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The Current and Future Trend of Rainfall and Its Variability in Adami-Tulu Jido-Kombolcha Woreda, Central Rift Valley of Ethiopia

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Abstract
The seasonality and availability of water in Ethiopia are influenced by the steep climatic gradients and physiographic contrasts. While large population of the country heavily relies on rain fed agriculture, the anomaly in rainfall has direct implications on the crop production and further food sufficiency. This study investigates the current and future trends of rainfall and its variability in Adami-Tulu Jido Kombolcha woreda, central Rift Valley of Ethiopia. Statistical tools like; PCI, CV, and SRA method were used to identify the variability of rainfall concentration test, the degree of variability of rainfall and characterize the drought frequency and intensity. Sen's estimator and Mann-Kendall's statistical tests were employed for trend detection. The HadCM3 A2 and B2 scenarios experiments were used for the climate projection. The current annual rainfall has increasing trends for all stations except Bulbula. However, the projection of future rainfall conditions suggest that the annual and seasonal rainfall in Adami Tulu Jido Kombolcha is most likely to decrease for both HadCM3-A2 and HadCM3-B2 scenarios, and found to be statistically insignificant at 5% significance level. The average annual precipitation concentration index (PCI) showed irregular distribution of annual rainfall for most stations except Bulbula that highlights the seasonality in rainfall distribution. Most of the stations showed moderate variation in annual rainfall (CV ranging from 20 to 30%) except for Ziway station, which has less variations (CV% < 20%). Generally, the rainfall trends in the study area are not uniform and consistent in both time and space until end of 2090.
Keywords: trend analysis, Climate Change, GCM, Scenarios, SDSM, Coefficient of Variation, HadCM3

1. INTRODUCTION

The amount and temporal distribution of rainfall is generally the most important determinant of inter-annual fluctuations in crop production in Ethiopia and has reported to have significant effects on the country's economy and food production for the last three decades (World Bank, 2006; Bewket and Conway, 2007). The Central Rift Valley (CRV) of country is further characterized by intricate problems of drought, resource degradation and low agricultural productivity (Holden and Bekele, 2004). With respect to natural changes some trends can be detected, for example Hengsdijk, 2007 found that annual temperature tends to increase, possibly resulting in higher evapotranspiration.

The climate of arid and semi-arid region of Ethiopia is characterized by high rainfall variability and unpredictability, strong winds, high temperature and high evapotranspiration (Mamo, 2005). The central rift valley of Ethiopia where is evidently the hardest hit region of the country in terms of drought (Bezabih et. al., 2010), study also reported that Adami Tulu Jido Kombolcha (ATJK) rainfall anomaly has become a serious threat for food security where agricultural production is very sensitive to meteorological conditions. Indeed the change in rainfall patterns combined with other environmental constraints such as soil degradation, plant pests, and diseases have contributed to decreasing crop production in arid and semi-arid parts of the country where agriculture is mainly rain-fed.

Hence, it's essential to analyze the trends of rainfall, rainfall variability, and drought to quantify their effects on economic activities such as rainfed agriculture, and drinking water supply due to their role in natural hazards such as droughts, floods and severe erosion. Therefore, the objectives of this study were to analyze the current and future trends of precipitation using the observed data, as well as downscaled climate projections and to study the rainfall variability, drought severity and frequency in ATJK, Central Rift Valley of Ethiopia.

2. MATERIALS AND METHODS

2.1. The study area

The study was conducted in the Central Rift Valley part of Ethiopia in Oromia Region, Adami Tulu-Jido Kombolcha woreda. Geographically the area is located between 38°25'E and 38° 55'E and 7°35'N and 8°05'N (Figure 1) and is bordered by Southern Nations, Nationalities and Peoples' Region (SNNPR) in the west and north west, Dugda-Bora woreda in the north, Arsi zone in the east and Arsi Negele woreda in the south. At a distance of about 160 km from Addis Ababa. The woreda has semi-arid and arid agro-climatic zones and lies between 1500 -

2300 m a.s.l. with exception to the areas found around Mount Aluto. Major rivers in the woreda include: Bulbula, Jido, Hora Kalio and Gogessa. Vitric Andosols and Mollic Andosols are the dominant soil group in the Woreda. Andosols soils originate from volcano-lucustrine deposits with volcanic ashes, ciders, pumic (graves) lapilli. The pH of soil is 7.88. Fine sandy loams exist with sandy clay having sand, silt, clay in proportion of 34%, 48% and 18%, respectively (Adami Tulu Research Center profile, 1998 cited in (Abdissa et al., 2011))

