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Research Article

Trend Analysis of Hydrometeorological Data of Gilgel Gibe Catchment, Ethiopia

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Trend analysis of hydrometeorological data is vital for proper water resources planning and management. This paper examines the trends of the hydrometeorological data in Gilgel Gibe catchment and whether the trends are significant. Daily rainfall, temperature, and streamflow data of the stations in/around (nearby) the catchment (7 stations for rainfall, 4 stations for temperatures, and 6 stations for streamflow) for a period longer than 25 years were collected and then analyzed to detect the variability and the changes in trend. Prior to conducting trend tests, the missed data were filled, and their inconsistencies were also adjusted. The nonparametric Mann-Kendall test along with Sen's slope technique was employed to detect monotonic trends in the data series. The results showed that, on average, the rainfall exhibits an insignificant increasing tendency. It was also observed that there is, in general, an increasing trend in temperature (both maximum and minimum) in the study area. The analysis of the stream flows indicated that only one station (Bulbul Nr. Serbo) showed a positive slope at a 5% significance level. Two stations (Aweitu Nr. Babu and Gibe Nr. Seka) showed a slightly increasing trend, whereas the remaining 3 stations (Gibe Nr. Assendabo, Aweitu at Jimma, and Kitto Nr. Jimma) indicated an insignificant decreasing trend. The streamflow of the catchment generally shows a tiny decreasing tendency (0.007% per year) at its outlet. However, the results in general specified statistically insignificant trend changes of the hydrometrological data of the study catchment.

1. Introduction

For a series of hydrometeorological observations over time (temperature, rainfall, or stream flow), it is vital to know whether the values are going up or down or staying the same. For example, the rainfall behavior, especially its variability and trends, is important for proper water resources planning and management [1]. The streamflow time series always exhibit seasonality owing to the seasonality of rainfall and other weather variables [2, 3]. It also reflects an integrated response of the entire catchment, while rainfall serves as one of the major inputs into the runoff processes. Trend analysis of the hydrometeorological data provides evidence that shows such variability and trends. It also shows the magnitude of the apparent components such as trends, jumps, and seasonality in hydroclimatic data. It has thus been extensively used to assess the potential impacts of climatic change and variability on hydrologic time series in various parts of the world for the past decades. A lot of research has been conducted to detect statistically significant trends in hydrometeorological time series in several tropical and temperate regions. In this case, the widely used nonparametric Mann-Kendall trend test was employed to detect significant trends of those hydrometeorological time series. Few of them are the rainfall and the temperature trends in the upper and middle parts of the Ganga basin in northern India [4], the seasonal rainfall trend in peninsula Malaysia [5], the trend in rainfall data for Ipoh, Perak conducted by Hashim et al. in 2010 [6], the trend in extreme precipitation indices in order to estimate the impacts of global climate change on the water source area of the middle route of South-North Water Transfer Project [7], the spatiotemporal trend of precipitation in Iran [1], the trends of the Canadian stream flows [8], the trends of stream flows in western

Britain [9], the trends and variability of rainfall series at Seonath River basin in Chhattisgarh (India) [10], the trends in the mean surface air temperatures over the southern parts of Ontario and Quebec in Canada [11], the trends of premonsoon precipitation in Nepal [12], the trends in the spatiotemporal variation of the air temperature, precipitation, and runoff in Xinjiang in China [13], the trend of premonsoon rainfall data for western India [14], the trend of the Assam (India) precipitation variation [15], the relationship between hydroclimatic trends and their impacts on water resources in Italian and Swiss Alps [16], the trend analysis of streamflow in Turkey [17], the long-term meteorological trends in the Indus Basin of Pakistan [18], the precipitation trend in the Upper Tennessee Valley in the vicinity of Chattanooga [19], the trends in hydroclimatic variables in the Wei River Basin in China [20], the rainfall trend in the Onkaparinga catchment in South Australia [21], the precipitation trend of in Slovakia [22], the spatial and temporal trends of precipitation and temperature in eastern India [23], the temporal trend in the mean of flood peaks in Quebec in Canada [24], the rainfall trends and their fluctuations over time in northern Bangladesh [25], the trends in Japanese precipitation [26], the long-term trend of the hydrological time series (temperature, precipitation, and streamflow) in the Tarim River basin, west China [27], the trends of the hydroclimatic variables in the Têt River in the South of France [28], the analysis of trend, independence, stationarity, and homogeneity of the maximum rainfall data of standard durations in Turkey [29, 30], the trend analysis of precipitation, temperature, streamflow, and groundwater levels in the Kizilirmak in Turkey [31], the study of impacts of climatic variables on water-level variations in two shallow Eastern Mediterranean lakes [32], the analysis of water-level change of lakes and sinkholes in Central Turkey under anthropogenic effects [33], trend analysis of lakes and sinkholes in the Konya Closed Basin in Turkey [34], the trend analysis of precipitation data of the Sindh River basin (SRB) in India [35], the trends of rainfall data in the Ken River basin (KRB) in Madhya Pradesh, India [36], the examination of the trends of hydrometeorological data in the Rietspruit subbasin in South Africa [37], and the identification of the trends of meteorological data for the state of Jharkhand [38]. These are a few of the recent studies.

This paper thus examines and evaluates the trends of the hydrometeorological data in Gilgel Gibe catchment in Ethiopia to see whether the data are following some trend, whether the trend is increasing or decreasing with time, and whether or not they are significant. It determines the rate of that change (if any), with respect to some principal value of the distribution such as the average or the middle value. The nonparametric Mann-Kendall test, which has been commonly employed to detect monotonic trends in a series of environmental data, climate data, or hydrological data, along with the nonparametric Sen's technique, was used. Nonparametric tests are generally distribution-free. They are very useful because most hydrometeorological time series data are not normally distributed [39]. The purpose of the test is to test for monotonic trend with the concept that the null hypothesis H_0 is rejected, indicating that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis H_A is that the data follow a monotonic trend. That is to say, if H_0 is rejected at a specified significant level, we conclude that there is a monotonic trend in data over time. In this study, daily rainfall, temperature, and streamflow data of the stations in Gilgel Gibe catchment were collected and aggregated into monthly and annual totals and then were analyzed to detect the variability and the changes in trend.

