Hindawi
Advances in Meteorology
Volume 2022, Article ID 3594641, 16 pages
https://doi.org/10.1155/2022/3594641

Research Article

Hydroclimatic Variability, Characterization, and Long Term Spacio-Temporal Trend Analysis of the Ghba River Subbasin, Ethiopia

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Received 22 May 2022; Revised 13 July 2022; Accepted 16 July 2022; Published 23 August 2022

Academic Editor: Upaka Rathnayake

Understanding hydroclimatic variability and trend for the past four decades in the Upper Tekeze River basin is significant for future sustainable water resource management as it indicates regime shifts in hydrology. Despite its importance for improved and sustainable water allocation for water supply-demand and food security, varying patterns of streamflow and their association with climate change are not well understood in the basin. The main objective of this study was to characterize, quantify, and validate the variability and trends of hydroclimatic variables in the Upper Tekeze River basin at Ghba subbasin using graphical and statistical methods for homogeneous stations for the time period from 1953 to 2017, not uniform at all stations. The rainfall, temperature, and streamflow trends and their relationships were evaluated using the regression method, Mann–Kendall (MK) test, Spearman's rho (SR) test, Sen's slope, and correlation analysis. The analysis focused on rainfall, temperature, and streamflow collected from 11 climate and six hydrostations. For simplicity to discuss the interannual and temporal variability the stations were categorized into two clusters according to their record length, category 1 (1983–2017) and category 2 (1953–2017). About 73% and 27% of the rainfall stations exhibited normal to moderate annual rainfall variability. The MK and SR test showed that most of the significant trends in annual rainfall were no change except in one station decreasing and the test also showed no significant change in temperature except in three stations showed an increasing trend. Overall, streamflow trends and change point timings were found to be consistent among the stations and all have shown a decreasing trend. Changes in streamflow without significant change in rainfall suggest factors other than rainfall drive the change. Most likely the observed changes in streamflow regimes could be due to changes in catchment characteristics of the subbasin. These research results offer critical signals on the characteristics, variability and trend of rainfall, temperature, and streamflow necessary to design improved and sustainable water allocation strategies.

1. Introduction

Climate change and human intervention combined with other driving factors have brought an apprehension in rainfall and streamflow variability over a basin on water resources management [1, 2]. Research by [3–9] identified how climate change mirrored in altering rainfall patterns and affecting hydrological regimes over river basins. Hence, understanding climate change and other driving forces on hydrological variability is important for improved water management and allocation.

Examining the streamflow and rainfall records and identifying their linkages and trend between them is fundamental to recognizing the impact of climate change on hydrology and, enabling us to look for climate-resilient water management techniques. Such studies have received increased attention from the scientific community over the last two decades [10–12] due to the rising need to secure water for human uses such as domestic, nondomestic, and irrigation, as well as for environmental flow. In addition, rising concern about climate change and its impacts on streamflow has been an important driver of such studies [13, 14]. Several studies have made known that rainfall is the main atmospheric factor that is directly related to the streamflow patterns [15–18]. Paudel and Acharya [19] studied trends for 40 years of climate data of the Chitwan River Basin, Nepal, in annual and seasonal records. They found a decreasing trend in streamflow, which was strongly correlated to precipitation. They also tried to check changes in streamflow with land use changes (forest cover) but proved that changes in plant cover had an insignificant impact on the streamflow. Studies by Pellicciotti et al [20], Zhang et al. [21], Gebert and Krug [22], Birsan et al. [6, 23], and Setegn et al. [24] showed that changes in rainfall are not enough to describe the trends in the streamflow. Studies by [23, 25] showed streamflow trends in the mountain basins, as in the current study of this chapter, are the most vulnerable environments in the context of climate change.

