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Hydro-Climatic Variability and Trend Analysis of Modjo River Watershed, Awash River Basin of Ethiopia

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Abstract

Climate change and variability is expected to trigger changes in temperature and precipitation series. This study aimed at assessing variability and trend of hydro-climatic variables at Modjo River watershed. Long-term climate data of 5 representative stations with in the watershed (1981-2010) and stream flow data of Modjo gauging station (1983 -2010) were used. Rainfall variability was analyzed using Coefficient of variation (CV), Precipitation concentration index (PCI) and Standardized anomaly index (SAI). Climate trends were evaluated using Sen's slope estimator and Mann–Kendall trend test methods. The study revealed Most of the stations showed low variation in annual rainfall (CV% <20) while the main (Kiremt) and short (Belg) season rainfall exhibited CV ranging from low to high. Both annual and seasonal rainfall showed a non-significant trend at all stations for the past 30 years. However, majority of stations showed an increasing trend in annual daily average temperature ranging from 0.2 to 0.6°C per decade. Following increases in temperature and the subsequent rise in evapotranspiration, stream flow has shown a high significant declining trend. The temporal decline in stream flow at Modjo watershed could likely affect downstream Koka dam water reserve. Thus, any watershed management strategy that can optimize water conservation for sustainable crop production and option that can improve flow to the reserve is vital.

Keywords: Climate change • Climate variability • Hydro-climate • Trend • Modjo River Watershed

Introduction

Climate is a vital natural resources on the earth which can be seen as the major backbone of all the water resources, and is one of the key variable that affect both the spatial and temporal pattern of water resources [1]. African continent exhibits higher inter-annual and intra-seasonal climate variability [2]. Ethiopia is one among countries most vulnerable to climate variability and change [3].

Climate change has contributed to climate variability and change in the frequency and intensity of extreme events. IPCC has showed that the historical climate record for Africa shows warming about 0.7°C, and a decrease in rainfall over large portions of the Sahel [4]. Similar reports also revealed that, in Ethiopia warming has occurred at variable rates but broadly consistent with global and African trends and rainfall has showed both an increasing and decreasing trend in different areas of the country [5].

Climate variability and change appears to have a very marked effect on many hydrological series [6]. Stream flow is mainly vulnerable to rainfall and temperature, and changes in their pattern which has a direct impact on stream flow change and variability [7]. Increased evaporation, combined with changes in precipitation, has the potential to affect stream flow, the frequency and intensity of floods and droughts, soil moisture, and available water for irrigation and hydroelectric generation [8].

Trend and variability analysis of rainfall and temperature series is necessary for agriculture production, energy production, drinking water supply, and management and utilization of resources [9]. Trend and variability analysis in precipitation and temperature series have been investigated by many researchers in Ethiopia, Ademe, et al. [10] for the Great Rift Valley Basins of Ethiopia, D Bekele et al. [9] for Keleta watershed of Awash River Basin, Bekele [11] in the Central Rift Valley of Ethiopia, Mengistu.et al. [12] in the Upper Blue Nile River Basin of Ethiopia, Tekle, et al. [13] in Bilate watershed of Ethiopian rift valley, Kassie et al. [14] in the Central Rift Valley of Ethiopia, SG Setegn, et al.[15] in Lake Tana Basin and Abdo et al. [16] in Gilgel Abay Catchment of Abay Basin, The reports agree that, temperature showed an increasing trend and except for few stations, no significant trend in the annual rainfall pattern was observed for the majority of stations studied and most of the studies indicated there is a variability in rainfall Tibebe, et al. [17] indicated that there is a variability of rainfall and stream flow whereas an increasing trend of stream flow was observed in most of the stations within Awash river basin.

Even though many researches have been conducted most of them has focused on trend and variability analysis of rainfall considering only the yield aspect. Even though Tadese and Gedefaw, et al. [18,19] has studied the hydrologic aspect still in a broader scale of Awash River basin not considering the specific condition. For instance Tibebe, et al. [17] associated the stream flow at Modjo gauging station with only rainfall from Modjo station whereas there are four other station which are not considered but covering the larger area of the watershed and have immense contribution to the stream flow. Thus there is a need to understand the temporal and spatial variation of hydro-climatic variables in a watershed scale since Modjo River watershed is major tributary to Koka dam, changes in any of the hydro-climatic variables in the watershed thus pose a great challenge [20]. The objective of the present study was to understand and characterize the variability and trend of the hydro-climatic variables in the study periods.

Materials and Methods

Study area description

Modjo River watershed having a total area of 1984.96 km2 is situated in the upper Awash River basin of Ethiopia (Figure 1). Geographically it is located between latitudes of 8° 25´ N and 9°07´N and longitude of 38°50´E and 39° 17´E. The watershed drains to Modjo river then to Koka dam and finally into Awash River. An altitude ranging from 1590 m asl at the river bed to above