2. Materials and Method

2.1. The Study Area. Gilgel Gibe catchment is found in the southwestern part of Ethiopia. It is geographically located in between 7°20′01.58′N to 7°59′15.32″N latitudes and 36°31′04.91″E to 37°13′31.07″E longitudes. It has a catchment area of about 2943 km^2 at its outlet "Gibe Nr. Asendabo" gauging station (Figure 1). The catchment is characterized by high relief hills and mountains with elevations in between 1692 m and 3304 m above sea level and largely comprises cultivated land. In general terms, the catchment is characterized by a wet climate with an average annual rainfall of about 1550 mm and an average temperature of 19°C. The rainy season in the catchment area is in the months of June to September, during which 80% of rains are received [2], and the minimum rainfall occurs in the months from November to February. The lowest monthly average maximum temperature occurs during the months of July and August, and the maximum monthly average minimum temperature occurs in the months from June to September. The major socioeconomic activities in the catchment are cultivating crops (maize, teff, sorghum, barley, pulses, and false banana) and rearing livestock [2].

2.2. Methodology. The spatial changes in streamflow trend can occur as a result of spatial changes in rainfall, temperature, and other catchment characteristics that translate meteorological inputs into hydrological response [8]. The variables chosen for this study are rainfall, temperature, and stream flows obtained from Ethiopian government agencies (National Meteorology Agency and Ministry of Water affairs). Here, we used the data from 7 rainfall stations, 4 temperature stations, and 6 stream-flow gauging stations. It is known that the hydrometeorological data are not always consistent; thus, it is vital to employ a method for determining whether or not a dataset is consistent. In this study, we used a double mass curve to check the consistency of the datasets, and some of the datasets were accordingly corrected prior to performing trend analysis. This analysis helps assess whether a data series shows an increasing or a decreasing trend at a specified significance level. The analysis also determines the rate of that change (if any), with respect to some principal value of the distribution such as the mean or the median. The nonparametric Mann-Kendall test was used for analysis [4] because there are very few underlying assumptions about the structure of the data, making it robust against departures from normality [40]. In addition, the use

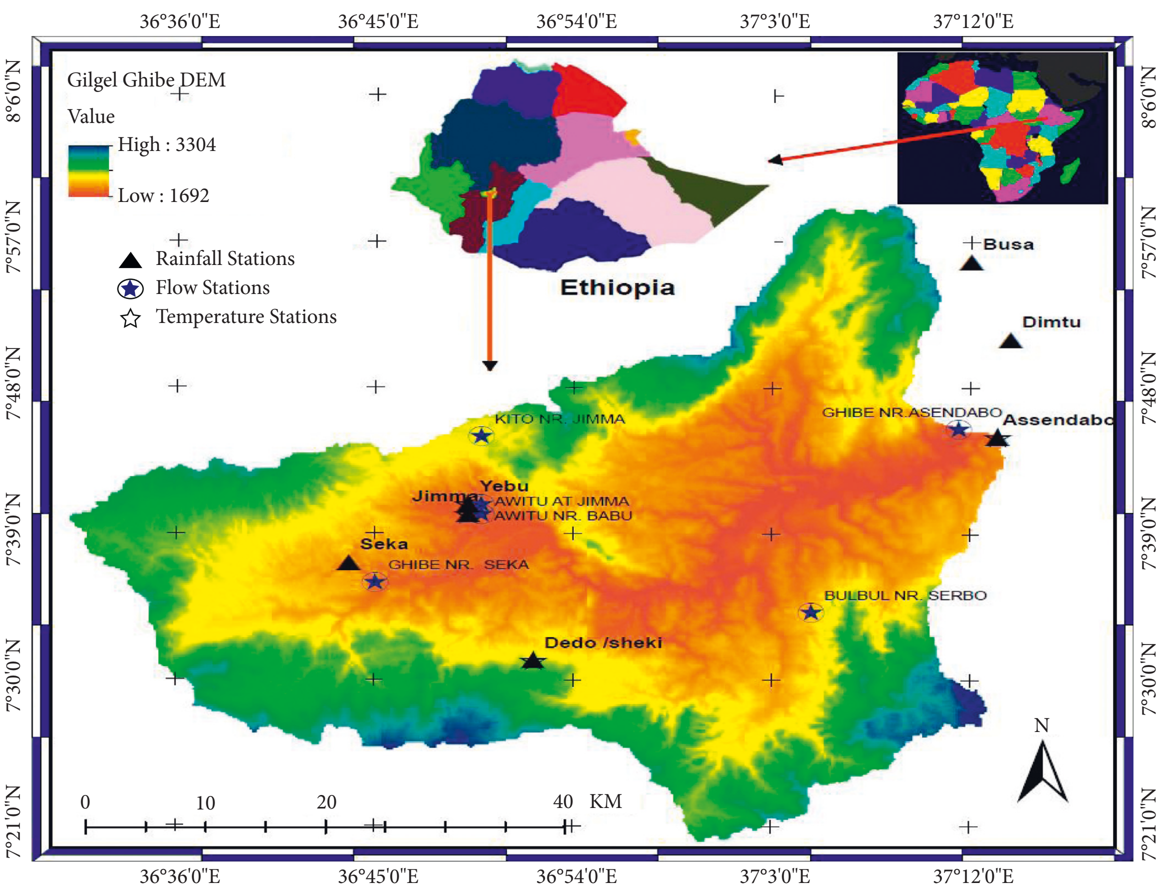

FIGURE 1: Location map of Gilgel Gibe catchment [3].

