Trend and variability analysis of rainfall and temperature in the Tana basin region, Ethiopia

Hailu Birara, R. P. Pandey and S. K. Mishra

ABSTRACT

Global warming and climate variability are emerging as the foremost environmental problems in the 21st century, particularly in developing countries. Ethiopia is one of the countries located in the sub-Sahara region and climate variability has a significant impact on the economy of the country. The aim of this study is to characterize annual and seasonal rainfall and annual temperature variability, and to measure trends on both the spatial and the temporal scale for ten selected stations in the Tana basin region, Ethiopia. The Mann–Kendall test and Sen's slope estimator were used to assess trends and variability of rainfall and temperature. The spatial distribution of rainfall and temperature was determined using the inverse distance weighted technique. Results indicated that the amount of rainfall decreased for the majority of the stations. The annual rainfall showed significant decreasing trends with a magnitude ranging from −5.92 mm/year at Injibara to −9.74 mm/year in Wegera. However, a positive trend of annual rainfall was observed at Addis Zemen (1.81 mm/year). The minimum, maximum and mean temperatures have increased significantly for most of the stations. An increasing trend of annual maximum temperature was obtained between 1980 and 2015; an increase of 1.08°C was observed.

Key words | Mann–Kendall test, rainfall, Sen's slope estimator, Tana basin, temperature, trend analysis

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INTRODUCTION

Climate change is not only a phenomenon of the future; we are already living with it. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5), the average temperature trends on a global scale showed a warming trend of 0.85°C (0.65–1.06) over the period 1880 to 2012 (IPCC 2013). Different incidents, such as sea level rise, polar ice melting, intense storms, floods, droughts, heat waves, and others, are likely to occur as a result of climate change (Stocker 2014).

In recent years, more attention has been given to climate change as well its associated impacts and vulnerabilities (Brown *et al.* 2005; IPCC 2013). The problems associated with climate change and global warming are regarded as the most serious environmental problems in the world today (Solomon 2007; Shongwe *et al.* 2011). Many parts of the world, particularly countries in sub-Saharan Africa, are affected by global warming owing to the changing temperature and precipitation patterns (Conway & Schipper 2011; Kløve *et al.* 2014). A very large consensus of literature for the coming decades states that higher temperature and changing precipitation intensity caused by climate change will reduce crop yields in many countries in the world, particularly in low-income countries where adaptive capacity for change is low (Stige *et al.* 2006; IPCC 2007). Since agricultural production remains the main source of income in most rural communities in developing countries, the agricultural sector's adaptation to the adverse effects of climate change will be crucial in protecting the livelihoods of the

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poor and ensuring food security. However, many countries in sub-Saharan Africa are becoming highly vulnerable and less adaptable to the impacts of climate change (Slingo *et al.* 2005; Thomas & Twyman 2005; IPCC 2012).

A developing country like Ethiopia in East Africa may also experience greater variability of precipitation and evapotranspiration due to climate change, and hence greater adverse impacts on its economy as it is largely dependent on rainfed agriculture (IPCC 2012). In the country, agriculture employs approximately 80% of the labour force and accounts for 45% of the gross domestic product (GDP) and 85% of the export revenue. The agriculture sector is highly sensitive to climate change-related hazards due to the fact that precipitation has greater inter-annual variability and rising trends of temperature are reported by Meze (2004) and Seleshi & Zanke (2004). One of the most reliable indicators of the sector's sensitivity to climate-related hazard would be the recent droughts in the years 1965, 1972–73, 1983–84, 1987–88 and 1997, which resulted in low agricultural production, followed by climate change-related hazards. Millions of rural poor farmers, pastoralists, and domestic and wild animals were seriously affected (Degefu 1987; Aredo & Seleshi 2003). Studies conducted on poverty and vulnerability in Africa, such as those by Adger & Vincent (2005) and Stige *et al.* (2006), categorize Ethiopia as one of the countries with the least capacity to respond to the impacts of climate change. The Ethiopian climate is changing, and extreme climate conditions are recorded every year (Belay *et al.* 2005; Ogutu 2007). As a result, floods and droughts are often massive in the country, aggravated by climate change, and this variability is experienced more frequently. Incidents of climate change-related hazards in Ethiopia have manifested in the form of recurrent drought, erosive rain, rainfall variability and flood (NAPA 2007; Hastenrath *et al.* 2010; Viste *et al.* 2013).

Several studies (Osman & Sauerborn 2002; Hagos *et al.* 2009) have examined the impact of rainfall variability on the Ethiopian economy – 20% of production deficit – hence, 25% of the poverty rate is caused by rainfall variability, which costs the economy over one-third of its growth potential. The authors of the above studies assessed the spatiotemporal trends of precipitation and temperature in different parts of the country. Osman & Sauerborn (2002) indicate high rainfall variability with negative trends during the main rainy season (June–September). Similarly, Cheung *et al.* (2008), in their study of the spatial distribution of the seasonal and annual distribution of rainfall in Ethiopia, report no significant change in annual rainfall for the 13th examined watershed, but a significant decline in seasonal rainfall (June–September, called *kiremt*) was recorded in the southwestern and central parts of Ethiopia. Verdin *et al.* (2005) also report a decreasing rainfall trend (annual and seasonal) over eastern, southern and southwestern Ethiopia. The National Meteorology Service Agency (NMSA 2001) has also reported a significant reduction in annual rainfall in the northern and southwestern parts of the country for the last five decades, while there has been an increasing trend in annual rainfall in the central part of Ethiopia.

Tana is one of the most sensitive basins to changes in temperature, rainfall and water resources variabilities in the country (Kim & Kaluarachchi 2009). However, the effects of climate change on water availability and agriculture in the basin have not been dealt with adequately, but are necessary to further understanding the future impact of climate change on the basin as a result of the changing climate. Assessing trends in precipitation and temperature characteristics based on past records is essential to mitigate climate change-related hazards and vulnerability, by implementing climate-related policies, and will help predict future climate scenarios. In view of the above, this study has been carried out to explore the variability of climate parameters (rainfall and temperature) on both annual and seasonal time scales.

METHODOLOGY

Study area

The Amhara National Regional State is found in the northwestern and northcentral parts of Ethiopia and lies in the 8° and 13° 45′ N and 36° and 40° 30′ E coordinates. It has a total area of 170,000 km^2, which is divided into 12 administrative zones and 105 *woredas* (districts) with different physical landscape characteristics; that is, rugged mountains, valleys and gorges with elevation ranging from 700 m in the eastern part to over 4,600 m in the northwest (CSA 2008).

