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Temporal and spatial variability of rainfall distribution and evapotranspiration across altitudinal gradient in the Bilate River Watershed, Southern Ethiopia

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Rainfall and evapotranspiration are the two major climatic factors affecting agricultural production. This study examined the extent and nature of rainfall variability from measured data while estimation of evapotranspiration was made from recorded weather data. Analysis of rainfall variability is made by the rainfall anomaly index, coefficient of variance and precipitation concentration index. The FAO-56 reference ET (ETo) approach was used to determine the amount of evapotranspiration. Estimation of the onset, end of growing season and length of growing period was done using Instat software. The results show that mean annual rainfall of the upper (2307 m.a.s.l), middle (1772 m.a.s.l) and lower (1361 m.a.s.l) altitude zones of the watershed are in the order of 1100, 1070 and 785 mm with CV of 12, 15 and 17% respectively. There was a high temporal anomaly in rainfall between 1980 and 2013. The wettest years recorded Rainfall Anomaly Index of +5, +6 and +8 for stations in upper, middle and lower altitude zones respectively, where the driest year recorded value is -5 in all the stations. The average onset date of rainfall for the upper zone is April 3 ± 8 days, for the middle zone April 10 ± 10 days and for the lower zone is April 11 ± 11 days with CV of 23%, 26 and 29% respectively. The average end dates of the rainy season in the upper and middle zones are October 3 ± 5 days and September 25 ± 7 days with CV 5 and 7%. The main rainy season ends earlier in the lower zone; it is on July 12 ± 10 days with CV of 14%.

Key words: Variability, days of the year (DOY), onset, end date, length of growing period (LGP).

INTRODUCTION

Variability is a very important inherent characteristic of climate and it varies on all timescales. There has been much recent public and scientific interest in climate variability and change, and the possible role of human activity in observed climate change (Braganza et al., 2003). So far, most studies have focused on measuring

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the impacts of changes in climatic averages on different sectors (Kucharik and Serbin, 2008; Lobell and Burke, 2008; Lobell and Field, 2007; Tao et al., 2008; Rowhani et al., 2011). Global scale assessments of climate change impacts on livelihoods and economic factors are commonly based on averages, rather than on the analysis of the variability or extremes (Adams et al., 1990; Penalbaa and Vargasa, 2008). Observations, however, suggest that climate change impacts on society result primarily from extreme events and their variability (IPCC, 2007). This is because, in addition to changes in climate means, climate variability is expected to increase in some regions in the future, including the frequency and intensity of extreme events (IPCC, 2007). Some have proposed that changes in extremes will have a more adverse impact on crop production than changes in climate averages alone (Morton, 2007; Tubiello et al., 2007).

Climate variability can be described as a combination of some preferred spatial patterns. The most prominent of these are known as modes of climate variability, which affect weather and climate on many spatial and temporal scales. The best known and truly periodic climate variability mode is the seasonal cycle. Others are quasiperiodic or of wide spectrum temporal variability (Blunden et al., 2011).

Rainfall variability receives higher attention among other climatic elements especially in relation to agriculture. The variability in rainfall can be explained either temporally or spatially or both depending on the purpose needed (Song et al., 2014). A better understanding of the spatial and temporal variations of precipitation on different timescales and the adjustment of specific theoretical models like models that generate design storms and models that allows for the simulation of continuous time series at a point or spatially distributed are important for many applications (Vernieuwe et al., 2015). The resulting models will lead to a better management of a great variety of problems associated with variations in precipitation and will make it possible to improve statistical weather forecasts and climate monitoring (Penalbaa and Vargasa, 2008).

Characterizing and quantifying these variability is of fundamental importance not only for purposes of detection and attribution, but also for strategic approaches to adaptation and mitigation.

Precipitation distributions over tropical East Africa exhibit pronounced regional variations, and the seasonal cycle is complicated (Cook and Vizy, 2012). In most regions, there are two peak rainfall seasons that are nominally associated with solar heating maxima in the equinox seasons, Sea Surface Temperature forcing, and teleconnections to the West African and Indian monsoon systems are among the other important factors influencing the timing and intensity of seasonal rainfall (Cook and Vizy, 2013). Topography is another factor that determines spatial distribution regardless of the impact of the equinox (Hession and Moore, 2011).

Rainfall in tropical East Africa, within about 15° of the equator, is often delivered during two seasons, which are governed by the seasonal oscillation of Intertropical convergence zone (ITCZ). As a result, one rainy period occurs during boreal spring, known as the spring rain ‘‘*Belg*’’ in Ethiopia. A second rainy period occurs in the boreal fall over much of the region, is known as the summer rain ‘‘*Keremt*’’ (Cook and Vizy, 2013).

Rainfall and evapotranispiration are two major climatic factors affecting agricultural production (Tilahun, 2006), and agricultural water resources face two major problems. One is the lack of available water supply in rain-fed agriculture, and the loss of available water through evapotranispiration (Wriedt et al., 2009; Derbile, 2013; Mou et al., 2014).

Evapotranspiration (ET) is an important hydrological process and its estimation is needed for many applications in diverse disciplines such as agriculture, hydrology, and meteorology (Suleiman et al., 2008) but usually the estimation of ET needs measurements of many weather variables such as atmospheric pressure, wind speed, air temperature, net radiation and relative humidity, but these weather variables are not easily obtainable from practical measurements in weather stations (Ishak et al., 2010) as the most prevailing weather stations in Ethiopia are class III meteorological stations that can collect only air temperature and rainfall and class IV stations that can collect only rainfall.

Potential Evapotranspiration (PET) is defined as the maximum ability to evaporate under the assumption of a well-watered surface. Accurate and timely estimates of PET are essential for agricultural and water resource planning as well as for understanding the impacts of climate variability on terrestrial systems (Kim and Hogue, 2008) and Reference Evapotranspiration (ETo) is the evapotranispiration from the reference surface, which is a hypothetical grass reference crop with an assumed height of 0.12 m, a fixed surface resistance of 70 S/m, and an albedo of 0.23, and closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground (Allen et al., 1998). The quantity ETo can be considered to be an upper limit of actual ET.

The Food and Agriculture Organization (FAO) adopted and modified (as FAO 56) the Penman–Monteith (PM) equation as the standard ETo estimation method (Allen et al., 1998). FAO-56 has been accepted worldwide as a good ETo estimator compared with other methods (McVicar et al., 2005; Sumner and Jacobs, 2005).