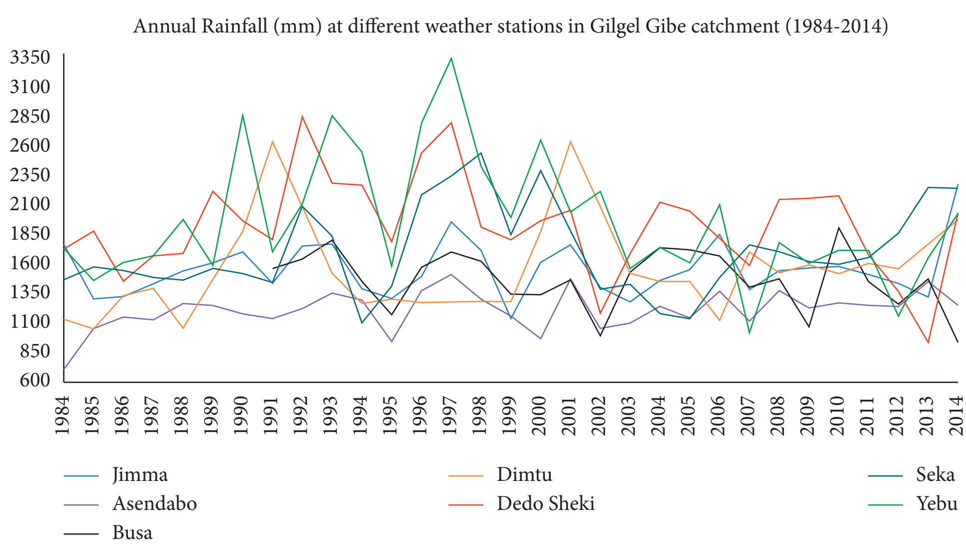

FIGURE 2: Time series of annual rainfall in mm at seven stations in/around Gilgel Gibe river catchment.

of ranks rather than actual values makes it insensitive to outliers and missing values [39].

2.2.1. Mann-Kendall (MK) Test. The MK test, a nonparametric approach, has been widely used for detection of trends in different fields of research, including hydrology and climatology [41, 42]. It is used for identifying trends in hydroclimatic data. Each data value is compared with all the subsequent data values. It is a simple test for trend, and as such, it is not dependent upon the magnitude of data, assumptions of distribution (does not have to have a normal/bell shape distribution), missing data, or irregularly spaced monitoring periods. It helps assess whether a data series shows a trend at a specified significance level [43].

Table 1: Summarized results of trend test for rainfall data.

Station/years	Observations (years)	Rainfall in mm			Std. deviation	Kendall's tau	MK statistic (S)	Var (S)	p value (two-tailed)	Alpha (α)	Z	Sen's slope estimate	Trend	Statistically significant
		Minimum	Maximum	Mean										
Jimma (1984–2014)	31	31.0	1143.8	2288.0	1562.0	0.0	19.0	666.3	0.5	0.05	0.31	1.089	Increase	No
Assendabo (1984–2014)	31	709.0	1518.8	1217.3	166.8	0.2	115.0	1785.5	0.007	0.05	1.94	5.668	Increase	Yes
Busa (1991–2014)	24	940.6	1916.1	1478.2	252.5	−0.2	−52.0	1625.3	0.206	0.05	−1.27	−9.999	Decrease	No
Dimtu (1984–2014)	31	1055.8	2649.3	1576.6	401.2	0.3	140.0	4299.2	0.034	0.05	2.36	15.412	Increase	Yes
DedoSheki (1984–2014)	31	940.1	2861.6	1932.9	414.1	0.0	−19.0	3461.7	0.760	0.05	−0.31	−2.053	Decrease	No
Seka (1984–2014)	31	1106.3	2552.7	1718.2	378.8	0.2	77.0	6606.3	0.350	0.05	1.29	7.517	Increase	No
Yebu (1984–2014)	31	1090.5	1783.4	1419.7	193.2	−0.1	−55.0	2763.3	0.304	0.05	−0.92	−6.850	Decrease	No

Table 2: Summary of the true slopes of the existing trend for rainfall data.

Station/years	Observations (years)	Rainfall in mm			Std. deviation	Sen's slope estimate	Value of B in Sen's equation	Change per year (%)	Status
		Minimum	Maximum	Mean					
Jimma (1984–2014)	31	31.0	1143.8	2288.0	1562.0	1.089	1524.77	0.071	Increase
Assendabo (1984–2014)	31	709.0	1518.8	1217.3	166.8	5.668	1129.60	0.502	Increase
Busa (1991–2014)	24	940.6	1916.1	1478.2	252.5	−9.999	1641.00	−0.609	Decrease
Dimtu (1984–2014)	31	1055.8	2649.3	1576.6	401.2	15.412	1197.30	1.287	Increase
Dedo Sheki (1984–2014)	31	940.1	2861.6	1932.9	414.1	−2.053	1951.14	−0.105	Decrease
Seka (1984–2014)	31	1106.3	2552.7	1718.2	378.8	7.517	1532.10	0.491	Increase
Yebu (1984–2014)	31	1090.5	1783.4	1419.7	193.2	−6.85	1908.90	−0.359	Decrease

The Seasonal Kendall (SK) test for trend [44] was also developed by the US Geological Survey (USGS) in the 1980s to analyze trends in surface-water quality throughout the United States. It performs the MK trend test for individual seasons of the year, where season is defined by the user. It then combines the individual results into one overall test for whether the dependent (Y) variable changes in a consistent direction (monotonic trend) over time [40]. Since then, it has become the most frequently used test for trends in the environmental sciences. The applications of this test have included tests for trends in biologic community structure, estuarine salinity, lake water quality, and atmospheric chemistry [40].

So, the Seasonal Kendall test [44] accounts for seasonality by determining the MK test on each of m seasons (in our case, m represents months) separately and then uniting the results into one general form. This means that January data are compared only with January, February with February only, and so on. No comparisons are made across season boundaries [2]. The Kendall statistic S measures the monotonic dependence of Y on T and is determined as follows:

$$S = P - M, \tag{1}$$

where P is the number of times the Y's increase as T's increase and M is the number of times the Y's decrease as the T's increase. When S is a large positive number, later-measured values tend to be larger than earlier values and an upward trend is indicated. When S is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of S is small, no trend is indicated. But, it is necessary to check whether the trend is significantly different from zero or not. Considering the variable Y (in this case rainfall, temperature, and streamflow) and time T, S can be calculated using equation (1), and note that there are $n\ (n-1)/2$ possible comparisons to be made among the n data pairs. If all Y values increased along with the T values, $S = n\ (n-1)/2$. In this situation, the correlation coefficient τ should equal +1. When all Y values decrease with increasing T, $S = -n\ (n-1)/2$ and τ should equal −1. Therefore, dividing S by $n\ (n-1)/2$ will give a value always falling between −1 and +1. This then is the definition of tau (τ), measuring the strength of the monotonic association between two variables. Hence, the definition of tau (τ) is

$$\tau = \frac{S}{n(n-1)/2}, \tag{2}$$

where S is the Kendall overall statistics and n is the number of data. If the number of seasons and years are sufficiently large (>25), the Z value may be compared to standard normal tables to test for a statistically significant trend [45]. The distribution of S can therefore be estimated well by a normal distribution with expectation (μ_S) equal to the sum of the expectations of the individual S_i under the null hypothesis and variance equal to the sum of their variances. S is standardized using equations (3), and the result, Z_S, is evaluated against a table of the standard normal curve [42].