Lake Tana basin is the largest sub-basin in the Amhara region, with an area of 15,096 km^2, including the lake area (Figure 1). The mean annual rainfall in the catchment area is about 1,280 mm. The annual actual evapotranspiration is estimated to be 1,036 mm (Allam *et al.* 2016).

The annual climate may be divided into the rainy and the dry season. The rainy season is divided into a minor rainy season from March to May (*belg*) and a major rainy season from June through September (*kiremt*). The dry season occurs between October and February (*bega*). The basin has a diverse nature with altitudes ranging from 1,327 to 4,009 m above sea level. The basin is of national importance due to its high potential for irrigation, hydroelectric power development, high-value crops and livestock production, and ecotourism. Lake Tana, the main source of the Blue Nile River, is the largest lake in Ethiopia and the third largest in the Nile Basin. It is approximately 84 km long and 66 km wide and is located in the country's northwestern highlands. The lake is natural freshwater, covering an area of 3,000–3,600 km^2 at an elevation of 1,800 m. The main tributaries of Lake Tana are the

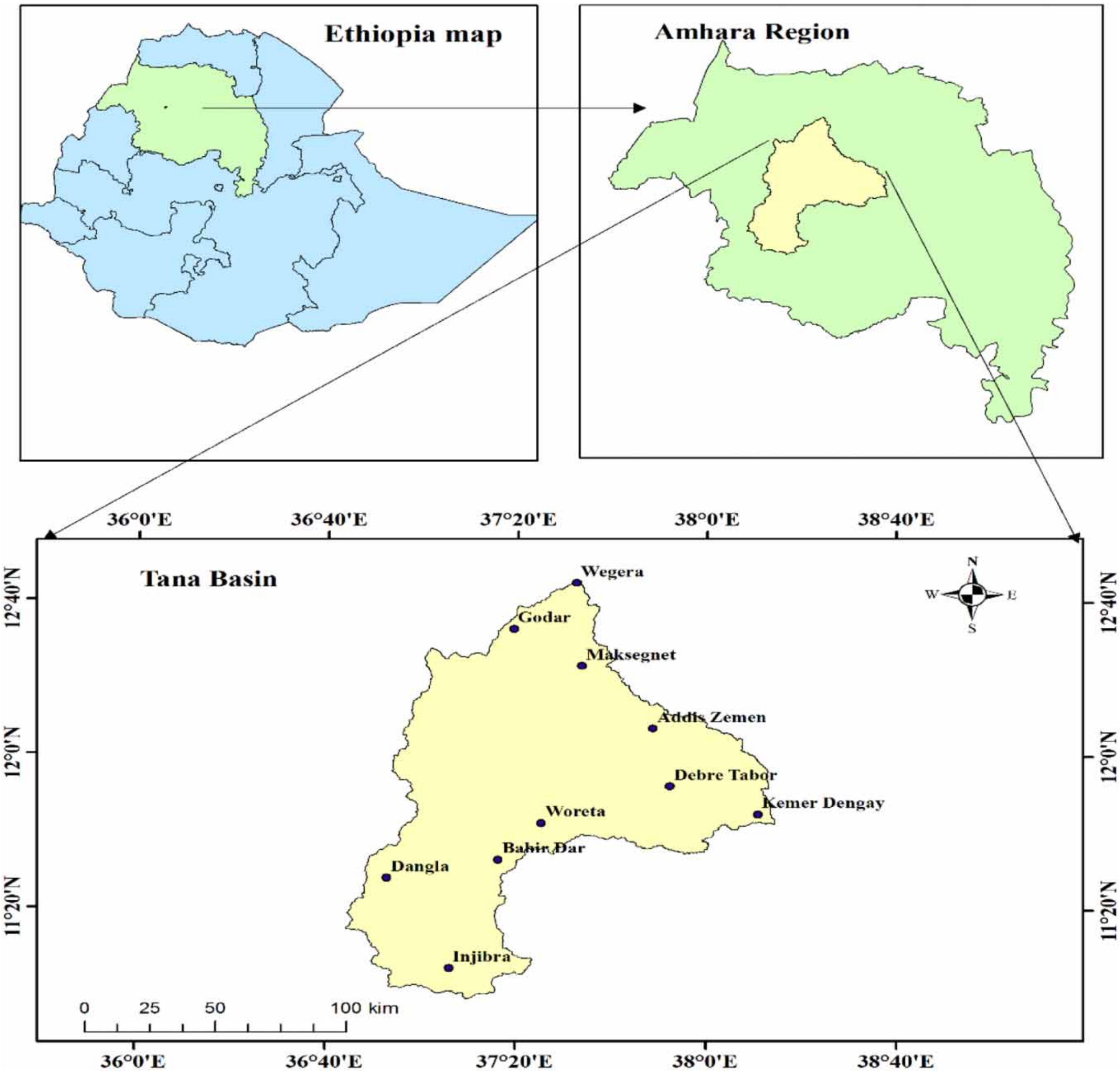

Figure 1 | Spatial distribution of the stations within the Tana basin.

Gilgel Abay, Gumera, Ribb and Megech rivers. The present study shows that these four rivers contribute to more than 45% inflow in the annual lake water budget. The only surface outflow is the Blue Nile (Abba) River with an annual flow volume of 4 billion cubic meters measured at the Bahir Dar gauge station.

Land use in the study area is classified based on the Abay River master plan study conducted by BCEOM (1998). About 51.37% of the watershed area is covered by agriculture, 21.94% by agropastoral livelihood, 0.15% by silviculture, 0.03% by sylvopastoral livelihood and 0.11% by urban use.

Data source and methods of analysis

Daily meteorological data (rainfall and temperature) from ten stations were obtained from the National Meteorological Service Agency (NMSA) of Ethiopia for the period 1980 to 2015. The stations were selected based on the length of record period and the relative completeness of the data. Based on the World Meteorological Organization, a minimum of 30 years' data are required for searching for evidence of climatic change in hydroclimatic time series. Hence, 36 years of past meteorological data for the ten selected stations within the basin were used, as shown in Table 1.

The missing values in the daily and monthly station records were estimated by interpolating values from the completed nearby weather stations if the missing values were less than 5% of the total weather stations' records for the whole study period.