Remarkable annual fluctuation of precipitation over the Blue Nile and Atbara basins resulted in a reduction in river flows between 1945 and 1984 [26]. On the contrary, recent studies agreed that rainfall over the Upper Blue Nile basin has had no significant trend for the last 45 years [27–31]. In the current study, anxieties around water resources and climate change have gained global significance in the study on hydroclimatic trends [32, 33]. By considering only one climate station it was tried to study the pattern of rainfall over the upper part of the Tekeze River basin [6, 34, 35]. Their output showed that the amount of rainfall remained constant for the past 40 years (1962–2002). Gebremicael et al. [6] studied that rainfall over the Nile basin headwaters has remained constant and a significant decreasing pattern of streamflow in the eastern and northern part of the basin was analyzed in the last four decades. Even with the reputation of streamflow to ensure sustainable water resource allocation and food security in the study area, long-term trends and change points of flow regimes and the relationship with climate change are not properly studied. Thus, it is vital to comprehend the linkages between rainfall and streamflow trends of the subbasin and establish whether hydrological variability is driven by changes in climate or any other driving forces. The main objective of this research is to identify, quantify and analyze recent trends in streamflow and climate data in the mountainous, semi-arid region of Ethiopia for improved water allocation planning in the subbasin. Hence, the 1st section contains the general introduction and literature review, and the rest of the study is organized as follows: Section 2 contains the methodology (method); Section 3 contains the results; Section 4 contains the conclusions and policy implications.

2. Data and Methods

2.1. Study Area. The Ghba subbasin is located in northern Ethiopia and covers from 38°38′ to 39°48′ Eastern longitudes and 13°14′ to 14°16′ northern latitudes as shown in Figure 1. The total area of the Ghba subbasin is about 5125 km^2 and comprises the Tigray regional state's capital city Mekelle. It forms the headwaters of the Upper Tekeze River basin, one of the major tributaries of the Nile River [36]. The landscape is characterized by highlands and hills in the north and northeastern, and highlands in the central part of the catchment [37]. The central highlands are divided by numerous rivers that flow towards the southwestern part of the subbasin and joins the main Tekeze River at Chemey [38]. As shown in Figure 1, the altitude varies from 3,300 meters above sea level (m.a.s.l.) at Mugulat Mountains near Adigrat town to 930 m.a.s.l. At the subbasin outlet [39]. The mean elevation of the catchment is 2144 m with a standard deviation of 361 m indicating that the topography is very rugged [38].

The Ghba subbasin is categorized under a semi-arid climate region where rainfall occurs generally from July to September and has a long period of the dry season. The high-intensity storm is falling between July and August [36]. The mean annual precipitation of the subbasin is between 450 mm in the eastern part to 850 mm in the northern and western parts of the subbasin [6]. The high variability of rainfall in the subbasin is mainly due to the complex topography nature and the seasonal migration of the intertropical convergence zone (ITCZ) [6, 40]. Hence, more than 85% of the total rainfall falls in the wet season between June to September with maximum effective rainfall of less than or to 60 days and a dry period extending up to 10 months [41]. The alterations are frequently associated with the seasonal relocation of the Intertropical convergence zone (ITCZ).

The LULC of the Ghba subbasin is characterized by severe land degradation through deforestation, overgrazing, and cultivation on the rugged topography. The dominant land use and land cover of the study area for the specified periods were rain-fed agriculture; the main crops included wheat, teff, sorghum, barley, maize, and pulses, followed by shrubs, bare land, wood, grassland, plantation, residential areas, forest, and water. Nevertheless, because of the governmental plan of millennium development the last 10 to 15 years irrigated agriculture of small-scale irrigation schemes have been increased significantly in the eastern, northern, and central parts of the subbasin [42–44].

Climate and hydrological spatiotemporal datasets are required to undergo analysis, quantify, characterize, and validate the variability and trends of hydroclimatic variables in the Ghba subbasin. The results of this study will assist in a better understanding of the system in the subbasin, including patterns, trends, and the extent of the changes in the hydrology regime. Thus, the study will help planners to propose climate-resilient water allocation strategies in the Ghba subbasin.