$$\begin{aligned} Z_s &= \frac{S-1}{\sigma_s}, \quad \text{if } S > 0, \\ Z_s &= \frac{S+1}{\sigma_s}, \quad \text{if } S < 0, \end{aligned} \tag{3}$$

where $Z_s = 0$, if $S = 0$, and the variance σ_s^2 is

$$\sigma^2 = \frac{\left\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j\left(t_j-1\right)\left(2t_j+5\right)\right\}}{18}, \tag{4}$$

where p is the number of the tied groups in the data set and t_j is the size in the jth tied group.

For a sample size of less than 10 data points, the S test can be employed, and for a sample size of 10 or more data points, the normal approximation can be applied [22, 46]. Now, it is to test the null hypothesis of no trend, H_0; that is, the observations Y_i are randomly ordered in time, against the alternative hypothesis, H_A, where there is an increasing or

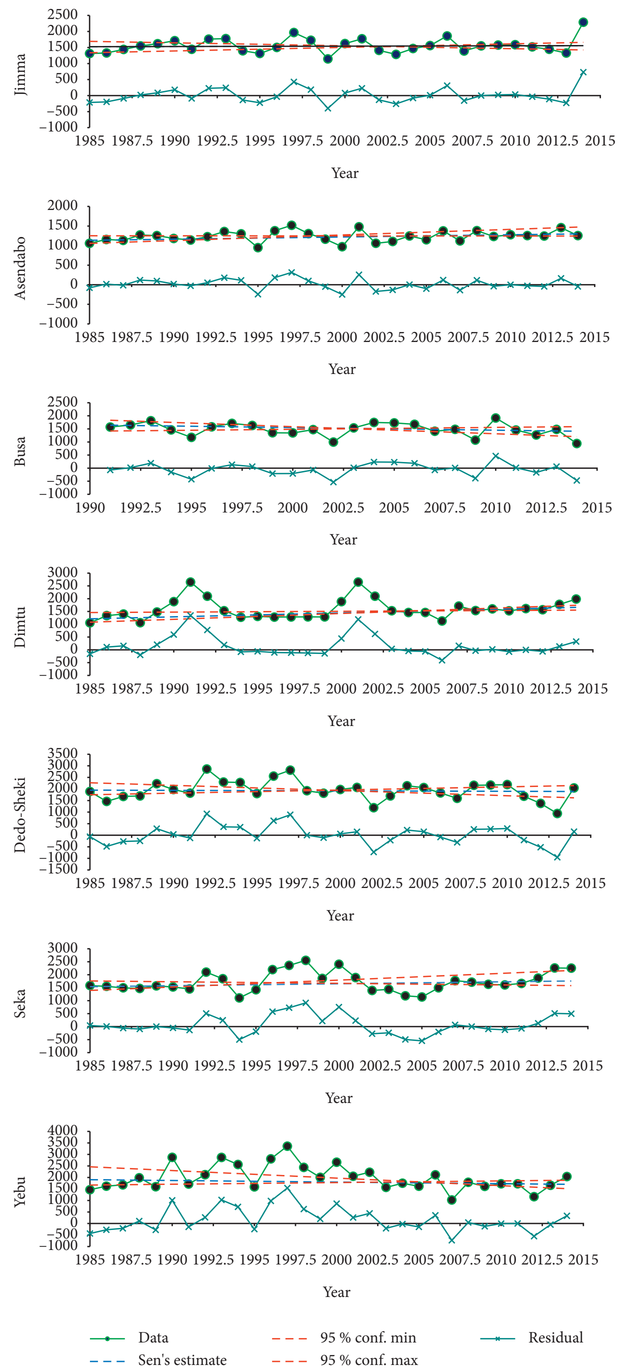

Figure 3: Trends in rainfall data at seven (7) stations in/around Gilgel Gibe river catchment.

decreasing monotonic trend at some specified predetermined significance level, α (say 0.001, 0.01, 0.05, or 0.1). For example, $\alpha = 0.001$ indicates that there is a 0.1% probability that the values Y_i are from a random sample and that the presence of a monotonic trend is very likely [39, 46].

The existence of a statistically significant trend is assessed by means of the value of Z_s. A (+) or a (−) value of Z_S specifies a rising or a falling trend. The statistic Z_s has a normal distribution. To test for an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z_s is greater than $Z_1 - \alpha/2$, where $Z_1 - \alpha/2$ is obtained from the standard normal cumulative distribution tables. If a significant trend is found, the rate of change can be measured with the use of the Sen's slope estimator [46].

2.2.2. Sen's Method. To evaluate the slope of a prevailing trend (as change per year), Sen's nonparametric technique was utilized [46]. This means that

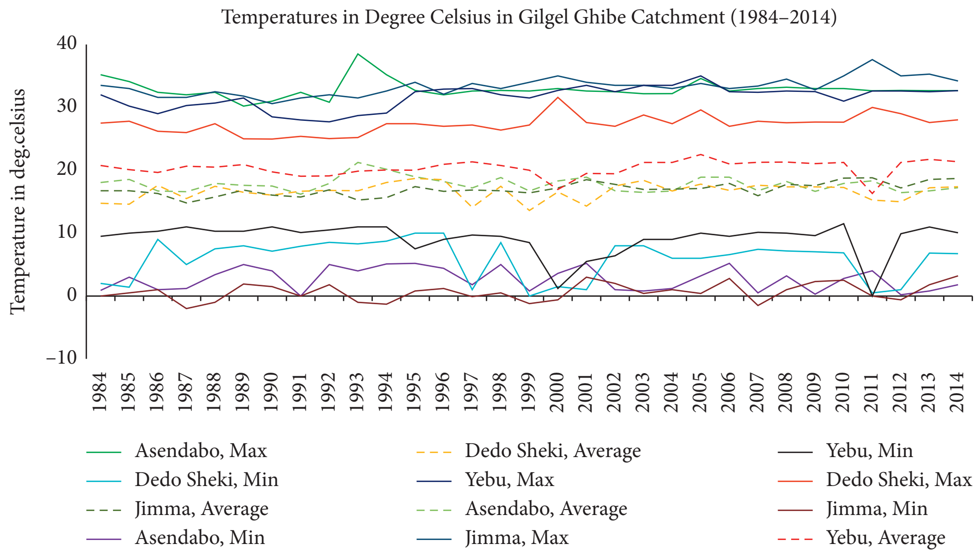

Figure 4: Time series of temperatures (maximum/minimum/average).

$$f(t) = Qt + B, \quad (5)$$

where Q is the slope and B is a constant.