Table 1 | Details of selected stations

S. No.	Name of station	Lat. (N)	Long. (E)	Alt. (m a.s.l)	Duration
1	Addis Zemen	12°12′	37°81′	1,815	1980–2015
2	Bahir Dar	11°71′	37°50′	1,800	1980–2015
3	Gondar	12°63′	37°45′	2,133	1980–2015
4	Maksegnet	12°39′	37°56′	1,794	1980–2015
5	Woreta	11°55′	37°42′	1,828	1980–2015
6	DebreTabor	11°86′	38°02′	2,706	1980–2015
7	Dangla	11°.25′	36°74′	2,122	1980–2015
8	Kemer Dengay	10°.92′	37°25′	2,560	1980–2015
9	Injibra	11° 70′	38°43′	2,672	1980–2015
10	Wegera	12° 75′	37°63′	2,796	1980–2015

Serial correlation

The existence of negative or positive autocorrelation affects the trend in a series (Hamed & Rao 1998; Yue *et al.* 2002). The serial correlation test was performed to check the independence and randomness in the time series. If lag-1 serial correlation coefficient is not statistically significant then the MK test is used (Modarres & da Silva 2007; Karpouzos *et al.* 2010). The autocorrelation coefficient r_k of a time series for lag-k is calculated as follows:

$$r_k = \frac{\sum_{k=1}^{n-k}(x_t - \bar{x}_t)(x_{t-k} - x_{t+k})}{\sqrt{\sum_{k=1}^{n-k}(x_t - \bar{x}_t)^2 (x_{t+k} - \bar{x}_{t+k})^2}} \tag{1}$$

where r_k is the lag-k serial correlation coefficient, k is the time lag, n is number of observations in the time series, X_t is observation at time t, and $\bar{x}$ is the mean of series.

H_o: r_1:0 against $H_1 / r_1| > 0$ using the test of serial correlation:

$$(r_k)t_g = \frac{-1 \pm tg(n-k-1)^{1/2}}{n-k} \tag{2}$$

where $(r_k)t_g$ is the normally distributed value of $\mathrm{r_k}$ and $\mathrm{t_g}$ is the normally distributed statistical level of significance. If $|r_k| \geq (r_k)t_g$ the null hypothesis of serial independence is rejected at the significance level α (0.05). The percentage change over a period of time can be calculated by assuming a linear trend from Sen's median slope, the length of the period, and mean of the variables (Yue & Hashino 2003).

Trend analysis

A number of tests are available to detect and estimate trends. Temperature and rainfall data indicate the long-term change pattern. The Mann–Kendall (MK) test is the most used mathematical method for detecting trends in time series. Therefore, the long-term trends of the precipitation and temperature changes were estimated using a statistical test which is less sensitive to outliers. The MK test is not required in normally distributed data and is less sensitive to abrupt breaks due to non-homogeneous time series (Jaagus 2006). The MK test checks increasing, decreasing or no trend on the hydrometeorological data series in each of the selected weather station data.

The MK test statistic is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} (X_j - X_k) \tag{3}$$

where x_k and x_j are the sequential data values of the time series in the years i and j $(j > k)$ and n is the length of the time series. Positive S value indicates an increasing trend and negative value indicates a decreasing trend in the data series. The sign function is given as:

$$Sign\,(X_j - X_k) = \begin{cases} +1, \;\ldots\ldots\ldots if\,(X_j - X_k) > 0 \\ \;\;0, \;\ldots\ldots\ldots if\,(X_j - X_k) = 0 \\ -1, \;\ldots\ldots\ldots if\,(X_j - X_k) < 0 \end{cases} \tag{4}$$

In cases where the sample size $n > 10$, the statistics S is approximately standard normal distribution with the mean zero and variance is denoted by the following:

$$Var\,(S) = \frac{1}{18}\left(n\left((n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k - 1)(2t_k + 5)\right)\right) \tag{5}$$

where n is the number of data, m is the number of tied groups (a tied group is a set of sample data with the same value), and it is the number of data points in the i^{th} group. First, the presence of monotonic increasing/decreasing trend was tested using the MK test. The highest positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var\,(S)}} & if\, S < 0 \\ 0 & if\, S = 0 \\ \dfrac{S+1}{\sqrt{Var\,(s)}} & if\, S > 0 \end{cases} \tag{6}$$

The test statistics Z is used as a measure of significance of trend. If the value of Z is positive, it indicates increasing trends, while negative values of Z show decreasing trends. Z_0 is a null hypothesis which signifies the trend is not significant, and is recognized if Z statistics are insignificant statistically $(-Z_{\alpha/2} < Z < Z_{\alpha/2})$, where $Z_{\alpha/2}$ is the standardized normal deviate (Modarres & da Silva 2007). Hence, for the purpose of this study, 1, 5 and 10% significance levels were considered.

Sen's slope estimator and percentage change

If a linear trend is present in the time series, the true slope can be estimated using a simple non-parametric test known as Sen's slope method. Sen (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$T_i = \frac{x_j - x_k}{j - k}\; For\, i = 1, 2, 3, \ldots N \tag{7}$$

where X_j and X_k represent the data value at the time-steps 'j' and 'k' with 'j' correspondingly greater than 'k'. The median of these 'N' values of T_i is termed as Sen's estimator of slopes and is calculated by the following formulae:

$$\beta = \frac{1}{2}\left(\frac{T_N}{2} + \frac{T_{N+2}}{2}\right) \ldots if\, N\, is\, even \tag{8}$$

$$\beta = \left(\frac{T_{N+1}}{2}\right) \ldots if\, N\, is\, odd \tag{9}$$

The β sign reflects data trend reflection, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of β at specific probability:

$$\%\, Change = \left(\frac{\beta * length\, of\, period}{mean}\right) \tag{10}$$

where β is Sen's slope.

In order to study monthly variability of rainfall in the study area of each weather station, a modified version of Oliver's (1980) Precipitation Concentration Index (PCI) was used. The guidelines for interpretation of PCI are presented in Table 2. Magnitude and variability of annual and seasonal

Table 2 | Interpretation of PCI results

PCI value	Interpretation
<10	Uniform distribution of precipitation (Low concentration)
11–16	Moderate distribution of precipitation (Moderate concentration)
16–20	Irregular distribution of precipitation
>20	Strong irregularity of precipitation distribution

precipitation total were investigated as PCI. The analysis was based on daily, monthly and annual precipitation data of all weather stations in the study area. According to the National Meteorological Agency of Ethiopia (NMSA 2001), three seasons, namely, *belg* season (March to May), *bega* season (October to February) and *kiremt* season (June to September) exist in Ethiopia. Therefore, PCI were determined based on annual and seasonal time scales for all stations.

