was done by Girma (2005) to classify central rift valley of Ethiopia and produced four homogenous areas of

variability. The stations whose monthly precipitation pattern is well correlated and in close proximity to each other tended to be clustered together forming 4 homogeneous rainfall zones (Girma, 2005). Using the PCA study, monthly rainfall values between 1968 and 1985 for 43 stations, models explaining at least 72 per cent of the variation in annual rainfall of Ethiopia were constructed for regions covering about 98 per cent of the country. PCA with covariance matrix, Varimax rotation and seven extracted components gave by far the best relationship between mean annual rainfall, elevation, and geographical location (Eklundh, and Petter ,1990)

2.5. Describing rainfall variability

Variability of rainfall can be expressed by statistical parameters such as mean, standard deviation, Skewnes, 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. Australian Bureau of Meteorology, (2010) used rainfall index for analysis of rainfall variability in Australia given as $(P_{90} - P_{10})/P_{50}$ where, P_n is n^{th} percentile of the data. The threshold value is given in the Table 1 below.

Table 1 Rainfall variability index and Coefficient of variation classes

Australian Bureau of Meteorology, (2010)		**Hare (1983) reference**	
Class	**Index**	**CV(%)**	**Class**
Very high	1.5-2	>30	Highly variable
High	1.25-1.5	20%-30	Moderate
Moderate to high	1-1.25	<20	low
Moderate	0.75-1.0		
Low to moderate	0.5-0.75		
Low	<0.5		

2.6. Trend test for annual rainfall data

2.6.1. Mann-Kendall test

The most hydrological time series are characterized by a high variability and large scale random variation about the mean value in spite of that, sometimes monotonic change in a mean value defined as trend is observed in such series (Duggal, and Soni, 2000).

Among many statistical tests available to detect existence of monotonic change (trend) in a time series, the Mann-Kendall rank statistic, the Spearman rank statistic and the least-square regression method are common (Dahmen and Hall, 1990). The Mann-Kendall rank statistic is a non-parametric test, which can be used to test for the existence of a linear trend while the Spearman's test confirms the result (Pilon, 2002).

The Mann-Kendall rank statistic t_m is computed, by first replacing the observations x_i's by their ranks k_i's such that each term is assigned a number ranging from 1 to n which reflects its magnitude relative to the magnitudes of all other terms. For each element k_i, the number N_i is calculated as the number of k_j terms preceding it such that $k_j > k_i$. Then t_m is given by,

$$t_m = \frac{4\sum_{i=1}^{n-1} N_i}{n(n-1)} - 1 \qquad (1)$$

t_m is distributed very nearly as a normal distribution for large n and can be used as the basis of a significance test,

$$r_m = \pm r_g\sqrt{\frac{4n+10}{9n(n-1)}} \qquad (2)$$

Where, r_g is the desired probability point of the normal distribution appropriate to a two-tailed test and r_m is Mann-Kendall's significance test statistics. If t_m lies inside the range $\pm r_m$ then the time series does not contain a trend (Kendall, 1975).

2.6.2. Spearman's test statistics

The calculation of the Spearman rank statistic r_s requires that the original observations x_i's are transformed to ranks k_i's by arranging them in increasing order of magnitude. Then by computing the quantity d_i as $d_i = k_i - i$, where i ranges from 1 to n, r_s is defined by the equation.

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} - 1 \qquad (3)$$

If t_s lies between $\pm t_{\alpha/2}$, at df (n-2) then the series does not have a trend (Dahmen and Hall, 1990 and Jayawardene *et al,* 2005**)**.

Where:

r_s=the Spearman's rank-correlation

n = the number of observations
i = the chronological order

The direction of trends was determined by sign of r_m or t_s although they do not indicate the magnitude. The straightforward technique that can be used to obtain the magnitude of a linear trend is the least-square regression An ideal trend-less (detrended) series has the value zero for r_S but this happens rarely in the hydro meteorological series of the natural phenomena. Hence the significance of the value to be different from zero is tested with the null hypothesis of HO: $r_S= 0$ (there is no trend) and an alternative hypothesis of HA: r_S 0 (there is a trend) using the t-test statistics with the following equation:

$$t_s = r_s\sqrt{\frac{n-2}{1-{r_s}^2}} - 1 \tag{4}$$

Where, t_s is the test statistics and a t-distribution is assumed for t_s with df = n-2 degrees of freedom. Therefore, at a significance level of 5% (two-tailed), the lower and upper limits for the acceptance region t_t are given as:

Lower limit = t[df, 2.5%];and the upper limit = t[df , 97.5%]

This method was used by different researchers for detecting the existence of trend in their work (Piyasiri *et al*, 2004; Jayawardene *et al*, 2005; Cheung *et al*, 2008; Woldeamlak, 2009 and Fitsume, 2009).

2.7. Rainfall Frequency Analysis

By assuming that the past and future data sets are stationary and have no apparent trend, one may expect that future time series will reveal frequency distributions similar to the observed one. It is obvious that the longer the data series the more similar the frequency distribution will be to the probability distribution. As the number of observations increases, the error in determining expected rainfall gradually diminishes. Although the required length of the time series depends on the magnitude of variability of the precipitation climate, a period of 30 years and over is normally thought to be very satisfactory. However, if interest lies in extreme rainfall events, larger number of years may be required (Raes *et. al*. 2006) Frequency analysis requires considerable computations and careful plotting.

Table 2: Estimating probabilities of exceedence (plotting positions) of ranked data

Method and (source)	**Estimate of probability of exceedence (%)**
California (California State Department, 1923)	$\frac{r}{n}x100$
Hazen (Hazen, 1930)	$\frac{(r-0.5)}{n}x100$
Weibull (Weibull, 1939)	$\frac{r}{(n+1)}x100$
(Cunnane 1978)	$\frac{(r-0.4)}{(n+0.2)}x100$

Source: (Raes *et al*., 2006)

Note: r = the rank number; n= number of observations

A probability plot is a plot of the rainfall depths versus their probabilities of exceedence as determined by one or another method (Table 2). When the data are plotted in a graph where both axes have a linear scale, the data are not likely to be on a straight line but to follow an S-shaped curve. By selecting a probability distribution, the vertical axis of the probability plot is rescaled so that the data will fall on a straight line if it is distributed as selected (Raes *et. al*. 2006).

2.7.1 Probabilistic treatment of rainfall data

The probability distribution specifies that, an observation x of the variable will fail in the range of x. For example, if x is annual rainfall data at a specified location, then the probability distribution of x specifies that the observed annual rainfall will lie to a defined range such as; less than 30 mm, or 30 mm – 40 mm and so on. The probability of an event; p (A) is the chance that will occur when an observation of the random variable is made. If the sample of n observation has n_A values in the range of event A (for example, the occurrence of annual rainfall less than 30 mm), then the relative frequency of A is $\frac{n_i}{n}$. As a sample size increases, the relative frequency becomes progressively better estimate of the probability of the event P (A) (Chow, 1988) as;

$$\mathrm{P}\ (\mathrm{A}) = \lim_{n\to\infty}\frac{\mathrm{n_A}}{n} \tag{21}$$

Such types of probabilities are called objective probabilities of random variables unlike to subjective, judgments based on experience of random event occurrence.

2.7.2 Frequency and probability functions

If the observation in the sample are identically distributed (each sample value drown from the same probability distribution), they can be arranged to form a frequency histogram. The variable data is divided in to discrete interval, and the number of observation falling in the range is counted and plotted as histogram. If the number of observation, n_i in the interval i covering the range (x_i-Δx, x_i) is divided by the total number of observation n, the relative frequency function f_s (x) results which is given as;

$$f_s(x) = \frac{n_i}{n} \quad (22)$$

This is an estimate of p (x_i-Δx ≤ x_i), the probability that the random variable x will lie in the interval (x_i-Δx, x_i). The subscript s indicates that the function is calculated from sample data. The sum of values of relative frequency up to a given point is the cumulative frequency function F_s (x_i) given (Chow, 1988) as;

$$F_s(x_i) = \sum_{j=1}^{i} F_s(x_j) \quad (23)$$

This is an estimate of p (X ≤ x_i) called cumulative probability of x_i.

2.7.3 Statistical methods

This method is based on mathematical principles that describe the random variation of a set of observations of process and they focus on the observations themselves rather than on the physical process which produced them. Statistics is a type of description but not causality because it assumes that the data is from pure random process (Chow, 1988). The sample estimate of population parameters are given in the following equations (Chow, 1988).

