

Trend Analysis of Climate variables, Stream flow and their Linkage at Modjo River Watershed, Central Ethiopia

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Abstract

Background: Trend and variability analysis of precipitation and stream flow series provides valuable information to understand hydrological changes associated with climate variability. In this study, annual and seasonal trends of precipitation and stream flow series and their relationship was investigated over the Modjo river watershed. The Mann-Kendall test and Sen's slope estimator were used for trend analysis and evaluation of its magnitude respectively, with an approach that corrects the serial correlation. The Pearson correlation analysis was also applied to evaluate the relationships between river flow and precipitation series.

Results: the mean and maximum stream flow series showed downward trends at the annual and kiremt time series, whereas no significant trend was observed for the minimum flow over the Modjo watershed. The study indicated that the mean annual and kiremt (monsoon) stream flow decreased significantly at a rate of 8.262 and 6.528 m³s⁻¹ per year respectively. In contrary to the river flow, there is no positive or negative trend in the annual and seasonal precipitation series although the tendency was towards increasing trends. It was evidenced that the annual, and kiremt season river flow series was affected abruptly since 2000, however for the same analysis period there was no evidence of changes in precipitation events, which is also not related significantly with the variability of river flow during the analysis period.

Conclusions: the river flow decreased dramatically in the Modjo watershed during the analysis period (1981-2015), however it was not primarily associated significantly with climate variability (precipitation & temperature). The result suggests the need of considering the unplanned water extraction and the poor land use management practices to sustain and restore river flow trend observed in the watershed.

Introduction

Water resources projects are planned, designed and operated based on the historical pattern of water quality, availability and demand with the assumption of constant climatic behavior. It is therefore important to investigate present and probable future climatic change patterns and their impacts on water resources so that appropriate adaptation strategies may be implemented by decision makers. Climate variability affects water flow directly. Specially, the variability of precipitation type, frequency, intensity, amount and duration, and also its trends (increasing or decreasing) can have significant impacts on water resource management, utilization, quantity and quality in general. That means, the sustainability of water resources (i.e., ground and surface waters) can be directly affected by the precipitation characteristics of the region. This in turn may have the potential to affect land productivity, agricultural activity, food security and ecosystems.

Abghari et al. (2013) indicated that climate change will lead to an intensification of the global hydrological cycle and can have major impacts on surface and groundwater resources. Over the last fifty years, it is evidenced that the greenhouse gases has affected the global water cycle by changes to the

intensity of heavy precipitation, increased frequencies, increasing annual runoff in some highland regions, and appearance of sudden droughts (Dai et al. 2004; Milly et al. 2005).

Spatial and temporal trend and variability analysis in hydrologic and climatic data obtained from instrumental records are valuable in water resource investigations. Changes in river flow regime are one of the most significant potential consequences of climate change (Khaliq et al. 2009). It is understood that if precipitation and temperature are changed, stream flow regimes can be changed significantly and as a result of this, it leads to the appearance of floods and droughts (Dai, 2013). In the recent times, time series analysis has emerged as a powerful tool for the efficient planning and sustainable management of the scarce water resources. Time series analysis on hydrological and climatological data have been carried out in different parts of the world in the last century, for example, to analyze historic rainfall data trends (Brunetti et al. 2000; De Luís et al. 2000; Astel et al. 2004; Kumar et al. 2010; Bekele et al. 2017; Mahtsente et al. 2019), for stream flow data trends (Burn, 2002; Fanta et al. 2001; Adeloye and Montaseri, 2002; Alemaw and Chaoka, 2002; Chen and Rao, 2002; Cunderlik and Burn, 2002; Kahya and Kalayci, 2004; Cherinet et al. 2019), and climate change impact detection (Yu et al. 2002).

The relationship between precipitation variability and river flow changes is an important watershed phenomena and that is why great concerns have been paid in most studies in the recent times. The studies by Jones et al. (2009) and Teng et al. (2012) on their respective catchments for example, indicated that changing precipitation patterns and intensity, together with changing temperatures, will hugely modify the stream flow of a basin. On the other hand, in the study conducted by Zhao et al. (2010) over the Poyang lake basin of China and Uddin et al. (2017) in the Kushiya river basin of Bangladesh the Pearson's correlation test was used to evaluate the correlation between stream flow and climatic variables. The results indicated that stream flow is more sensitive to changes in precipitation than potential evapotranspiration at the respective catchments. Furthermore, the study conducted by Akter et al. (2019) investigated the relation between stream flow and precipitation, and their finding revealed that strong relationships between river discharge and precipitation at the annual and seasonal over the study area. It is clear from the literatures reviewed above that the hydro and climatic parameters can be correlated using the Pearson's coefficient, and indicated that precipitation and stream flow are major hydrologic variables followed by temperature, which attracted the attention of researchers from different parts of the world for applying different time series analysis approaches.

Almost all agricultural activities in Ethiopia are done by waiting the seasonal rainfall. For this reason, trend and variability analysis in precipitation and stream flow is important to understand the past and for sustainable planning and development of water resources of the future. Furthermore, the choice of crops, grown times, cropping pattern and the agricultural productivity in catchments are also hugely determined by hydrologic and climatic conditions of that area and its neighbors. Even though several studies have been conducted on trend and variability in precipitation and river discharge and their relationships all over the world, a few studies have been conducted in Ethiopia at spatial and temporal time scales (for example, Edossa et al. 2010; Tesemma et al. 2013; Wagesho et al. 2013; Mengistu et al. 2014; Bekele et al. 2017; Mahtsente et al. 2019) are some of the studies conducted at large basin such as the upper Blue

Nile and Awash river basins. But no adequate attention has been given to trends and variability of rainfall and river flow, and their relationships at the watershed scales.

Modjo watershed is one of the intensively cultivated watersheds in Ethiopia. As in the other parts of the country, the agricultural activity of this watershed is entirely dependent on rainfall and only small amount of irrigation has been practiced at individual levels. For an area that is entirely rely on natural rainfall, understanding of the hydro-climatic condition is highly valuable; first to know their trends and variability through time and secondly the impact of one would have on the other parameters. The Modjo river shows a decreasing trend but there is no study conducted before to understand the cause of this trend. Therefore, this is the first attempt on hydrology and climate trend analysis in the watershed. With this consideration in mind and to add some valuable points onto the existing literatures, therefore, a thorough investigation of hydro-climatic data was conducted to analyze temporal trends of precipitation and stream flow records and their relationship for the period 1981–2015. The specific focuses of this study were; (1) to examine trends of hydro-climate variables at annual and seasonal time series, (2) to detect the abrupt change point in precipitation and stream flow series, and (3) to analyze the relation between stream flow and precipitation to understand the impacts of climatic changes on river flow. The findings of this study are expected to assist water resource managers and policy makers for better water resource planning decisions in the study watershed.

Materials And Methods

Description of the study area

The Modjo river watershed is the sub basin of the Awash river basin, of Ethiopia. It is located in the central part of Ethiopia between latitude of 8°35'00"N to 9°05'11"N and longitude of 38°54'35"E to 39°15'30"E. The study watershed is drained to Awash river by the Modjo river (Fig. 1). This watershed is characterized by a rugged and undulating topography with higher elevation at upstream of the watershed, and its elevation varies between 1568 m and 3084 m above sea level, which shows that the elevation difference between the highest and lowest point (i.e. outlet) of the watershed is more than 1500 m, indicating part of the Ethiopian highlands.

On the basis of the 1981–2015 recorded data, the watershed receives mean annual rainfall between 950 mm and 1100 mm. The annual mean minimum temperature varies between 11–12 °C and mean maximum temperature varies between 26–30 °C, whereas the annual average temperature of the watershed is estimated and varies between 19 °C and 21°C. The Modjo river and its tributaries have been used as the main source of water supply to major towns such as Bishoftu, Modjo, Edejere, Chefe donsa, Koka town and other rural communities within Oromia regional state.