This index is described as:

$$PCI_{annual} = \left[\frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2}\right] * 100 \quad (11)$$

where Pi is the rainfall amount of the ith month, and Σ is the summation over the 12 months.

The calculated PCI value is multiplied by 33.3 (for *kiremt* season), 41.69 (for *bega*) and 25 (for *belg*) seasons based on the seasonal classification of Ethiopia described above.

Interpolation method

In this study, the spatial variation and trends in annual and seasonal rainfall and temperature were determined using the inverse distance weighted (IDW) interpolation technique using ArcGIS 10.4.

The basic theory behind IDW is based on the assumption that the interpolated surface has the most influence of nearby points and least influence of distant points (Ayalew *et al.* 2012; Duhan & Pandey 2013). The IDW is flexible, and available with almost any GIS software and common spatial interpolation method, particularly in relatively flat zones (Franke & Nielson 1991; Duhan & Pandey 2013). All stations were used simultaneously for the study because the Tana basin is mostly plain except for a very small part near to a remote boundary which is mountainous/hilly. Hence, the IDW technique has been used for spatial interpolation of temperature and rainfall data over the study area.

The following is the general formula of IDW:

$$R_P = \sum_{i=1}^{n} w_i R_i \quad (12)$$

$$W_I = \frac{di^{-a}}{\sum_{i=1}^{n} di^{-\alpha}} \quad (13)$$

where R_p is the unknown rainfall data (mm); R_i is the rainfall data from known rainfall station (mm); n is the number of rainfall station; W_i is the weighting of each rainfall station; D_i is the distance from each rainfall station to the unknown site; and a means the power, and is also a control parameter.

RESULTS AND DISCUSSION

Annual and seasonal rainfall patterns

The study area has three distinct seasons: the rainy season (*kiremt*) from June to September (in which much of the rainfall is concentrated during the season); the dry season (*bega*) from October to February; and the small rainfall season (*belg*) from March to May. According to the rainfall data analysis, the long-term mean annual rainfall in 36 years in the region is 1,284 mm. However, as shown in Table 3, the mean annual rainfall ranges from 1,097 to 1,500 mm. The lowest rainfall (1,097) was observed in the northern part of the basin, Maksegnet, and the highest rainfall (1,500) was recorded in the southwest of Injibara, with a standard deviation of 215.55 and 156.446 mm and a coefficient of variation of 0.24 and 0.10, respectively (Table 3). This indicates that the rainfall coefficient of variability is high in the area with low annual rainfall. This is supported by Bewket & Conway (2007), whose study confirms the relationship between the area with low annual rainfall and high variability of rainfall. The mean monthly rainfall

Table 3 | Annual and seasonal mean rainfall (mm), coefficient of variation and PCI 1980–2015

	Annual			***Kiremt***			***Bega***			***Belg***		
Station	**Mean**	**CV**	**PCI**	**Mean**	**CV**	**PCI**	**Mean**	**CV**	**PCI**	**Mean**	**CV**	**PCI**
Addis Zemen	1,187.48	0.28	20[a]	1,028.74	0.22	9.8[b]	37.18	0.50	25.00[a]	113.14	0.52	8.60[b]
Bahir Dar	1,291.68	0.19	20[a]	945.71	0.19	9[b]	92.86	0.31	26.40[a]	276.88	0.25	12.6[c]
Gondar	1,165.04	0.18	22[d]	939.20	0.21	13[c]	69.44	0.56	19.00[a]	156.40	0.33	7.00[b]
Maksegnet	1,097.97	0.24	21[a]	952.03	0.17	8.4[b]	35.85	0.38	21.00[d]	110.09	0.59	10.00[b]
Woreta	1,262.80	0.17	23[d]	1,123.77	0.17	9[b]	47.96	0.47	19.60[a]	82.44	0.33	12.00[c]
Debre Tabor	1,401.60	0.18	17.2[a]	1,124.99	0.17	8.3[b]	46.60	0.34	14.00[b]	230.01	0.47	9.00[b]
Dangla	1,485.47	0.12	18[a]	1,113.23	0.13	8[b]	142.89	0.26	16.70[a]	229.35	0.33	13.00[c]
Kemer Dengay	1,223.94	0.14	19[a]	1,172.25	0.11	11.7[c]	140.62	0.42	18.60[a]	187.39	0.41	8.00[b]
Injibra	1,500.25	0.10	18[a]	1,017.34	0.14	9.5[b]	65.05	0.28	17.80[a]	141.56	0.22	11.00[c]
Wegera	1,227.14	0.12	19[a]	989.19	0.12	9[b]	114.17	0.26	19.20[a]	123.79	0.40	14.30[c]

[a] Irregular distribution.
[b] Uniform distribution.
[c] Moderate distribution.
[d] Strong irregular distribution.

amount at the basin from the ten stations was averaged by aggregating the last three and a half decades of rainfall data. Based on this information, the basin receives the highest mean maximum rainfall in July and the minimum rainfall in December and January (Figure 2).

The PCI is computed and presented in Table 3 for the seasonal and annual distribution of rainfall at the station. Accordingly, a uniform concentration of precipitation has been observed in the *kiremt* and *belg* seasons' rainfall during the last 36 years in 80% and 50% of the stations, respectively (Table 3). On the other hand, the long hydrological time series of the *bega* season shows that rainfall distribution has been more erratic as the PCI value is irregular. Also shown in Table 3, the PCI of annual rainfall is categorized as high to very high for year-to-year distribution (17 in Debre Tabor and 23 in Woreta). The *kiremt* rainfall contribution to the mean annual rainfall shows that July receives peak rainfall (378.8 mm), which contributes 36.4%, followed by 28.33% in August (294.88 mm), 21.26% in June (221.24 mm) and 14% in September (145.69 mm).