2.2. Data Preparation. The long-term hydroclimatic data were collected from the Ethiopian National Meteorology Services Agency [45], and the hydrological shape files were

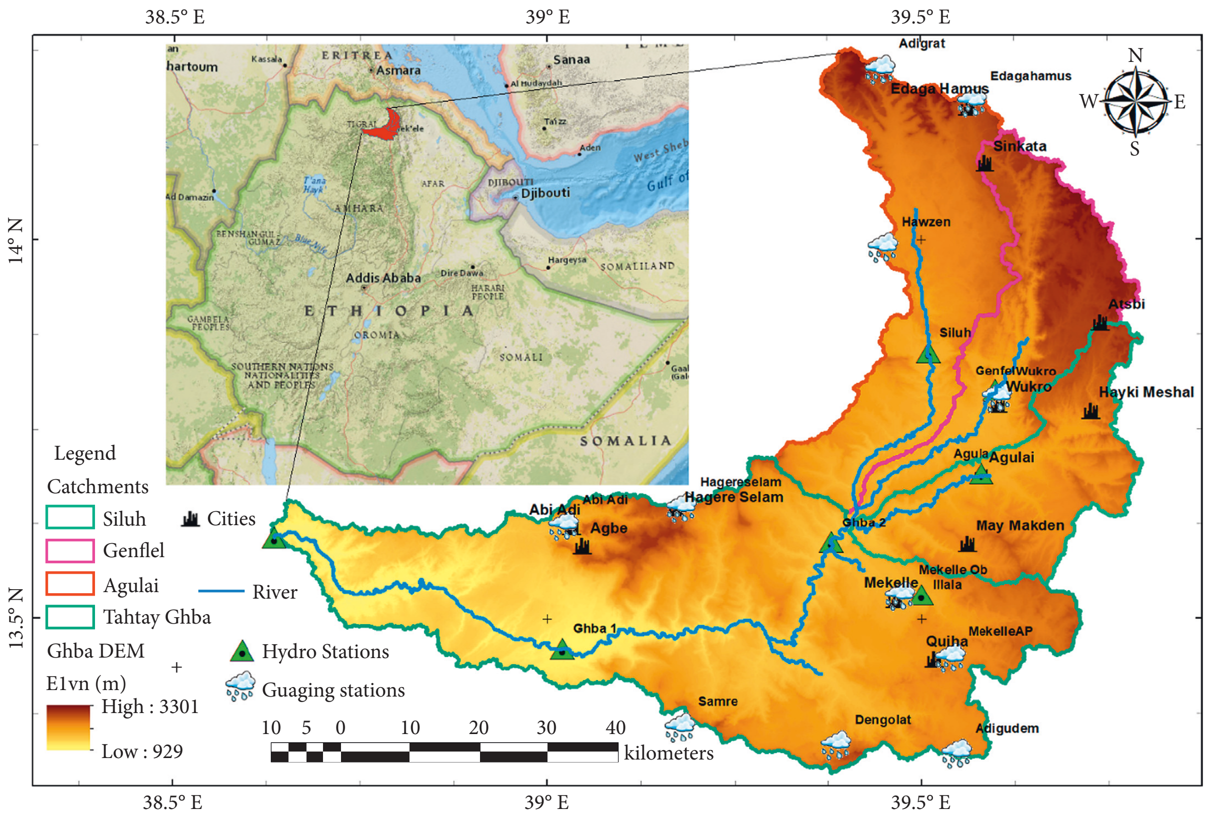

Figure 1: Location of the study area.