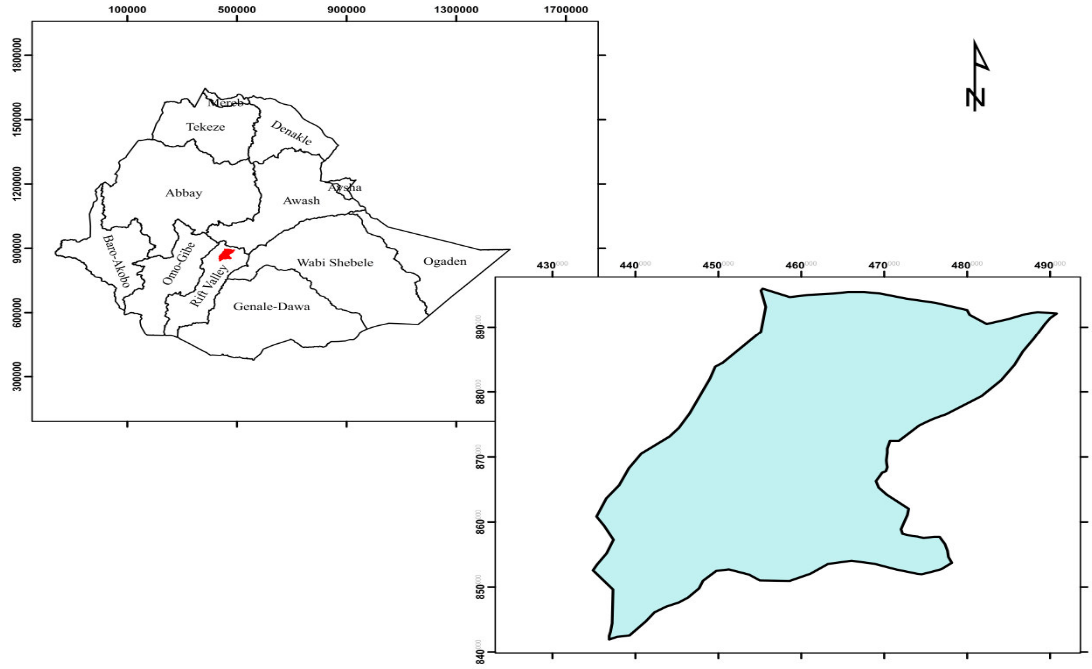

Figure 1 Location of Adami Tulu Jido Kombolcha Woreda

2.2. The data set

The rainfall data for the selected stations (Figure 2), from the period 1984-2013 were obtained from the National Meteorological Agency of Ethiopia (NMA). In order to fill the missing rainfall data, joint application of the spatial interpolation techniques are used to complete short and long period breaks in data series for a given meteorological stations. The daily areal rainfall is calculated from the daily point measurement of rainfall in and around the catchments by Thiessen polygon method. Catchments of Thiessen polygon with four measuring stations are drawn by using Arc GIS in order to estimate the areal rainfall.

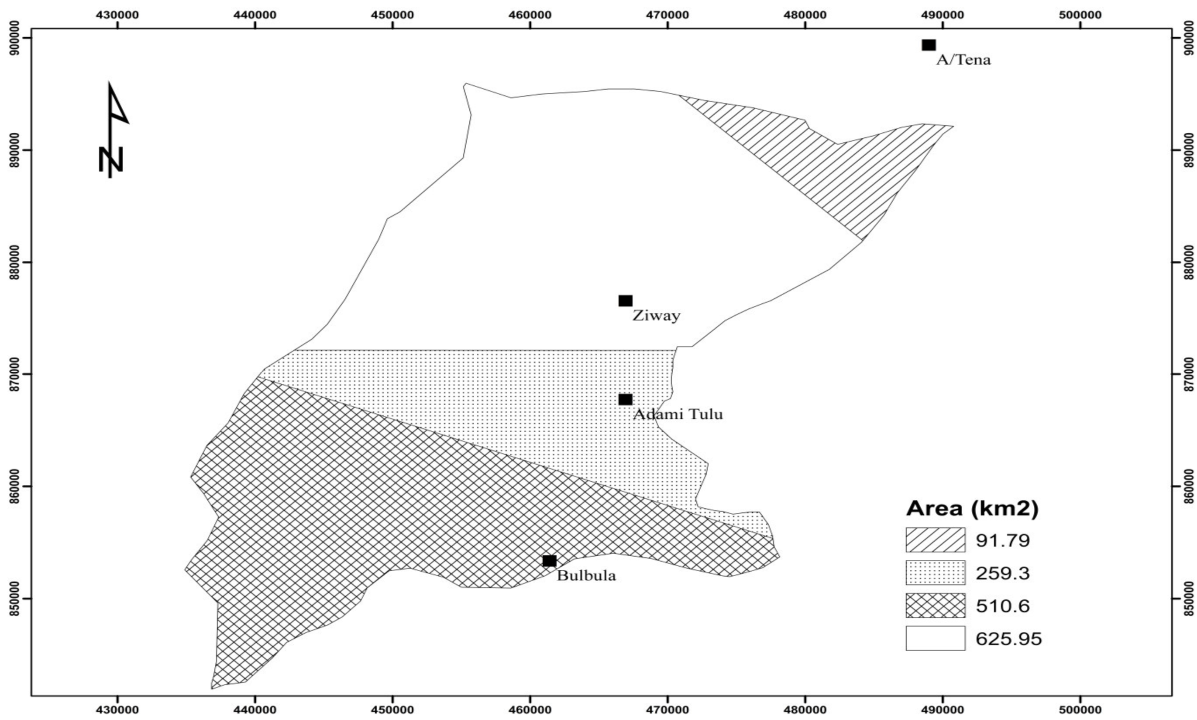

Figure 2 Thiessen polygons areas (Km^2) for estimating areal rainfall

The data homogeneity test; which refers to study meteorological or hydrologic records by means of a frequency analysis and to test the homogeneity of the record was done by using RAINBOW. If the cumulative deviation crosses one of the horizontal lines the homogeneity of the data set is rejected with probabilities of 90, 95 and 99%, respectively. The probability of rejecting the homogeneity of the data set for selected stations are reported in the table below

Table 1 Probability of Rejecting Homogeneity of Annual Rainfall for each Station.