This study was conducted to statistically analyse the temporal variation in monthly and annual rainfall and determine reference evapotranspiration ETo using FAO *ETo calculator* (Raes, 2009) for *Hosana, Alaba Kulito* and *Bilate* meteorological stations representing upper, middle and lower altitude zones of the Bilate watershed respectively. Then, to determine the average onset, end

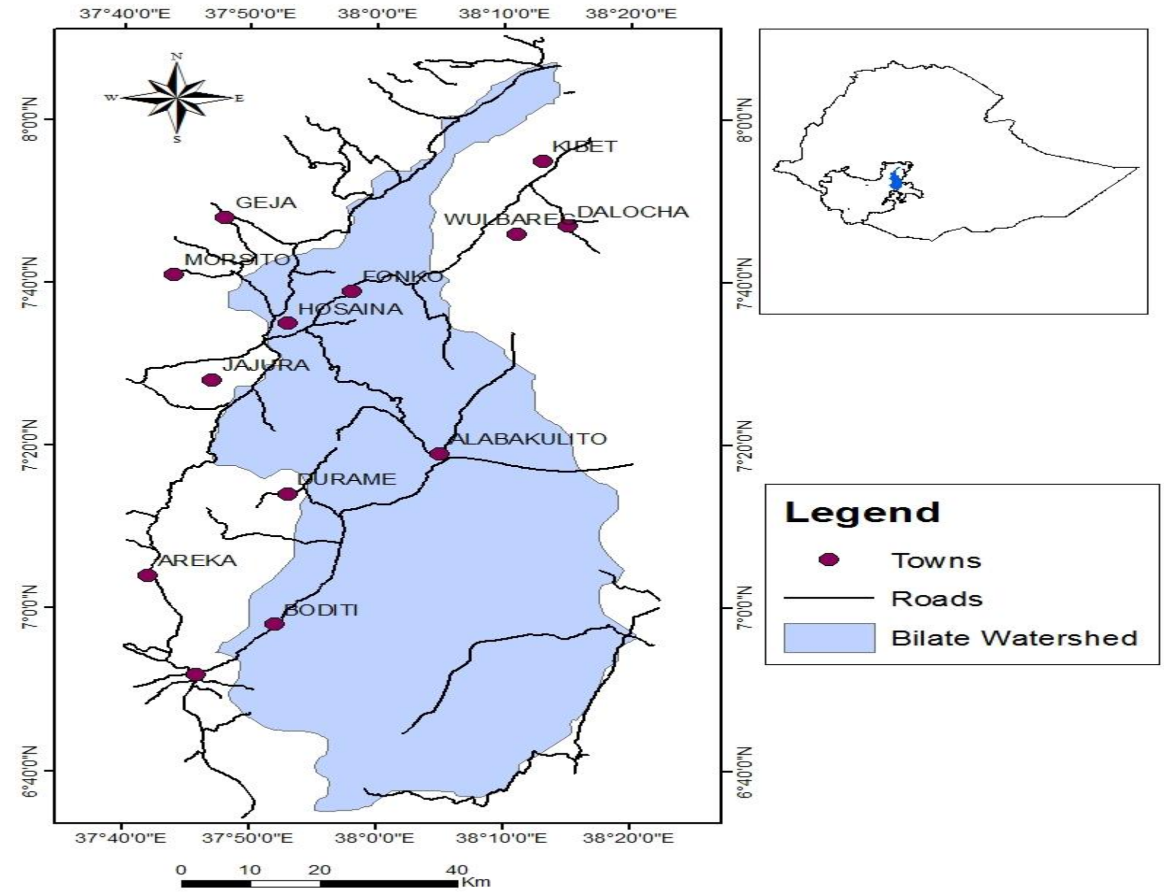

Figure 1. Location map of the Bilate River Watershed.

date and length of growing period for areas in the watershed and finally compare the monthly rainfall and evapotranspiration at different exceedance probability levels for stations in the watershed.

MATERIALS AND METHODS

Study area description

This study was conducted in the Bilate River Watershed. Bilate River is one of the inland rivers of Ethiopia that drains the northern watershed of the Lake Abaya-Chamo drainage basin which forms part of the Main Ethiopian Rift and in turn is part of an active rift system of the Great Rift Valley in Africa. The Bilate River watershed (BRW) covers an area of about 5625 km^2 and is located in the southern Ethiopian Rift Valley and partly in the Western Ethiopian Highlands. The altitude of the watershed ranges from 1300 at Lake Abaya to 3050 m above sea level at Mt. Ambaricho (Figure 1).

The population distribution of the watershed has two characteristics. The first one is maximum rural population density in the upper and middle course areas of the western part of the basin, while the second is the eastern part that is dominantly known for agro-pastoralism and relatively sparse population distribution. As discussed above, parts of the areas under Bilate watershed are known for their high density of population. This may be related to the suitable agro-climatic condition, soil type and availability of water resources. In these areas maximum rural population density is the highest in Ethiopia, which exceeds 500 persons/km^2 (CSA, 2013).

The ethnic and cultural distribution within the watershed is highly diversified. There are more than eight ethnic groups dwelling within the watershed. Their contribution to the environment depends also on their cultural agricultural and land management practices. For example, the ethnic groups living near the mouth of the Bilate River or northern part of Lake Abaya are more of agro-pastoralists. On the other hand the people living in the western part of the watershed are known for their intensive and mixed farming culture.

Data source

Time series rainfall data of the stations in the study watershed were obtained from the Ethiopian National Meteorological Agency (NMA). For the time period of Jan/01/1980 to Dec/31/2013, rainfall stations with an amount of daily data above 75% were selected. From around 18 available stations inside and around the watershed, 11 stations satisfied the criteria. The selected stations with their mean annual value and the percent of daily missing rainfall data for the 30 years period under study is summarized in Table 1.

The recent 30 years records of daily rainfall, maximum and minimum temperature data which used to show the spatial and temporal variability of rainfall and temperature in the BRW is obtained from Ethiopian National Meteorological Agency. For the sake of data management and analysis comparison was made

Table 1. Rainfall stations in the Bilate River Watershed.

S/N	Station name	Longitude (E)	Latitude (N)	Altitude (m)	Missing daily %	Mean annual rainfall (mm)
1	Alaba Kulito	38° 05' 38.00"	7° 18' 38.00"	1772	0.74	1025
2	Angacha	37° 51' 26.00"	7° 20' 25.99"	2317	17.82	1223
3	Bilate	38° 05' 0.00"	6° 49' 0.00"	1361	6.03	781
4	Boditi	37° 57' 18.00"	6° 57' 13.00"	2043	1.97	1154
5	Durame	37° 57' 0.00"	7° 11' 59.99"	2000	5.16	1031
6	Fonko	37° 58' 4.99"	7° 38' 31.99"	2246	9.17	1093
7	Hosana	37° 51' 14.00"	7° 34' 1.99"	2307	3.74	1100
8	Imdiber	37° 56' 10.00"	8° 07' 5.99"	2082	8.19	1068
9	Mayokote	37° 51' 11.00"	6° 53' 8.99"	2121	22.29	1173
10	Shone	37° 57' 9.99"	7° 00' 0.99"	1959	1.72	1353
11	Wulbareg	38° 07' 13.00"	7° 44' 11.00"	1992	3.69	1131

Table 2. Summary of selected meteorological stations.