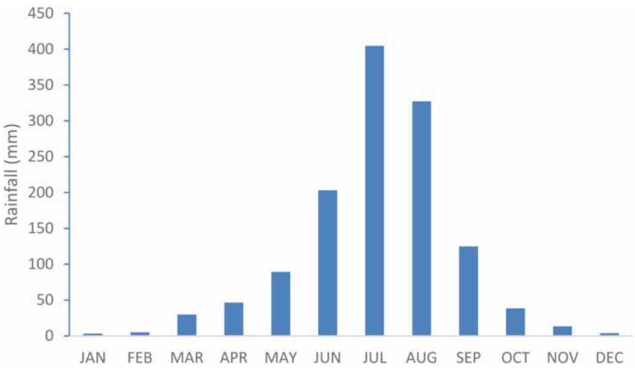

Figure 2 | Mean monthly rainfall distribution in Tana basin region (1980–2015).

Despite the apparent uneven distribution of all annual and most seasonal rainfall in the study area, the *bega* (October–February) and *belg* (March–May) seasons are much more variable than the *kiremt* season (Table 4). Similar

Table 4 | Average contributions of the three seasons to the annual rainfall (%)

Station	***Kiremt* rainfall**	***Bega* rainfall**	***Belg* rainfall**
Addis Zemen	87.24	3.15	9.59
Bahir Dar	72.19	7.09	21.14
Gondar	80.62	5.96	13.42
Maksgnet	86.71	3.27	10.03
Woreta	89.88	3.84	6.59
Debre Tabor	80.26	3.32	16.41
Dangla	74.94	9.62	15.44
Kemer Dengay	78.14	9.37	12.49
Injibra	83.12	5.31	11.57
Wegera	80.61	9.30	10.09

studies by Bewket & Conway (2007) and Ayalew *et al.* (2012), on a different part of the Amhara region that is prone to drought, show that rainfall variability is high in the *bega* and *belg* seasons in most stations. A further rainfall and precipitation variability study by Mekasha *et al.* (2014) shows that in Ethiopia a general tendency of increase in warm temperature and extreme variability as well as inconsistency in precipitation is observed.

The percentage contribution of seasonal rainfall to the annual average shows a different value. The *kiremt* season receives 1,020 mm of the mean annual rainfall, and all stations receive more than 900 mm of rainfall per year during the *kiremt* season. The maximum mean *kiremt* rainfall was recorded in Injibara (1,172 mm), followed by that in Debre Tabor, which was 1,124 mm.

The maximum and the minimum percentage for *kiremt* rainfall contribution to the mean annual total were observed in Woreta (89%) and Bahir Dar (72%) (Table 4). On the other hand, *belg* rainfall contribution to the annual total is considerable in the Bahir Dar station (21.14%) and small in Woreta (6.5%).

Spatial variability of rainfall and temperature

To analyse the observed spatial variability of annual and seasonal rainfall and temperature trend, the IDW method, the simplest method for interpolation, has been used to illustrate the spatial variability for annual and seasonal (*kiremt*, *bega*, and *belg)* rainfall and temperature distribution over the study period of 1980–2015, as shown in Figures 3 and 4.

As described above, the annual mean rainfall of the basin is 1,284 with a standard deviation of 157. Hence, the annual spatial variability of rainfall within the basin is 12.2%. This shows that rainfall spatial variability over the basin is considered less. Likewise, high rainfall variability is observed on the average of the *bega* and *belg* seasons (45% and 38%, respectively), and less variability on the *kiremt* season (16%) has been recorded over the basin.

Results of rainfall distribution in Figure 3 show a general increase of the annual mean rainfall from the north, Gondar, to the southwest Dangla station. It also shows that the annual mean rainfall is high in the east of Debre Tabor. The range of variability from <1,100 mm in the northern part (Gondar, Addis Zemen) to >1,400 mm in the southwestern (Dangla, Injibara) and eastern (Debre Tabor) parts is highly affected by orographic barriers, as those stations (Dangla, Injibara and Debre Tabor) located near the mountainous area in the region receive higher amounts of rainfall as compared with the stations at lower elevations. A similar study by Haile *et al.* (2009) on rainfall variability in the Blue Nile region concludes that the probability of rainfall occurrence is high at stations in mountainous areas compared with stations located at lower elevations.

In terms of rainfall magnitude, the highest rainfall distribution in both the *kiremt* and the *bega* season is observed in the eastern and southwestern parts of the basin. On the other hand, lower rainfall is observed in the central and northwestern part as well as in some other parts in the north. In both seasons, the northern, southwestern and eastern parts of the basin receive a higher amount of rainfall than other parts. However, rainfall decreases in the southwest to the northern parts of the basin during the *belg* season.

The spatial distribution of annual temperature between maximum, minimum and mean temperature for the past 36 years is presented in Figure 4. The greater relative annual maximum temperature (28.2°C) was recorded in the central part of Bahir Dar, which was higher by 5.57°C than the relatively low annual maximum temperature in the eastern section of Debre Tabor (22.5°C). The coefficient of variation between the annual maximum and minimum temperature revealed that the minimum temperature coefficient of variation doubled in Bahir Dar, Gondar, Debre Tabor and Wegera, compared with the maximum temperature in the same area in 1980–2015.

The long-term seasonal temperature in the basin also showed that the highest maximum and the mean temperatures are observed during the *belg* season (32°C and 23°C, respectively). On the other hand, the highest minimum temperature was observed during the *kiremt* season (15.2°C). The mean minimum temperature varies from 6.5°C to 15.2°C over the basin. The lower minimum temperature is observed over the eastern part of Debre Tabor at an altitude of 2,700 m and over the lowland area around Bahir Dar near Lake Tana, while the northern part of Gondar experiences the minimum temperature (15.2°C). Generally, the temperature gradient around Lake Tana (Bahir Dar station) and the northern part of the station