	Ziway			Alem Tena			Adami Tulu			Bulbula		
Probability of Rejecting	90	95	99	90	95	99	90	95	99	90	95	99
Range of Cumulative deviation	No	No	No	No	No	No	Yes*	No	No	No	No	No
Maximum of cumulative deviation	No	No	No	No	No	No	No	No	No	No	No	No

**Estimate of change point in 2006*

The SDSM predictor data files, HadCM3 are downloaded from the Canadian Climate Change Scenarios Network (CCCSN) website http://www.cccsn.ec.gc.ca/scenarios/sdsm/select.cgi. The model output of HadCM3 was employed for the A2 (Medium-High Emissions) and B2 (Medium-Low Emission) Scenarios.

2.3. Methods

Trend Analysis

In this study, Mann Kendall trend analysis used for the assessment of current and future rainfall trend at annual and seasonal time scales for Bulbula, Adami Tulu, Ziway, Alem Tena stations which are located in and around the study area by using XLSTAT software. Data for performing the Mann-Kendall analysis should be in time sequential order. The first step is to determine the sign of the difference between consecutive sample results. Sgn (Xj - Xk) is an indicator function that results in the values 1, 0, or –1 according to the sign of (Xj – Xk) where j > k, the function is calculated as:

$$S = S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k) \qquad 1$$

$$Sgn(X_j - X_k) = \begin{cases} +1, if(X_j - X_k) > 0 \\ 0, if(X_j - X_k) = 0 \\ -1, if(X_j - X_k) < 0 \end{cases} \qquad 2$$

Where Xj and Xk are the sequential precipitation or temperature values in months j and k(j > k) respectively whereas; A positive value is an indicator of increasing(upward) trend and a negative value is an indicator of

decreasing (downward) trend.
The slope of a linear trend is estimated with the nonparametric Sen's slope estimator's method (Gilbert, 1987). It is the best method to detect trend because it is not affected by outliers and missing data (Stern et al., 2006). The slope of n pairs of data points was estimated using the Sen's estimator is calculated as:

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1 \ldots N \qquad 3$$

Where, x_j and x_k are data values at times j and k, (j>k) respectively. The median of these N values of Q_i is Sen's estimator of slope.

The presence of a statistically significant trend is evaluated using the Z value. To decide whether the null hypothesis is to be accepted or rejected, a test statistic is computed and compared with a critical value obtained from a set of statistical tables. Ho is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$ and then the trend is considered as significant, where $Z_{1-\alpha/2}$ is obtained from the standard normal distribution.

Rainfall variability and Drought Analysis

The rainfall variability for representative meteorological stations was determined by calculating the coefficient of variation (CV) as the ratio of the standard deviation to the mean rainfall in a given period (CV%, when expressed as a percentage) (NMSA, 1996). The Coefficient of variation (CV) can be calculated using the following formula;

$$CV = \frac{\sigma}{x} \qquad 4$$

Where σ = Standard deviation; X= mean
Based on the values of CV, (NMSA, 1996), has classified the rainfall variability of an area as;
CV < 20 % less variable, CV 20 % -30 % moderate variable and CV > 30 % high variable
Heterogeneity of monthly rainfall amount was investigated using the precipitation concentration index (Bewket, 2008). The precipitation concentration index used for characterizing the monthly rainfall distribution is given by Oliver (1980):

$$PCI_{annual} = 100 * \left[\frac{\sum_{i=1}^{12} pi^2}{(\sum_{i=1}^{12} pi)^2}\right] \qquad 5$$

Where, **PCI**= Precipitation Concentration Index, **Pi**=is the rainfall amount of the i^{th} month; and **Σ**=Summation over the 12 months.
Rainfall during a year occurs in different seasons. Unlike most of the tropics where two seasons are common (one wet season and one dry season), three seasons are known in Ethiopia, namely Bega (dry season) which extends from October-January, Belg (short rain season) which extends from February-May, and Kiremt (long rain season) which extends from June-September (NMA, 2007). Precipitation Concentration Index on seasonal scale has been calculated as:

$$PCI_{seasonal} = 33.333 * \left[\frac{\sum_{i=1}^{4} pi^2}{(\sum_{i=1}^{4} pi)^2}\right] \qquad 6$$

According to Oliver (1980), if PCI values are below 10 indicates uniform distribution (low precipitation concentration), values from 11 to 15 denotes seasonality in rainfall distribution (indicates moderate precipitation concentration); for PCI between 16 and 20 indicates irregular distribution and finally for PCI > 20 indicates a strong irregularity (i.e., high precipitation concentration).
As described by Bewket, W. and Conway, D. (2007), Agnew and Chappel (1999) the standardized rainfall anomaly (S) is used to characterize the drought frequency and intensity and well as evaluate inter annual fluctuations of rainfall as given below.

$$S = [P_t - P_m]/\sigma \qquad 7$$

Where, S= standardized rainfall anomaly, P_t = annual rainfall in year t, P_m = long-term mean annual rainfall, over a given period of observation, σ= standard deviation of rainfall over the period of observation.
The drought severity classes are extreme drought (S< -1.65) with 95 percentile, severe drought (-1.28 > S > -1.65) with 90 percentile, moderate drought (-0.84 > S> -1.28) with 80 percentile, and no drought (S > -0.84). The class intervals correspond with the 95, 90, and 80 percentiles assuming that annual rainfall data are normally distributed.