Station name	Longitude (E)	Latitude (N)	Altitude (m.a.s.l)	Missing %
		Maximum and minimum temperature		
Hosana	37° 51' 14.00"	7° 34' 1.99"	2307	17.79
Bilate	38° 05' 0.00"	6° 49' 0.00"	1361	14.86
Alaba Kulito	38° 05' 38.00"	7° 18' 38.00"	1772	6.16
Angacha	37° 51' 26.00"	7° 20' 25.99"	2317	23.02
Wulbareg	38° 07' 13.00"	7° 44' 11.00"	1992	14.71
Boditi	37° 57' 18.00"	6° 57' 13.00"	2043	1.95
		Rainfall		
Alaba Kulito	38° 05' 38.00"	7° 18' 38.00"	1772	0.74
Angacha	37° 51' 26.00"	7° 20' 25.99"	2317	17.82
Bilate	38° 05' 0.00"	6° 49' 0.00"	1361	6.03
Boditi	37° 57' 18.00"	6° 57' 13.00"	2043	1.97
Durame	37° 57' 0.00"	7° 11' 59.99"	2000	5.16
Fonko	37° 58' 4.99"	7° 38' 31.99"	2246	9.17
Hosana	37° 51' 14.00"	7° 34' 1.99"	2307	3.74
Imdiber	37° 56' 10.00"	8° 07' 5.99"	2082	8.19
Mayokote	37° 51' 11.00"	6° 53' 8.99"	2121	22.29
Shone	37° 57' 9.99"	7° 00' 0.99"	1959	1.72
Wulbareg	38° 07' 13.00"	7° 44' 11.00"	1992	3.69

among selected meteorological stations, but only few meteorological stations have continuous datasets of the total timeframe (Table 2).

The appropriate daily rainfall, minimum and maximum temperature data was arranged by the day of a year (DOY) entry format. Data quality control was done by careful inspection of completeness, spatial and temporal consistence of the records in the study area. The missing values of daily data were calculated and simulated by using INSTAT +v.3.36 first and second order Markov-chain simulation models (Stern et al., 2006). A Markov-based random model was established to generate simulated time series of daily precipitation, and the simulated statistic parameters demonstrated good consistency with their observational equivalents (Yuguo et al., 2010). The inbuilt Markov chain model of InStat software performs the simulation of the missing data in two steps. First, it determines the probability of dry and wet weather from the input climate data of the recorded dates, the model depicts rainfall or no rainfall dates. If there is rainfall, then it comes to the second step which is simulating the precipitation amounts.

Analytical methods

Rainfall data of daily records for 30 years (1984 to 2013) of three weather stations were used for these analyses. Hosana, Alaba Kulito and Bilate weather stations were selected to represent the upper watershed, the mid watershed and the lower watershed respectively. The selection is also based on the completeness of the daily data and the stations reside totally inside the watershed. Seasonal rainfall variability was analysed for onset, end date and Length of Growing period (LGP). Other statistical parameters like the mean, standard deviation and coefficient of variation were also determined.

To determine the onset, end date and LGP the definition from Stern et al. (2006) was used. By this definition, a day with accumulated rainfall amount of 20 mm in three consecutive days and not followed by greater than 9 days of dry spell length within 30 days from the planting day is defined as the onset date.

The end of the growing season is determined by the amount of water which is stored in the soil and accessible to the crop after the rain stops. For this study the end of the rainy season was defined as any day when the soil water reaches zero with the assumption of a fixed average evapotranispiration of 5 mm per day and 80 mm/meter of soil water holding capacity (Stern et al., 2006; Hoefsloot, 2009). By using this definition the built-in Instat statistical software version 3.36 was used for the analysis and on the way LGP was determined by taking the difference between the end date and the onset. The count of wet and dry days was made with the 3 mm rainfall threshold for the agricultural water management purpose (Abiy et al., 2014).

The coefficient of variance (CV) statistics were used to test the level of mean variations of seasonal rainfall, CV is defined as the ratio of standard deviation to mean in percent, where mean and standard deviation are estimated from rainfall data.

$$CV = \frac{S.d}{\bar{X}} * 100 \quad (1)$$

Where: CV = coefficient of variation; S.d = standard deviation; $\bar{X}$=Mean of rainfall (mm).

NMSA (1996) used CV to classify degree of variability of rainfall as less when (CV<20%), moderate when (CV from 20-30%) and highly variable for values of (CV>30%).

To describe annual rainfall variability, the (Van-Rooy, 1965) rainfall anomaly index (RAI), which has been modified to account for non-normality is calculated as follows:

1. for positive anomalies:

$$RAI = \frac{1}{3}\left[\frac{RF-M_{RF}}{M_{H10}-M_{RF}}\right] \quad (2)$$

2. For negative anomalies:

$$RAI = -\frac{1}{3}\left[\frac{RF-M_{RF}}{M_{L10}-M_{RF}}\right] \quad (3)$$

Where: RAI stands for the annual rainfall anomaly index, RF is the actual rainfall for a given year, M_{RF} is mean for the total length of record; M_{H10} is the mean of the 10 highest values of rainfall on record, and M_{L10} is the mean of the 10 lowest values of rainfall on record. The RAI of Van Rooy has been shown to be very effective index of to compute seasonal variability for both positive and negative anomalies (Tilahun, 2006; Kisaka et al., 2015).

To study monthly variability of rainfall in the BRW Precipitation Concentration Index (PCI) was used. PCI is described as:

$$PCI = 100X\left[\frac{\sum Pi^2}{(\sum P_i)^2}\right] \quad (4)$$

Where: Pi is the rainfall amount of the ith month, and $\sum Pi$ is Summation over the 12 months.

PCI values of less than 10 indicate uniform monthly distribution of rainfall, PCI values between 11 and 20 shows high concentration and values more than 21 shows a very high concentration in the distribution of rainfall (Taye and Zewdu, 2012).

The FAO-56 reference ET (ETo) approach (Allen et al., 1998) was used to determine the amount of evapotranispiration in the study area because it would provide the best estimate of ET under various climatic conditions (Suleiman et al., 2008). The ETo Calculator software Version 3.1, is used to calculate the reference ET. The reference evapotranspiration from meteorological data is assessed in the ETo calculator software by means of the FAO Penman-Monteith (FAO-56) equation and all the assumptions made during ETo calculation were discussed in Dirk (2009):

$$ETo = \frac{0.408\,\Delta\,(Rn-G)+\gamma\,\frac{900}{T+273}\,\mu_2\,(e_s-e_a)}{\Delta+\gamma(1+0.34\,\mu_2)} \quad (5)$$

where R_n is the net radiation (MJ m^2/day), G the soil heat flux (MJ m^2/day), T the mean daily air temp (°C), u_2 the mean daily wind speed at 2 m height (m/s), e_s - e_a the saturation vapor pressure deficit (kPa), Δ the slope of the vapor pressure–temperature curve (kPa /°C), and γ the psychometric constant (kPa/ °C).