To find out Q in equation (5), we should first compute the slopes of all data pairs. Here, if there are n values x_j in the time series, we get as many as $N = n(n-1)/2$ slope estimates Q_i. Sen's estimator of slope is the median of these N values of Q_i. N values of Q_i are arranged in ascending order of magnitude, and Sen's estimator is [47] determined as

$$Q = Q_{[(N+1)/2]}, \quad \text{if } N \text{ is odd},$$
$$Q = \frac{1}{2}\left[\frac{Q_N}{2} + \frac{Q_{N+2}}{2}\right], \quad \text{if } N \text{ is even}. \quad (6)$$

The confidence intervals of the median slope were computed at $\alpha = 0.05$, considering the two-sided confidence interval about the slope estimate. For larger data size, the critical value $Z_1 - \alpha/2$ from a table of standard normal curve gives the upper and lower ranks of the slopes corresponding to the ends of the confidence interval [2, 43, 46]. The value of Z at $\alpha = 0.05$ is 1.96. Using equation (7), Ml and Mu are found as follows [47]:

$$\text{Ml} = \frac{N - 1.96\sigma_s}{2},$$
$$\text{Mu} = \frac{N + 1.96\sigma_s}{2}, \quad (7)$$

where N is the total number of slope estimates and σ_s as given in equations (3). The lower and upper limits of the confidence interval of the slope are the Ml^{th} and the $(\text{Mu}+1)^{\text{th}}$.

In this study, the "MAKESENS" tools were also used to detect the trends in data. The values of Kendall's tau, the Kendall score (S), its variance, and its two-sided p value along with alpha value were displayed. These values were computed separately for each month and each year at each station. The MAKESENS technique calculates the confidence limits at two dissimilar significance levels: $\alpha = 0.01$ and $\alpha = 0.05$ [43].

In the beginning, we compute [47]

$$C_\alpha = \left(Z_1 - \frac{\alpha}{2}\right) \times \sigma_s, \quad (8)$$

where σ_s has been defined in equations (3) and $Z_1 - \alpha/2$ can be obtained from the standard normal table. Then, $\text{M1} = (N - C_\alpha)/2$ and $\text{M2} = (N + C_\alpha)/2$ are determined. The lower and upper confidence limits, $Q_{\min}$ and $Q_{\max}$, are the M1^{th} largest and the $(\text{M2}+1)^{\text{th}}$ largest of the N ordered slope estimates Qi. If M1 is not a whole number, the lower limit is interpolated. Correspondingly, if M2 is not a whole number, the upper limit is interpolated.

To obtain the value of the linear constant B in equation (5), the n values of differences $x_i - Q_{ti}$ are determined. The median of these values gives an estimation of B [46]. The estimations of B for lines of the 99% and 95% confidence limits are computed following the same steps.

3. Results and Discussion

3.1. Trend Analysis of Rainfall. In this analysis, monthly and annual totals were calculated using daily rainfall data from seven stations in/near the Gilgel Gibe catchment. Here, the daily rainfall data for the period 1984–2014 was aggregated into monthly and annual totals for Jimma, Asendabo, Dimtu, DedoSheki, Seka, and Yebu stations. Likewise, the available rainfall data for the period of 1991–2014 for Busa rainfall station were used. The time series of the annual rainfall of those stations is shown in Figure 2. The trend analysis of rainfall was carried out, and the results of the analysis are presented in Table 1 and successive graphs as indicated in Figure 3. The summary of the true slopes of the prevailing trend (change per year) for annual rainfall data of the seven stations estimated by Sen's nonparametric technique was also shown in Table 2.

Table 3: Summarized results of trend test for temperatures.

Station/years	Variable	Observations (years)	Temperature in degree Celsius				Kendall's tau	MK statistic (S)	Var (S)	p value (two-tailed)	Alpha (α)	Z	Sen's slope estimate	Trend	Statistically significant
			Minimum	Maximum	Mean	Std. deviation									
Asendabo (1984–2014)	Maximum	31	28.5	30.7	29.5	0.5	0.3	150	3460.7	0	0.05	2.5	0.035	Increase	Yes
	Minimum	31	5.7	10.8	8.4	1.3	−0.1	−58	6756	0.5	0.05	−1	−0.034	Decrease	No
	Average	31	17.9	20	19	0.6	−0.1	−53	6484.1	0.5	0.05	−0.9	−0.008	Decrease	No
Dedo Sheki (1984–2014)	Maximum	31	23.3	27.5	24.9	0.8	0.2	80	4377	0.2	0.05	1.34	0.024	Increase	No
	Minimum	31	2.8	10.9	9.2	1.7	−0.1	−39	3459.7	0.5	0.05	−0.65	−0.009	Decrease	No
	Average	31	14.2	18.8	17	0.9	0.2	85	5684	0.3	0.05	1.43	0.025	Increase	No
Jimma (1984–2014)	Maximum	31	28.5	31	29.9	0.6	0.4	187	5913.8	0.016	0.05	3.16	0.045	Increase	Yes
	Minimum	31	6.1	8.9	7.4	0.8	0.4	175	3461.7	0.003	0.05	2.96	0.049	Increase	Yes
	Average	31	17.7	19.5	18.6	0.5	0.6	270	5826.6	0	0.05	4.57	0.046	Increase	Yes
Yebu (1987–2014)	Maximum	31	27.70	35.00	31.60	1.83	0.4	169	7759.9	0.1	0.05	3.14	0.089	Increase	No
	Minimum	31	0.00	11.50	9.10	2.62	0	15	2498.6	0.8	0.05	0.92	0.074	Increase	No
	Average	31	16.30	22.50	20.35	1.29	0.4	179	3461.7	0	0.05	2.64	0.038	Increase	Yes