Furthermore, there have been a number of water wells (i.e. hand dug and tube-wells) bored near the river-bed to exploit ground water for domestic and other different types of industries (for example, Paint industry, Textiles, Tanneries, steel industries, Oil factors, etc.), which are currently existing in the

watershed. In general, the river becomes of water-stressed because of high competing demands and improper land use and management practices. However, the impact of these demands, relative to the natural flow regime, is of high and significant. In addition, from socio-economic, hydrological and geomorphological characteristics points of view, the catchment is highly susceptible for surface erosion & sediment deposition problems; reduction in surface water flow, intensively cultivated; highly grazed and relatively densely populated area.

Data types and sources

For this study, precipitation (4 stations), stream flow and runoff data were used to evaluate trends in climate and hydrology and relationships between them. The daily stream flow and runoff record data needed for the study were obtained from the Ministry of Water Resources, Irrigation & Electricity (MoWIE 2019) of Ethiopia for the period 1981 to 2015. The gauging station is located at Modjo river, south part of Modjo town.

The time series of daily precipitation data was obtained from the National Meteorological Agency (NMSA 2019) of Ethiopia for the period 1981–2015. There are four active weather stations within the Modjo watershed (Chefe donsa, Debre zeit, Edjere and Modjo). The stations were selected based on their location within the studied watershed. The spatial distributions of the four weather stations are shown in Fig. 1 and Table 1 presents the geographical location and some statistical description of the stations.

Table 1 Geographic coordinate, observation periods & precipitation data considered stations (NMSA 2019)

Stations	Altitude (m)	Longitude (E°)	Latitude (N°)	Observation period (year)	Missing data	Mean Precipitation (mm)
Debre zeit	1900	38.95	8.73	1981-2015	-	951.8
Chefe donsa	2392	39.12	8.97	1981-2015	-	985.1
Edjere	2254	39.26	8.77	1981-2015	-	991.6
Modjo	1763	39.11	8.61	1981-2015	-	1097.8

Statistical Methods

In this study, all the trend tests are conducted through the ‘Monte-Carlo experiments’ featuring over 10,000 runs (unless stated otherwise) using precipitation and river flow time series data of record length, $N = 35$. Four types of tests were used: Mann–Kendall (a trend test); Sen’s slope estimator (a trend magnitude test); Pettit (a change-point test) and Pearson’s coefficient (correlation test), as described in sections below:

The Mann-Kendall (MK) test

The MK test series (Mann, 1945; Kendall 1975; Zhang et al. 2006) is a powerful tool in exploring trends of hydro-climatic time series. The test is robust and very useful in many hydrological studies for detecting trends (Hirsch and Slack 1984), and also recommended by the World Meteorological Organization (WHO)

to assess the significance of monotonic trends in stream flow series (Mitchell et al. 1966). The null hypothesis H_0 states that the de-seasonalized data (x_1, \dots, x_n) are a sample of 'n' independent and identically distributed random variables (Yu et al. 1993). The alternative hypothesis H_a of a two sided test is that the distribution of x_k and x_j are not identical for all $k, j \leq n$ with $k \neq j$ (Kahya and Kalayci 2004). Equations (1) and (2) are used to calculate the test statistic (S):

$$S = \frac{\sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i)}{\sigma_s} \quad (1)$$

$$\text{Sgn}(x_j - x_i) = \begin{cases} 1, & \text{if } x_j > x_i \\ 0, & \text{if } x_j = x_i \\ -1, & \text{if } x_j < x_i \end{cases} \quad (2)$$

Where: x_j and x_k are annual values in the year j and k , $j > k$ respectively. The trend test is applied to x_k data values (ranked from $k = 1, 2, \dots, n - 1$) and x_j (ranked from $j = i + 1, 2, \dots, n$). For the sample size, n lower than 10, then the Mann-Kendall test statistic, S is correlated directly to the theoretical distribution. However, for a sample size larger than n ($n \geq 10$), with the mean $E(S) = 0$ and standard deviation σ_s is given by

$$\sigma_s = \sqrt{\frac{n(n-1)(2n+5) - \sum_{i=1}^r t_i(t_i-1)(2t_i+5)}{18}} \quad (3)$$

Where: n is the number of observations; x_j and x_k are the data values in two consecutive periods, r is the number of tied groups, and t_i is the number of ties (i.e. equal values, of extent i). The Z_{MK} trend test statistic was used as a measure of trend magnitude. The results of 'S' and ' σ_s ' are used to estimate the standard normal variant Z_{MK}

$$Z_{MK} = \begin{cases} \frac{S-1}{\sigma_s} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma_s} & \text{if } S < 0 \end{cases} \quad (4)$$

As it can be referred from different literatures, the standardized Z_{MK} statistic of the MK follows the standard normal distribution with mean of zero and variance of one. In a two-sided test for trend at a selected significance level, if $|Z_{MK}| > Z_{\alpha/2}$, the null hypothesis H_0 of no trend should be rejected at a significance level of α . In this study, trends were identified at $\alpha = 5\%$ significant level or confidence level, $\beta = 1 - \alpha = 0.95$ (with $Z_{\alpha/2} = Z_{0.025} = 1.96$). For our decision, positive values of Z_{MK} were considered for increasing trends, whereas negative values of Z_{MK} for decreasing trends. The MK test does not account for the serial correlation (Yue et al. 2002). To investigate serial correlation, the data was correlated through trend free pre-whitening (TFPW) approach to remove the correlation for the MK test.

Pettit change point detection test

The Pettit's test is recognized as a useful method for change point detection (Love et al. 2010; Gao et al. 2011; Tekleab et al. 2013). According to this test, for a sequence of random variables X_1, X_2, \dots, X_T there is

a change point at τ (X_t) for $t = 1, 2, \dots, \tau$ have a common distribution function $F_1(x)$ and X_t for $t = \tau + 1, \dots, T$ have a common distribution function $F_2(x)$, where $F_1(x) \neq F_2(x)$ (Pettit 1979). The formula shown in Eq. (5) was used to estimate the non-parametric test statistic:

$$K_T = \max_{1 \leq t \leq T} |U_{t,T}| \quad (5)$$

$$\text{Where, } U_{t,T} = \sum_{i=1}^t \sum_{j=i+1}^T \text{sgn}(x_i - x_j) \text{ and } \text{Sgn}(x_i - x_j) = \begin{cases} 1, & \text{if } x_i > x_j \\ 0, & \text{if } x_i = x_j \\ -1, & \text{if } x_i < x_j \end{cases}$$

In which: K is the location of the final change point and T is the date of change provided that the statistic is significant. The significance probability associated with the rejection of H_0 , within 1% for $p < 0.5$ is approximated by:

$$p \approx 2 \exp\left(\frac{-6K^2}{n^3 + n^2}\right) \quad (6)$$

Equation (6), however does not give any confidence that T is the date of a shift, as it merely reports the greatest likelihood of a change in the median. In general, the test was evaluated against a user-defined significance level ($\alpha = 5\%$ in this case) and when p is smaller than the specified significance level, the null hypothesis (that states no significant difference between the mean values of the two sub-series) is rejected.