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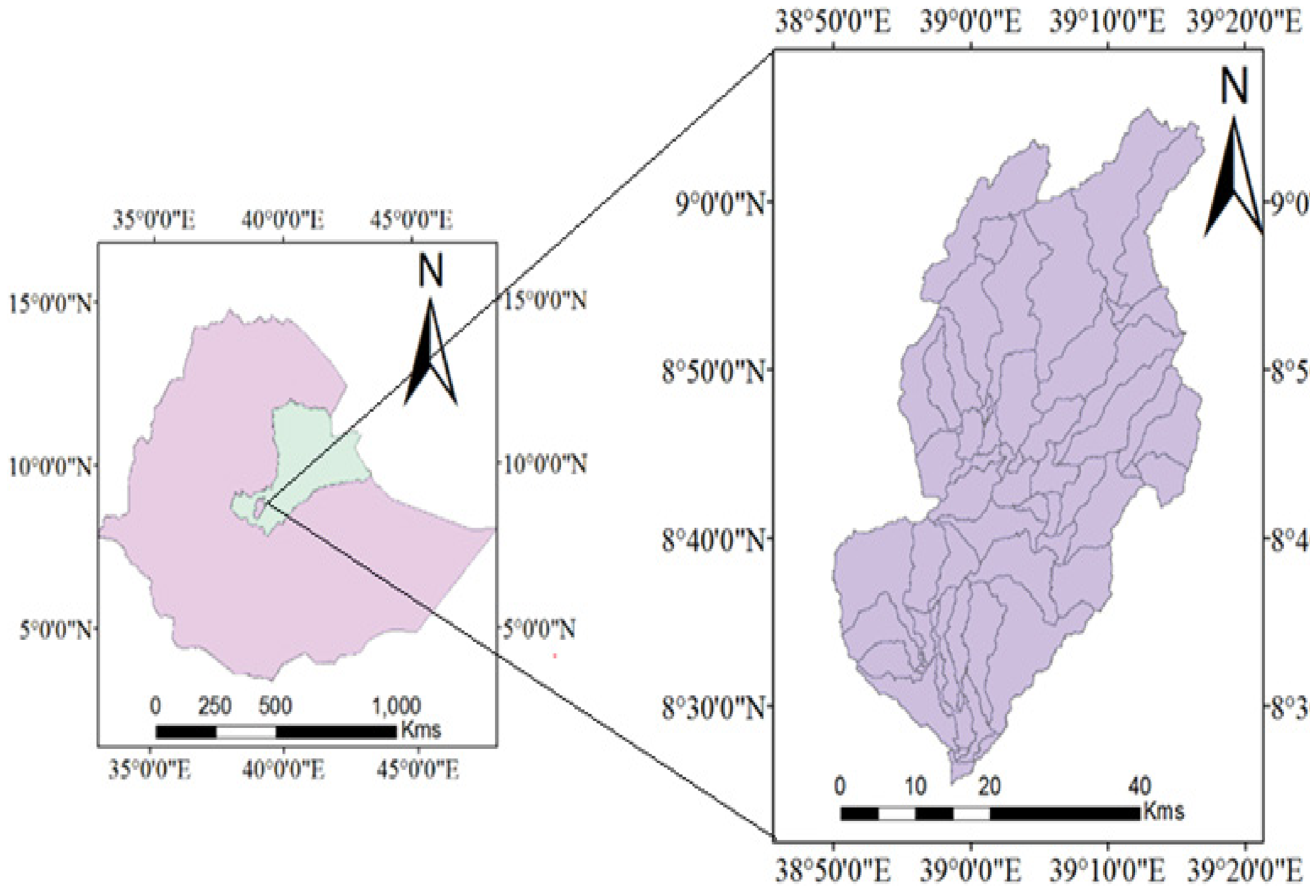

Figure 1. Location of the study area.

3000 m a.s.l at the upper part characterize the watershed [20].The watershed is characterized by bimodal rainfall pattern with picks in April and July. More than 80% of the annual rainfall is received during June to September (locally known as Kiremt) whereas the short season extends from February/March to May (locally known as Belg).The total annual rainfall of the watershed is 940 mm. The mean maximum temperature of the watershed is ranging from 21°C to 27°C [20]. The watershed is dominated by agricultural land use. According to FAO the major dominant soil types of the watershed is Pellic Vertisol [21].

Data source

Daily meteorological variables such as daily rainfall, daily maximum and minimum temperature, has been collected from National Meteorology Agency (NMA) for stations present in the watershed boundary for the period 1981-2010 (http://www.ethiomet.gov.et). The data were selected, which have relatively long periods of data records (at least 30 years) and have no more than 10% missing values based on recent changes in rainfall and rainy days in Ethiopia [22]. Similarly, stream flow data of Modjo gauging station (1983 -2010) was obtained from ministry of water, irrigation and electricity of Ethiopia.

Data quality assessment

Data quality was ensured for presence of outliers, homogeneity and missing data before using the time series climate data for further analysis. Climate data collected from each station has been arranged and outlier has been detected following Tukey fence method [23]. The outliers were then culled out from the analysis. Similarly, most of the long-term climatic time series can be affected by number of non-climatic factors which make the data unrepresentative of actual climate variations occurring over time [24]. Thus observed data taken from weather stations should be tested for reliability and homogeneity before they are utilized. The cumulative deviation test was used to detect inhomogeneity in the meteorological time series data [23,25]. According to Buishand, et al. [25] the data series was examined for homogeneity and no heterogeneity was detected for this study. Negative daily rainfall records and temperature data with daily maximum value less than the daily minimum value were removed and considered as missing values. Missing data in time series were then re-filled using first order Markov chain model with INSTAT plus (v 3.37) software by Stern et al. [26] before using it for further analysis.