Aridity index (AI) was computed by using the UNESCO aridity index (Rodier, 1985) as follows:

$$AI = \frac{P}{ET_o} \quad (6)$$

Where P is the mean annual rainfall and ETo is the mean annual reference evapotranispiration. UNESCO adopted a classification for degrees of aridity as follows: AI < 0.05 is hyper-arid zone, 0.05 < AI < 0.20 is an arid zone, 0.20 < AI < 0.50 is a semi-arid zone, 0.5 < AI < 0.65 is a Dry sub-humid zone and AI > 0.65 is humid (Rodier, 1985).

RESULTS AND DISCUSSION

Trend of annual and seasonal rainfall

The recent 30 years mean annual rainfall in the BRW ranges between 721 and 1353 mm which shows large spatial variability with a maximum rain fall of as large as 1.87 times the minimum rainfall. Areas that belong to the part of the Western Ethiopian Highlands show higher rainfall on annual base while the part of the watershed that belongs to the Ethiopian rift valley shows lower rainfall. Based on the interpolation method used, the mean annual rainfall of the period 1984 to 2013 is estimated to be 1121 mm.

The statistical trend results for the time series of rainfall observed at three stations is presented in Table 3. The table shows a non-significant trend at 95% confidence level in all the stations. Although it is non-significant at 95% confidence level at Hosana, the "*Belg*" season can be explained to significantly decreasing (p = 0.05). The variability in rainfall in the watershed can be shown by the trend variation of the annual rainfall with decreasing trend in Hosana station (3.43 mm/year) to increasing trend in Bilate station (4.76 mm/year). As depicted in Table 3, there was a decreasing trend during *Belg* season in Hosana area of the watershed. In Alaba Kulito and Bilate area there is increasing trend both in the *belg* and *Kiremit* seasons, which are known to be the wettest part of the year. But in all the causes the trend is not significant at 95% confidence level.

Table 3. Total Annual and seasonal precipitation trends of three selected stations.

Stations	Mean (mm)	SD (mm)	Slope (mm/year)	Significance (P value)
Seasons				
Hosana				
Annual	1100.2	128.20	-3.43	0.12
Bega	120.25	51.38	-0.64	0.28
Belg	407.71	95.98	-4.00	0.05
Kiremt	572.28	67.37	1.20	0.68
5 years mean	1042.86	183.14		0.50
10 years mean	1064.34	147.35		0.30
15 years mean	1086.95	133.03		0.12
Alaba Kulito				
Annual	1069.96	156.55	0.35	0.60
Bega	173.6	71.76	-1.36	0.11
Belg	391.83	88.08	1.49	0.85
Kiremt	505.19	86.14	0.22	0.70
5 years mean	1123.92	170.83		0.89
10 years mean	1086.16	141.93		0.86
15 years mean	1066.69	136.33		0.88
Bilate				
Annual	785.11	133.45	4.76	0.90
Bega	168.13	47.62	1.01	0.85
Belg	289.4	60.48	0.04	0.41
Kiremt	327.57	91.31	3.71	0.96
5 years mean	907.84	229.70		0.59
10 years mean	823.52	190.74		0.95
15 years mean	816	165.37		0.81

There was a high temporal anomaly in rainfall between 1984 and 2013. It is shown in Figure 2 that none of the stations depicted years with persistent near average rainfall with RAI = 0. In Bilate the wettest year recorded in 2000 (RAI = +5) and in 2010 (RAI = +4). In Alaba Kulito the highest positive anomalies recorded in 1984 (RAI = +6), 1998 (RAI = +4) and 2012 (RAI = +5). The three wettest years of Hosana are 1984 (RAI = +8), 2007(RAI = +4) and 2011 (RAI = +5). Hosana station has more number of years (seven out of 30 years) with average annual rainfall amount (RAI = 0) and the three driest years in Hosana were recorded in 1990 (RAI = -5), 2010 (RAI = -4) and 2012 (RAI = -5).

A 30 year time-series analysis of the rainfall dataset (Table 3 and Figure 2) showed more frequent rainfall anomalies in the BRW. The results of rainfall analysis for anomalies show that, the BRW is characterised by periodic fluctuation of the dry and wet years. Even if, it is not in consecutive years Hosana station has seven out of 30 years with average annual rainfall amount (RAI = 0), otherwise the results of Rainfall Anomaly Index (RAI) depicted that in all the stations there is no persistent trend showing near average rainfall with RAI = 0. Relatively, being an area having near average rainfall Hosana area also experienced a very dry years in 1990(RAI = -5), 2010 (RAI = -4) and 2012 (RAI = -5). In contrast Bilate area, driest of all stations, also experienced wettest years recorded in 2000 (RAI = +5) and in 2010 (RAI = +4). The variability in rainfall in the watershed can also be explained by the trend variation of the annual rainfall with decreasing trend in annual rainfall in Hosana with the average amount of decrease over the last 30 years is 3.43 mm every year whereas the increasing trend in Bilate station is an average 4.76 mm rainfall every year. Clearly, the trend analysis results depend on the study period chosen. That means if the time period were changed or extended, a different conclusion may be drawn. This result of increasing trend in rainfall in Bilate and decreasing trend in rainfall in Hosana with all the anomalies shown in the watershed is in agreement with the previous studies of Abiy et al. (2014). Generally, the mean annual rainfall increases moving to southwest and with an increasing elevation, ranging from 781 mm at Bilate up to 1100 mm at Hosana.