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (24)$$

Where, $\bar{X}$ is sample mean
n is number of observation
x_i is individual observation for i= 1, 2, 3…n
The variance s^2 and standard deviation $\sqrt{s^2}$ respectively are given as;

$$s^2 = \frac{1}{n-1}\sum_{n-1}^{n}(x_i - \bar{X})^2 \quad (25)$$

$$s = (\frac{1}{n-1}\sum_{i-1}^{n}(x_i - \bar{X})^2)^{1/2} \quad (26)$$

Similarly, the coefficient of variation CV is given as;

$$CV = \frac{s}{\bar{X}}\, x\, 100 \quad (27)$$

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The Southern Nation and Nationalities and People Regional State (SNNPRS) is a vast region covering an area of about 118,000 sq. km, and it covers about 10 percent of the total area of the country. It is bounded in the northwest by Gambella Regional State, in the northeast and southeast by Oromiya Regional State, in the west by the Republic of the Sudan and in the south by the Republic of Kenya. The region lies between $4^0 27'$ and 8^0 30'N latitude and 34^0 21' and 39^0 11'E longitude (BoPED, 1996).

The total population is 14,929,548 and it is the third most populous region of country (CSA, 2007). A rapidly growing population is also a unique characteristic of the region. Among the nine zones and five special woredas of the region, the highest population sizes are recorded in North Omo, Sidama and Gurage accounting for 25.1%, 19.7% and 15% of the regional population respectively. The Omo basin is a major ecological feature in the region separating two different physiographic regions into western and eastern parts (CRDA, 1998).

Topography in the western part of the region is undulating and rises in elevation forming the northern and north-eastern highland sub regions. The altitudinal variation of the region ranges between 376 masl (at lake Rudolf in south Omo) to 4207 masl (at mount Guge in North Omo zone). Based on traditional classification of altitude and climate, the region is grouped into five major agro- ecological systems or zones viz. Kolla (50% (lowland), Woina Dega (37% a ,mid-altitude) and Dega (6.5%, high altitude) (BoPED, 1996).

In SNNPRS, the rainfall regimes are similar to those of the rest of the highland regions of the country. However, due to physiographic and direction of moisture bearing wind, rainfall varies both in distribution and amount. The mean annual precipitation is classified into two major rainfall regimes, mostly occurring in highlands. Kaffecho / Shakecho, Maji, parts of North Omo, Kembata, Alaba and Tembaro (KAT), Hadiya and Guraghe get greater amounts of rainfall for eight months (during March to October). The highland area of north Omo, south Omo and the northern parts of Sidama receive rain for nine months (March to October). The second rainfall regime includes north and south Omo, southern parts of Sidama, Gedeo, Amaro and Burji. The rainy season lasts for eight months (February to July, and September and October) in this sub region with the highest amount of rainfall occurring during April.

Generally, rainfall amount and distribution increases from south (semi-arid area) towards the north and northeast. Mean annual rainfall of the region ranges between 200 and 2200 mm (CRDA, 1998).

Temperature of the region decreases from the south towards the north, northeast and northwest with the mean annual temperature ranging from 15^0C to 26^0C. About 11 percent of the total area of the region is covered by forest. The north-western part of the region is covered with dense mountain forest, whereas the southern part is covered with open grasslands and woodlands. Drought occurs in most parts of the region very frequently

(Aregay, 1999).

The distribution of soils in the region is dominated by the widespread occurrences of the two major soil types Orthic Acrisols and Drystric Nitosols. Each soil type occurs in a continuous spread over the western and east central part of the region. These soils together cover about half of the total area of the region. Other types of soils in the region are Fluvisols, Nitisols (Eutric), Vertisols, Luvisols and Phaeozem (EMA, 1988)

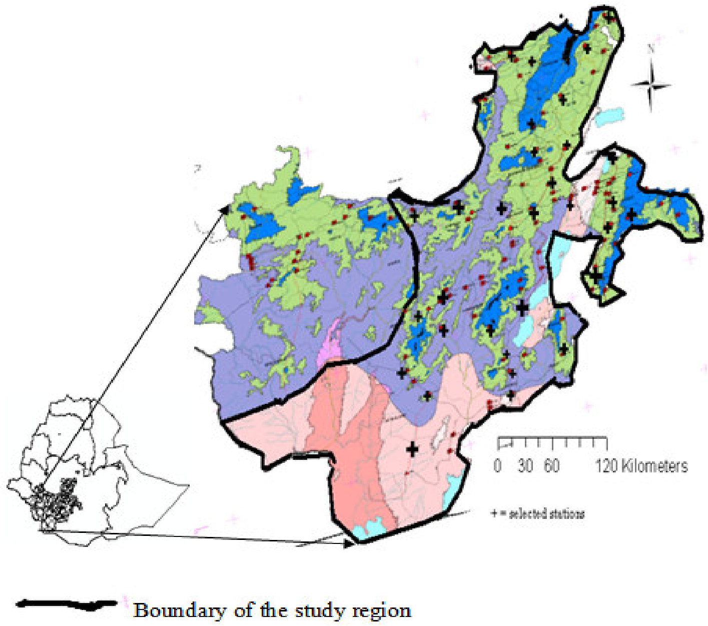


Figure 1: Distribution of meteorological stations in the region and selected areas and representative stations of the AEZ in this study.

Source: Regional Cartography and GIS department, (2004)

3.2. Analytical Methodology

Daily rainfall data of three weather stations having varied time series were used for these analyses. Hosaina, Welkite and Gato representing Dega (highland), Weynadega (midland) and kolla (lowland) AEZ were chosen based on the criteria like Agro ecological setting, total length of data more than 30years, no missing years or very less and their potential for crop production in the study area. Though the data is point weather data, it is believed that the analysis would serve a wider area of the study (Mersha, 2003). The data of all stations is shown in Appendix Table 1.

3.2.1. Data pre-processing

The daily rainfall data were obtained by courtesy of the National Meteorological Agency (NMA) of Ethiopia. Data were captured into Microsoft Excel 2000 spreadsheet following the days of year (DOY) entry format. In order to make the series amenable to further analyses, the missing values were patched using first order markov chain model of INSTAT (Haan, 1982; Stern *et. al,* 2006) while the homogeneity of the data series of stations was checked by using cumulative deviation test method which uses chi-square ($\chi 2$) and Kolmogorov-Smirnov (KS) at 90, 95 and 99% significance level (Raes, *et.al* 2006). In this study western and North- western part of the region is not included because of absence of consistent data and also it is believed that, the area has no limitation in rainfall distribution for rainfed agriculture as it has 8-10 months rainy period (Messay, 2006). However the selected stations represent all the agro-ecological zones (AEZ) in the region from which one can get information for water resource planning.

3.2.2. Data analysis

Firstly, in three selected stations, the variability of seasonal rainfall was analysed for its onset, end date, LGP; amount and the number of rainy days. Statistical packages like the mean, standard deviation and coefficient of variation were determined and interpreted based on Hare (1983) and Australian Bureau of Meteorology rainfall index, (2010).

For this study determining the onset, end date and LGP was performed by adapting definition from Stern et al, (2006). Accordingly, the day with accumulated rainfall of 20mm over three consecutive days that were not followed by greater than 9 days of dry spell length within 30 days from planting day was said to be onset date. The condition of having no dry spell of more than 9 days after start of growing season eliminates the possibility of a false start of the season. In this case, March 1st was picked as a potential planting date for long cycle belg season crops like maize for Hosaina area and short period crops for Gato area while April 1st was picked as a potential planting date for Welkite area.

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 end of the rainy season adopted in this case was defined as any day after the first of September/October/, when the soil water balance reaches zero (Stern *et. al*, 2006). In addition, a fixed average 5mm of Evapotranspiration per day, and 80mm/meter of the maximum soil water holding capacity of the area (Hoefsloot, 2009) were considered. Given the above definitions, Instat Statistical programme Version 3.36 (Stern *et al*., 2006) was used for analysis using January to December calendar. The LGP was determined by subtracting onset date from end date.

For the study of wet and dry days as well as probability of getting rain, 3mm rainfall threshold was selected conservatively for the agricultural water management purpose. Therefore, the day with rainfall below 3mm is considered to be dry day. Accordingly the analysis was performed for the probability of wet days in growing season in three stations.

In the case of dry spell length analysis, daily rainfall was fitted to the simple Markov Chain model to determine the probability of dry spell length exceeding 7, 10, 15 and 20 days within the growing season (March-September) using Instat Statistical software Version 3.36, (Stern *et al*., 2006).