Future Climate Scenarios

Downscaling is the process of transferring the climate information from a climate model with coarse spatial and temporal scales to the fine scale required by models that address the impacts of climate. A viable alternative that is adequate for many applications is to use statistical downscaling, which has the advantage of requiring considerably less computational resources. (Salathe, 2006).

The future time scales from the year 2014 until 2099 were divided into three climate periods of 30 years and their respective changes were determined for precipitation from the base period values by using the Statistical Downscaling Model (SDSM) techniques. This study incorporated GCM (General Circulation Model) data from the UKMO (United Kingdom Meteorological Office) called HadCM3. HadCM3 was chosen on the basis that it is not only cheap to run but can allow the aims of the project to be achieved in the time available. Another main point to consider this model was the fact that HadCM3 has good representation of the African monsoon and a good record for Africa (Xue, et al., 2010).

SDSM Modeling Approach and Procedures

Before starting the main SDSM downscaling operation, quality control of the data was undertaken to check an input data file for missing and unreasonable values. The procedures to be taken in the SDSM methods are can be summarized as follows (Wilby et al., 2004):

- Prepare input data of predictands and GCM predictors at daily time scale.
- Screen the most potential predictors.
- Fit the SDSM to reanalysis predictors and observed predictands.
- Drive this fitted SDSM with independent temporally reanalysis predictors.
- Compare the statistical properties of the results of step 4 with those of observed predictands. A good agreement implies that the SDSM can reconstruct the climatology of the observed local variables well, when driven by large scale observation.
- Drive the SDSM fitted to observed time series in step 3 with control GCM predictors and generates a simulated time series.
- Compare the simulated time series in step 6 with observed time series. Good agreement implies that the GCM predictors can adequately simulate the local climate variables.
- Drive the SDSM fitted to observed time series in step 3 with future GCM scenarios and generates a future simulated time series of climate variables.

RESULTS AND DISCUSSIONS

Annual and seasonal rainfall trends of Adami Tulu Jido Kombolcha

The time series of annual rainfall at the four selected stations in the study area are shown in figure 4, along with the linear trend lines for the period 1984-2013. As presented in figure, three of the four stations considered, have shown linear increasing trends while one station, Bulbula has shown decreasing trend in annual rainfall.

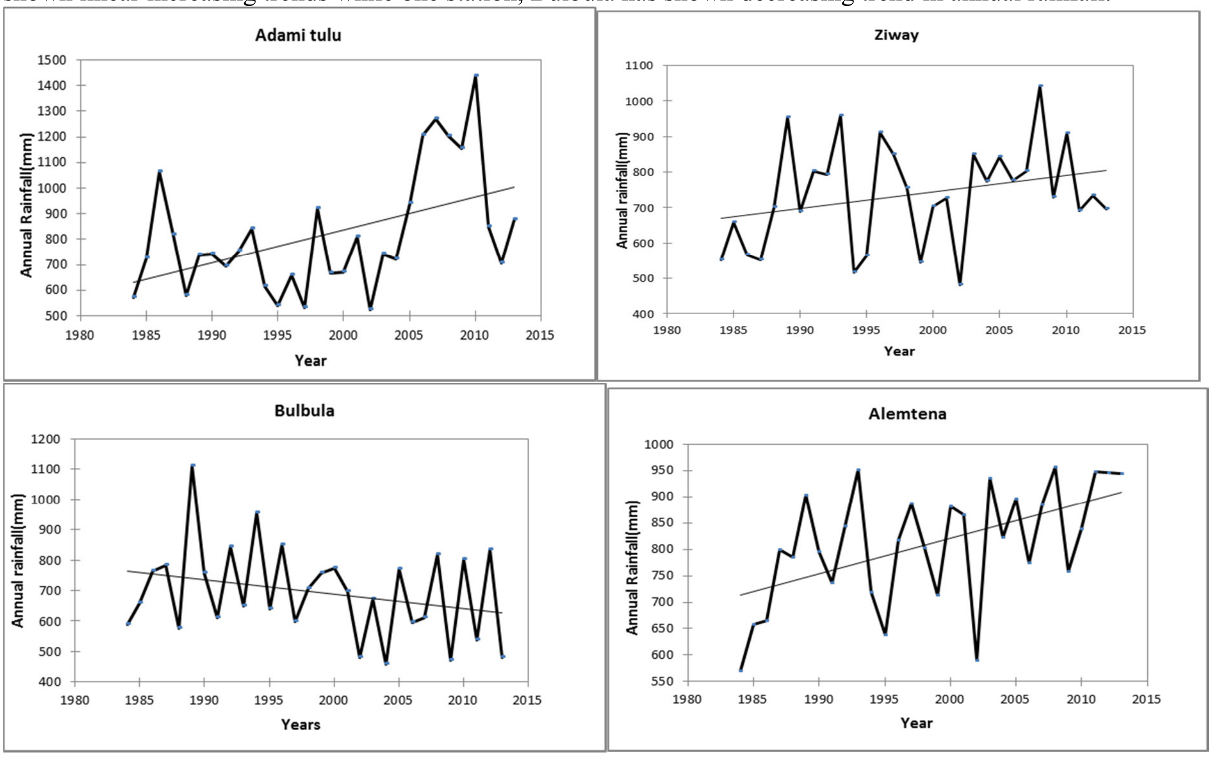

Figure 4 Trends of annual rainfall for Adami Tulu Jido Kombolcha a period of 30 years (1984-2013).