In addition, statistical features of the segments divided by change points are detected by the mean and coefficient of variation (CV). In this case, the mean is the arithmetic average of random variables and calculated using:

$$\bar{X} = \sum_{i=1}^n \frac{x_i}{n} \quad (7)$$

A dimensionless measure of dispersion is the coefficient of variation, defined as the standard deviation divided by the mean. The coefficient of variation (CV) is estimated using Eq. (8):

$$CV = \frac{S_x}{\bar{X}}, \text{ where } S_x = \sqrt{\frac{\sum_{i=1}^k (x_i - \bar{X})^2}{n-1}} \quad (8)$$

Sen's trend slope estimator

The change per unit (true slope) is estimated by using the Sen's method, which is a simple and nonparametric technique developed by Sen (1968). This method is selected as it is more robust to outliers compared to the parametric tests such as linear regression (Hirsch et al. 1982). For two data points of x_j and x_k at j and k (where, $j > k$), the slope, β was estimated using Eq. (9):

$$\beta = \text{Median} \left(\frac{x_j - x_k}{j - k} \right), \text{ for } i = 1, 2, \dots, N \quad (9)$$

Considering t as the length of analysis period (in years), the following equation gives the trend magnitude in percent change over the analysis period (Lehmann et al. 2005).

$$\% \text{ change} = (e^{\beta} - 1) \times 100t \quad (10)$$

Relations between climatic and river flow

The correlation of parameters is a useful statistical analysis approach that can be used to construct comprehensive relationships between parameters in the baseline period (Hastenrath, 1990; Chen et al. 2007; Burn 2008; Xu Jianhua et al. 2008; Zhao et al. 2009 and Uddin et al. 2017). In this study, the relation between trends in precipitation and stream flow was examined using the Pearson correlation coefficient at 5% significance level. For this purpose, Eq. (11) was used to estimate the correlation between stream flow (X_i) and precipitation (Y_i) variables:

$$r = \frac{\sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^N (x_i - \bar{x})^2 \sum_{i=1}^N (y_i - \bar{y})^2}} \quad (11)$$

Where: N is the series length, $x - \bar{x}$ and $y - \bar{y}$, are departures from the mean values of \bar{x} and \bar{y} , respectively, “ r ” is Pearson’s coefficient of correlation. Then, the Student’s t -distribution with degrees of freedom $n - 2$ was used to assess the significance of the Pearson’s product moment correlation coefficient (Hirsch et al. 1993). The estimated correlations were tested for statistical validity at the 5% level of significance. The r values -1 and $+1$ correspond to perfectly negative and perfectly positive linear correlation, respectively, while $r = 0$ indicates there is no correlation between parameters (i.e. stream flow & precipitation in our case).

To indicate the proportion of the variance in the dependent variable (i.e., the one predictable from the independent variable), we used the coefficient of determination (i.e., the square term of coefficient of correlation, r), which is usually used by different research studies (for example, Numanbakhth et al. 2019; Akter et al. 2019). In addition, to determine the reliability of Pearson’s CC, we used the probable error (PE) approach shown by Eq. (12)

$$PE = 0.6745X \frac{1-r^2}{\sqrt{N}} \quad (12)$$

In this case, if the $|r| < 6PE$: the values of Pearson’s CC are not statistically significant. That means there is no evidence of correlation for the specific case. Whereas, if the $|r| > 6PE$, the Pearson’s CC values are statistically significant, indicating that there is an evidence of correlation between the parameters correlated.

Results And Discussion

Change point detection in Precipitation and Stream flow

The Modjo watershed experienced significant change points for stream flow but not for precipitation time series in most of the stations. The analysis showed that there was a statistically significant change point for annual precipitation only at Modjo station in the year 2000, whereas in the rest three stations experienced homogeneous datasets (there is no significant change point) during the analysis period. Regarding watershed mean annual precipitation, there was statistically insignificant change point around the year 2002 ($p > 0.05$) during the study period (Table 2). In general, the result of the change point analysis demonstrates how the precipitation variability impacts on stream flow records in the watershed.

Table 2 Abrupt change in annual & seasonal precipitation as determined by using Pettit test

Stations	Location	Time frames	K	P value	T	Risk to reject Ho while it is true (%)	Shift
Chefe donsa	Upper part	Annual Precipitation	120.0	0.188	2002	18.8	-
		Kiremt Precipitation	150.0	0.053	2002	5.29	-
		Belg Precipitation	94.0	0.45	1990	44.6	-
Debre zeit	Central part	Annual Precipitation	93.0	0.46	2007	45.73	-
		Kiremt Precipitation	87.0	0.531	2008	53.14	-
		Belg Precipitation	73.0	0.73	1987	72.99	-
Edjere	Central part	Annual Precipitation	122.0	0.165	1995	16.48	-
		Kiremt Precipitation	200.0	0.003	1997**	Lower than 0.25	upward
		Belg Precipitation	104.0	0.318	1987	31.81	-
Modjo	Lower part	Annual Precipitation	192.0	0.003	2002**	Lower than 0.33	upward
		Kiremt Precipitation	148.0	0.055	2002	5.51	-
		Belg Precipitation	74.0	0.711	1987	71.1	-
Watershed mean		Annual Precipitation	148.0	0.058	2002	5.76	-
		Kiremt Precipitation	146.0	0.059	2002	5.93	-
		Belg Precipitation	100.0	0.362	1987	36.16	-

**indicate significant trend ($p \leq 0.05$); ** highly significant trend ($p < 0.01$); k: Pettit's test statistics; T: Abrupt change year*

The abrupt change point analysis for stream flow revealed that a significant change points for annual and kiremt (monsoon) season flow series were detected in the year 2000 for both cases, whereas the significant change point for the bega (dry season) flow was in the year 1992. However, no significant change was detected during the belg (small rainy) season runoff during the analysis period. Form the

result; it can be concluded that the abrupt change periods of stream flow appeared without any significant change in precipitation during the analysis period.

Table 3 Summary of change detection in mean annual & seasonal stream flow series (1981-2015)

Parameters	k	P value	T	Risk to reject Ho while it is true (%)	Shift
Annual mean flow	276.0	< 0.0001	2000**	Lower than 0.01	downward
Kiremt mean flow	258	< 0.0001	2000**	Lower than 0.01	downward
Belg mean flow	96	0.411	1987	41.06	-
Bega mean flow	182	0.008	1992**	Lower than 0.77	downward

**Indicate significant trend ($p \leq 0.05$); ** highly significant trend ($p < 0.01$); k: Pettit's test statistics; T: Abrupt change year*

In the watershed, obvious reduction occurs stream flow in all months; belg (i.e., March–May), kiremt (i.e., June–September), and bega (October–February) during the after change period (2001–2015) as compared with the before change (1981–2000) period (Fig. 2). The variation in flow between the dry and the wet months of the two period was very high (i.e., 254.7mm to 50.8mm), indicating that a decline in flow by 80.05% between the two months. Meanwhile, decreasing values in the coefficient of variation (CV) for monthly stream flow was observed during the period 2001–2015 (after change period). The decreasing coefficient of variation in monthly stream flow during 2001–2015 supposedly results from decreased stream flow in the flood season.

On the basis of the change point of the annual stream flow, the study period of the watershed was divided in two parts: period-I (1981–2000), and period-II (2001–2015), which represents 'before change' and 'after change' periods respectively. To understand the changes in the hydrological regime, the statistical differences in the mean of runoff was calculated for the two periods at annual and seasonal time-scales. The mean annual flow for the two periods is 685.96mm and 119.04mm respectively. This shows the annual runoff values decreased by 82.65 % during the 'after change period' in comparison with the 'before change period'. In similar manner, the monsoon (kiremt) season runoff showed that the after change period (2001–2015) flow decreased considerably compared with the before change time (1981–2000) by 80.57% (545.08 mm to 105.9 mm), respectively. Since 2000, the decline in runoff during the wet season has been severe at the 5% significant level.