For trend analysis, the annual data series of 17 stations with above 30years long data were selected and tested for the existence of significant trend by Mann-Kendal test method and to confirm the result, Spearman's test was also used (equations 2 and 4). Least square regression method was fitted to determine the direction as well as the magnitude of change of linear trend and for testing of slope. Similar method was used by Cheung *et al* (2008), Woldeamlak (2009) and Fitsume, (2009) for their rainfall analysis work.

Secondly, for developing homogenous rainfall areas, total of 29 stations having 17years long data were used to classify the area in terms of belg and kiremt seasonal variability. In this case, the selected weather stations cover the whole region except western, north-western and south-western parts of the region (Fig 1). For determining pattern of variability, *belg* (March-May) and *kiremt* (June-Sept) monthly averages of 17 years (1991-2007) rainfall amount as cases and 29 stations as variables were entered to SPSS statistical software. This enables to identify smaller regions of coherent variability other than those obtainable by analysing rainfall over the whole of the country. Such smaller regions would be more useful for regional planning. Determination of the number of components to be used in PCA was performed using eigenvalues more than 1. Eigenvalues >1 means that all selected factors explain more variance than single variable (Kaiser, 1960 cited in Smith, 2002). The boundary separating the regions was loading greater than 0.6 in PCs (Ehrendorfer, 1987 and Smith, 2002). Accordingly, different homogenous rainfall areas were identified for the seasonal rainfall series.

4.RESULTS AND DISCUSSIONS

First, the variability of seasonal rainfall in Hosaina, welkite and Gato stations in terms of onset, end date, length of growing period of crops (LGP), amount and number of rainy days were discussed. Then after, testing the trend of annual rainfall data of 17 stations was followed. Finally the *belg* and *kiremt* rainfall homogenous areas were identified and discussed thoroughly.

4.1. Onset, End and Length of the Growing Period

The result in the Table 3 and Fig 2 below revealed that, on an average, the long rainy season (Belg-Kiremt) starts on April 01 (Day of the year (DOY) 92 ±8) for Hosaina, April 26 (117 DOY±6) for Welkite, and on March 24 (84 DOY±4) for Gato station with CV of 26%, 17% and 16% respectively. On average, the rainy season ends on Oct 12(286 DOY±7), Oct 16 (290 DOY±4) Hosaina and Welkite with CV 8% and 4% respectively. The main season for Gato has the mean end date of 25 May (146 DOY±7). The result is also similar to that done by Hoefsloot, (2009) which indicates that onset of rainfall in Hosaina and Welkite area varies from 7- 11 decade with mean of 9 decade. The mean starting date of the growing season, belg-kiremt, in Hosaina has high standard deviation of 24 days and hence, the onset date of the season is not stable because it is out of 7-8 decade suggested by Reddy, (1990). The higher standard deviation of the onset date of the seasons implies that patterns could not be easily understood and consequently decisions pertaining to crop planting and related activities will be made with high risk.

The length of growing period (LGP) for maize production in the main rainy season in Hosaina area ranges from 124 to 253 days with a mean of 193 ±12days, CV and SD of 8% and 35days respectively. Similarly, in Welkite station LGP shows variation from 134-217days, with mean 169 ±7days, CV 13% and SD of 21 days.

Table 3: Onset, end and length of the growing period (LGP) in three stations

station		Hosaina (MAMJJAS)	Welkite (AMJJAS)	Gato (MAM)
Onset*	Max	141	170	122
	Min	61	92	61
	mean	92	117	84
	CI(no. of days)	92±8	117±6	84±4
	SD	24	20	13
	CV	26%	17%	16%
	25thpercentile	72	98	74
	50th percentile	90	118	86
	75th percentile	112	133	93
End*	Max	338	318	190
	Min	245	267	122
	mean	286	290	146
	CI(no. of days)	286±7	290±4	146±7
	SD	22	12	20
	CV	8%	4%	14%
	25th percentile	268	281	125
	50th percentile	287	288	148
	75th percentile	301	298	162
LGP@	Max	253	217	121
	Min	124	134	6
	mean	193	169	62
	CI(no. of days)	193±12	169±7	62±9
	SD	35	21	26
	CV	18%	13%	42%
	25th percentile	163	152	41
	50th percentile	199	167	64
	75th percentile	220	184	81

*measured in DOY; @ measured in number of days; CI is for confidence interval

From table 6 above, it is clear that two stations can produce maize cultivars which need LGP less than 170 days with no risk. However cultivars more than 170 days long could not be produced in welkite area. It is expected in 3 out of 4 years that, the LGP will be 220 days or below in Hosaina area and 184 days or below in welkite area.

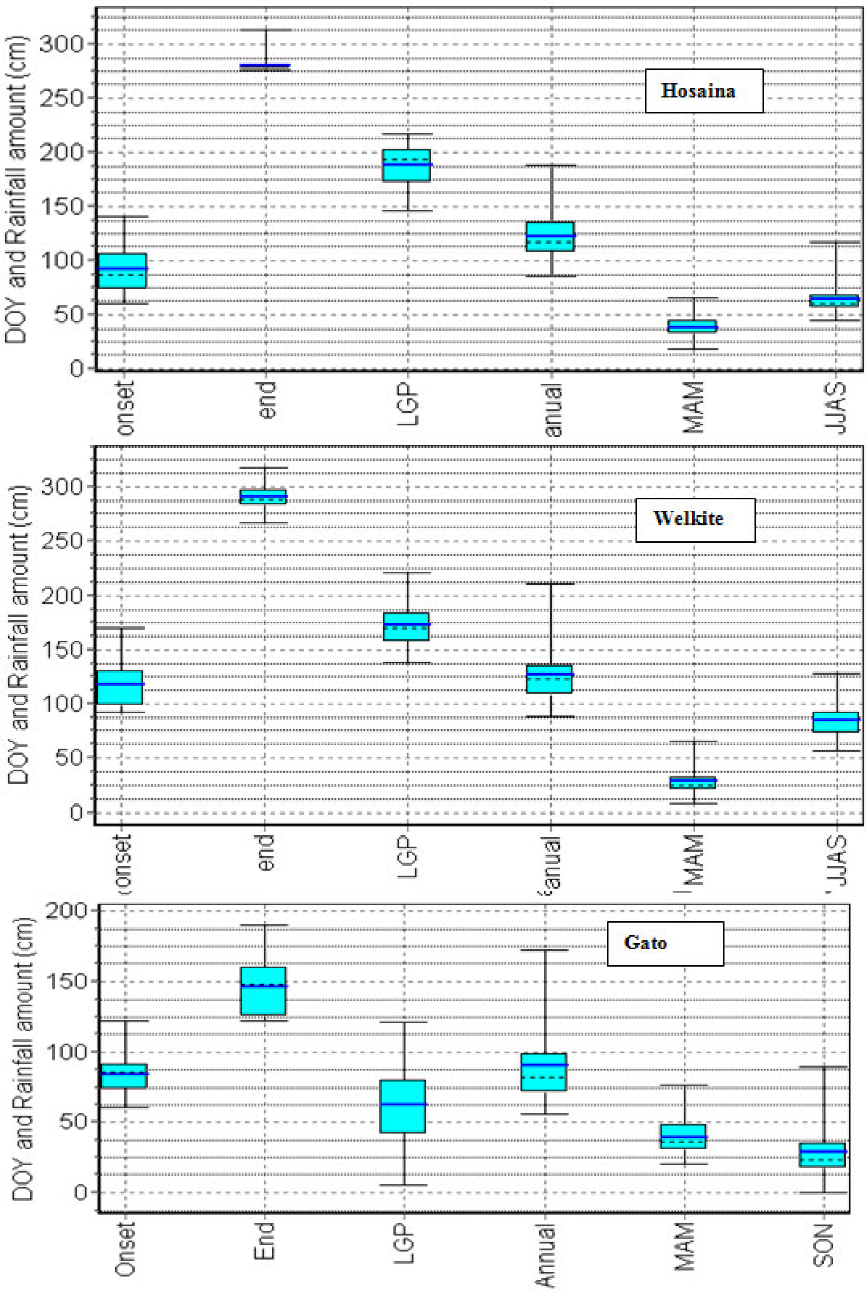


Figure 2: Box plot explaining variability of rainfall events in three stations[1]

The risk of onset date of rainfall for MAM season in Gato station is lower than the two stations although its variation in end date and LGP is higher than the two indicating instability. According to Messay, (2006), the main rainy season in southern part of the region (Gato area) is MAM and therefore, this result is also strengthening the good start of the season. The probability of getting onset date on April 01(92 DOY) or below is 75 % (3 out of 4 years) in the area but one can also expect it at DOY 73 (March 13) in 1 out of 4 years.