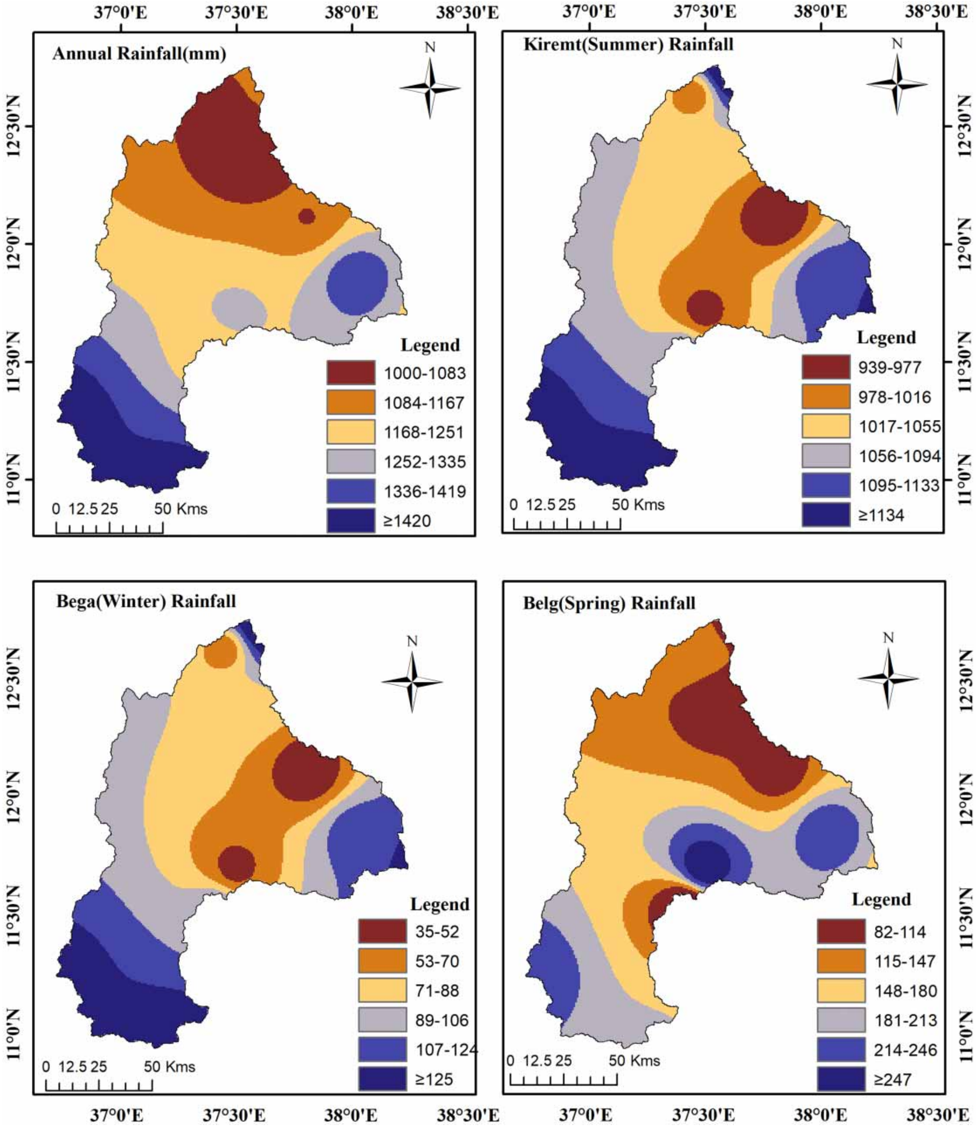

Figure 3 | Spatial distribution of annual and seasonal mean rainfall (mm) of Tana basin region (1980–2015).

recorded the highest magnitude. The southwestern part (Injibara, Dangla) and eastern part (Debre Tabor, Kimerdengay) also experienced the lowest magnitude of the annual maximum, minimum and mean temperature in 1980–2015.

Trend analysis

Rainfall trend analysis

The result of the MK test was applied to analyse the mean annual and seasonal rainfall and temperature trend for the period of 1980–2015 for all the ten stations in the Tana basin region in Ethiopia. Similarly, Sen's slope and percentage change were used to examine the magnitude and change of the variables. The results of the MK trend, Sen's slope and percentage change of rainfall are given in Table 5.

The annual and seasonal trend and the change rate vary widely from place to place. The trend indicates the mean annual and seasonal rainfall increase (positive trend), reduction (negative trend), and no trend for all stations in the basin.

Accordingly, annual rainfall shows a decreasing trend in 70% of the stations. Out of these stations, only four have a

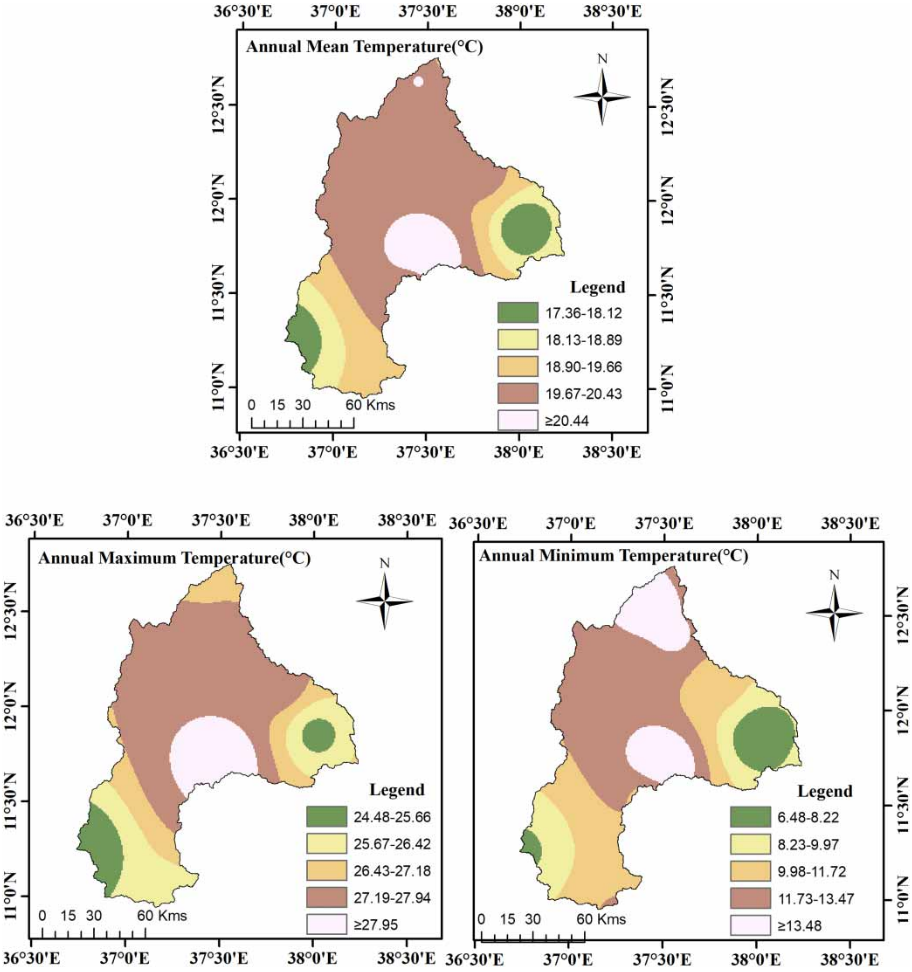

Figure 4 | Spatial distribution of annual maximum, minimum and mean temperature of Tana basin region (1980–2015).