Hydro meteorological variability analysis

The temporal variability of rainfall and discharge for the study watershed (representative meteorological stations) was determined by three commonly used statistical rainfall variability descriptors. The coefficient of variation (CV), which is the ratio of the standard deviation to the mean in a given period is useful when interest is in the size of variation relative to the size of the observation. In comparing different years of rainfalls with different means, the CV is a more useful basis of comparison than the standard deviation (Equation 1). The precipitation concentration index was employed to investigate monthly distribution of rainfall (Equation 2). Inter-annual variability was evaluated using standardized anomalies (SAI) with respect to the long-term average conditions for a specific time scale (Equation 3).Different studies have used this methods to describe variability [9,10,14,27]. The variability descriptors can be written as:

$$CV = \left[\frac{S}{X}\right]*100 \quad (1)$$

Where, S and X denote standard deviation and long term mean of rainfall, respectively. In this study, a CV of <20%, between 20–30%, and >30% was considered as low, moderate and highly variable, respectively.

$$PCI = \frac{\sum pi^2}{\left(\sum pi\right)^2 *100} \quad (2)$$

Where, Pi is the rainfall amount of the ith month. PCI values of less than 10 indicate uniform monthly rainfall distribution in the year, whereas values from 11 to 20 denote seasonality in rainfall distribution. PCI values above 20 correspond to substantial monthly variability in rainfall amounts [27].

$$SAI = \frac{x-\mu}{\sigma} \quad (3)$$

Where, x is the annual rainfall, μ is long term mean annual rainfall over the period of observation and σ is the standard deviation of annual rainfall. Positive normalized rainfall anomalies indicate greater than long-term mean rainfall, while negative anomalies indicate less than the mean rainfall. When averaged over several stations, the normalized rainfall anomaly yields a normalized rainfall anomaly index.

Trend analysis: Trend was tested using Mann-Kendall's and Sen's Slope estimator tests for annual, Kiremt and Belg seasons of the study watershed for the period of 1981 to 2010. Both Mann-Kendall's and Sen's Slope test are none parametric test [28-31]. The Mann-Kendall test is based on the test statistics defined as follows [28].

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_j - X_i\right) \ldots\ldots.. j > i \quad (4)$$

where, the Xj and Xi are the sequential data values, n is the length of the data set, and

$$\operatorname{sgn}(X_j - X_k) = \begin{cases} 1\, if\, (X_j - X_k) > 0 \\ 0\, if\, (X_j - X_k) = 0 \\ -1\, if\, (X_j - X_k) < 0 \end{cases} \quad (5)$$

Mann (1945) and Kendall (1975) have documented that when n ≥ 8, the statistic S is approximately normally distributed with the mean and the variance as follows. E(S)=0

$$Z = \begin{cases} \frac{s-1}{\sqrt{\operatorname{var}(s)}}\, if\ s > 0 \\ 0\, if\ s = 0 \\ \frac{s+1}{\sqrt{\operatorname{var}(s)}}\, if\ s < 0 \end{cases} \quad (7)$$

The standardized Mann-Kendall statistic Z follows the standard normal distribution with mean of zero and variance of one. In Sen's Slope test true slope of a trend is estimated, Sen's test is used when the trend is assumed to be linear. Sen's Slope is computed by Salmi, et al. [29].

$F(t)=Q_t+b$ (8)

Where, f(t) = increasing or decreasing function of time, Q = the slope, B = intercept (constant) The slope of each data pair Qi is calculated as:

$$Q_i = \frac{X_j - X_k}{j-k} \quad (9)$$

Where, j > k and, if there is n number of in the time series, we get as many as $N = \frac{n(n-1)}{2}$

Result and Discussion

Climatic characteristics of Modjo River watershed

The monthly rainfall distribution of stations situated at Modjo River watershed is shown in Figure 2. The mean monthly rainfall distribution of all the representative stations follow a bimodal rainfall pattern picks in April (Belg) and July (Kiremt).About 72% of the rainfall is received during Kiremt (June to September) in the watershed. Monthly distribution of total rainfall received in the watershed varies widely from as small as 3.5 mm for the driest month (December) at Modjo station to 290.7 mm for the wettest month (July) at Aleltu. The mean annual distribution of rainfall within the watershed ranges from 1040 mm in the upstream to 873 mm in the downstream (Table 1). The annual weighted average rainfall of the study watershed is 950 mm with an elevated standard deviation of 107 mm likely resulted from altitudinal variations existed in the watershed. Following variations in elevation, temperature also exhibited variations across the study watershed. The mean annual minimum and maximum temperatures are 9.7°C and 25.6°C, respectively. The mean maximum temperature of the watershed ranges from 24°C to 27.6°C and the highest being recorded in the month of May and the lowest in August. While the mean minimum temperature ranges from 6.3°C to 12.8°C the highest being recorded in the month of July and the lowest in the month of December. The annual mean temperature of Modjo river watershed is about 17.6°C for the recorded historical period. The Kiremt season has minimum temperatures of 7.5°C to 16.5°C and maximum temperatures of 19°C to 30°C. For Belg season, the minimum temperature ranges from 6 to 16.4°C and the maximum temperature varies from 21°C to 33.6°C. Aligned with this study, BT Kassie, et al. [14] indicated the annual mean temperature in the CRV is 18.9°C and the annual mean minimum and maximum temperatures are 12°C and 26°C respectively.