Table 2 and 3 present Sen's slope estimates and Mann-Kendall trend test results for the annual and seasonal rainfall of representative stations in the study area. The annual rainfall shows positive trends in most stations. Except Bulbula all stations have increasing trend, in rainfall per year was obtained, as it was in Table 2 below. This may be due to land surface changes that can affect local precipitation and temperature (De Sherbinin, 2002). The trends of the annual and seasonal rainfall are not statistically significant at 5 % significance level in Adami Tulu, Ziway, Alem Tena and Bulbula stations. Over the 30-years period, the rainfall increased by 4.2 mm on an average per annual over the study area.

Table 2 Trends of annual rainfall for the period 1984-2013 in Adami Tulu Woreda.

Stations	Mann-Kendall	Mann–Kendall test statistic	Sen's Slope	Risk to say there was a trend in %
Adami Tulu	129	0.29 ns	9.82	4.02
Ziway	75	0.17 ns	4.6	4.81
Alem Tena	163	0.37 ns	6.7	0.92
Bulbula	-57	-0.13 ns	-3.76	99.76

Slope (Sen's slope) is the change (mm)/annual; ns is non-significant at 0.05 Significance level.

Table 3 Trends of seasonal rainfall for the period 1984-2013 in Adami Tulu Woreda.

Stations	Belg			Kiremt		
	S	Z_{MK}	Slope	S	Z_{MK}	Slope
A/Tulu	-1	-0.002 ns	-0.003	139	0.32 ns	9.7
Ziway	-23	-0.05 ns	-0.70	73	0.168 ns	2.78
Alem Tena	-45	-0.103 ns	-1.513	73	0.16 ns	3.39
Bulbula	-115	-0.26 ns	-4.68	-11	-0.02 ns	-0.49

S is Mann–Kendall trend, Z_{MK} is Mann–Kendall test statistic, Slope (Sen's slope) is the change (mm)/seasonal; ns is non-significant at 0.05 Significance level.

Likewise, all stations had revealed an increasing trend of Kiremt rainfall totals, and had shown a decreasing trend during Belg season in the study area. According to IPCC, 2007 which stated that there was an increasing of rainfall in parts of east Africa and the historical observed data also revealed which is similar with the results obtained in the study over Adami Tulu Jido Kombolcha woreda. The Mann-Kendall trend test results showed that the annual rainfall showed increasing trends for all stations except Bulbula and, Kiremt showed positive trend in seasonal rainfall. Belg season showed negative trend. The obtained results indicated that the rainfall was increasing and the test statistic didn't exceed the critical value in seasonal rainfall, the trend was statistically independent.

Statistical Modeling of Climate change model results

The base line scenarios downscaled the daily data from 1984-2013 is selected to represent baseline for this study which is the current climate conditions. Mean sea level pressure, Surface wind direction , airflow strength at 500 hpa, geopotential height 850 hpa and Surface specific humidity are selected predictors which have high correlation with their respective predictand (rainfall) in all months. The HadCM3 was downscaled for the baseline period for two emission scenarios (A2 & B2) and the statistical properties of the downscaled data was compared with observed data. The generated data for the period 2014-2099 were used for the future climate forcing. The calibration was carried out over 1984-1998 for fifteen years and the withheld data during 1999-2013 were used for model verification. The R^2 values of Calibration for the SDSM downscaling of precipitation, is 0.74. Even though there were little variations in individual months which are due to local effects, the simulated values have good concurrence with observed data as shown in figure 5.

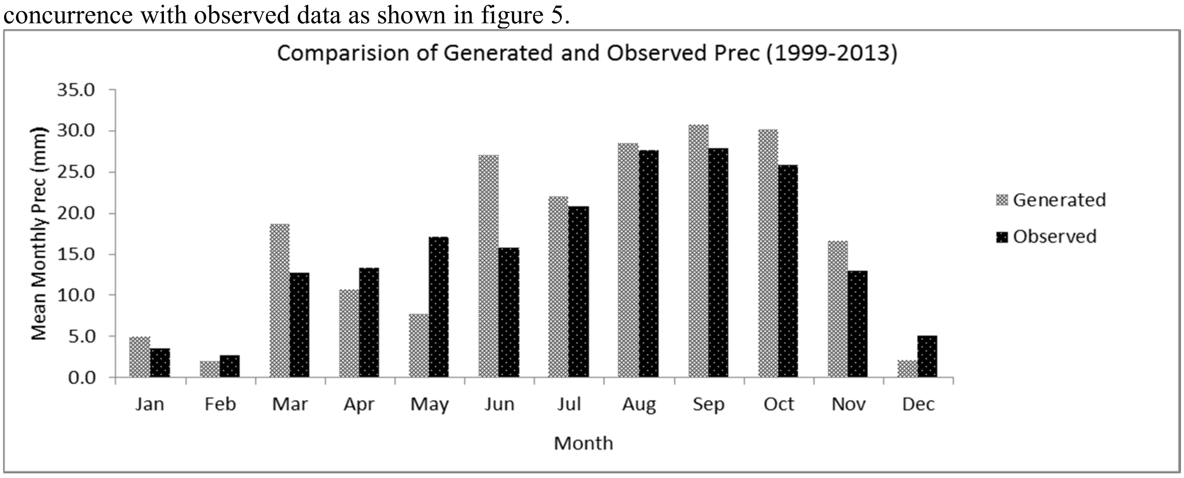

Figure 5 Validation result of SDSM downscaling for Maximum Temperature (1999-2013) over the study area