Table 5 | Trend analysis of annual and seasonal *(Kiremt, Bega and Belg)* rainfall of Tana basin region (1980–2015)

	Annual			**Kiremt**			**Bega**			**Belg**		
Station	Z_{mk}	β	% Δ	Z_{mk}	β	% Δ	Z_{mk}	**Slope**	% Δ	Z_{mk}	β	% Δ
Addis ZZemen	1.34*	1.81	5.48	2.30*	2.51	8.74	0.01	0.40	37.7	−0.27	−1.54	−48.93
Bahir Dar	−0.15	−6.02	−16.77	−1.17	−8.84	−33.65	−0.05	−0.48	−18.5	0.09	1.80	23.49
Gondar	1.10	0.59	1.82	−0.07*	−0.95	−3.63	−0.25	−0.70	−36.2	−2.45*	−2.63	−60.53
Maksegnet	−0.32*	−8.62	−28.26	−0.22	−4.34	−16.41	−0.89*	−0.67	−67.4	−0.30*	−2.76	−90.35
Woreta	0.29	1.75	4.98	0.13	0.86	2.74	−1.25	−0.54	−40.9	−0.34	−2.51	−45.56
Debre Tabor	−0.27*	−6.07	−15.59	−0.19	−4.08	−13.07	−2.13*	−0.90	−69.5	1.2**	3.89	61.01
Dangla	−0.02	−6.64	−16.09	0.11	2.56	8.28	−0.94*	−3.31	−83.1	−2.08	−1.28	−20.15
Kemer Dengay	−0.17	−4.24	12.47	0.21*	3.94	12.09	−0.76	−2.31	−58.1	−0.03	−0.43	−8.22
Injibra	−2.23*	−5.92	−14.20	−2.03*	−4.50	−15.94	0.35	1.70	89.0	0.05	0.39	10.09
Wegera	−0.5**	−9.74	−28.57	−0.32	−5.49	−19.9	0.59	1.92	59.9	−1.3**	−2.12	−61.50

*,**, and % Δ denote significant level at 5%, 10% and percentage change, respectively.

significant level (5% and 10%). From these, a decreasing trend has been observed to be significant at Debre Tabor (−6.07 mm/year), Injibara (−5.92 mm/year), Maksegnet (−8.62 mm/year) and Wegera (−9.74 mm/year) with a percentage change of −15.59, −14.20, −28.26 and −28.57, respectively. Two stations, namely, Gondar and Woreta, show a non-significant increasing trend at 0.6 and 1.75 mm/year, with a percentage change of 1.82% and 4.98%, respectively. However, a significant increasing trend in the mean annual rainfall was observed in Addis Zemen (1.81 mm/year) with a percentage change of 5.48%, which is statistically significant at 0.05 significance level. A similar study by Bewket & Conway (2007) in the drought-prone area of the Amhara region, Ethiopia, indicates that a decreasing trend was observed in a majority of the selected stations for annual rainfall. Another study in another area also shows a decreasing trend in the annual and seasonal rainfall in a majority of the stations (Modarres & Sarhadi 2009; Tabari & Talaee 2011; Chakraborty *et al.* 2013). Much of the decreasing trend in rainfall is due to lower rainfall during the severe drought years in the country in 1983–84 and 1987–88, which were observed in the eastern part of the Debre Tabor and northern Wegera stations.

A significant increasing trend is observed in Kimerdengay (3.94 mm/year) and Addis Zemen (2.5 mm/year) with percentage changes of 12.09 and 8.74, respectively, during the *kiremt* season (Table 5). On the other hand, stations in Bahir Dar, Wegera, Maksegnet and Debre Tabor show a statistically insignificant decreasing rainfall trend during this season. Statistically significant decreasing *kiremt* rainfalls in Gondar (−0.94 mm/year) and Injibara (−4.506 mm/year) were noted at <0.05 significance level with a percentage change of −3.63% and −15.94%, respectively.

Very similar rainfall patterns and trends were observed between annual and *kiremt* rainfall, which indicates the *kiremt* rainfall contribution to annual rainfall is a major one in all stations during the last 36 years. The result is in line with other study results (Bewket & Conway 2007; Pingale *et al.* 2014), which indicate the major contribution of *kiremt* rainfall to annual rainfall. The *belg* and *bega* seasons showed a decreasing rainfall trend in a majority of the stations. Of these stations, only three from the *bega* season and three from the *belg* season were found, and one increasing *belg* trend was also significant at 5% and 10% significant levels.

Maximum temperature

Using the same procedure applied for rainfall, the temperature trend for the long time series (1980–2015) was analysed over the Tana basin region. April is the hottest month (28.8°C), followed by May (27.3°C) and July is the coolest month (13°C), followed by August (14.6°C). A significant increase of the annual maximum temperature is observed. Annual maximum temperature indicates a significant increase in Gondar, Debre Tabor, Bahir Dar and Injibara (through the MK test) with a minimum of 0.03°C/year at Debre Tabor and a maximum of 0.05°C/year at Bahir Dar with a percentage change of 4.36% and 6.2%, respectively, at 5% significance level. On the other hand, a significant decreasing trend is observed in Addis Zemen (−0.0085°C/year) with a percentage change of −1.04% at 10% significance level, and the remaining station shows no significant trend of the maximum annual temperature even at a 10% significance level. Details of Sen's slope magnitude and percentage change for maximum, minimum and mean temperature are found in Table 6.

To see the aggregate impact of climate change on the Tana basin from the given data, an increasing trend of the annual maximum temperature was observed, which is 1.08°C/36 years with an average rate of 0.27°C/decade. This result is supported by a similar study by UNDP on the climate change profile of Ethiopia (Sweeney & Lizcano 2008), which revealed that the mean annual temperature increased by 1.3°C during the last four and half decades with an average rate of 0.28°C/decade, namely, 2.8 by the end of the century. This indicates that the temperature in the region as well as in the country is increasing as a result of global climate change. A significantly increasing trend in the maximum temperature has been reported by other researchers (Parry 2007; Mekasha *et al.* 2014).