obtained from the Ministry of Water, Irrigation, and Energy (MoWE). The current analysis focused on the three hydroclimatic variables: rainfall, temperature, and streamflow of the study area. After screening independent, nonstationary, and homogeneous stations were selected for trend analyses. Furthermore, long-term data availability and the percentage of missing data were considered. The duration selected was more than 25 years and the length of data recorded in all rainfall stations are varying. However, all are more than 30 years, and although the recording of flow data over the subbasin started in the late 1960s, it was discontinued for most of the gauging stations during the civil war in the 1980s. However, the stations in the subbasin have an extended period of more than 25 years of data and these were used in the analyses. The location and general information of hydroclimatic data of the subbasin are shown in Figure 1. In this study, sites with less than 10% of the missing data were selected for both rainfall and streamflow stations. Missing gaps greater than or equal to 5% were completed using missing data estimation methods. Literature such as the studies by [46, 47]were reviewed and noted that the inverse distance weighting (IDW) method is a frequent and commonly used method for estimating missing data in the fields of hydrology. Studies by Teegavarapu and Chandramouli [48] and Teegavarapu et al [49] provided several alternatives to IDW methods. Teegavarapu et al [50] used connotation rules within weighting methods to improve estimates of missing precipitation data. Global estimation methods that use trend and regression analysis are also applicable for spatial interpolation. However, the selection of the appropriate estimation tool stances a major problem due to the large range of candidate functions [51, 52]. In the study area, four estimation methods were selected: arithmetic average (AA), inverse distance weightage (IDW), normal ratio weightage (NRW), and coefficient of correlation weightage (CCW). Besides, these methods were compared with their performance of estimations by introducing uncertainty techniques of sampling, i.e., creating different percentages of missing data (5%, 10%, 15%, 20%) from the available dataset later to be used for calibration purpose to the estimated data. Thus, the results with the minimum RMSE and MAE and highest positive correlation coefficients of the estimator were selected as the best method of the estimator. Hence, the proximity and coefficients of correlation in the IDW and NRW methods improved the rainfall and streamflow estimates and were chosen for filling the missing data where it best fits.

In the current study, annual, monthly, and seasonal daily rainfall and streamflow data were organized. The subbasin was subdivided into four catchments based on their location and physical factors as can be seen in Figure 1. Furthermore, the 11 homogeneous rainfall stations and their valued contribution to each catchment were computed using GIS by the Theisen polygon method as given in Table 1. Siluh catchment covering the northern and northwestern of the subbasin; Genfel catchment covers the central part of the subbasin; Agluai catchment covers the eastern part of the subbasin; and last, Tahtay Ghba covers the southern and

Table 1: Results of rainfall contribution of stations to each catchment by the Theisen polygon method.

S/N		Stations										
	Catchments	AbiAdi	Adigrat	Adigudem	Dengolat	E/Hamus	Hawzen	H/Selam	MekelleAP	Mekelle Ob	Samre	Wukro
1	Siluh		13			17	33	5		5		27
2	Genfel					22	3			5		70
3	Agulai								6	30		64
4	Tahtay Ghba	31		3	10			16	12	14	13	

southwestern part of the subbasin. A time series data with similar time and length was required to evaluate the relation of interannual and temporal variability over different locations [32]. One of the major challenges in the Ghba subbasin was less data availability with similar time and length (varying duration). Thus, the rainfall and streamflow data have different periods with different start and end dates. In order to address this challenge and to get representative stations within the subbasin, stations with a similar period were clustered. Datasets of 35 years were categorized in one group and, datasets from 43 years up to 65 years were categorized in the second group.

Hydroclimatic data quality checks and analyses were performed to characterize, quantify and validate their variability and trend in the subbasin. While dealing with hydroclimatic extremes and trend analysis, it is always affected by data inhomogeneity [53]. In this study, the coefficient of variation (CV), standardized anomaly index (SAI), and graphical methods were used to understand the system. First, the normality test of the annual and seasonal discharge and rainfall time series data was performed. Second, the hydroclimatic variability and trend were tested using different statistical and graphical methods. Thus, the rainfall and streamflow trends and their relationships were evaluated to the selected homogeneous time series of annual and seasonal rainfall, temperature, and discharge using the regression method, Mann–Kendall (MK) test, SR test, Sen's slope estimator test, and correlation analysis to show whether increasing or decreasing trends in the data series. As briefly discussed in Sections 2.3 and 2.4, the method of selecting annual and three seasonal periods, rainy (June–September), dry (October–February), and short rainy (March–May), helps to provide a seasonal comparison of changes in the hydroclimatic variables.