Hydro-climatic variability analysis

Most of the stations showed normal variation in annual rainfall (CV% <20) except for Modjo station exhibits moderate variation (CV 26%). The precipitation concentration index (PCI) value is more than 11% for all of the stations indicating the seasonality in rainfall distribution [27]. Normalized rainfall

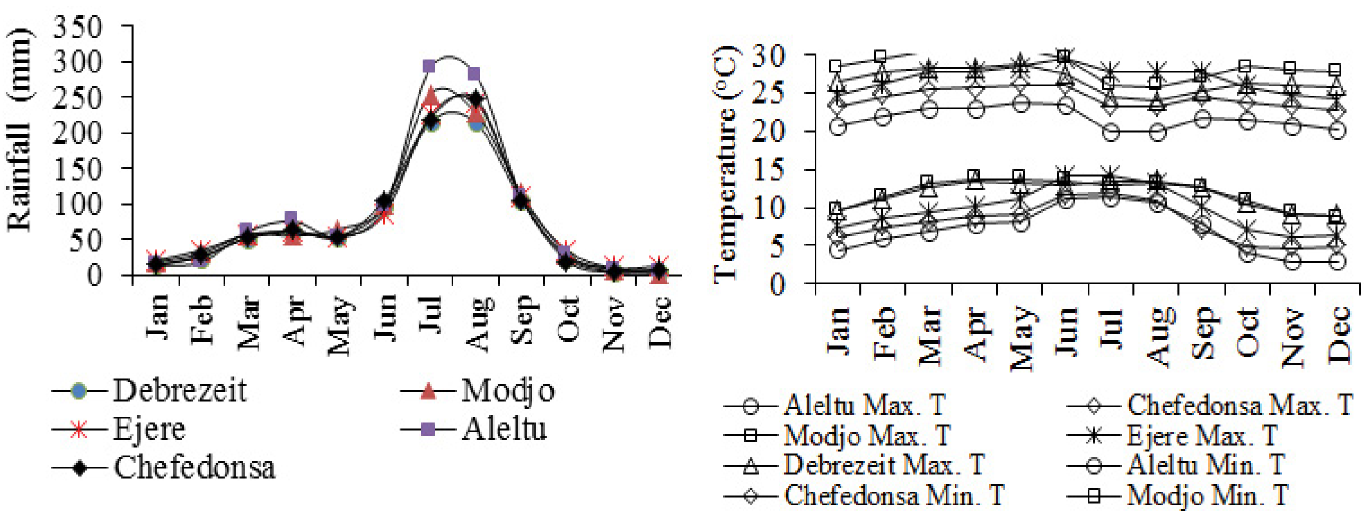

Figure 2. The mean monthly rainfall, maximum and minimum temperature of Modjo River watershed.

anomaly index calculated for a period of 30 years (1981-2010) for all stations also indicate that the annual rainfall of Modjo river watershed showed both wet and dry conditions with negative anomalies 43.3%, 53.3%, 50%, 53.3% and 50% of the years for Debrezeit, Modjo, Ejere, Aleltu and Chefedonsa stations respectively. The coefficient of variation of the main (Kiremt) and short (Belg) season rainfall ranged from low to high. It can be noted that some of the station (Debrezeit and Ejere) showed low variability while (Aleltu, Chefedonsa and Modjo) fall under moderate variability range (20% to 30%) for June to September rainfall. Unlike Kiremt rainfall of the stations, the Belg seasonal rainfall showed a high degree of variability for all stations. The short season is very prone to risk for rain-fed agriculture and almost all of the stations in the study watershed clearly indicate high (43.6% to 61.1%) ranges of rainfall variability (Table 2). Similar result has also been found [9,10,14], they emphasized that the causes of annual and seasonal inter-annual variability of precipitation over Ethiopia is due to the forward and retreat pace of the African sector of the intertropical convergence zone (ITCZ). The high variability in Belg rainfall will cause unfavorable condition for agricultural production [14].

Stream flow characteristics and variability

The mean monthly Average, maximum and minimum River discharge of Modjo River watershed is shown in Figure 3. The mean monthly average discharge was low from November to June, and started to increase in the month of June as the highest flow was recorded in the month of August. The maximum mean discharge was low from mid-November to mid-April and has at least one event maximum flow from mid-April to first days of November. The highest discharge was 91.5, 216.4 and 14.1 m^3/s (on the month of August) for average maximum and minimum discharge respectively. The lowest record is 0.37m^3/s 0.64 m^3/s in the month of January, for mean average and maximum discharge and 0.09 m^3/s in the month of November for minimum discharge respectively.

The result of variability analysis in maximum, minimum and average stream flow at Modjo gauging station indicates that there is a high variability (CV>30) for both annual and seasonal basis. The annual and Kiremt discharge showed relatively medium CV while the Belg discharge showed very high CV (118.5, 115.8 and 134.7) for maximum, minimum and average discharge respectively. Similar study conducted in Awash River Basin has also indicated a very high variability of discharge for both annual and seasonal basis and correlated the variability of discharge with the variability of rainfall [17].

Trend analysis

Rainfall: Analysis of annual, Kiremt and Belg precipitation indicated that none of the stations in the study watershed showed significant increasing or decreasing trend over the last 30 years (1981-2010) (Table 3). The analysis however depicted that a numerical increment in precipitation was observed in three of the stations for annual trend and four of them showed increasing signals in its Kiremt precipitation. The Belg season however showed a non-significant declining trend in precipitation for four of the five representative stations.

The rainfall of Aleltu station indicated a decline in trend of rainfall on

Table 1. Rainfall (mm) variability characteristics of stations within Modjo River watershed (1981-2010).

Stations	Annual	CV	*Kiremt*	CV	*Belg*	CV	PCI
	Mean		Mean		Mean		
Aleltu	1040	15.5	774.4	22.3	189.7	49.5	18.3
Chefedonsa	922	19.6	680	22	169	49.4	16.8
Debrezeit	873	16	629.5	17.4	169	61.1	16.1
Ejere	951	17.9	662.5	16.8	173.7	52.8	15.6
Modjo	964	26.1	694.7	26.5	178.2	59.8	16.4
Watershed AV.	950	11.3	688.2	14.8	175.9	46.3	16.6

Table 2. Average, maximum and minimum discharge (m^3/s) variability characteristics of Modjo River watershed (1983-2010).