The box-plot also indicates that the LGP of the growing season in the MAM season (Gato) is very variable from 6-121 days (CV=42%) which needs more attention for planning of agricultural water for crop production. This variation is highly correlated with end date (R^2=0.80) than onset (R^2=0.4). However in 3 out of 4 years there is the chance of getting LGP of 81days with the mean of 62days. In addition, the onset and end dates, and LGP variability for kiremt (JJAS) season for all remaining stations of the region experiencing kiremt rainfall is given in Appendix Table 8.

[1] Solid line crossing the box shows the mean of data; the upper and lower tip of whiskers shows maximum and minimum values; upper and lower sides of box represent 75th and 25th percentile respectively; and the median is (dot line in the box).

4.2. Rainfall Amount Variability and Monthly Contribution

As shown in Table 4 below, the average annual rainfall of Hosaina, welkite and Gato were observed as 1231mm, 1271mm and 908 mm with CV of 18.5%, 22.4% and 32.3% respectively. Similarly, the average *kiremt* rainfall amounts of Hosaina and welkite stations were happened to be 641.7 mm and 844.4 mm with SD of 140 mm and 156 mm and CV of 22 % and 18% respectively. High CV was observed in *belg* rainfall amount than annual and *kiremt* in Hosaina and Welkite stations. From the result it was clear that, Gato area was vulnerable to drought (CV > 30%). Knowledge of monthly distribution of rainfall is important because it tells how much water is available for the biomass in rain-fed areas. Aghajani, (2007) determined that the threshold of rain-fed agriculture was 250 mm.

As indicated in Table 5, in Hosaina station, months from April to September totally contributed 76% to the annual. However, 32% and 52% of annual rainfall occurred in *belg* and *kiremt* season respectively in the area although only 8% was contributed by March for MAM season. In the case of Welkite; March, April and May each contributed only 6%, 7% and 10% which highly differed from the month of June (15%). Unlike Hosaina, the rainfall pattern in Welkite was highly concentrated in June to September (*kiremt*) contributing 66% of annual rainfall with maximum of 21% by July while that of belg was 24%. In general, planting maize in the Welkite area need proper planning so as to be productive because, as the result indicates, planting prior to second dekad of March has high probability of failure.

Similarly at Gato area, about 43% of the annual rainfall was occurred in *belg* (MAM) and 32% at September October-November (SON), small rainy season. MAM season is main growing season in the lowland area (NMA, 1996) of the region and the result of this study shows also the stability of belg than autumn (SON) season. As shown in Table 5, MAM is unreliable in Welkite area (CV 48%) than in Hosaina due to the effect of lesser amount of rainfall in the month of March.

Table 4: Statistical parameters of rainfall amounts of the three stations

	Annual			Kiremt			Belg		
Stations	**Welkite**	**Hosanna**	**Gato**	**Welkite**	**Hosanna**	**Gato**	**Welkite**	**Hosanna**	**Gato**
Mean	1270.7	1230.6	907.5	844.4	641.7	208.4	288.1	388.2	390.3
SD	284.3	228.1	293.3	156	140.1	107.8	138.5	114.5	138.2
Min	884.1	850.3	561.6	565.8	455	69.7	84.7	185.9	201.9
Max	2109.6	1882.4	1722.2	1279.2	1166	432.1	651.7	664	766.4
CV	**22.4**	**18.5**	**32.3**	**18**	**22**	**52**	**48**	**29**	**35**
SER	44.9	38	50.3	24.7	23.4	18.5	21.9	19.1	23.7
Median	1232.7	1177.2	816.7	843.1	608	191	255.1	381.6	359.3
25%	1087	1076.6	717	742.5	552.5	114.7	273	317.2	297.9
75%	1370.1	1356.7	993.8	938.6	688	271.4	531	455.1	484.1
80%	1412	1488.9	1162.7	949.1	711.7	311.6	341.8	458	503.5

Table 5: Amount and monthly percentage contribution of rainfall in three stations

	Jan	Fe	M	A	M	Jun	Jul	Au	Sep	Oct	N	D	Belg	JJAS	SON
Average monthly rainfall (mm)															
Hosana	34	48	102	135	151	130	165	181	167	77	20	22	**388**	**642**	ns
Wolkite	22	39	71	93	124	184	269	246	145	50	17	10	**288**	**844**	ns
Gato	29	45	95	171	125	48	35	40	84	125	84	26	**390**	ns	**293**
Percent contribution to annual (%)															
Hosina	3	4	8	11	12	11	13	15	14	6	2	2	32	52	ns
Welkite	2	3	6	7	10	15	21	19	11	4	1	1	23	66	ns
Gato	3	5	10	19	14	5	4	4	9	14	9	3	43	ns	32

ns =not significant; JJAS =Kiremt; SON= September-October-November

4. 3. Probability of Exceedence of Rainfall Events

The probability of exceedence of rainfall events such as onset, end, LGP, and amounts in three stations was summarized in Figure 3.

As indicated in Figure 3, at 80% probability of exceedence, MAM rain in Hosaina, Welkite and Gato were estimated as 458mm, 342mm and 503mm or below respectively. The onset date at 80% of probability or below were DOY 120(April 29) for Hosaina, 145 (May 24) for Welkite and 95 (April 04) for Gato area. On the other hand, at 80% of probability level Hosaina has the LGP of 210 days or below, while 190 days and 83 days or below for Welkite and Gato respectively. This indicates that the Gato area at risk to satisfy maize production. Information on rainfall amount and variability is important for improved decisions concerning choice of crops and crop varieties to grow in the region. The amount of rain during the growing season is important for the crop to give the highest yield. For example, optimum rainfall for maize is between 500 mm and 800 mm (Aghajani, 2007). However, there was no time of getting more than 750 mm of rainfall in Gato. This makes it risky to produce less drought-tolerant crops like maize unless water-harvesting measures are adopted. Although highly variable, SON rainfall in October can be captured by any water harvesting practise to be used later for early planting however, fail may be realised due to excessive water losses.