2.3. Variability Analyses. The CV is a statistical measure that expressed the difference of data about the mean; it is the ratio of standard deviation to the mean (equation (1)). In the current study, a CV of <20, ≥20 ≤ 30, and >30 was taken as normal, moderate, and highly variable, respectively. In many studies, the CV (equation (1)) was used to characterize the variability of rainfall [32, 54, 55].

$$CV = \frac{\sigma}{\overline{X}}, \tag{1}$$

where σ and $\overline{X}$ denote the standard deviation and mean of rainfall or streamflow, respectively. The SAI indicates a measure of distance between the data and its mean (equation.(2)). It shows the probability of being of an observed rainfall or streamflow quantity related to the long-term mean rainfall or streamflow. Many studies were undertaken to illustrate SAI (equation (2)) in examining rainfall and streamflow variability [56–58].

$$SAI = \frac{(x - \overline{X})}{\sigma}, \tag{2}$$

where x represents the rainfall, and $\overline{X}$ and σ denote the mean standard deviation of the rainfall or streamflow data.

2.4. Mk Test and Sen's Slope. In this study, the modified Mann–Kendall trend is used [59, 60]. This test is primarily innovated by Mann–Kendall [61, 62]. Mann–Kendall (MK) and Sen's slope tests are helpful for efficient water resource management [63]. Furthermore, these tests were used for the selected homogeneous hydrological and meteorological variables. Trend analysis is an effective method of noticing alterations in climatic and hydrological variables [63–68]. Hence, the Mann–Kendall test has been commonly applied to identify trends in hydroclimatic variables such as reference evapotranspiration, temperature, rainfall, and streamflow time series in different regions of the world [60, 62, 68–71]. In the current study, a modified Mann–Kendall trend test was used to notice the alteration in precipitation, streamflow, and average temperature. Mann–Kendall trend test and Sen's slope were applied to evaluate the trend of rainfall, streamflow, and mean annual temperature in the study area. The Mann–Kendall statistic output of the time series data was analyzed to compare whether the trend of the hydroclimatic variables has been noticed to the critical values to test or not. Input data arrangement must be in time sequential while performing the Mann–Kendall analysis. Thus, the first step is to govern the sign of the difference between consecutive sample results. Sgn ($X_j - X_k$) is an indicator function that results in the values 1, 0, or −1 referring to the sign of $X_j - X_k$ where $j > k$. A positive value is an indicator of an increasing (upward) trend and a negative value is an indicator of decreasing (downward) trend. This MK statistic (S) is given by the following equations (3) and (4):

$$\left\{ s = \sum_{i=1}^{n=1} \sum_{j=1+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \text{where} \theta = \left(x_j - x_i\right). \right. \tag{3}$$

$$\operatorname{sgn}(\theta) = \begin{cases} +1 & \\ 0 & \text{if} \\ -1 & \end{cases} \begin{bmatrix} \theta > 0 \\ \theta = 0 \\ \theta < 0 \end{bmatrix}, \tag{4}$$

where x_j and x_i represent the data points in period j and I, while the size of the data series is larger than or equivalent to ten ($n \geq 10$); since $n \geq 10$, the MK test is then categorized by a standard distribution with the mean E (S) = 0 and variance Var (S) is given as

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)\right], \quad (5)$$

where S and V (S) are Kendall's statistics and variance (equation (6)), respectively.

$$Zs = \begin{cases} \dfrac{s-1}{\sqrt{Var(s)}} & \\ 0 & \text{if} \begin{bmatrix} S>0 \\ S=0 \\ S<0 \end{bmatrix}. \\ \dfrac{s+1}{\sqrt{Var(S)}} & \end{cases} \quad (6)$$

In a Z test, the null hypothesis (H_o) implies no trend, and the alternative hypothesis (H_a) means a significant change in time series. The positive Z value indicates an increasing trend, whereas the negative z value indicates a decreasing trend. A significant trend at 0.1, 0.05, and 0.01 significance levels exist when the $|Z| > 1.645$, $|Z| > 1.96$, and $|Z| > 2.576$, respectively [59, 72]. Thus, in the current study, 90, 95, and 99% confidence levels were applied to analyze the hypothesis.