Trends of future generated precipitation

The results of downscaling the future precipitation for 2020's, 2050's and 2080-99 using HadCM3 are presented, along with the current observed values for comparison. The precipitation projection exhibited a decrease in annual mean precipitation in the 2020s ,2050s and 2080s (Table 4).

Table 4 Trends of future annual rainfall over the study area.

	Future Precipitation (HadCM3-A2)			Future Precipitation (HadCM3-B2)		
	2020s	2050s	2080s	2020s	2050s	2080s
S	-17	-35	-21	-10	-35	-147
Z_{MK}	-0.039^{ns}	-0.080^{ns}	-0.065^{ns}	-0.023^{ns}	-0.080^{ns}	-0.452^{ns}
Sen's	-0.125	-0.14	-0.2	-0.026	-0.125	-0.1056

S is Mann–Kendall trend, Z_{MK} is Mann–Kendall test statistic, Slope (Sen's slope) is the change (mm/annual); ns is non-significant at 0.05 Significance level.

As can be seen in Figure 6, there may be a decrease in precipitation for all months except October and November for both scenarios (A2 and B2) in 2020s and 2050s. In 2020s, the A2 scenario showed annual mean precipitation decrease up to -0.125 mm/annual and B2 showed a decrease up to -0.026 mm/annual. In the 2050s, the decrease in annual mean precipitation may reach up to -0.14 mm/annual in the A2 scenario and -0.125 mm/annual in the B2 scenario in all months except October and November. In 2080s, there may be decrease in annual mean precipitation by -0.2 mm/annual in all months for A2 scenario and -0.1056 mm/annual in the B2 scenario.

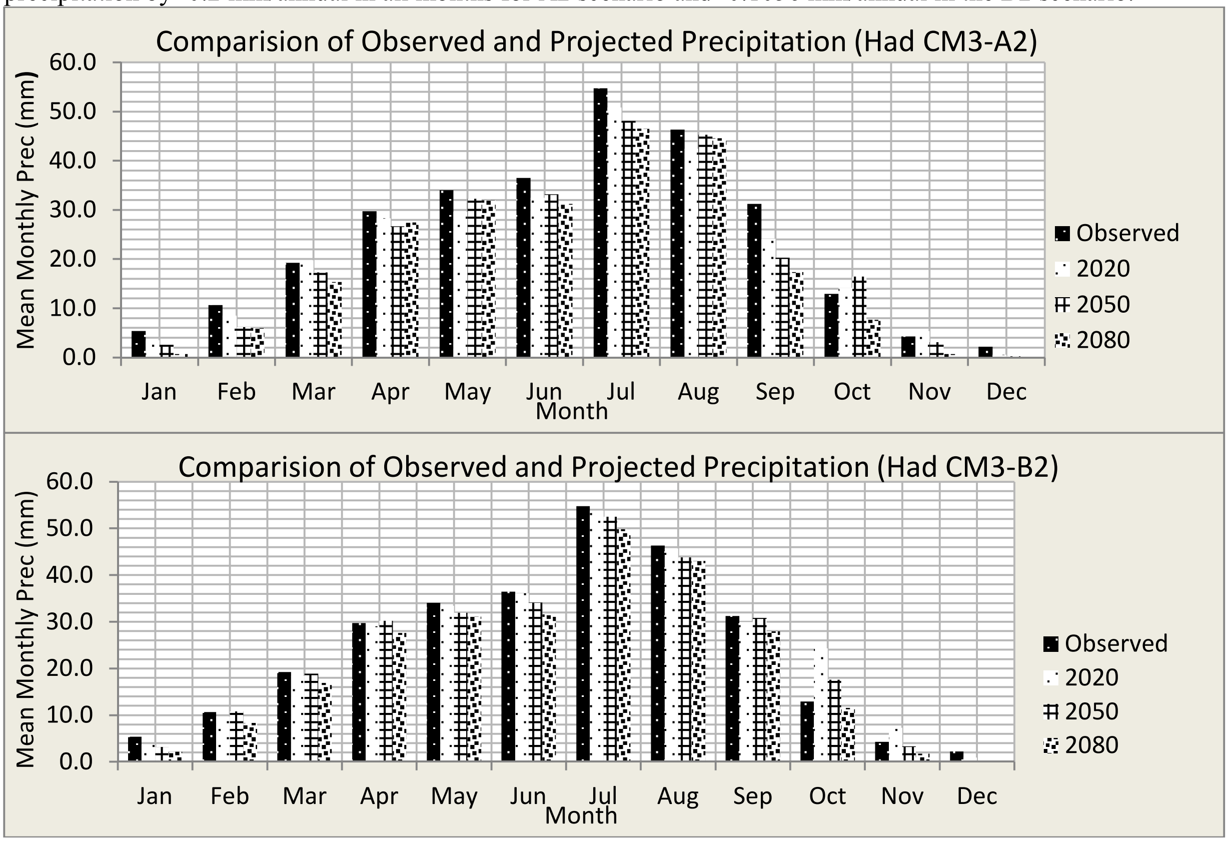

Figure 6 Comparison of the observed mean monthly precipitation with future HadCM3 generated precipitation for A2 and B2 scenarios.