Annual and Seasonal trends in Precipitation series

Annual trends in precipitation

The monthly precipitation amount is highest in August and lowest in December at all the stations. The annual mean precipitation of the study watershed is 1006.6mm, with coefficient of variability (CV) of 15.24% during the analysis period (1981–2015). The highest and the lowest annual precipitation occurred in Modjo station (1097.8 mm) and Debre zeit station (951.6 mm), respectively. The main rainy season or kirem (June–September) precipitation receives on average 74.1% of total annual precipitation of the watershed and for belg (March–May) and bega (October– February) seasons it is 19.04% and 6.9%,

respectively. In general, precipitation amounts in this watershed do not follow the elevation condition of the areas; it is highest at the southern part (elevation: 1763m) and lowest in central part (elevation: 1900m) throughout the year.

The Mann-Kendall (MK) and Sen's slope estimator tests for trend analysis was applied for annual precipitation series at station and watershed scales between 1981 and 2015. The MK test result for precipitation trends is shown in Table 4. Evaluating all the station recorded data; the result indicated that there were no positive and negative significant trends in the annual precipitation time series in any of the stations over the analysis period. As indicated by MK test, except at Debre zeit station the annual mean precipitation trend was insignificantly increasing at 5% significant level. At Debre zeit station, there was insignificant increasing trend for the analysis period. Although none of the precipitation trends are statistically significant, there is a general increase in the annual precipitation series throughout the watershed. From the trend analysis result, it can be concluded that the null hypothesis (H_0) of the MK trend test have been confirmed between the years 1981 and 2015 both at station and watershed scales.

Table 4 Mann-Kendall trend test statistics for annual precipitation over Modjo watershed (1981-2015)

Stations	MK Statistics (S)	Kendall's tau	Var (S)	P value	Sen's Slope	% change	Trend test Interpretation
Chefe donsa	1	0.002	0.0	1.0	2.6×10^{-4}	0.03	Accept H_0
Debre zeit	-61	-0.103	4956.33	0.394	-0.054	-6.95	Accept H_0
Edjere	35	0.059	6.0	0.632	0.038	4.69	Accept H_0
Modjo	127	0.213	8.0	0.074	0.2	22.32	Accept H_0
Watershed	47	0.079	8.0	0.517	0.056	6.82	Accept H_0

Seasonal trends in Precipitation

Trend analysis was also evaluated for the seasonal precipitation data in the Modjo watershed for the same analysis period. The MK test statistics of the seasonal precipitation is shown in table 5. During the study period, the seasonal precipitation showed non-significant trends in most of the stations. Precipitation in the monsoon (kiremt) and pre monsoon (belg) months showed non-significant trend in most of the stations except at Edjere. At Edjere station statistically significant increasing trend was detected during the main rainy months (June to September), with a trend slope of 0.126mm/year during the analysis period. In general, the monsoon months precipitation was insignificantly decreasing at Debre zeit and Edjere stations, whereas at Chefe donsa and Modjo stations statistical non-significant increasing trend were exhibited at 5% significant level (Table 5). During the 1981-2015 period, the small rainy or belg months (March to May) precipitation generally indicates non-significant decreasing trend ($p > 0.05$) in all the stations we considered (Table 5).

Table 5 Mann-Kendall trend test statistics for seasonal precipitation series in Modjo watershed (1981-2015)

Stations	Seasons	MK Statistics (S)	Kendall's tau	Var (S)	P value	Sen's slope	% change	Trend test Interpretation
Chefe donsa	kiremt (JJAS)	52	0.087	4957.33	0.469	0.049	8.06	Accept Ho
	belg (MAM)	-36	-0.061	4957.33	0.619	-0.018	-12.24	Accept Ho
Debre zeit	kiremt (JJAS)	-41	-0.069	4956.33	0.570	-0.029	-5.07	Accept Ho
	belg (MAM)	-30	-0.051	4955.33	0.680	-0.022	-14.5	Accept Ho
Edjere	kiremt (JJAS)	149	0.25	8.0	0.035	0.126	21.44	Reject Ho
	belg (MAM)	-25	-0.042	8.0	0.735	-0.014	-9.53	Accept Ho
Modjo	kiremt (JJAS)	131	0.22	14.0	0.065	0.158	23.71	Accept Ho
	belg (MAM)	-43	-0.072	38.0	0.554	-0.038	-21.08	Accept Ho
Watershed Mean	kiremt (JJAS)	95	0.16	6.0	0.184	0.082	13.47	Accept Ho
	belg (MAM)	-43	-0.072	8.0	0.554	-0.023	-14.69	Accept Ho

Similar to the annual precipitation trend analysis, here also the alternative hypothesis (H_0) of the MK trend test of “there is no trend in time series” has been confirmed during the study period. Precipitation data from the four stations were used to evaluate trends in the Modjo river watershed during the period 1981-2015. The analysis of annual and seasonal trends generally indicated that no significant trends were detected in the annual and seasonal precipitations over the watershed. This may be due to the sample size we considered. Hence, to get clear trends in the recorded data, it should be tried by using better sample size.

Previous studies have found almost similar results with this study for the annual rainfall totals in central highlands of Ethiopia (Seleshi and Zanke **2004**), in which our study area is located. This study is partially in a good agreement with the study conducted by Mahtsente et al. (**2019**) who did not detect any statistical significant trends in annual and belg season rainfall series at Modjo and debre zeit stations.

Annual and Seasonal trends in river flow

Annual trends in river flow

The annual trends were evaluated for the three distinct hydrologic variables: minimum flow, maximum flow and mean flow statistics for the period of record 1981-2015. The annual minimum flow occurs in the dry (bega) months, hence increasing/decreasing flow during these months can result increasing/decreasing flow in annual minimum flow. The annual minimum (base flow) flow series showed insignificantly increasing trend ($p>0.05$) during the studied period. Normally, the minimum flow

refers the river discharge generated from the movement of water from the subsurface into the stream channel, typically after with no rainfall times. Similarly, for reasons not fully understood the Pettit homogeneity test confirmed that strong homogeneity in the annual minimum flow series data, indicating the annual minimum flow did not change significantly over the Modjo river watershed, which is important positively for the water resource and hydrology of the watershed. The precipitation data also showed insignificant trend during the dry months, hence the minimum flow data was likely related to the no trend condition of the dry month precipitation.

During the analysis period (1981–2015) the annual maximum stream flow record indicated highly significant decreasing trend, with trend slope of $-16.85 \text{ m}^3\text{s}^{-1}$ per year at a 5% significant level (Table 6). Comparing the results of trend analysis in precipitation and stream flow, different and almost opposing behavior of trends were found in annual stream flow series for the analysis period. In the absence of significant trends in annual precipitation, significant trends in annual mean and maximum flows were identified over the Modjo watershed. This may be explained by the length of recorded data and the sparse distribution of weather stations in the watershed.