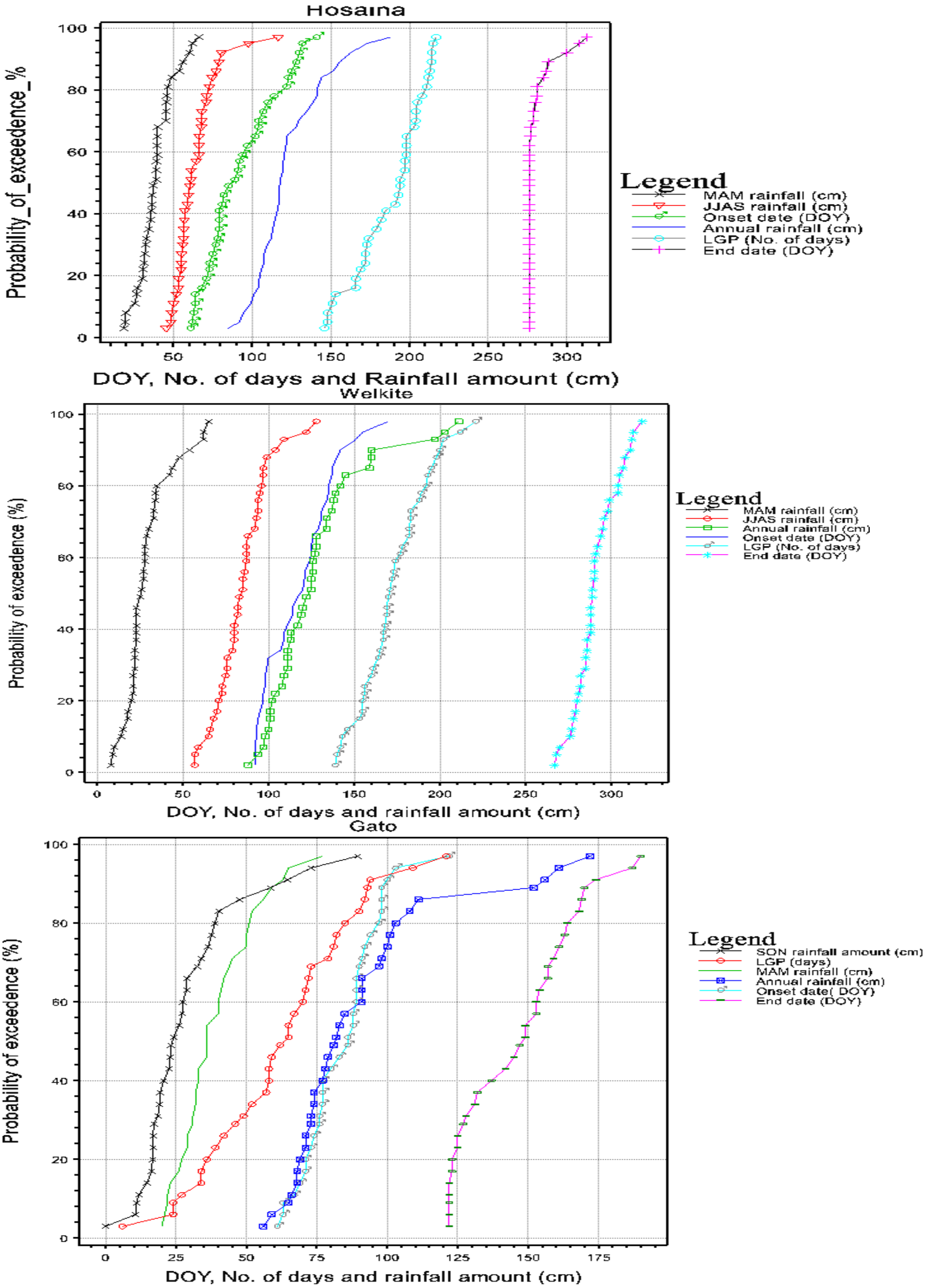


Figure 3: Probability of exceedence of rainfall events in three stations

4.4. Rainy Days and Probability of Rainfall

4.4.1. Number of rainy days and probability of rain in Hosaina area

As indicated in Fig. 4 below, the mean of rainy days in growing season increases from March to August then decrease at September. The minimum mean of 6days occurred in October and maximum 18 days in August. This also shows March is at risk in Hosaina with CV 35%.

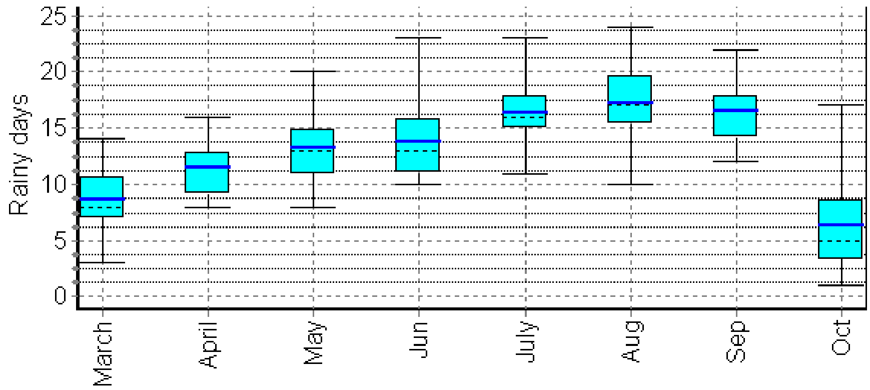


Figure 4: Box plot showing the variability of rainy days in monthly bases in Hosaina station

The probability of getting rain in a given date (R^2=0.82) is also shown in Fig 5 below. The maximum probability for a wet day was 50% in August. The probability of getting rain in April, May, June, and July were 25%, 35%, 37%, and 45% progressively increasing. However, it drastically decreases at the end of September signifying the end of season. As the rainfall pattern in Hosaina is unimodal, 84% of annual rainfall occurred from March to September with maximum 15% contributed by August. Hosaina area is almost dry for the rest of the season (October to February) in which one can perform construction of soil and water conservation structures. The intensity of rainfall was high during June to September so that, runoff and soil erosion would be very high which need different soil and water conservation structures to be implemented.

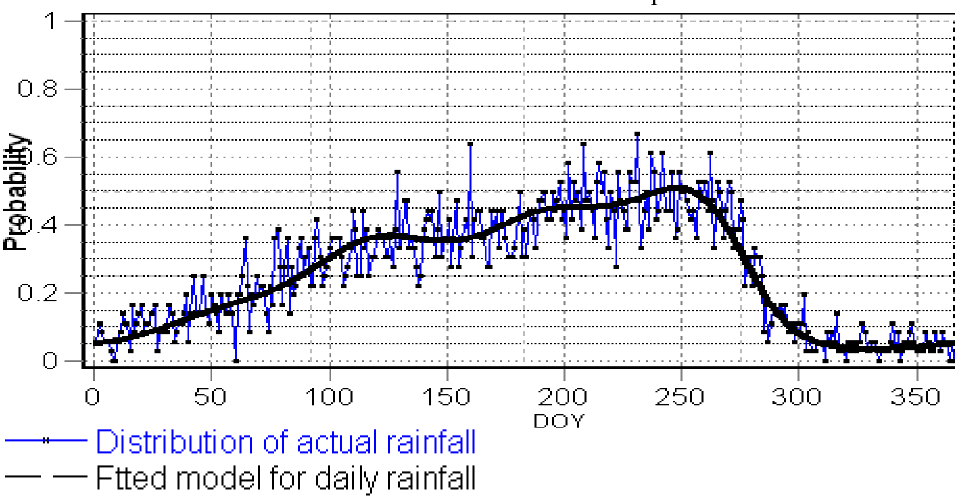


Figure 5: Probability of rainfall occurrence in Hosaina station

4.4.2. Number of rainy days and probability of rain in Welkite area

The Figure 6 of box-plot below shows the monthly distribution of rainy days. The variation of number of rainy days is higher in September than others and minimum mean day was observed in October and March (75th percentile less than 8 days). The mean number of rainy days in area varied from 9 days in April to 24 days in July. Solid line crossing the boxes show increasing value up to July and then decreasing, indicating that the rainfall pattern in Welkite area was unimodal with the maximum in July.

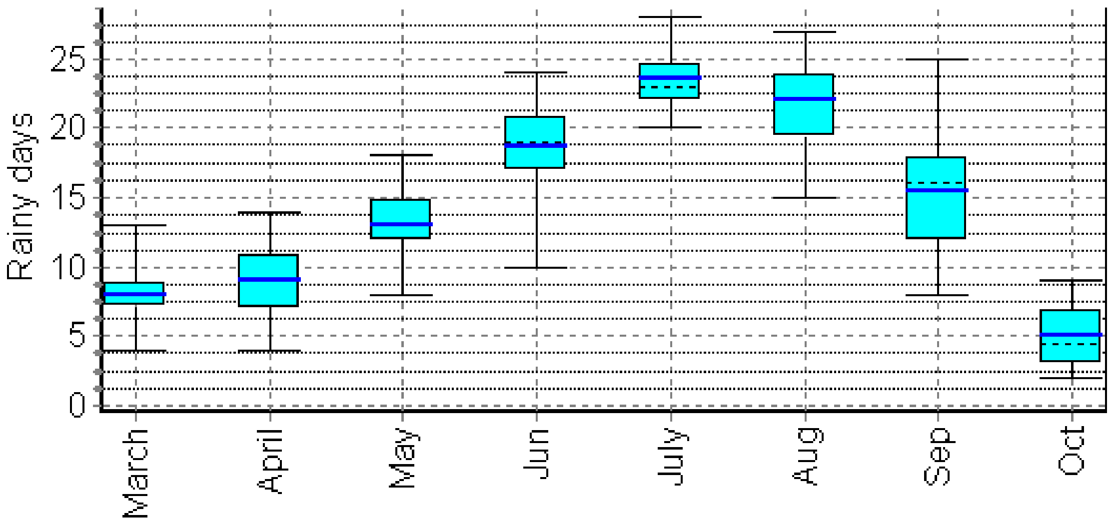


Figure 6 Box-plot showing the variability of the no. of rainy days in Welkite area

The probability of getting rain in the area (R^2=0.89) is also shown in Fig 7 The rainy days significantly increased after second dekad of May and reduced significantly after second dekad of September. From the figure, the probability of daily rainfall occurrence on a specific month or dekad or week in a year can also be inferred. The maximum probability of a wet day was happened to be 60% in DOY 210 at the start of August. The probability of getting rainfall in March, April and May had been only 15%, 20% and 25% respectively, critically indicating that the belg rainfall in Welkite area was being failed to satisfy rainfed agriculture than Hosaina area. In this study the average onset of rain in the Welkite area was also April 26 (DOY 117) which confirms the shifting progress of belg season towards kiremt.