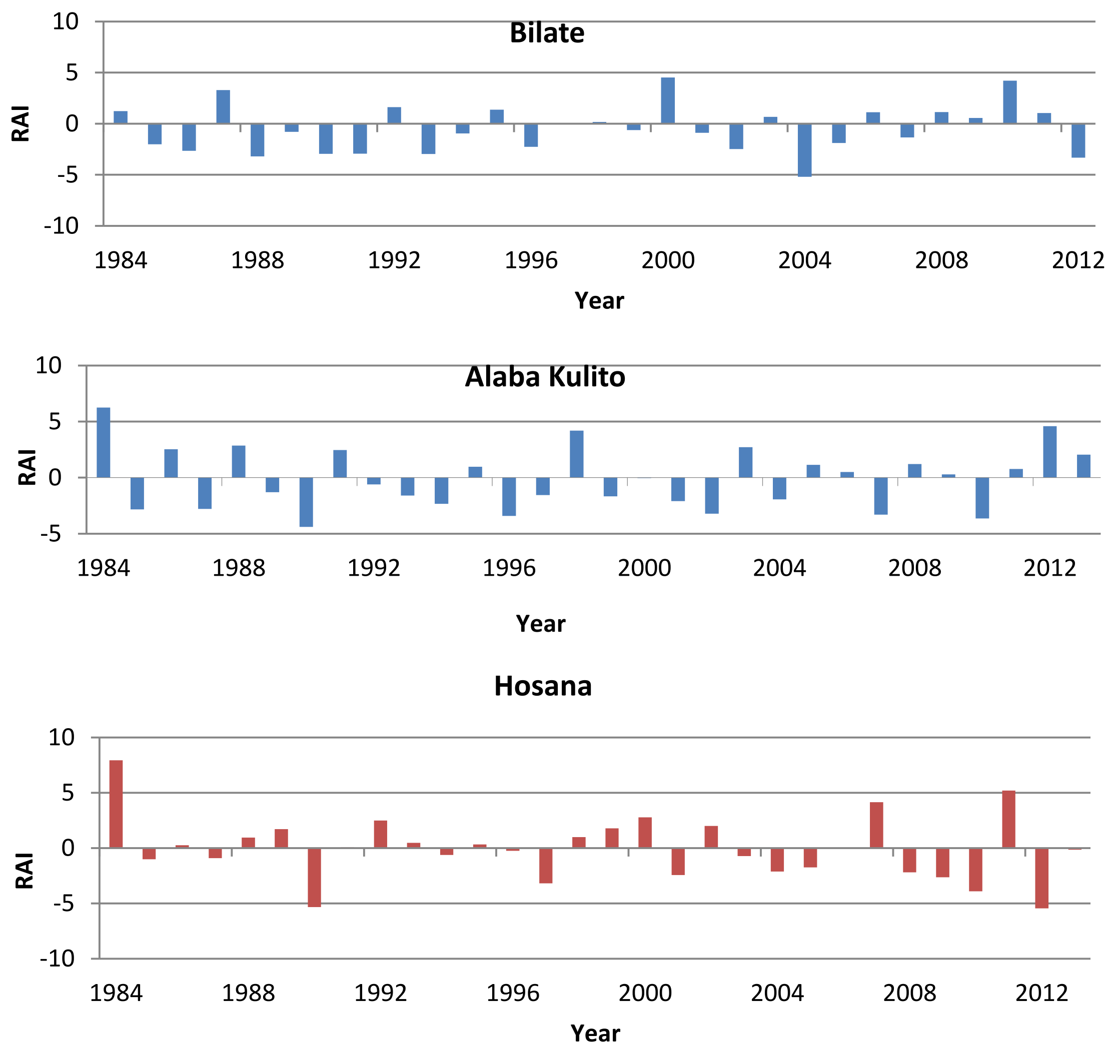

Figure 2. Rainfall anomaly index for the study period in three selected stations.

This is also in agreement with Kassa (2015).

Monthly variations in rainfall amounts and number of rainy days

The results in Table 4 showed that rainfall amounts received in the long rainy season (belg-kirmt) from March to September were highly variable in Alaba Kulito and Bilate all with CV > 0.3. The CV in Rainfall Amounts (CV-RA) was higher in Months of March and October in all the three stations. For Hosana March (CV-RA = 0.44) and October (CV-RA = 0.56), for Alaba Kulito and Bilate both March (CV-RA = 0.47) and October (CV-RA = 0.47).

Variability in number of rainy days (CV-RD) is also higher for the two mentioned months. For Hosana station March CV-RD = 0.39 and Oct. CV-RD = 0.53, in Alaba Kulito the CV-RD of March and October was 0.41 and 0.52 respectively. The Bilate station an exception to have the highest CV-RD in months of June (CV-RD = 0.42) and July (CV-RD = 0.41) unlike other stations.

There is high variability in the amount of rainfall in a given month and the number of raining days in that month in all the stations of the watershed. Bilate station is an exception to have the highest variation in the number of rainy days to have in months of June (CV-RD = 0.42) and July (CV-RD = 0.41), otherwise the highest CV-RD happened in March and October in other stations. The onset month (March) and end month (October) showed higher variability in rainfall amounts and the number of rainy days compared to mid seasonal months. This result shows that the main problem of the watershed was not the total amount of annual rainfall. The fluctuation of onset dates and end dates of the farming period or more specifically delay of the starting dates and early cessation of rain relative to the average dates of the past. Lower values of CV-RD shows that the variation in rainy days is more or less consistent compared to variations in the

Table 4. Variability in rainfall amount and number of rainy days.

Hosana	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
RA (mm)	85.0	131.0	145.0	135.0	144.0	150.0	144.0	50.0
CV-RA	0.44	0.43	0.33	0.23	0.28	0.19	0.37	0.56
RD	8.0	10.0	12.0	11.0	13.0	14.0	12.0	4.0
CV-RD	0.39	0.39	0.22	0.21	0.23	0.18	0.29	0.53
Alaba Kulito								
RA (mm)	60.0	93.0	106.0	97.0	83.0	74.0	72.0	67.0
CV-RA	0.47	0.32	0.34	0.51	0.46	0.39	0.38	0.47
RD	7.0	9.0	9.0	9.0	9.0	12.0	9.0	5.0
CV-RD	0.41	0.34	0.24	0.33	0.29	0.25	0.26	0.52
Bilate								
RA (mm)	60.0	93.0	106.0	97.0	83.0	74.0	72.0	67.0
CV-RA	0.47	0.32	0.34	0.51	0.46	0.39	0.38	0.47
RD	6.0	8.0	9.0	8.0	7.0	7.0	7.0	7.0
CV-RD	0.39	0.32	0.3	0.42	0.41	0.3	0.34	0.36

Table 5. Annual and seasonal mean of rainfall (mm), standard deviation (mm), Coefficient of variation (%) and Precipitation Concentration Index (PCI %).

Station	**Annual**			***Kiremt***			***Belg***			***Bega***			**PCI %**
	Mean	**CV**	**SD**	**Mean**	**CV**	**SD**	**Mean**	**CV**	**SD**	**Mean**	**CV**	**SD**	
Alaba Kulito	1070	15	157	505	17	86	392	22	88	173	41	71	10
Boditi	1197	14	173	556	20	109	455	24	108	185	28	53	10.38
Bilate	785	17	133	328	28	91	289	21	60	168	28	48	9.67
Hosana	1100	12	128	572	12	67	408	24	96	120	43	51	11.05
Wulbareg	1202	15	179	687	18	123	417	25	103	98	58	56	11.87

monthly rainfall amounts and the higher variability in the onset and end of rainy season is known to affect the cropping calendar of rain-fed agriculture (Kisaka et al., 2015).

Variability of rainfall amount and monthly contributions

From Table 5, the recent 30 years mean annual rainfall of Hosana, AlabaKulito and Bilate is found to be 1100, 1070 and 785 mm with CV of 12, 15 and 17%, respectively. The mean *Kiremt* and *Belg* rainfall for Hosana is 572 and 408 mm with SD of 67 and 96 mm. The CV is higher for Hosana and Alaba Kulito in *belg* season than the annual. As the *belg* rainfall is very important, for crops like maize and sorghum which are known for their longer growing period, higher variability in the *belg* rainfall will hinder the agricultural production of the area.