Table 6 Mann-Kendall trend test statistics for annual & seasonal river flow data of Modjo river (1981-2015)

Parameters	Time frames	MK Statistics (S)	Kendall's tau	Var (S)	P value	Sen's slope	% change	Test Interpretation
Minimum flow	Annual flow	37.0	0.062	8.0	0.612	0.026	2.07	Accept Ho
	Kiremt (JJAS)	13.0	0.022	8.0	0.866	0.01	1.86	Accept Ho
	Belg (MAM)	14.0	0.024	4957.33	0.854	0.001	0.42	Accept Ho
	Bega (ONDJF)	179.0	0.301*	24.0	0.011	0.025	5.26	Reject Ho
Maximum flow	Annual flow	-263.0	-0.442**	8.0	0.00	-16.85	-84.51	Reject Ho
	Kiremt (JJAS)	-251.0	-0.422**	8.0	0.00	-14.45	-87.04	Reject Ho
	Belg (MAM)	-87.0	-0.146	6.0	0.224	-1.242	-59.69	Accept Ho
	Bega (ONDJF)	65.0	0.109	6.0	0.366	0.055	4.41	Accept Ho
Mean flow	Annual flow	-255.0	-0.429**	56.0	0.00	-8.262	-142.17	Reject Ho
	Kiremt (JJAS)	-197.0	-0.331**	6.0	0.005	-6.528	-136.6	Reject Ho
	Belg (MAM)	-65.0	-0.109	6.0	0.366	-0.102	-19.0	Accept Ho
	Bega (ONDJF)	177.0	0.297*	14.0	0.012	0.048	7.55	Reject Ho

**Indicates a significant trend ($p \leq 0.05$); ** indicates a highly significant trend ($p < 0.01$)*

Analysis of the mean stream flow recorded data at Modjo river (1981–2015) indicated the mean stream flow was peaks during the 1996's ($1296.24 \text{ m}^3\text{s}^{-1}$) than any decade since its monitoring time (1968's). The magnitude of stream flow events that occurred during the 1996's was atypical of historical peaks of the river. However, the MK trend analysis revealed that a highly significant decreasing trend was detected

in the mean stream flow records with an estimated trend slope about $8.262\text{m}^3\text{s}^{-1}$ and a significance of 0.00 during the analysis period (Fig. 4). In general, the downward trends in the annual mean and maximum flows may be explained by the impacts of uncontrolled water use/extraction for different purposes, and the availability of lakes and wetlands in the watershed.

Seasonal trends in river flow

Three distinct seasons have been considered for trend analysis, they are bega or base flow (October – February), kiremt or high flow (June -September) and belg (March – May). During bega (dry) period, stream flow is fairly uniform and follows at constant rate. The flow during the kiremt period follows the rainfall period and generally begins about early in June and extends until September. Usually, river flow during the Ethiopian summer period is highly variable. During this period, the stream flow decreases fairly quickly after peaking in August. In the belg season flow begins early in March and extends until about May. Early in this period, stream flow increases substantially from base-flow conditions (Fig. 5).

In this study, no statistically significant trends have been detected in the minimum flow (base flow) series during the kiremt and belg seasons over the watershed at 5 % significant level. However, this flow showed a significant increasing trend during the dry period with a rate of $0.025\text{m}^3\text{s}^{-1}$ per annum (Table 6).

Maximum flow is usually associated with floods in the central highlands of Ethiopia as it induced by kiremt season precipitation. The maximum stream flow series during kiremt season (June - September) showed highly significant decreasing trend, with a percentage decline of 87.04% over the study period (Table 6). However, the belg (March to May) and bega (October - February) seasons of the maximum flow data experienced statistically non-significant decreasing & increasing trends, in that order at 5% significant level. In summary, there was no uniformity in trends between precipitation and river flow series in the study area and in fact, opposite trend directions (non-significant for precipitation and significantly decreasing for river flow) were observed over the analysis period.

The mean flow series during kiremt season (monsoon) showed a significant decreasing trend at a rate of $8.262\text{ m}^3\text{s}^{-1}$ per year (Table 6). Whereas, during the dry (bega) season the stream flow showed statistical significant increasing trend with a rate of $0.048\text{ m}^3\text{s}^{-1}$ (7.55%). This is very important for the area as the local communities are mostly rely on surface waters sources (i.e. river and lakes) and its small tributaries for their various uses. On the contrary, the small rainy (belg) season flow record experienced statistically non-significant downward trend at a decline rate of $0.102\text{m}^3\text{s}^{-1}$ (19%) per year at 5% significant level.

For the same analysis period, precipitation and river flow showed an inverse trend both for the annual and seasonal time series. The river flow, showing a drying tendency since it showed a statistically significant declining trend (particularly in the annual and wet seasons) during the study period (Fig. 5 & 6). From the statistical analysis, a downward trend in mean and maximum stream flow series was obtained without any significant changes in precipitation in the study area. Therefore, human factors (such as land

use/land cover changes, ground water abstractions, watershed development and storage) may be attributed the stream flow declining trends as there is no dramatic changes in precipitation over the analysis period. A stream flow change without any change in rainfall was also reported by the study conducted by Nune et al. (2012). Furthermore, the decrease in the peak and mean river flows during the annual and wet seasons has critical implications for both the quantity and the quality of water available for domestic uses and livestock watering, which needs due consideration by the concerned bodies.

Relationship between stream flow and climate variability

The annual mean flow for the catchment shows a significant decreasing trend over the period 1981–2015, however no station gave us indications that the precipitation suffered significant increasing or decreasing trends over times (Tables 4, 5 & 6). Hence, it is apparent that annual flow and annual precipitation exhibits inverse trends. The results of the correlation analysis clearly showed that the stream flows are positively correlated with the precipitation and negatively with mean temperature at watershed level. Although it is non-significant, the correlations of the annual stream flows with annual station precipitation are distinctly increasing from upstream to downstream parts of the watershed. The probable reason for this phenomenon might be due to the storage effects of the different types of lakes and wetlands in the catchment.

The correlation coefficients between river discharge and climate variables on annual and seasonal bases were shown in table 7 a & b. The annual mean flow showed a positive with the annual amount of watershed mean precipitation ($r= 0.044$) and negative correlation with the annual mean temperature ($r=-0.252$), indicating small dependence on the annual stream flow on the annual climate variables. Considering the r^2 (i.e., the coefficient of determination), therefore, only 0.2% and 6.4% of the annual stream flow variation was explained by annual mean precipitation and temperature in that order. Therefore, as indicated by Pearson's coefficient of correlation (CC), the annual stream flow variation was weakly affected and explained by the climate variables of the watershed. Similarly, the "r" values for kiremt (monsoon), belg (small rainy season) and bega precipitations are 0.016, 0.288 and 0.097 respectively. This indicates that there is a small positive relationship between the seasonal flows and the corresponding precipitations. Whereas a small negative relationship with that of mean temperature at the studied watershed. However, the correlations among the variables are statistically insignificant except correlation with kiremt temperature. The coefficient of determination (r^2) for kiremt, belg and bega are 3×10^{-3} , 0.083, and 9.4×10^{-3} in that order. That means only about 0.03%, 8.3% and 0.94% of kiremt, belg and bega river flow variations depend on seasonal (kiremt, belg and bega) precipitations, whereas 11.6, 1.7 and 1.6% of kiremt, belg and bega river flow variations correlated with kiremt, belg and bega seasons mean temperatures, respectively.

There may be several possible reasons for the weak relationship between the hydrology and climatic events. These may be includes: (i) the length of the record period that could explain the decrease trend in stream flow without a corresponding significant trends in precipitation during the analysis; (ii) human activities through water extraction and land use changes within the watershed could have modified the

hydrologic response of the watershed to precipitation events; (iii) the sparsely distribution of precipitation stations could have inadequately measured annual precipitation in the watershed, and therefore the relation between precipitation and stream flow was not accurately defined; (iv) due to the availability of several natural lakes and seasonal wetlands (which may be an indication of precipitation contribution for groundwater recharge instead of direct surface water), could altered the watershed responses to climate events; or (v) due to a combination of the above stated core reasons.

Evaluating the observed relationship between stream flow and precipitation events is an innovative for the Modjo river watershed. For this reason, the result obtained during the analysis cannot directly be compared with other result findings.