Variables	Annual		*Kiremt*		*Belg*	
	Mean	CV	Mean	CV	Mean	CV
Maximum Discharge	268.8	40.1	266.7	41.1	56.3	118.5
Minimum Discharge	0.14	63	0.35	55.2	0.21	115.8
Av. Discharge	17.5	72.4	49.3	73.7	2.9	134.7

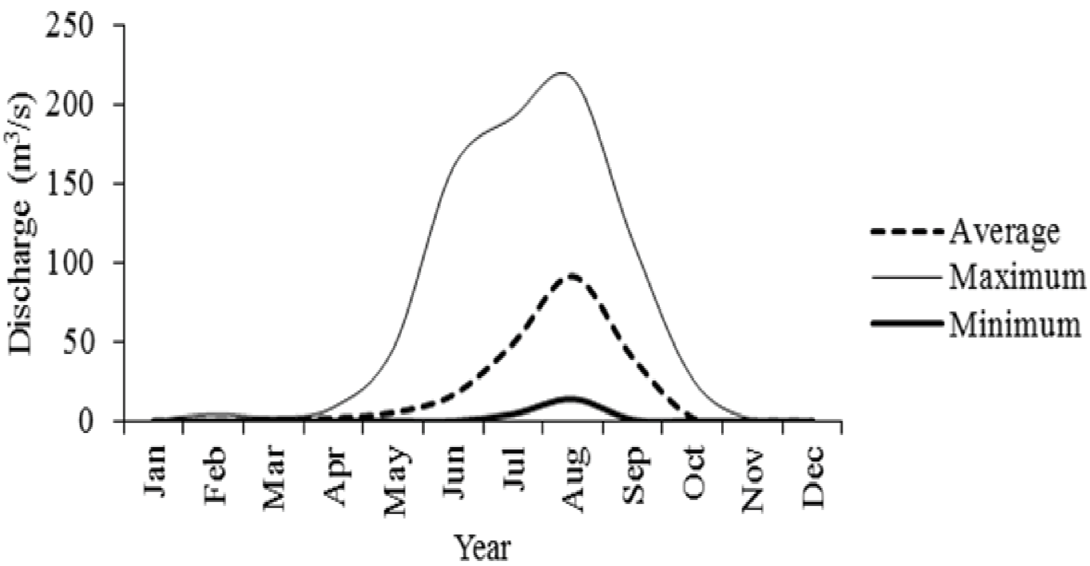

Figure 3. The mean monthly average, maximum and minimum River discharge of Modjo River watershed.

average 41, 17.4 and 28.5 mm/decade respectively for annual, Kiremt and Belg seasons. Similarly, rainfall of Ejere station for annual and Beg season and Debrezeit station for Beg season showed declining trend over the past 30 years. The rest of the stations showed an increasing trend of rainfall for all season. The overall result of weighted rainfall value of Modjo river watershed showed there is an increasing trend of 38.4 and 26.3 mm/decade of rainfall for annual and Kiremt, respectively. The Belg season however showed a non-significant declining trend during the observed period.

Aligned with this, studies conducted in Central Rift valley of Ethiopia showed, out of the sixteen tested stations the trends of the annual and seasonal rainfall of most of the stations did not showed statistically significant trend for the period of 1977 to 2007 [14]. Similarly, Ademe et al. [10] found only one out of seventeen stations with significant changes in the annual rainfall during the record period for the Great Rift Valley Basins of Ethiopia. They reported however that, the majority of the stations show a non-significant positive trend in the range of 0.66 to 4.25 mm/yr and some stations showed a non-significant negative trend ranging from 0.55 to 3.17 mm/yr. Likewise [9] revealed that the direction and magnitude of annual and seasonal rainfall trend was not uniform throughout different stations found in Awash River Basin Ethiopia. Although non-significant statistically, the majority of the studies indicated a numerically declining trend of rainfall in most of the tested stations [9,10,12,14].

Temperature: Unlike precipitation, temperature has showed a statistically very high significant trend ($p \le 0.01$) for all mean annual and seasonal maximum, minimum and average temperatures in the study watershed during 1981-2010 observed periods (Table 4). The mean annual maximum temperature increased very significantly across all stations in the watershed ranging from 0.2°C - 0.6°C per decade for annual trends. Minimum temperature however showed inconsistent trend across the stations in the watershed. Consequently, Aleltu, Ejere and Chefedonsa experienced a significant increase in minimum temperature 0.5°C per decade each while at Modjo, minimum temperature showed a cooling trend of about 0.5°C per decade. Debrezeit however didn't show any significant trend for minimum temperature. On a seasonal basis, the Belg maximum temperature increases with the range of 0.4°C -0.6°C and the minimum temperature with 0.01°C - 0.6°C per decade. The Kiremt maximum temperature increased with 0.1°C-0.8°C per decade and its minimum temperature with 0.2°C -0.3°C per decade. The overall result of the study watershed temperature showed there is an increment trend of both minimum and maximum temperature of Modjo River watershed.