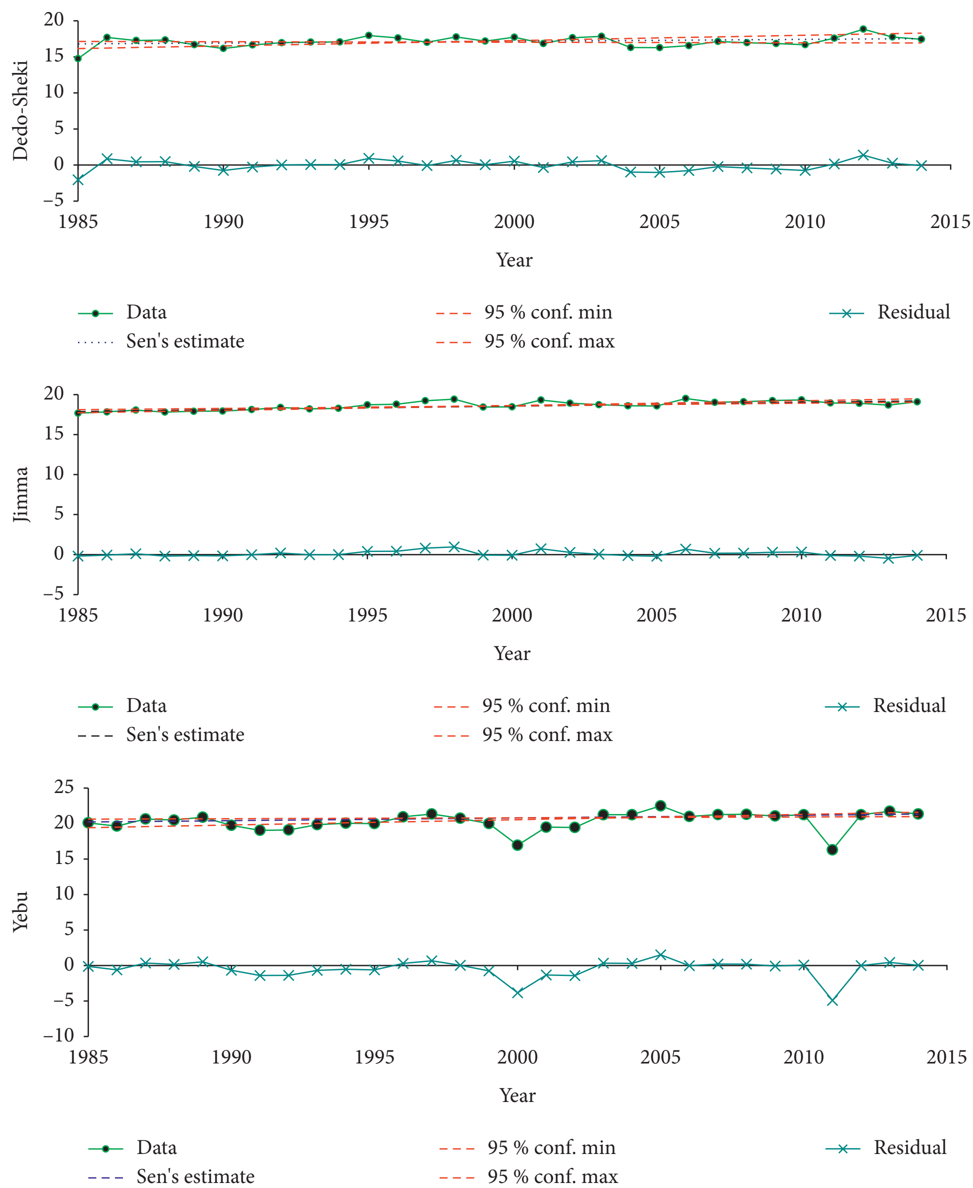

Figure 5: Trends for temperature data at three stations in Gilgel Gibe river catchment.

Table 4: Summary of the true slopes of the existing trend for temperatures.

Station/years	Observations (years)	Annual average temperature in degree Celsius				Sen's slope estimate	Value of B in Sen's equation	Change per year (%)	Status
		Minimum	Maximum	Mean	Std. deviation				
Asendabo (1984–2014)	31	17.9	20	19	0.6	−0.008	18.98	−0.04	Decrease
DedoSheki (1984–2014)	31	14.2	18.8	17	0.9	0.025	16.77	0.15	Increase
Jimma (1984–2014)	31	17.7	19.5	18.6	0.5	0.046	17.82	0.26	Increase
Yebu (1987–2014)	31	16.3	22.5	20.35	1.29	0.038	20.19	0.19	Increase

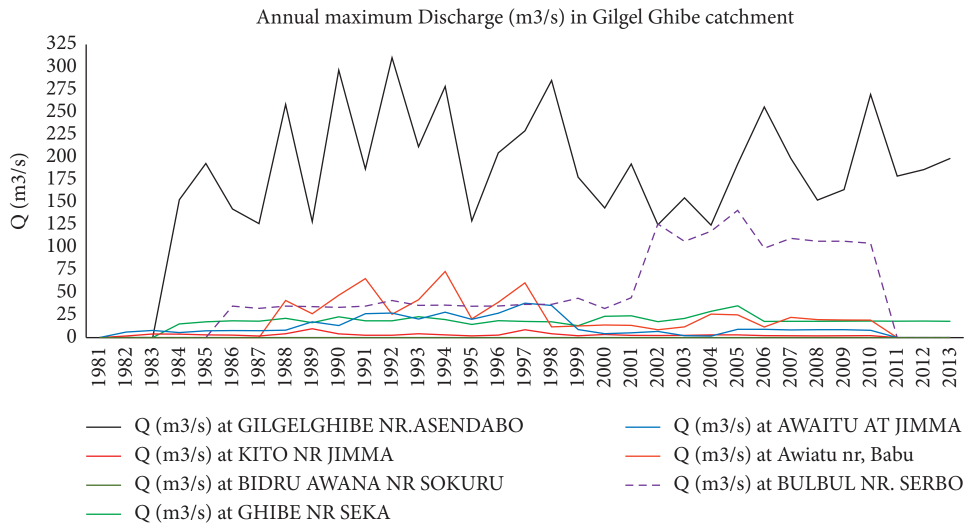

Figure 6: Time series for stream flows.