Table 7 Relation between climate variables with river flow

a) River flow vs. watershed precipitation events (1981-2015)

Dependent variable	Independent variable	r value	Standard error	Probable error	Coefficients of determination (r ²)
Annual stream flow	Annual precipitation	0.044	0.169	0.11	0.002
Kiremt flow	kiremt precipitation	0.016	0.169	0.114	0.0003
Belg flow	belg precipitation	0.288	0.155	0.105	0.083
Bega flow	bega precipitation	0.097	0.167	0.113	0.0094

*r: coefficient of correlation

b) River flow vs. watershed mean temperature (1981-2015)

Dependent variable	Independent variable	r value	Standard error	Probable error	Coefficients of determination (r ²)
Annual river flow	Annual Tmean	-0.252	0.156	0.107	0.064
Kiremt flow	kiremt Tmean	-0.341	0.150	0.146	0.116
Belg flow	belg Tmean	-0.129	0.166	0.112	0.017
Bega flow	bega Tmean	0.127	0.166	0.112	0.016

*r: coefficient of correlation

Conclusions

In this study, the long-term trends in precipitation and stream flow were examined based on daily hydro-meteorological records in the Modjo river watershed using statistical methods. The correlation between precipitation and stream flow was also investigated on the annual and seasonal basis between 1981 and 2015. Based on the results of the analysis, the major conclusions of the study are as follows: (i) The trend analysis result clearly revealed that annual precipitation experienced non-significant trends. However, the mean and maximum annual stream flow trends behaves differently by showing significant down ward trend at 5% significant level, with a declining rate of 8.262 and 16.85 m³s⁻¹per annum respectively in the study watershed. The dramatic declining trends of the river flow; likely seems to be a potential threat for water shortage in the watershed over the next few decades; (ii) During the analysis period, except monsoon (kiremt) season precipitation at Edjere station, seasonal precipitation trends were showed non-significant trend in most of the stations. Conversely, mean and maximum stream flow during the main rainy season (kiremt) exhibited significant declining trends, with a rate of 6.528 and 14.45 m³s⁻¹per year respectively; (iii) Trends for the annual and seasonal minimum (base flow) data were not

significant in the same study period. Moreover, the mean flow series during dry (bega) season in the same study period showed a significant weak increasing trend; with a rate of $0.06 \text{ m}^3\text{s}^{-1}$ (7.3%), which has a positive advantage for the watershed; (iv) The abrupt change point for stream flow did not detected simultaneously with the precipitation change point in the watershed. The analysis result identifies the year 2002 non-significant change point for the annual watershed precipitation; however the year 1999 is statistically significant change point for the annual stream flow series at 5% significant level. Furthermore, the correlation analysis between river discharge and climate variables was weak; indicates climate variability (precipitation & temperature) was not the main factor in causing the declining trend of the river discharge at the Modjo watershed. Finally, the finding of this study suggests the need of considering the poor land use/land cover planning and management practices to sustain and restore the dramatically declining trends of the river flow in the study watershed.

Abbreviations

MK: Mann-Kendall; m^3s^{-1} : meter cubed per second; mm: millimeter; CV: coefficient of variability; Q: Stream flow; r: correlation coefficient

Declarations

Authors' contributions

Kokeb Z has conceived of the study. He has also participated in data collection, statistical analysis, interpretation of results and write-up the article. Both Tamene A and Fekadu F have made substantial contributions in its design, coordination, and critically revising the manuscript. All authors read and approved the final version of the article.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

All the data are included in the manuscript.

Consent for publication

We have agreed to submit for Environmental Systems Research journal and approved the manuscript for submission.

Ethics approval and consent to participate

Not applicable since human participants was not involved in this research to evaluate health related outcomes.

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Availability of the data and materials

The data is included in the manuscript.