Minimum temperature

The minimum temperature showed the significantly increasing trend in the annual time scale for a majority of the stations in the Tana basin region. The magnitude and

Table 6 | Trend analysis of annual temperature and percentage change of Tana basin region (1980–2015)

	T_{max}			T_{min}			T_{mean}		
Stations	Z_{mk}	β slope	% Δ	Z_{mk}	β slope	% Δ	Z_{mk}	β	% Δ
Addis Zemen	−0.55**	−0.008	−1.04	0.06	0.04	12.89	0.07	0.02	3.67
Bahir Dar	2.87*	0.05	6.23	1.08*	0.04	10.96	0.05*	0.031	5.27
Gondar	0.62*	0.009	7.19	2.03**	0.03	7.46	2.05*	0.03	5.37
Maksegnet	0.509	0.013	1.69	0.04	0.06	17.43	0.06	0.04	7.20
Woreta	0.768	0.037	4.78	1.06	0.03	3.15	0.07	0.03	5.47
Debre Tabor	1.421*	0.031	4.36	2.04*	0.03	11.19	3.05	0.05	10.36
Dangla	2.499	0.036	5.20	0.04	0.02	7.91	0.05	0.01	2.06
Kemer Dengay	0.549	0.006	0.82	3.02	0.07	21.53	1.04*	0.009	1.71
Injibra	0.48*	0.011	5.45	0.02	0.03	9.55	0.04	0.04	7.48
Wegera	0.35	0.001	0.27	−0.02**	−0.008	−2.55	−0.04**	−0.008	−1.54

*,** and % Δ denote significance level at 5%, 10% and percentage change, respectively.
T_{max}, T_{min} and T_{mean} indicates maximum, minimum and mean temperature, respectively.

percentage changes of the trend obtained from the MK test in the annual time scale for all stations are shown in Table 6. The maximum value of the annual minimum temperature was observed to significantly increase in Bahir Dar (0.041°C/year) with a percentage change of 10.9%, and the minimum value was also observed in Debre Tabor and Gondar (0.024°C/year) with similar percentage changes of 11.21% and 7.4%, respectively, which are also statistically significant at 5% and 10% significance levels. On the contrary, a significantly decreasing trend of the minimum temperature was observed in Wegera (−0.008°C/year) with a percentage change of −2.55% at 90% significance level. The remaining station had a positive nonsignificant trend in the minimum temperature during the last three and half decades in the Tana basin region. From the general analysis, it can be observed that the minimum temperature increases by 0.29°C/decade, and it clearly indicates that the magnitude of the minimum temperature trend over the Tana basin was comparatively higher than the magnitude of the maximum temperature trend.

Mean temperature

The significantly increasing trend was also found in the mean temperature over the Tana basin within 36 years, with the highest significant increase observed in Bahir Dar and Gondar (0.031°C/year) with similar percentage changes of 5.25% and 5.34%, respectively. On the other hand, the lowest significant increase was observed in the eastern part of Kimerdengay (0.009°C/year) with a percentage change of 1.71% at 5% significance level. A nonsignificant decrease of the mean temperature was observed in Wegera (−1.66%), and the rest of the stations showed a nonsignificant positive mean temperature.

The most notable observation based on the results is that almost all the regions have rising temperatures, which are mostly significant with a higher percentage of change values. The higher rate of rise in temperature will lead to more evaporation in the area. The rise in the magnitude of the mean temperature is also confirmed in a study by Omondi *et al.* (2014).

CONCLUSIONS

A set of ten stations in the Tana basin were used for the trend analysis of rainfall and temperature. The trend of climatic variables with their fluctuation and variability of rainfall and temperature in the Tana basin for all stations were analysed. The record for the historical climatic trend during annual and different seasons was used for the study. The study area is vulnerable and susceptible to climatic fluctuation and variability; the climatic trend is more likely to result in an increase in the number and severity of natural disasters. The serious impact of variability in Ethiopia is high, particularly in communities that rely on natural resources – which are more susceptible and sensitive to climatic shock – and on rainfed crop production.

The yearly and seasonal trends for rainfall and temperature variables (i.e., seasonal rainfall, annual rainfall, minimum temperature, maximum temperature and mean temperature) were analysed. The findings of the study indicate that there are significant seasonal and annual rainfall fluctuations and trends in the long time series with a different rainfall variability and PCI. The MK test was used to detect rainfall and temperature trends and the magnitude of Sen's slope. A consistent decreasing trend in annual and seasonal rainfall amounts was detected in most stations over the basin during the last three and half decades. These decreasing trends are particularly significant in the southwestern and northern parts of the watershed, which indicates that this decreasing trend is observed in almost all parts of the watershed. The range of rainfall in the watershed varies from −9.7 mm/year in the northern part (Wegera) to 5.96 mm/year in the southwest (Injibara). Similar to annual rainfall, a majority of the stations in the three seasons demonstrated a more decreasing rainfall trend. In view of that, a significantly decreasing trend was more in the *bega* season than the other seasons.

The temperature trend indicates that the maximum, minimum and mean temperatures over the Tana basin have increased in the past 36 years in almost all of the stations. Both a significant and a nonsignificant increase in temperature were found, and a significant increase in the maximum temperature was observed, with its highest at 0.009°C/year and its lowest at 0.005°C/year over the central and eastern parts of the watershed, respectively. The magnitude of Sen's slope estimator reveals that the annual maximum temperature has been found to be lower than the annual minimum temperature. Thus, annual and seasonal decrease in rainfall and increase in temperature are the indicators of global warming with a possibility of more water loss through evaporation and drought. These will have an adverse effect on developing countries such as Ethiopia, which are more than 85% dependent on rainfed agriculture.

The assessment of the recent trend of rainfall and temperature in Ethiopia as a watershed or on a broad regional basis is crucial since climate change and its effects have not yet been fully investigated in the country. This paper develops a full picture of the recent rainfall and temperature trends over the Tana basin in both seasonal and inter-annual distribution, which is important for policy making, planning and management of natural resources and, hence, for future adaptation. It can also serve as a reference for further agriculture and climate research in the country.

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