The results of the analysis indicate that, out of the 7 rainfall stations, 2 stations (Asendabo and Dimtu) showed an increasing trend at a 5% significance level. The remaining 5 stations (Jimma, DedoSheki, Seka, Yebu, and Busa) did not show any significant trend at a 5% significance level. But stations Jimma and Seka exhibited a slight increment in trend, whereas stations DedoSheki, Yebu, and Busa showed a decreasing trend. Generally, the Gilgel Gibe catchment has been receiving more or less an increasing magnitude of annual rainfall though not significant. This finding, which is based on rainfall data of a few stations, is in agreement with other studies conducted at the national level in Ethiopia. For example, Africa Climate Change Resilience Alliance [48, 49] specified that there is no statistically significant trend in observed mean precipitation in any season in Ethiopia between 1960 and 2006. Similarly, al.the nationwide and basin-level investigations indicated that neither the basins nor the nation was found to be facing any major changes with yearly precipitation for the time period covered by theinvestigations [2].

3.2. Trend Analysis of Temperature. Similarly, the annual average monthly maximum/minimum temperatures as well as average annual temperature data of Assendabo, DedoSheki, Jimma, and Yebu weather stations for the period of 1984–2014 were analyzed for trend. The time series of the temperatures (maximum/minimum/average) at those stations is indicated in Figure 4, the results of the trend analysis are presented in Table 3, and the successive graphical representations of the results of trend analysis are also shown in Figure 5. The summary of the true slopes of the prevailing trend (change per year) for the average annual temperature data of those four stations estimated by Sen's technique was also presented in Table 4.

Trend analysis for temperature data by the Mann-Kendall method indicates that the temperatures (maximum, minimum, and annual average) at Jimma station, the annual average temperature at Yebu station, and the maximum temperature at Asendabo station showed an increasing trend at a 5% significance level. In addition, the annual average and the maximum temperatures at Dedo Sheki station and the temperatures (maximum and minimum) at Yebu station indicated an increasing trend at a 5% significance level, though not significant. In contrast, the minimum and annual average temperatures at Asendabo station and the minimum temperature at Dedo Sheki station showed a decreasing trend at a 5% significance level. Generally, there is an increasing trend in temperature in the study area. McSweeney et al. [49] also confirmed that the mean annual temperature in Ethiopia has risen by 1.3°C from 1960 to 2006, with an average increment rate of 0.28°C per decade. The increment in temperature in Ethiopia has been most prompt in the months of July, August, and September ("JAS"), which was at a rate of 0.32°C per decade. The national picture regarding climate change also indicates that a range of studies of national climate trends since the 1960s show that mean annual temperatures in Ethiopia have risen by between 0.5 and 1.3°C [2].

3.3. Trend Analysis of Streamflow. Likewise, the streamflow data at six (6) gauging stations (Gibe Nr. Assendabo, Gibe Nr. Seka, Aweitu Nr. Babu, Aweitu at Jimma, Bulbul Nr. Serbo, and Kitto Nr. Jimma) in the catchment were analyzed for trends. Figure 6 shows the time series of the annual maximum discharge at those gauging stations. The summary of the trend test results by the Mann-Kendall method for annual maximum stream flows is given in Table 5 and by the subsequent graphical representations of the results of trend analysis in Figure 7. The summary of the true slopes of the prevailing trend (change per year) for the annual maximum stream flow data of the six stations estimated by Sen's technique was also specified in Table 6.

The results of the trend assessment of the stream flow highlighted that only one station (Bulbul Nr. Serbo) showed a positive slope at the 5% significance level. Two Stations (Aweitu Nr. Babu and Gibe Nr. Seka) indicated a slight increment in streamflow. This could be due to the increment

Table 5: Summarized results of the trend test for stream flows.

Station/years	Observations (years)	Maximum discharge in cubic meters per second				Kendall's tau	MK statistic (S)	Var (S)	p value (two-tailed)	Alpha (α)	Z	Sen's slope	Trend	Statis. significant
		Minimum	Maximum	Mean	Std. deviation									
Gibe Nr. Assendabo (1984–2013)	30	124.7	310.4	195.0	55.4	0.2	−36	3068.23	0.186	0.05	−0.02	−0.013	Decrease	No
Gibe Nr. Seka (1984–2013)	30	13.2	35.3	19.6	4.3	0.2	46	18.66	0.8974	0.05	0.68	0.0263	Increase	No
Aweitu Nr. Babu (1988–2010)	23	1.7	73.3	26.8	22.5	0.4	44	491.3	0.056	0.05	0.81	7.132	Increase	No
Aweitu at Jimma (1982–2010)	29	1.7	38.2	13.9	10.9	0	−6	5502.6	0.946	0.05	−0.12	−0.044	Decrease	No
Bulbul Nr. Serbo (1986–2010)	25	6.9	141	51.7	37.803	0.543	102	1632.7	0.012	0.05	3.28	1.108	Increase	Yes
Kitto Nr. Jimma (1982–2010)	29	1.8	9.8	3.5	2	0	−8	429.3	0.735	0.05	−0.18	−0.011	Decrease	No