In line with this a study conducted in the Central Rift valley of Ethiopia indicated an increasing trend of temperature ranging from 0.12 to 0.54°C per decade for different stations [14]. Supporting the finding of this study Meehl Gerard et al. [32] stated the global average temperature has risen by 0.74°C in the last century [4]. Affirmed the historical climate record for Africa showed warming about 0.7°C, and cover most of the continent during the 20th century. Correspondingly, [5] indicated in Ethiopia temperature has raised consistent with global and African trends. In general, studies conducted in different parts of Ethiopia were proved increases in temperature.

Stream flow: Stream flow trend over time at Modjo River watershed is shown in Table 5. The result of trend analysis in stream flow at Modjo gauging station indicates that there is a highly significant declining trend ($p \le 0.01$) of both annual and Kiremt maximum and mean discharge. The annual minimum discharge showed a non-significant inclining trend, Kiremt minimum showed a significant increasing trend ($p \le 0.05$) and no change was detected for Belg minimum discharge. Considering a significant observed increase in minimum flow during Kiremt would signal exposure of the land through time aggravating water loss from the catchment area. On the other hand, the annual maximum and mean discharge respectively declines by -5.85 and -0.81 m^3/s/year and Kiremt maximum and mean discharge decreases by -5.85 and -2.35 m^3/s/year, respectively. Similar study conducted at Awash River Basin indicated that decreasing trend for annual and seasonal streamflow at Modjo gauging station [17]. The decreasing trend of discharge in this study may be attributed to a decreasing trend in rainfall at some stations (Aleltu and Ejere) and an increasing trend in temperature along with other factor [17] suggested the stream flow reduction might be related to climatic factors, environmental change and other factors [33]. Also indicated mainly a decrease in stream flow in the Blue Nile Basin is attributed to the catchment dynamics especially land cover change and climate (rainfall and temperature) changes over the river basins. The high significant decreases in annual and Kiremt flow will highly likely impact the sustainability of Koka dam reservoir and needs careful measure.

Relationship between hydro-climatic variables

Rainfall vs. Discharge: The relationship between rainfall and cumulative

Table 3. Mann-Kendall (Z) and Sen's Slope (Q) trend (mm/year) result for annual, Kiremt and Belg precipitation of stations in Modjo River watershed during 1981 to 2010.

Station Name	Annual			*Kiremt*			*Belg*		
	Z	Q	P-value	Z	Q	P-value	Z	Q	P-value
Aleltu	-0.12	-4.14	0.17	-0.05	-1.74	0.72	-0.12	-2.86	0.36
Chefedonsa	0.07	2.91	0.61	0.1	2.12	0.44	0.07	0.56	0.61
Debrezeit	0.04	0.76	0.76	0.06	0.86	0.65	-0.13	-1.94	0.33
Ejere	-0.02	-0.25	1	0.14	2.33	0.27	-0.09	-1.25	0.45
Modjo	0.09	2.79	0.48	0.11	3	0.39	0.09	1.33	0.48
Watershed Av.	0.14	3.85	0.26	0.17	2.64	0.19	0	-0.03	1

Table 4. Mann-Kendall (Z) and Sen's Slope (Q) trend (0C/year) result for Annual, Kiremt and Belg temperature of stations in Modjo River watershed during 1981 to 2010.

Station Name	Variables	Annual			*Kiremt*			*Belg*		
		Z	Q	P-value	Z	Q	P-value	Z	Q	P-value
Aleltu	T_{max}	0.48	0.06	0.00**	0.46	0.08	0.00**	0.38	0.06	0.00**
	T_{min}	0.44	0.05	0.00**	0.48	0.03	0.00**	0.39	0.05	0.00**
Chefedonsa	T_{max}	0.5	0.06	0.00**	0.42	0.08	0.00**	0.41	0.06	0.00**
	T_{min}	0.5	0.05	0.00**	0.37	0.03	0.00**	0.48	0.06	0.00**
Debrezeit	T_{max}	0.34	0.02	0.02**	0.2	0.01	0.13	0.28	0.04	0.03*
	T_{min}	0.03	0.01	0.81	0.23	0.02	0.07	0.01	0.001	0.95
Ejere	T_{max}	0.45	0.05	0.00**	0.38	0.05	0.00**	0.37	0.05	0.00**
	T_{min}	0.5	0.05	0.00**	0.41	0.03	0.00**	0.49	0.05	0.00**
Modjo	T_{max}	0.47	0.06	0.00**	0.29	0.05	0.02*	0.27	0.05	0.03*
	T_{min}	-0.29	-0.05	0.00**	-0.16	-0.04	0.21	-0.33	-0.06	0.01**
WS Av.	T_{max}	0.53	0.06	0.00**	0.41	0.06	0.00**	0.41	0.05	0.00**
	T_{min}	0.11	0.01	0.39	0.07	0.01	0.59	0.2	0.02	0.11

** significant at 99% confidence level, *Significant trend at 95 % confidence level discharge of the watershed is portrayed in Figure 4. The annual rainfall of the different stations and discharge at Modjo river watershed indicated a positive correlation except at Modjo station. A very low correlation was observed for Ejere (r =0.04) while the highest was shown for Aleltu (r = 0.43). The average rainfall of the whole watershed showed a positive but relatively weak correlation (r= 0.22) with discharge. Likewise, a very low coefficient of determinations values ranging from 0.16% at Ejere to 17.8% at Aleltu was calculated. The low values in coefficient of determination might indicate high unaccounted variations in discharge that could not be explained by rainfall alone. However numerical analysis result indicates that discharge of Modjo river watershed at (Modjo gauging station) is majorly influenced by the rainfall of Aleltu (R2=17.8%) followed by Chefedonsa (R2=9.96%)and Debrezeit (R2=7.15%) than the rest of the stations. The weighted watershed rainfall and discharge has a positive correlation with coefficient of determination 4.89% which was low implying rainfall amount alone cannot describe variations in stream flow in the watershed. Similar to the result obtained by Milliman et al. [34] reported trends in annual stream flow for many rivers were driven by changes in precipitation. Other study conducted in Awash River basin also reported a positive correlation between rainfall and stream flow [17]. The direction of stream flow change generally followed the direction of changes in rainfall [8].