As shown in Table 6 half of the year from April to September contributed 77% to the annual rainfall in Hosana station, for which *belg* contributed 37% and *Kiremt* contributed 52%. The monthly contribution January, February and March is 3, 4 and 8% which is very low compared to August (14%). The annual rainfall CV in all stations is below 20% which is said to be less (NMSA, 1996) but the CV of *belg* season, which is known to be main maize growing season for the area, is higher than the annual amount. Similarly at Alaba Kulito 36.64% of annual rainfall was occurred in *belg*, while 47.2% of the annual rainfall occurred in *kiremt.* The Precipitation Concentration Index (PCI) is 11.05, 10 and 9.67% in Hosana, Alaba Kulito and Bilate Stations respectively.

The Precipitation Concentration Index (PCI) of all the stations is near or above the threshold value of PCI = 10% for uniform rainfall distribution throughout a year. March, April and May (MAM) contribute 33% of annual rainfall in the Bilate station which shows that MAM is, relatively the main growing season in the lowland areas (NMSA, 1996).

Onset, end and length of growing period

The computation of onset, end and LGP is done by following the days of year (DOY) entry format for a year

Table 6. Mean monthly amount and percentage contribution of rainfall for selected stations.

Station	Jan	Feb	mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean monthly rainfall (mm)												
Hosana	29	47	85	131	145	135	144	150	144	50	25	17
Alaba Kulito	36	52	93	118	128	118	118	150	120	74	37	26
Bilate	27	30	60	93	106	97	83	74	72	67	42	33
Percent contribution to annual (%)												
Hosana	3	4	8	12	13	12	13	14	13	5	2	2
AlabaKulito	3	5	9	11	12	11	11	14	11	7	3	2
Bilate	3	4	8	12	14	12	11	9	9	8	5	4

Table 7. Onset, end and length of growing period (LGP) in three selected stations.

Station		Hosana	Alaba Kulito	Bilate
Onset	Max	127	158	158
	Min	51	53	43
	Mean	94	101	102
	CI	94 ± 8	101 ± 10	102 ± 11
	SD	22	26	29
	CV	0.23	0.26	0.29
End	Max	302	311	254
	Min	247	245	149
	Mean	277	269	194
	CI	277 ± 5	269 ± 7	194 ± 10
	SD	15	19	28
	CV	0.05	0.07	0.14
LGP	Max	229	252	150
	Min	131	87	29
	Mean	183	168	92
	CI	183 ± 10	168 ± 13	92 ± 13
	SD	26	34	35
	CV	0.14	0.2	0.38

Onset and End measured in DOY, LGP measured in number of days, CI stands for Confidence interval at α = 0.05.

beginning in January and ending in December and using daily rainfall data of 30 (1984 - 2013) years for three rainfall stations. The results in Table 7 showed that the average onset date of rainfall for Hosana is 94 ± 8 DOY (April 3), for Alaba Kulito 101 ± 10 DOY (April 10) and for Bilate is 102 ± 11 DOY (April 11) with CV of 23, 26 and 29% respectively. The average end dates of the rainy season in Hosana and Alaba Kulito are October 3 (277 ± 5 DOY) and September 25 (269 ± 7 DOY) with CV 5 and 7%. The main rainy season ends earlier in Bilate, it is on July 12 (194 ± 10 DOY) with CV 14%. The length of growing period (LGP) in Hosana varies from 131 to 229 days with 30 years mean value of 183 ± 10 days, CV 14% and SD of 26 days. The result of LGP for Alaba Kulito varies from 87 days to 252 days with mean value of 168 days, CV 20% and SD of 34 days.

The box plot in Figure 3 shows that the LGP is very variable in all the three stations, but it is highly variable (from 29 - 150 days) in Bilate station with CV of 38% and SD of 35 days. Ethiopia is known to have three distinct seasons. The first is the “Belg” Season (February, March, April and May) which is the main growing season for most of the long duration crops like maize and sorghum (NMSA, 1996; Abiye et al., 2014), the second is “Kiremet” Season (June, July, August and September) which is responsible for up to 57% of annual rainfall in the study area and the third is the “Bega” Season (October, November, December and January) which is usually a dry season known to be non-growing season. From the above discussion it is clear that the long rainy season (Belg - Kiremt) runes from February to September and the computation of onset, end and LGP is done within