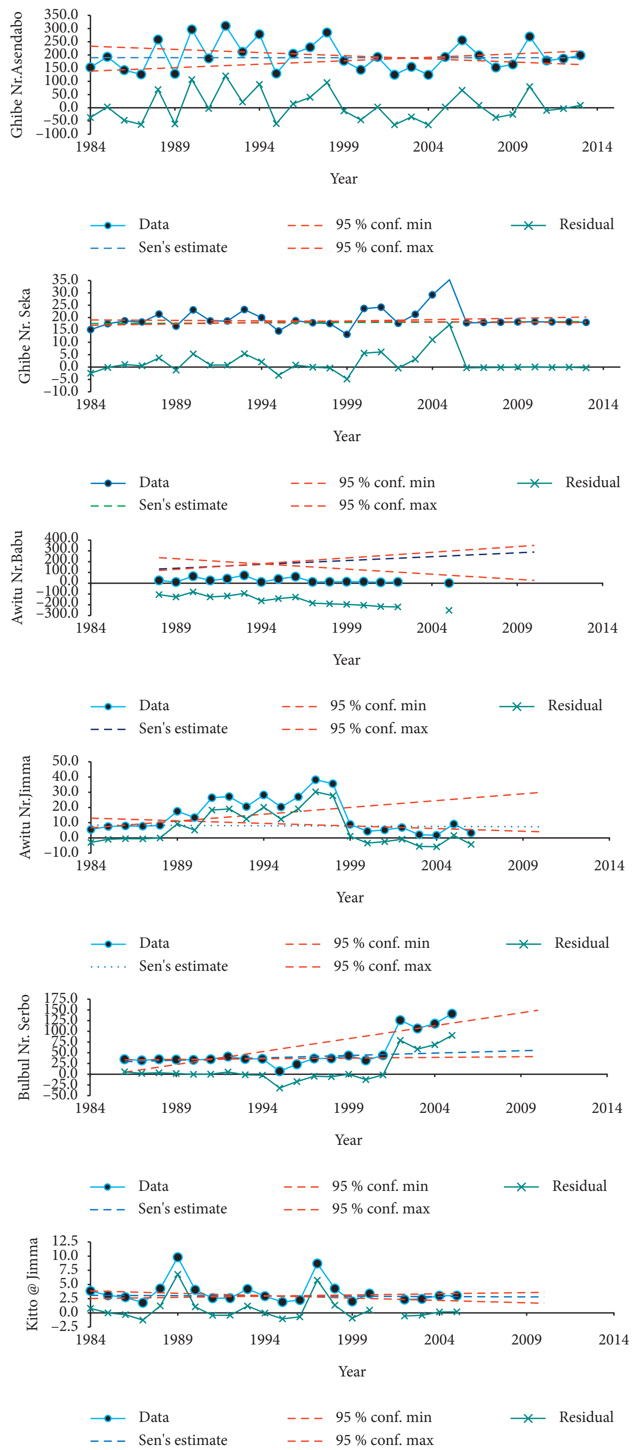

Figure 7: Trend for stream flows at six stations in Gigel Gibe in the catchment.

of rainfall over the catchment as explained earlier. In addition, the increase in recorded temperature experienced in the catchment could not significantly reduce the surface water due to evaporation. Other activities, such as river water abstractions/diversions for agricultural purposes that could possibly reduce the streamflow amounts, are not so significant within and around the catchment.Whereas, the remaining 3 stations (Gibe Nr Assendabo, Aweitu at Jimma, and Kitto Nr. Jimma) indicated a very little decreasing trend. The changes in stream flow records might be on account of land use change besides the annual and seasonal distribution of rainfall. However, the impact of land use alteration on stream flow in the catchment was not considered in this study.

Table 6: Summary of the true slopes of the existing trend for stream flows.

Station/years	Observations (years)	Maximum discharge in cubic meters per second				Sen's slope estimate	Value of B in Sen's equation	Change per year (%)	Status
		Minimum	Maximum	Mean	Std. deviation				
Gibe Nr. Assendabo (1984–2013)	30	124.7	310.4	195.0	55.4	−0.0133	189.85	−0.007	Decrease
Gibe Nr. Seka (1984–2013)	30	13.2	35.3	19.6	4.3	0.02634	17.61	0.150	Increase
Aweitu Nr. Babu (1988–2010)	23	1.7	73.3	26.8	22.5	7.132	131.84	5.410	Increase
Aweitu at Jimma (1982–2010)	29	1.7	38.2	13.9	10.9	−0.044	8.53	−0.516	Decrease
Bulbul Nr. Serbo (1986–2010)	25	6.9	141	51.7	37.8	1.108	29.25	3.788	Increase
Kitto Nr. Jimma (1982–2010)	29	1.8	9.8	3.5	2	−0.011	3.11	−0.353	Decrease

4. Conclusion and Recommendation

The subject of trend detection in hydrometeorological data has received a great deal of attention lately, especially in connection with the anticipated changes in global climate [42]. For example, the knowledge of the precipitation behaviors, especially its variability and trends, is important for the proper design of water-related structures for which estimation of design flood is required. Time series analysis can show the magnitude of the apparent components such as trends, jumps, and seasonality of such hydroclimatic data. Hydrologic time series always exhibit seasonality due to the periodicity of the weather in that climatic variability, which is reflected in hydrologic data, can adversely affect trend test results [42]. A trend may be identified in the present but may turn out to be part of a periodicity (seasonality) when looked at over a longer period of time. The fact that a trend has not been identified does not necessarily mean that such a change is not happening. This could be attributed to the small sample size. In the trend analysis of hydrometeorological time series, a null hypothesis of "no trend" was assumed. Failing to reject the null hypothesis does not mean that it has been adequately proved that there is no trend. Rather, it implies that the evidence available is not sufficient to conclude whether there is a trend. Efforts were made to include as much data as possible for this study. This study thus examines the trends of the hydrometeorological data in Gilgel Gibe catchment and whether or not they are significant. The nonparametric Mann-Kendall test along with Sen's slope technique was employed to detect monotonic trends in the data series. Daily rainfall, temperature, and streamflow data of the stations in/nearby the study catchment for a period longer than 25 years were employed to detect the variability and the changes in trend by using the nonparametric Mann-Kendall test. The outcomes of the investigation showed that there is a minor increasing trend in annual precipitation data in the study area. However, the results indicated no significant trend in monthly and seasonal rainfall data. But the streamflow showed an infinitesimal decreasing tendency (0.007% per year) at the outlet (Gibe Nr. Asendabo gauging station). An increasing trend in temperature was observed in the study area as well. The results of this study are also in agreement with the study conducted earlier in Ethiopia [49], which confirmed that the mean annual temperature in Ethiopia increased by 1.3°C between 1960 and 2006, an average rate of 0.28°C increment per decade. The results of trend change in general were statistically insignificant. Although the Mann-Kendall method, which considers skewed, cyclic, and serially correlated data, was used to determine magnitudes of trend, better quality longer time series is recommended for better indications of existence and magnitudes of the trend.

Data Availability

Data are available upon reasonable request.

Disclosure

This paper is the revised form (major revision) of the source document indicated at https://researchspace.ukzn.ac.za/handle/10413/16191.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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