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Figures

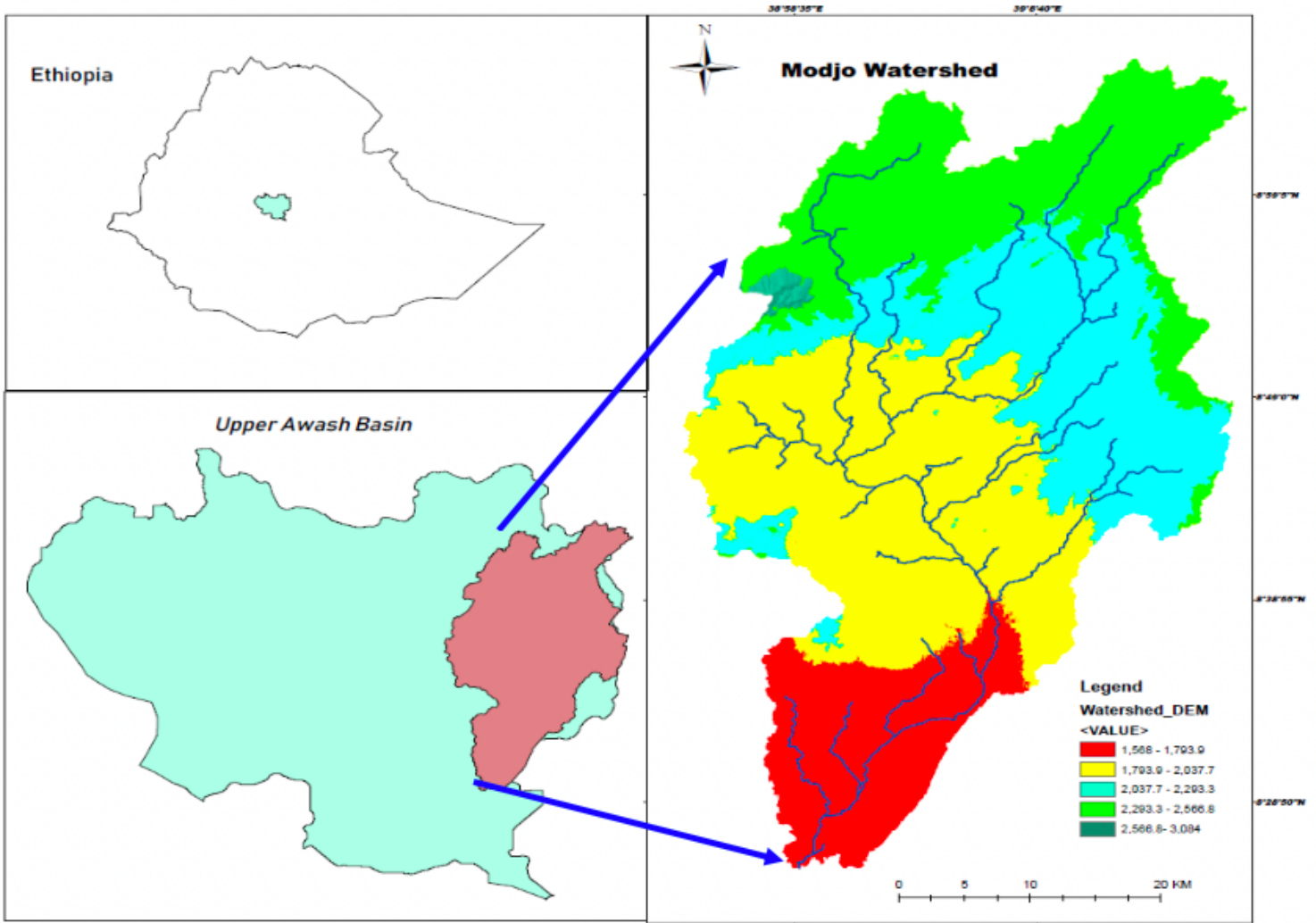


Figure 2

Location map of Modjo watershed, central highlands of Ethiopia

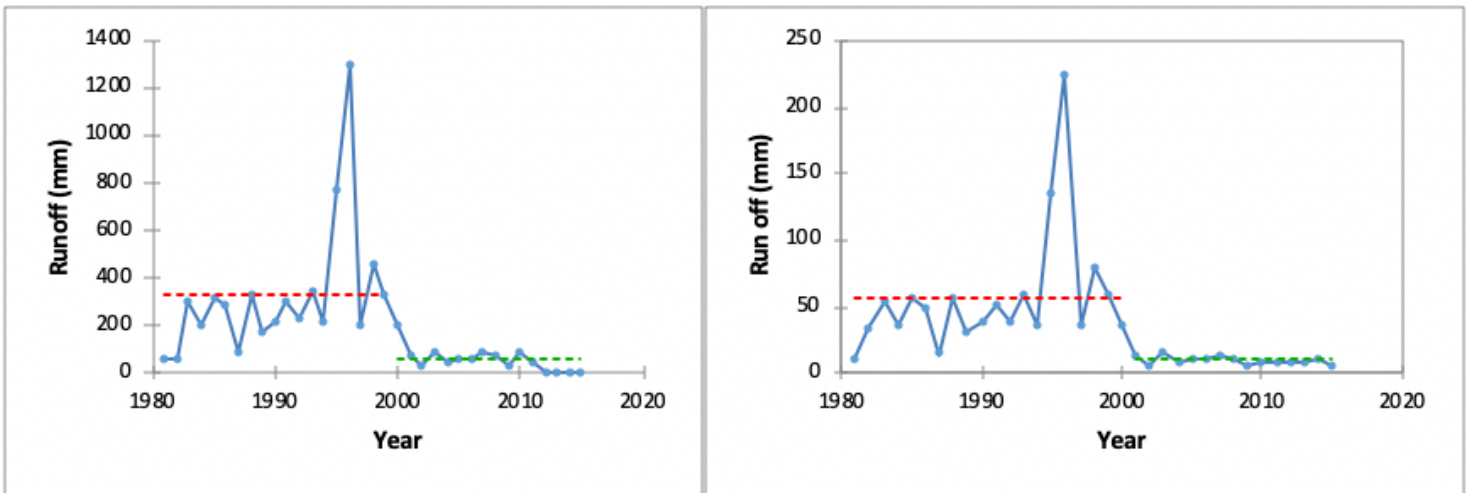


Figure 4

Change point detection for annual runoff using: a) Cumulative Deviation test & b) Pettit test

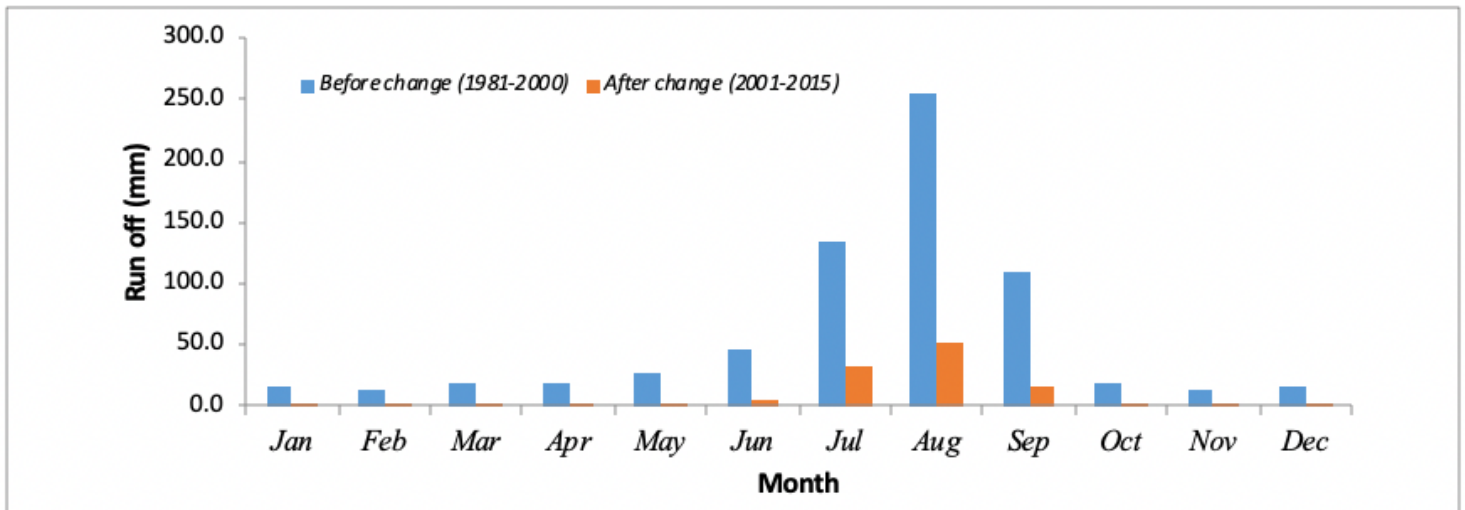


Figure 6

Comparison of monthly stream flow of 'before change' and 'after change' periods (Modjo station)

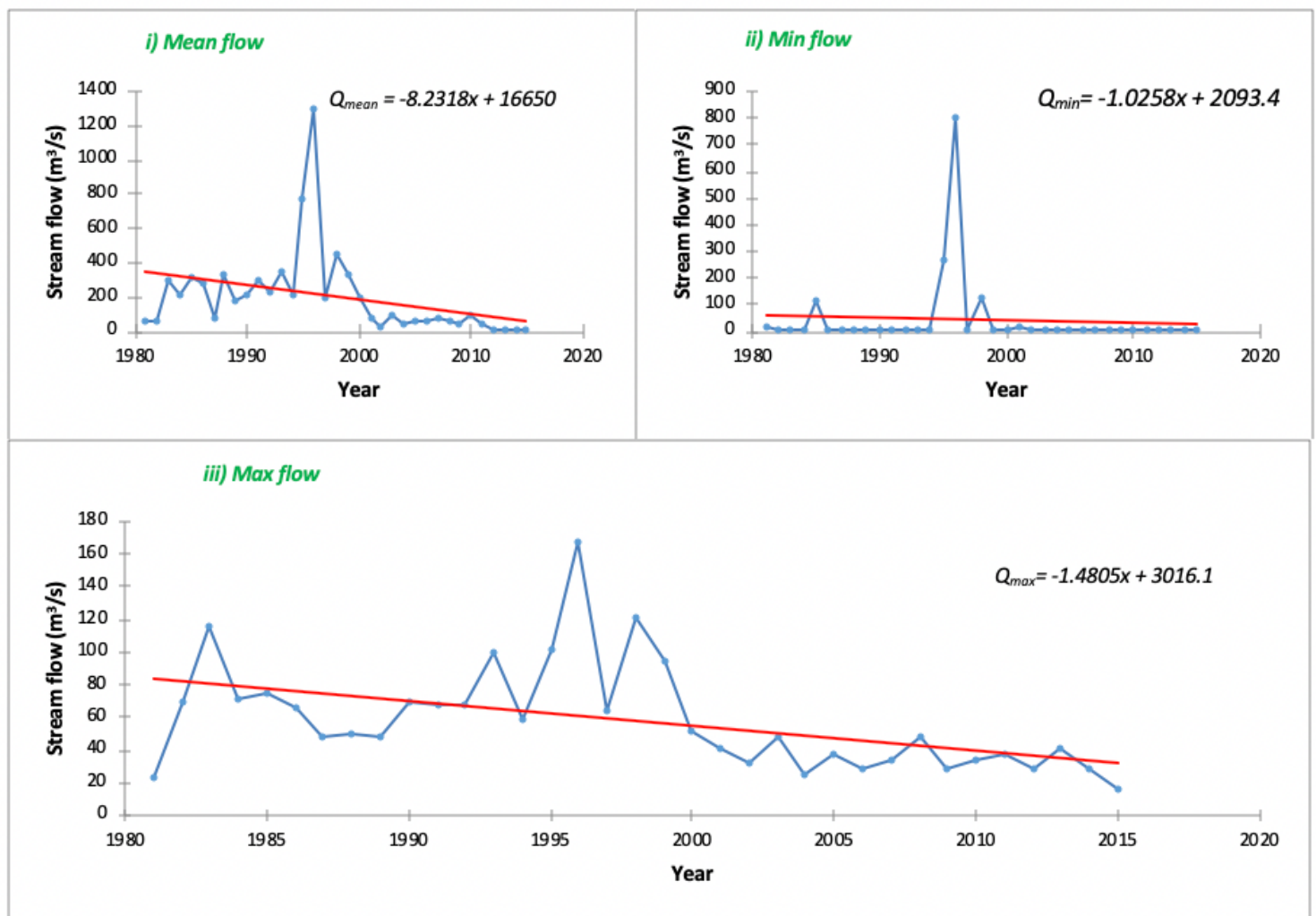


Figure 8

Mean, minimum and maximum annual stream flow trends of Modjo watershed (1981–2015)