Projection of future rainfall conditions suggest that the annual and seasonal rainfall in the CRV is most likely to decrease. Associated with the declining trends in seasonal rainfall, the growing season in the study area is also predicted to be shortened (Kassie, 2014). So, this is true as shown in the Figure 6, there is decrease in precipitation in Kiremt and Belg seasons in the next 90 years. Kiremt (wet season) and Belg (less rainy season) are the cropping seasons in Ethiopia. Hence this study can give us an insight on the possible impact of climate change on the agriculture in the study area.

The long term trend analysis is exhibited in Figure 7, which shows that the Areal Precipitation in the study area may decrease by -0.155 mm/annual and -0.402 mm/annual for the A2 and B2 scenarios, respectively for the coming 90 years. However, the Mann-Kendall trend test showed that the precipitation for both HadCM3-A2 and HadCM3-B2 scenarios, is not statistically significant (there is no the significance difference) at 5 % significance level over the study area.

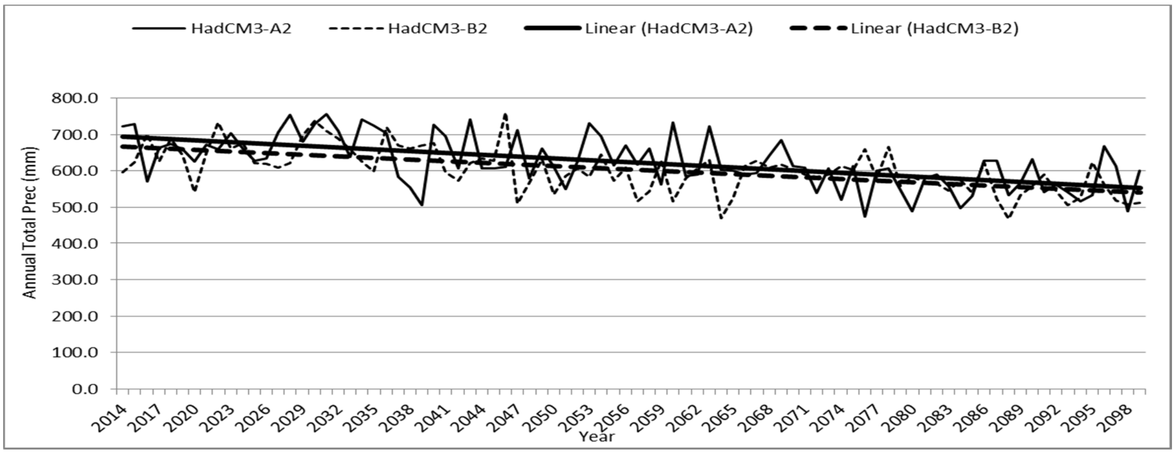

Figure 7 Generated HadCM3-A2 and HadCM3-B2 scenarios precipitations on yearly basis.

Precipitation was characterized by a typical annual pattern with low rainfall totals during Belg and Bega seasons and high during Kiremt season in the study area for all the stations. Annual mean precipitation of all the stations in the study area varies from 695mm to 819 mm.

Table 5 Annual Rainfall PCI and CV of the stations in the study area

Station	Adami Tulu	Ziway	Alem Tena	Bulbula
PCI	16.2	17.4	16.8	12.4
Annual CV	29.0	19.41	23.5	21.6

Based on the modified Oliver (1980), it can be seen from the Table 5 the annual precipitation concentration index (PCI) is more than 16 for the stations Alem Tena, Ziway and Adami Tulu indicating irregular distribution of annual rainfall, while Bulbula highlights the seasonality in rainfall distribution. Also, as shown in Table 5 the annual CV based on daily rainfall indicates considerable variability of rainfall in a year.

The seasonal CV and PCI for Belg and Kiremt (Table 6) show relatively higher variability and lower PCI when compared to annual, in general. Also, the rainfall variability for the dry season Belg is more than for Kiremt. Similarly, the PCI values are lower for Kiremt than for Belg indicating more uniform rainfall distribution in Kiremt.

Table 6 Variability of seasonal rainfall by using PCI and CV for stations in study area.

	Belg		Kiremt	
Stations	CV	PCI	CV	PCI
Adami Tulu	52.7	13.9	34.1	9.7
Ziway	45.6	14.1	22.2	11.3
Alemtena	46.0	14.8	28.1	12.2
Bulbula	53.8	14.2	28.0	13.4

The climate parameters have high impact on agriculture and social livelihood in different ways. So the variability of rainfall has seen examined on both annual and seasonal basis wisely by using precipitation concentration index (PCI) and Coefficient of variation (CV) methods. As shown in Table-6, the CV on annual basis was smaller than that on seasonal basis for Belg (February, March, April, and May), Kiremt (June, July, Augusts and September) seasons for all stations found in the study area. The stations showed moderate variation in annual rainfall (CV% 20-30%) except for Ziway station, which has less variations (CV% < 20%). In Belg seasonal total rainfall varied from 210.3 to 231 mm and (CV% 45-53) which is highly variable i.e. CV greater than 30 % in all stations over the study area. The Kiremt season has a total rainfall varied between 412 and 518.7 mm (CV% 22-34), moderate variable in most stations and highly variable in Adami Tulu station.