Temperature vs. Discharge: The relationship between temperature and discharge is indicated in Figure 5. The average temperature and discharge at Modjo river watershed indicated a negative and relatively strong correlation for three out of five stations (Figure 5). The calculated correlation coefficients were (-0.54, -0.48, -0.46) for Chefedonsa, Ejere and Aleltu stations. The rest stations such as Modjo and Debrezeit however showed a non-considerable positive correlation. The increase in average temperature at Chefedonsa, Ejere and Aleltu have resulted a decreasing trend in stream flow. The average annual temperature of Modjo River watershed has a negative correlation with the annual average discharge with a correlation coefficient of -0.54 where about 54% of decline in discharge is brought by a unit increase in temperature anomaly in the watershed. Increases in temperature of the stations has drastically decreased runoff volume which might result from increased loses of water by evapotranspiration. Supporting the findings of the study [35] reported a significant increasing trend of annual mean temperature and potential evapotranspiration were partly responsible for the significant declining trend of annual stream flow [36]. Also indicated the increasing trend of air temperature

Table 5. Mann-Kendall (Z) and Sen's Slope (Q) trend (m^3/s) result for Annual and seasonal maximum minimum and mean discharge of Modjo River watershed during 1983 to 2010.

Variables	Annual			*Kiremt*			*Belg*		
	Z	Q	P-value	Z	Q	P-value	Z	Q	P-value
Maximum Discharge	-0.44	-5.85	0.001**	-0.42	-5.85	0.002**	-0.15	-0.8	0.28
Minimum Discharge	0.07	0.001	0.62	0.28	0.005	0.037*	0.027	0	0.85
Mean Discharge	-0.42	-0.81	0.001**	-0.39	-2.35	0.003**	-0.026	-0.006	0.86

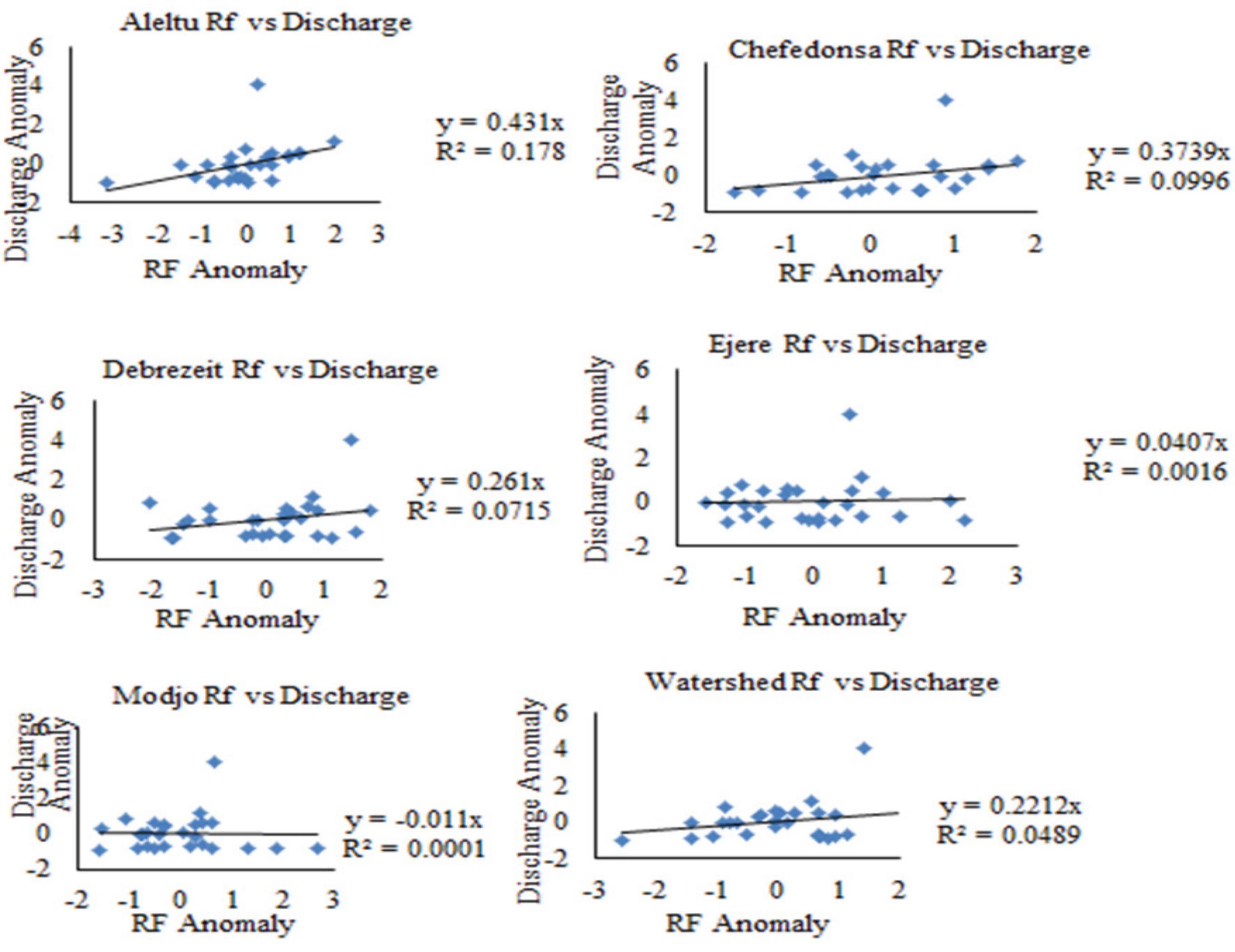

Figure 4. Relationship between rainfall and stream flow trend.