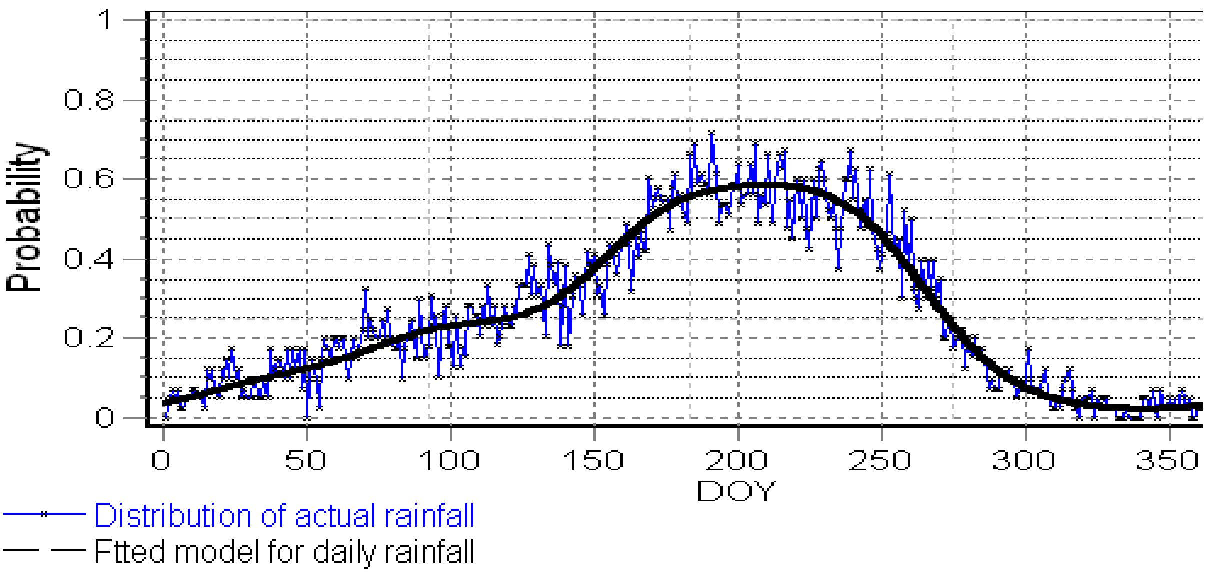


Figure 7: The probability of rainfall in Welkite area

4.4.3. Number of rainy days and probability of rain in Gato area

Table 6 shows that, an average rainy day in Gato for two seasons is below 15 days with maximum of 18 days in April and 14 days in October. For short season (SON), the CV of rainy days in September and November were very high (above 33%) than October (below 25%) with mean of 6, 10 and 6 days for respective months which is unsatisfactory for rainfed agriculture without supplementary water. Similar situation was observed for May (CV=43%) indicating that maturity of belg crop would be at high risk unless irrigation is supplied.
The rainfall pattern in Gato area is bimodal with two rainfall peaks: one occurring in the period from March to May and the other from September to November (Figure 8). The coefficient of determination of fitted model was R^2=0.86 indicating that, 86 % of variation was explained by the fitted model. The first peak was occurred in the

second dekad of April and the second smaller peak occurred at the third dekad of November. It indicates that the probability of getting rain was 38% during the first peak period and 30% during the second peak. Dry months in the Gato were observed from mid-June to August, and December-mid February

Table 6: Statistical parameters for no. of rainy days in Gato station

	March	April	May		Sept	Oct	Nov.
min	4	7	3		2	4	1
max	13	18	16		12	14	10
mean	8	12	9		6	10	6
SD	2	3	4		3	2	2
CV	**28%**	**23%**	**43%**		**42%**	**20%**	**33%**

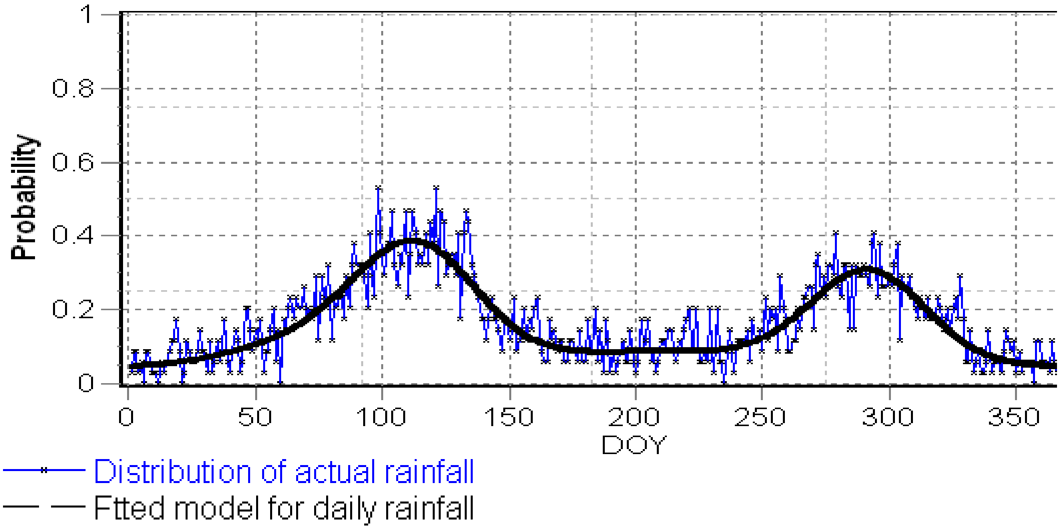


Figure 8: Probability of rainfall in Gato area

4.5. Trend of Annual Rainfall

As indicated in Table 7 below, both Mann-kendall and Spearman tests indicate that there are significant negative trends in Sawla and Chida stations. Butajira station shows somewhat significant trend compared to other stations in both tests and least square fitness for slope. Although it is not significant at the 95% confidence level it can be justified for this study for Butajira, as having significant increasing trend since it has 93% confidence which is at the boundary condition for decision.

High variability in annual rainfall in the region is also indicated by the variations in trend of rain with highly decreasing in Chida station (16.08mm/yr) to highly increasing trend in Butajira station (6.26mm/yr). The regression results show the largest decrease in rainfall amounts of 16.08mm/yr at Chida, north of the region. Having good mean annual rainfall, the decreasing trend of rainfall in Chida area may be due to increasing deforestation in the area. The second largest decrease is observed at Gato and the third at Sawla as 11.66 mm/yr and 9.15 mm/yr respectively. Generally, although there is no significant trend change (negative/positive) in the region, least square method apparently shows a decreasing linear trend for 10 stations out of 17 with significant at Sawla, Gato and Chida. The trend may be explained if the recording time length was longer than this. Though, the north-east parts (Welkite, Butajira, Hosaina, Bele, Emdibr and Billate) are stable or not suffering from negative trend, the southern parts (Gato, Burji and Sawla) as well as south eastern part (Fisagenet and Hagereselam) of the region is suffering from decreasing trend of annual rainfall. The mean annual rainfall of the stations is shown in the 15th column with maximum 1634 mm/yr at Chida and 774mm/yr at Billate stations. Generally, the similar results obtained by two methods of testing gave strength to the output. The spatial variation of the rainfall trend is, due to the changes in the intensity, position, and direction of movement of the rain-producing systems over the country and complex topography (NMA, 1996b; Camberlin, 1997 and Taddesse, 2000.)