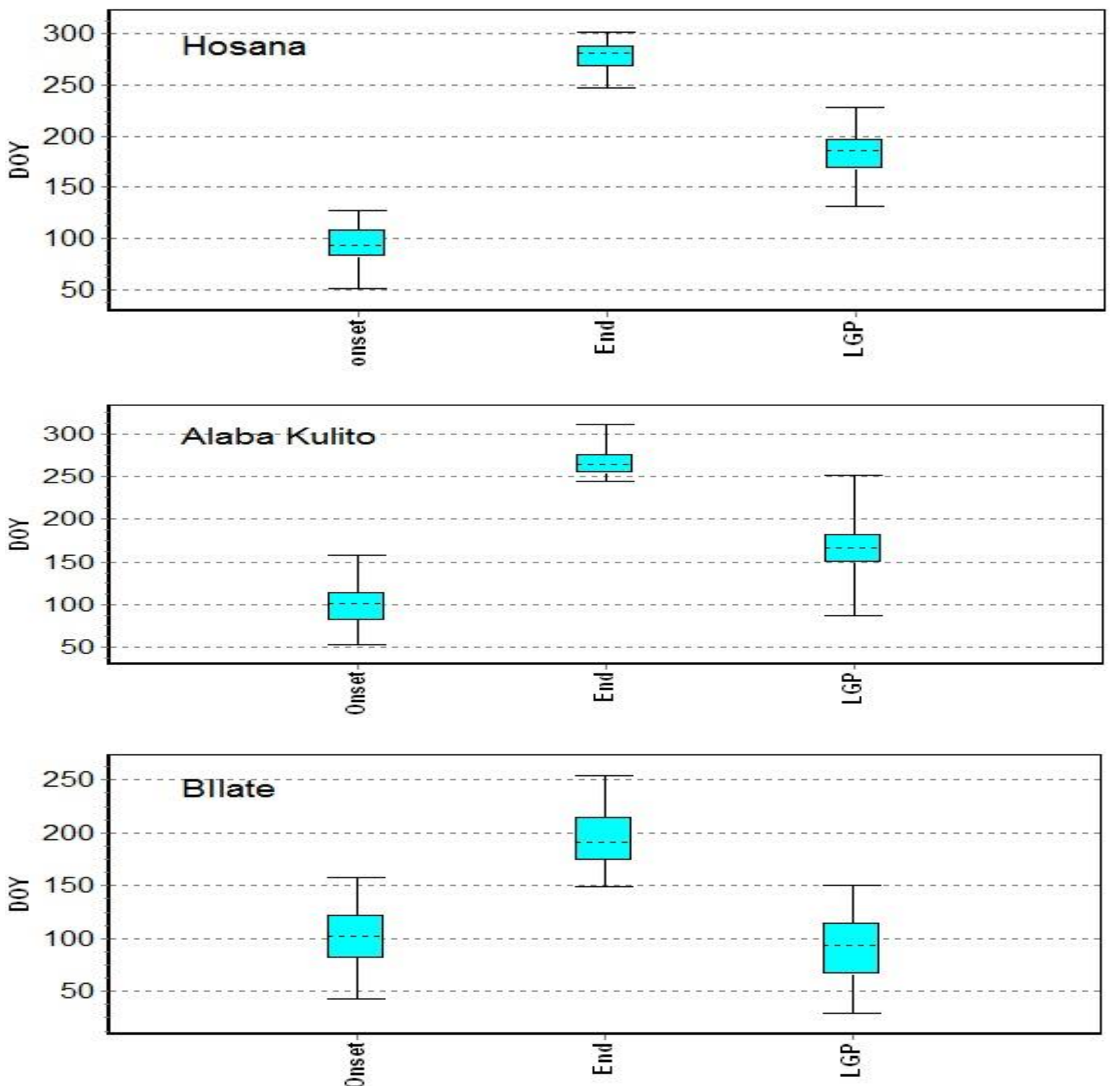

Figure 3. Box plot graph of onset, end and LGP in three stations. The upper and lower tip of the whiskers shows the maximum and the minimum values, the upper and lower sides of the box represent 75th and 25th percentile and the dot line inside the box indicates the median dates.

these months by following the days of year (DOY) entry format for a year beginning in January and ending in December and using daily rainfall data of 30 (1984 - 2013) years for three rainfall stations.

As shown in Table 7 there is no big difference in the mean on set date of rainfall in the watershed with the first and second week of April is the average on set date of rainfall in all the stations. But the average end date and so the LGP is different from station to station in the watershed. Based on the 30 years result, the mean end date of the rainy season in Hosana, Alaba Kulito and Bilate station was October 3, September 25 and July 12 respectively, giving the stations mean the Length of Growing Period of 183, 168 and 98 days respectively and this results are in agreement with the findings of Abiyet al. (2014).

Analysis and comparison of evapotranspiration

As shown in Figure 4, in Hosana station the mean monthly rainfall exceed the evapotranispiration for months from April to September and there is water deficit in the area for the rest of the year. Hosana, with 30 years mean Aridity Index (AI) of 0.8 is classified as a humid zone even though there is water deficit for half of the year. In Alaba Kulito, an area with 30 years mean AI = 0.6 (Dry sub-humid zone) the evapotranispiration values exceed the rainfall amount for most of the months except July and August. As shown in Figure 4, in Bilate area, the evapotranispiration values exceed the rainfall amount for all of the months, showing that rain fed agriculture is not feasible. The AI of Bilate area is 0.43, so that the area is classified as semi-arid zone according to UNFCCC

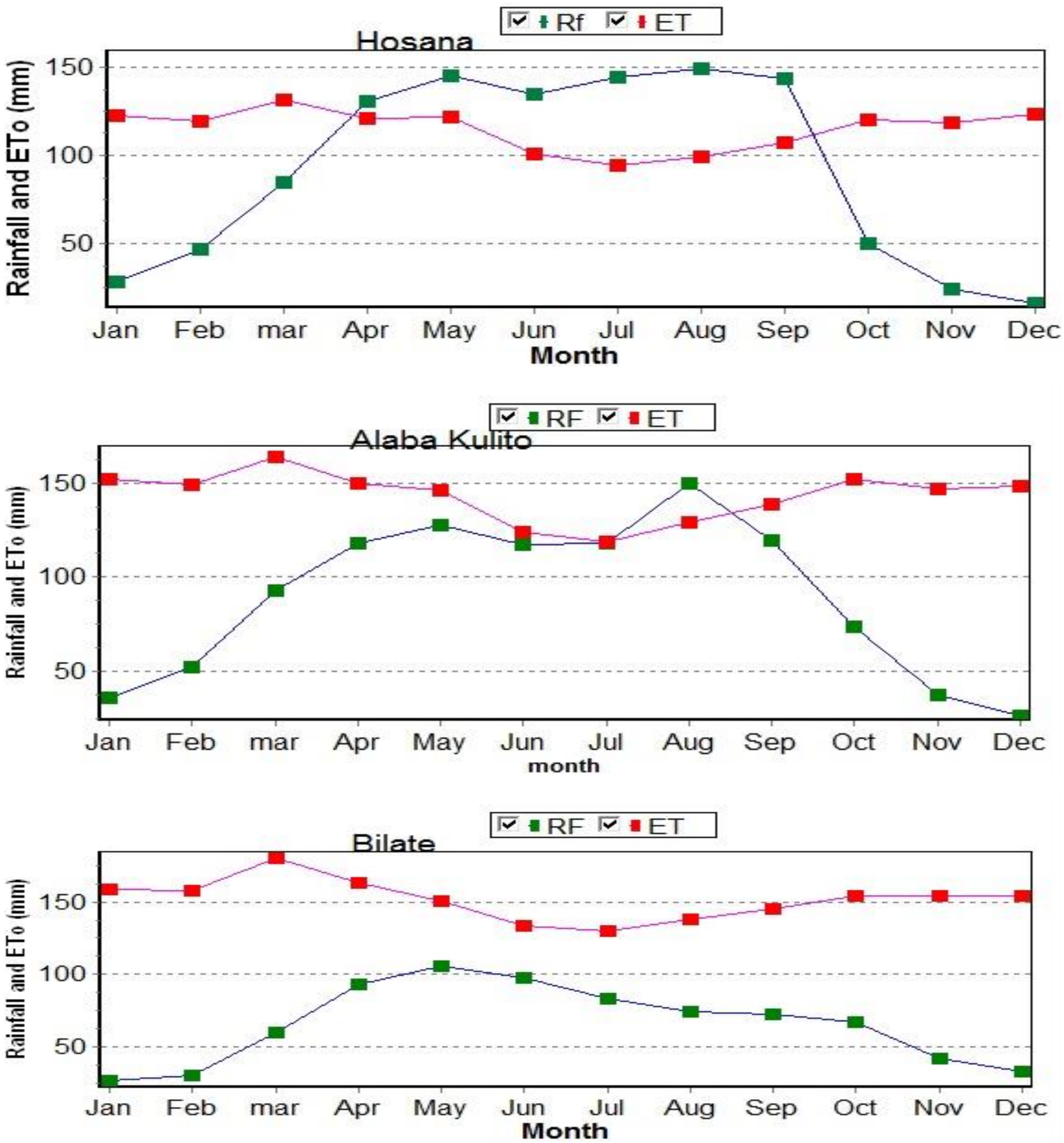

Figure 4. Comparison of monthly rainfall and reference evapotranspiration.

(Rodier, 1985).

The relationship between 20, 50 and 80% exceedance levels of monthly rainfall representing wet, normal and dry years respectively and the reference crop evapotranspiration of 20, 50 and 80% exceedance levels is shown in Figure 5 for three selected station. For Hosana station the rainfall expected in normal year is less than the reference crop evapotranispiration for half of months of the year. In a wet year (20%RF) two more months with expected rainfall higher than the reference crop evapotranispiration at 20, 50 and 80% will be added. Furthermore, the monthly 80% dependable reference evapotranispiration is in the range of ± 31 mm of the monthly mean value, which shows that there is a probability of the reference evapotranispiration exceeds the mean monthly rainfall leaving the area with deficiency of crop water.