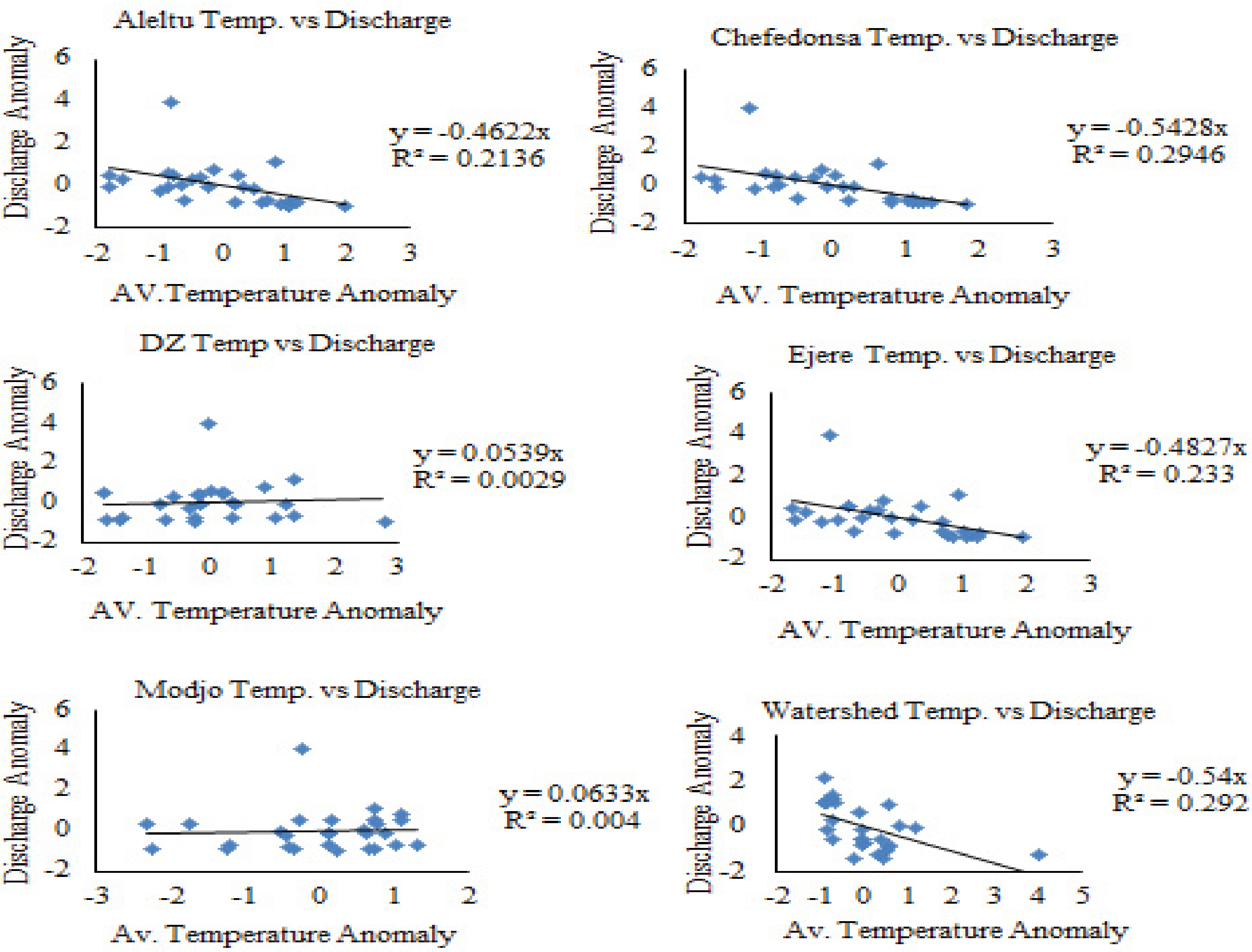

Figure 5. Relationship between temperature and stream flow trend.

increases the atmospheric water demand through higher evapotranspiration and contributes to the increased water loss from the basin and decreases trend in stream flow. There are studies which indicated an increase in trends of temperature causing an increasing evapotranspiration consequently causing decline in stream flow.

Conclusion

Climate change and variability is expected to trigger changes in temperature and precipitation series that would affect the flow volume and patterns in a watershed. The study conducted at Modjo River watershed revealed a significant increase in temperature during the historical (1981-2010) period. During the same period, precipitation however did not show any significant changes although numerical decline in amount was observed. Consequent to changes in temperature, stream flow reduced significantly during the analysis period owing to increased demands of evapotranspiration triggered by temperature increase. Relatively high correlation was observed between temperature and discharge than between rainfall and discharge signifying greater dependence of temperature with flow amount in the watershed. Hence, warming future will have a significant effect in the watersheds water output posing challenge on Koka water reserve for hydroelectric power. Thus, any watershed management strategy that can optimize water conservation for sustainable crop production and option that can improve flow to the reserve is vital.

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