Table 7: Existence and significance of the trend of annual rainfall and its least square line fit test for slope in 17 stations (27-40yrs)
N= No. of years; DT= Decreasing trend; IT= Increasing trend; Exist= significant trend observed; No= Non significant trend; tm and rm = Mann-

Ser.No	Station	N	Mann-kend.test t_m	r_m	P-value	Trend exist	spearman test r_s	t_s	$t_{\alpha/2}$,df(n-2)	Trend exist	Least square method slop (mm/yr)	P-value	Trend	Rainfall (mm/yr)	R^2
1	Wolkite	40	0.07	0.22	0.5	No	0.11	0.68	1.98	No	1.92	0.62	IT	1231	0.01
2	Sawla	40	-0.23	0.22	0.05	**Exist**	-0.33	-2.13	1.98	**Exist**	-9.15	0.04	DT	1632	0.15
3	Butajira	39	0.2	0.22	0.07	No	0.28	1.78	1.98	No	6.26	0.07	IT	1029	0.01
4	Wulbareg	38	-0.04	0.22	0.69	No	-0.03	-0.2	1.98	No	-2.65	0.5	DT	1318	0.03
5	Hosaina	36	0.07	0.23	0.56	No	0.13	0.79	1.98	No	-0.17	0.96	DT	1234	0.02
6	Hag/selm	35	-0.04	0.23	0.73	No	-0.08	-0.49	1.98	No	-3.97	0.36	DT	1377	0.02
7	Awasa	35	0.03	0.23	0.83	No	0.02	0.12	1.98	No	0.85	0.7	IT	959	0.03
8	wolyta	35	0	0.23	0.98	No	-0.05	-0.3	1.98	No	-2.49	0.67	DT	1361	0.01
9	Bele	34	-0.03	0.24	0.82	No	-0.05	-0.29	1.98	No	2.34	0.6	IT	1173	0.01
10	Gato	34	-0.16	0.24	0.18	No	-0.25	-1.48	1.98	No	-11.66	0.02	DT	1112	0.16
11	Jinka	33	0	0.24	0.98	No	0.02	0.1	1.98	No	0.94	0.85	IT	1291	0.03
13	Burji	33	-0.19	0.24	0.11	No	-0.27	-1.53	1.98	No	-5.55	0.07	DT	951	0.1
14	Emdibr	30	0.08	0.26	0.58	No	0.12	0.66	2.04	No	3.93	0.5	IT	1065	0.01
15	Billate	30	0	0.26	0.98	No	0.01	0.03	2.04	No	0.4	0.9	IT	774	0.01
16	Fisagnet	27	-0.17	0.27	0.2	No	-0.21	-1.1	2.05	No	-5.8	0.66	DT	1425	0.02
17	Chida	27	-0.33	0.27	0.01	Exist	-0.49	-2.83	2.05	Exist	-16.08	0.05	DT	1634	0.14

Kendal parameter given in equation 2. r_s= spearman's parameter given in equation 4; t_s= calculated spearman's test statistics; P-value is probability level at 95% confidence to check the significance of the trend.

4.6. Identifying homogenous rainfall areas

The major modes of spatial and temporal variation of seasonal rainfall over the region performed using PCA. Two PCs were used to identify 2 homogeneous sub regions of coherent rainfall variability for seasonal time scales for belg and kiremt and discussed as follows.

4.6.1. Belg (MAM) rainfall homogenous areas

Table 8 indicates that, significant two PCs were extracted for belg seasons. Two PCs explained the whole variance in the belg data series in 100%. They are explained by the first and the second PCs constituting about 63% and 37% of total variability respectively. However, 9 stations in belg were not assigned on either PC because their correlation was significant with both PCs so that it is difficult to infer their pattern of variation unless it is explained by only one PC (Appendix 2). The result of zoning is shown in Figure 15 below.

Zone 1 (Southern and central part of region) includes stations such as Sawla, Bilate, Angecha, Hosaina, Gidole, Beto, Keyafer, Kulito, Bulkimender, Konso, Jinka, and Arbaminch that stretches from Angecha (central) down to Konso in the south. In this area, except some pocket areas, there is a relatively high belg season rain between mid February to April, but with unreliable and longer dry spells being common. The mean annual rainfall ranges between 780-1726 mm and belg rainfall from 362 mm (Konso) to 539 mm (sawla).

Zone 2 encompasses tip of Northern part including Bue, Butajira, Chida Welkite and Emdibr stations. This area is relatively with low belg season rainfall and its onset occurs after mid April. The amount of mean belg rainfall ranges between 246 mm in Bue to 447 mm in Chida stations. The eastern part is not categorized under one of the PC but the area is affected by the effect of both weather systems (PC score >0.6). The area is characterized by sharing the property of eastern part and central highlands of the country. In addition it is also around rift valley area and has possible effect from lake. The stations under respective PCs are Hawasa, Wolyiata, Teferikela, Bodity, Wulbareg, Hagereselam, Fisagenet and Yirgalem.

During *belg*, the Arabian ridge or anticyclone (when it is displaced to the north Arabian Sea), the penetration of deep, large-amplitude troughs in the westerlies into the lower latitudes, and the southward bend of the subtropical jet stream (STJ) at the upper levels are the major rain producing mechanisms from Feb. to May (Fekadu, no date). According to Seleshi, and Zanke, (2004) belg season in the country is generated by weather systems that originate over the Indian Ocean. The seasonal and annual rainfall variations are the results of the macro-scale pressure systems and monsoon flows which are related to the changes in the pressure systems (Beltrando and Camberlin, 1993; NMA, 1996b).

Table 7: PCA for belg seasonal variability

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% loading of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	45015.6	90.963	90.963	45015.6	90.96	90.963	31052	62.747	62.747
2	4472.477	9.037	100	4472.47	9.037	100	18435.	37.253	100
3	0	0	100						
4	0	0	100						

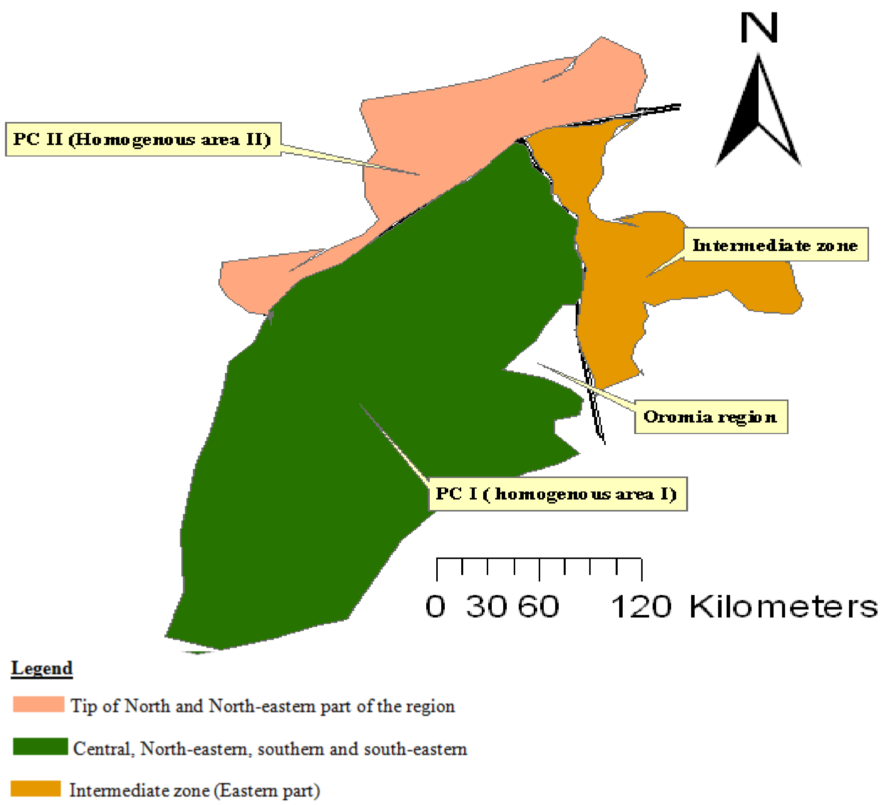


Figure 9**:** Map of two homogenous belg (March-April-May) seasonal rainfall and intermediate zone.