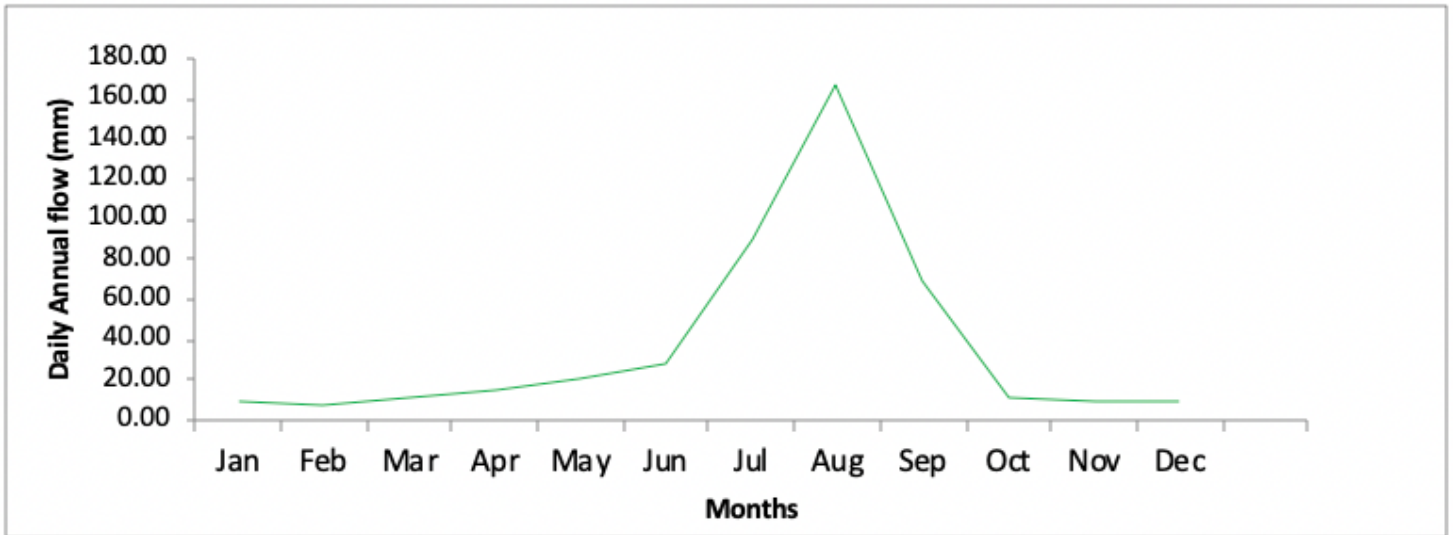


Figure 10

Annual average daily river flow at Modjo river (1981-2015)

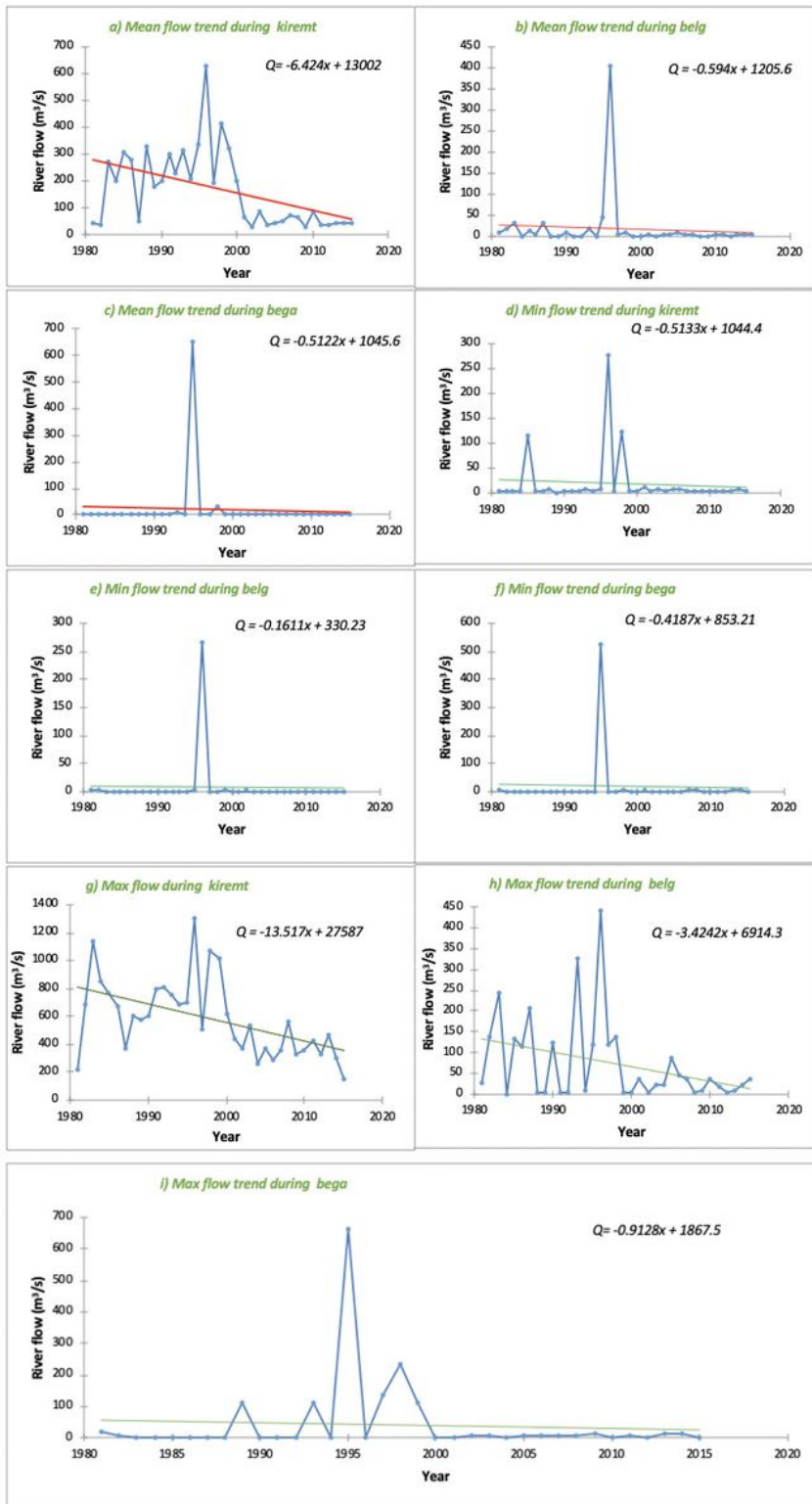


Figure 11

Linear trend test for mean, min and max flow during kiremt, belg & bega months (1981–2015)