Both Adami Tulu and Bulbula stations show high year-to-year variability with above 50% of CV for Belg season. Standardized Rainfall Anomaly (SRA) is simplest and can be applied to any location using a single meteorological variable, precipitation to describe water deficit. The drought by definition is vast and difficult to see from all perspective for a given region. In this study the meteorological drought was analyzed by using standardized rainfall anomaly indices. Standardized Rainfall Anomaly index calculated for a period of 30 years (1984-2013) for all the stations also indicate that the annual rainfall of Adami Tulu Jido Kombolcha (ATJK) woreda, exhibit cyclic wet and dry conditions with positive and negative anomalies. It's noted that during the major drought years of 1973, 1984 and 2001 covered the whole of Ethiopia (Seleshi and Zanke, 2004) and the well-known drought period that occurred from 1978 to 1986 ATJK woreda was also affected by drought.

By using Standardized Rainfall Anomaly (SRA) time series against drought index gives a good indication of the temporal drought history of each station which is seen from the figure 8 given below most of the drought years were associated for each station; even if for some stations the occurrences of drought year varies by year. In 1984-85, 1988, 1990-91, 1995, 2000, and 2002 show that almost all stations indicate there was drought in the study area even if the drought severity degree was different spatial and temporal. From all these drought years 2002 and 1984 drought years were extreme (SRA < -1.65).

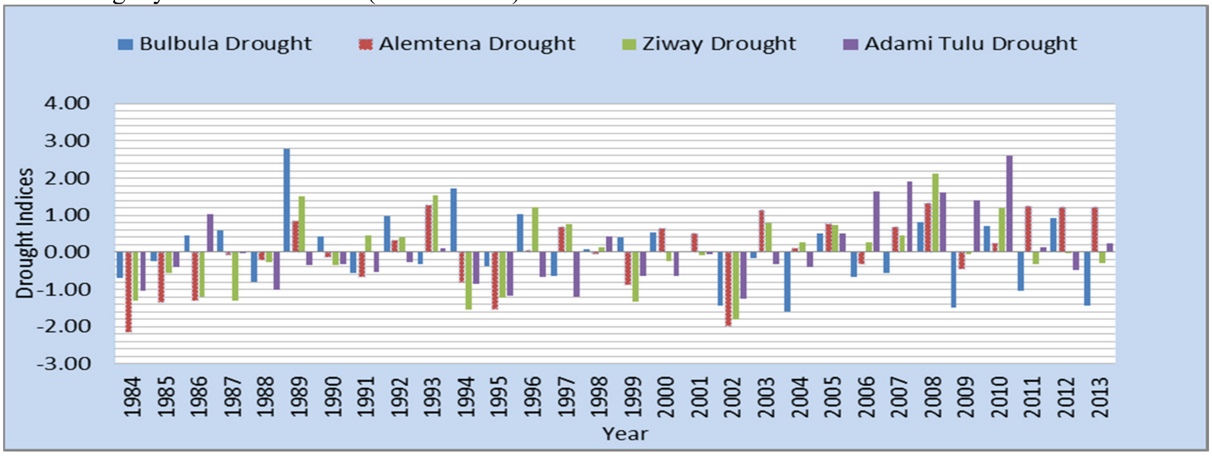

Figure 8 Standardized anomalies of annual rainfall in the study area.

CONCLUSIONS

The main findings of the study are summarized below.

The current annual rainfall shows positive trends in most stations except Bulbula. Over the 30-years period, the rainfall is increased by 4.2 mm per annual on an average over the study area. All stations had revealed an increasing trend of Kiremt totals, and had shown a decreasing trend during Belg season rainfall in the study area. The results of the future climate projection showed that, there will be a decrease in precipitation for all months except October and November using HadCM3 for both scenarios (A2 and B2) in 2014-2099 along with the current (1984-2013) observed values for comparison. The Mann-Kendall trend test result showed that the precipitation for both HadCM3-A2 and HadCM3-B2 scenarios, are not statistically significant. The increase of temperature will increase the rate of crop water use adding to the currently frequent water stress of crops. Rainfed crop production in the study area, which is already impacted by the current climate variability, is likely to be further challengable with future climate change.

The average annual precipitation concentration index (PCI) showed irregular distribution of annual rainfall in most stations except Bulbula that highlights the seasonality in rainfall distribution. Most of the stations showed moderate variation in annual rainfall (CV% 20-30%) except for Ziway station, which has less variations (CV% < 20%). The result of standardized rainfall anomalies also indicated that inter annual variability of rainfall during 1984 to 2013 for almost all the stations which were found in the study area. Generally, for improving precision and reliability of the application of the findings for practical use, providing accurate prediction and projection of climate variability is so important, especially the downscaling of information for agricultural uses and addressing issues related to specific requirements of users such as amount of rainfall, temperature and wet/dry spells to help make decision would be crucial.

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