Similarly, in Alaba Kulito station in a normal and dry years (50 and 20% RF) rainfall is less than the reference crop evapotranispiration throughout the year. In Bilate station only 20% RF in wet years exceeds the reference evapotranispiration in couple of months giving the area a slight chance of rain-fed agriculture with mean Length of Growing period (LGP) less than 90 days.

For all the stations monthly reference evapotranispiration was computed and compared with the monthly mean rainfall. This helps to determine the period with moisture deficit and times when the need for

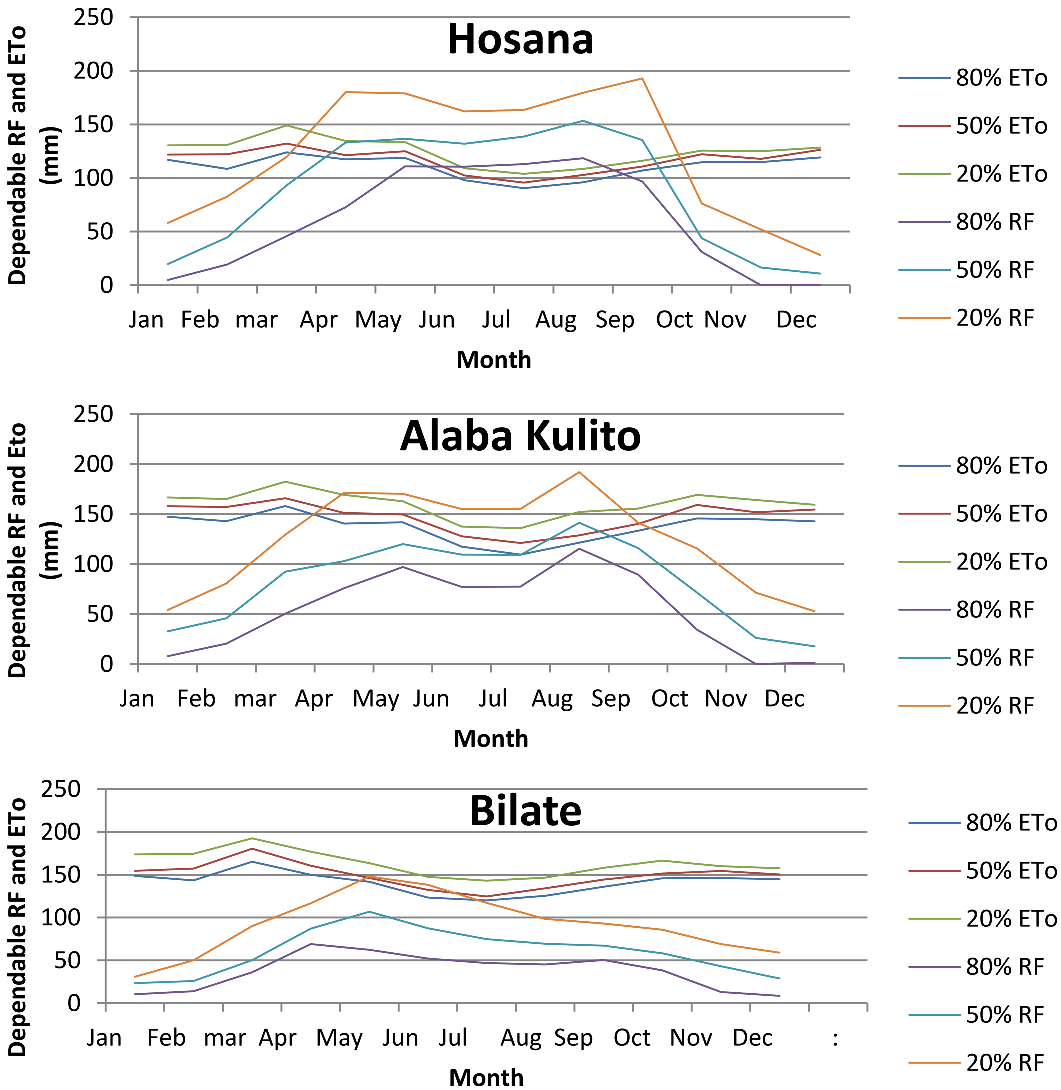

Figure 5. Monthly rainfall and evapotranspiration at three exceedance probability levels for selected three stations.

water from other sources is high and the farmers cannot depend only on rain for their agricultural production. As shown in Figure 4, in Hosana station the mean monthly rainfall exceed the evapotranispiration for months from April to September and there is water deficit in the area for the rest of the year. In Alaba Kulito, an area with 30 years mean AI = 0.6 (Dry sub-humid zone) the evapotranispiration values exceed the rainfall amount for most of the months except July and August. As shown in Figure 4, in Bilate area, the evapotranispiration values exceed the rainfall amount for all of the months, showing that rain fed agriculture is not feasible but only 20% RF in wet years exceeds the reference evapotranispiration (Figure 5) in couple of months giving the area a slight chance of rain-fed agriculture with mean Length of Growing period (LGP) less than 90 days, otherwise the area is having rainfall below the threshold of rain-fed agriculture of 250 mm (Aghajani, 2007). The Aridity Index (AI) of Bilate area for the last 30 years is 0.43, so that the area is classified as semi-arid zone according to UNFCCC (Rodier, 1985).

Conclusion

In this study rainfall variability including the onset, end and length of growing period with the number of raining days and over all statistical parameters was analysed. The reference evapotranispiration (ETo) was also determined from other directly measured climatic variables and compared with the annual and seasonal rainfall trend as this is the determining factors of planning and management of water resources and agricultural practices. Rainfall is the major climatic parameter that needs to be analysed for its statistical characteristics in order to conduct successful rainfed agriculture, while evapotranspiration is another factor that can be estimated from other climatic parameters. The result showed that, there was a considerable spatial variation of rainfall and temperature over Bilate watershed. The annual total rainfall of the watershed varies from a little over 780 mm in Bilate station to over 1350 mm in Shone station. From the different rainfall features considered in the study, onset and end dates of rainfall and so the Length of growing period was also found to considerably variable. The main climatic problem of all the stations for their rainfed agriculture is a Pseudo onset of the rain, days with limited amount of rainfall that are followed by dry spell of more than 9 days within a month time. From the comparison of rainfall and evapotranispiration mean values for the last 30 years, it has been seen that the areas in upper and mid part of the watershed experience a water deficit from 6 to 9 months of the year, while area in the lower part of the watershed experience moisture deficit throughout the year which necessities supplementing the rainfed agriculture with other sources of water for irrigation. The Impact of large-scale climate anomalies, such as ENSO on the main growing period (Belg and Kiremt seasons) of the BRW needs to be addressed by further research.

Conflict of Interests

The authors have not declared any conflict of interests.

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