4.6.2. Kiremt rainfall homogenous areas

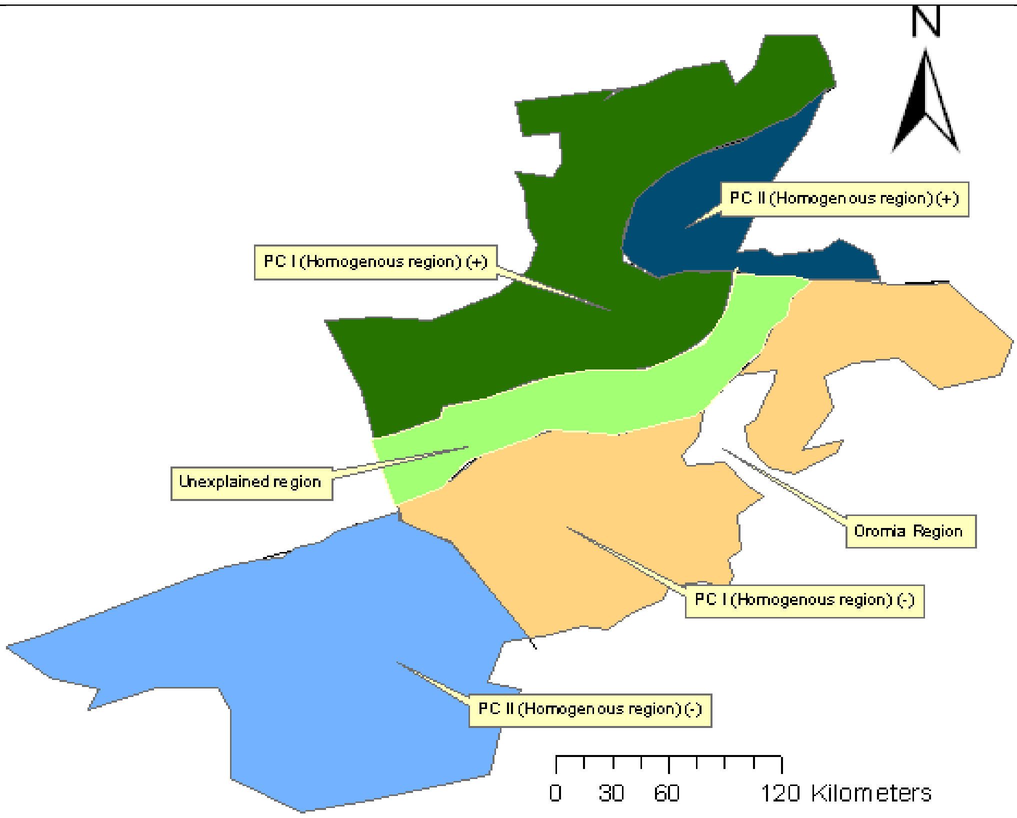
As indicated in Table 9, the whole variance in the kiremt data series was explained by the two PCs as 91%. The first PC explained 71% and that of the second component explained 20% variation in kiremt season. Although the variation seems more of complex in terms of classified map (Fig 16) to different colour, the pattern of variation is clearly obtained.

Zone 1 includes Northern, central, Southern and South-eastern part of the region. Dipole was observed in this zone as Northern (affect positively) and southern (affect negatively)

Northern part positively affected includes areas of Emdibr, Bue, Butajira, Welkite, Wolyta, Bodity and Chida, while Southern part includes Teferikela, Fisagenet, Gidole, Beto Arbaminch, Burji, Bele, Gato, Yirgalem, and Konso were negatively affected. The dipole shows that high frequency of weather system represented by PC-I has direct impact on northern part while at the same time it has negative effect in southern part of the region. It can be inferred that below normal rainfall will occur in southern part during the frequent event of weather system of PC-I meaning, when high rainfall is observed in northern part, very low rainfall would be expected in southern area due to the effect (Appendix Table 3). Zone 2 encompasses the north-eastern and south-western part of the region having high score in the direction along the rift valley but with dipole as zone one from Hawasa and Hosaina (north-east affected positively) to Dimeka (south-west affected negatively). The property of dipole in this zone can be interpreted as the case of zone one. The intermediate zone (central part along rift valley from eastern to south-western) was also observed. However it was not explained by either of the two significant PCs. Kassahun (1999); Seleshi and Zanke, 2004 and Segele *et al.,* (2008) justified that, the seasonal oscillation ITCZ is the predominant mechanism for the rainfall during the Kiremt except southern and south eastern part of the country which is affected by south west Indian ocean. The result of classification of area in this study shown in Fig. 16 is also consistent with their justification.

Table 8: The result of PCA for Kiremt (JJAS)

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% loading of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	16903	79.20	79.205	16903	79.20	79.205	15294	71.66	71.665
2	3459	16.20	95.414	3459	16.20	95.414	4186	19.61	91.28
3	978	4.586	100	978.	4.586	100	1861	8.72	100
4	0	0	100						
5	0	0	100						
6	0	0	100						



Legend
Tip of North, North-eastern, part of central region (PC-I (+))
Part of southern, South-eastern, and Eastern region (PC-I (-))
Part of North-eastern and Eastern (PC-II (+))
Southern part (PC-II (-))
Part of Central (Intermediate zone) along the rift valley

Figure 10: Map of two homogenous Kiremt (JJAS) seasonal rainfall and intermediate zone

5.CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Annual as well as seasonal rainfall is important in the rainfed agriculture in Ethiopia since more than 85% of population is dependent on agriculture especially on rainfed farming. As a result of the rainfall variation, the country generally and the region specially, becomes vulnerable to recurrent droughts. Therefore, analysis of its variability is very crucial for planning and management of water resource and agricultural practices. In response to this determining rainfall variability, the analysis was made for annual, kiremt and belg rainfall amounts; onset, end and LGP; for the number of rainy days in a year and annual rainfall trend analysis. Identification of homogenous seasonal rainfall areas for the selected region was also the part of this work.

The annual total rainfall in the region varied from slightly over 780 mm in Bilate station to more than 2110 mm in Gerese station with mean, standard deviation and CV values as 1200 mm, 197 mm and 25% respectively; and that of kiremt varied from 157 mm in Konso to 844 mm in Welkite with mean, SD and CV values as 506 mm, 202 mm and 39% respectively. Belg seasonal rain varies from 863 mm in Gerese to 246 mm in Bue with mean, standard deviation and CV of 409 mm, 121 mm and 30% respectively. The high variation was observed in areas with high amount of rainfall than those with low amount. CV above 30% in 4 stations, 20-30% in 15 stations and below 20% in 14 stations were observed. Excluding areas which do not use kiremt rainfall, 7 stations with CV value of >30%, 10 stations of 20%-30% and 5 stations below 20% were identified for the season. In the case of *belg*, 21 stations out of 33 experienced CV value of above 30%; 11 stations with 20-30% and only 1 station had below 20% indicating the unreliability of this season. The calculated variability using rainfall index and CV showed good agreement in evaluating the variability indicating that, there was high variation in rainfall during *belg*, kiremt and annual respectively in decreasing order. The contribution of kiremt rainfall to the annual totals varied from 20% in southern part of the region, to 67% in northern part of the region. Stations in the southern part contribute considerable amount of belg rainfall (40-47%) to their annual total. Topographical setting may be the main factor for this variation.

The average onset dates of rainy season in Hosaina, Welkite and Gato stations in DOY were found to be 92 (April 01), 117 (May 26) and 84 (March 24) respectively with CV of 26%, 17% and 16%; whereas for end dates as 286 (Oct 12), 290 (Oct 16) and 146 (May 25) with CV of 8%, 4% and 14% respectively. The mean LGP were estimated as 193 days, 169 days and 62 days with CV of 18%, 13% and 42% respectively for said stations. The result is also in line with the works reported by Hoefsloot (2009).

The OLS method shows not significant decreasing trend of annual rainfalls of 10 stations while the trend was significantly decreasing in 7 stations. However, according to both methods of trend test, significant decreasing trend was observed in Sawla (P= 0.04) and Chida (P= 0.05) stations.

Using PCA, 2 PCs (patterns of variations) were obtained for each *belg* rainfall (northern and southern) and *kiremt* rainfall (one at north-south pattern and the other from north-east to south west along rift valley). This classification is useful for detail local level water management options and for prediction purpose.

5.2. Recommendations

Depending on the result obtained in this work, the following limited but very useful points are being forwarded as recommendation;

1.The planting time for long cycle crops like maize and sorghum around Hosaina and Welkite area should be performed after the end of March and April respectively. However, since very high rainfall is expected in these areas during July/August and also the *kiremt* teff production, which highly aggravates soil loss, is common in the areas, proper design of soil and water conservation structures should be performed with caution.

2.In lowland (Gato) area, planting crops before second dekad of March is risky and crops which need LGP of more than 70 days should be planted with additional irrigation water for completing their maturity properly. On the other hand, as SON rainfall is erratic but with less period of duration (40 days), water harvesting technique should be used for short duration crops like vegetables as well as seedling preparation may be performed for the coming main season planting.

3. Regional-based management of water resource should consider the result of homogenous rainfall zones for prediction of rainfall condition and for sustaining agricultural and industrial productivity in the areas.

4. Further studies focusing on extreme rainfall (PMP) analysis, should be performed in the areas where unexpected rainfall and flooding is common and accordingly proper design of flooding and soil and water conservation structures could be adopted.

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