Sen's slope test [73] calculates the extent of the identified trends. Numerous studies [63, 71, 74, 75] used Sen's slope estimator for trend detection. This test calculates both the slope (i.e., the linear rate of alteration) and intercept. Thus, according to Sen's method of analysis first, a set of linear slopes is calculated as

$$Q_i = \frac{x_j - x_k}{j-k}, \quad \text{for } i = 1\ldots, N, \quad (7)$$

where x_j are the data values at j and x_k give the data values at k ($j > k$). When there is one data point in each time period, then $N = (n(n-1)/2)$, where n is the number of time periods. However, if there are more data points then, $N < (n(n-1)/2)$, where n is the total number of observations. The values of N are arranged from minimum to maximum values. Then, the median of slope or Sen's slope estimator (Q_{mid}) was computed as

$$Q_m = \begin{cases} \dfrac{Q_{N+1},}{2} & \text{if } N \text{ odd}, \\ \dfrac{Q_{(N/2)} + Q_{(N+1/2)}}{2}, & \text{if } N \text{ odd}. \end{cases} \quad (8)$$

When the value $Q_{mid} > 0$, it indicates an increasing trend, whereas $Q_{mid} < 0$ represents a decreasing trend.

2.5. Spearman's Rho (SR) Test. The SR test [76, 77] is similar to the MK method and is a nonparametric test. Spearman's rho (SR), the test is a simple method with uniform power for linear and nonlinear trends and is frequently used to confirm the absence of trends [78, 79]. In this test, the null hypothesis (H_0) is that all the data in the time series are independent and identically distributed, while the alternative hypothesis (H_1) is that increasing or decreasing trends exist [80, 81]. The SR test statistic D and the standardized test statistic Z_{SR} is computed as follows:

$$D = 1 - \frac{6\sum_{i=1}^{n}(R_i - i)^2}{n(n^2-1)}, \quad (9)$$

$$Z_{SR} = D\sqrt{\frac{n-2}{1-D^2}}, \quad (10)$$

where R_i is the rank of i^{th} observation X_i in the time series and n is the length of the time series. Positive values of Z_{SR} indicate upward trends, while negative Z_{SR} indicates downward trends in the time series.

3. Results and Discussion

3.1. Monthly and Seasonal Rainfall Characteristics. The mean monthly rainfall of the stations in the Ghba subbasin varied from 1 to 252 mm in the period 1952–2017, as shown in Figure 2. Relatively, Figure 2 shows the monthly rainfall was low from October to February but started to increase in June Besides, comparatively heavy rainfall was received between June and August, with the maximum mean monthly rainfall received in August at the Abi-Adi station. The minimum monthly rainfall was recorded in all stations and the lowest rainfall occurred in the dray season (October through January). As shown in Figure 2, the mean monthly rainfall in the Siluh, Genfel, and Agulai catchments varied almost similar from 2.4 to 196, 1.2 to 195, and 1.2 to 194 mm, respectively. However, the mean monthly rainfall in the Tahtay Ghba catchment varied from 1 mm to 252 mm. Thus, according to the data series in the study area, the minimum rainfall was documented in December and the maximum in August.

3.2. Interannual and Temporal Rainfall Variability. The chart in Figure 3 displays the annual rainfall of the 11 rainfall stations in the Ghba subbasin; the annual rainfall varied from 280 to 1191 mm in the analysis period. In the current study, the Hagere Selam and Wukro stations recorded the highest and lowest annual rainfall, respectively, as shown in Figure 3. For simplicity to discuss the interannual and temporal variability the stations were categorized into two clusters according to their record length.

The chart in Figure 4 displays the annual and seasonal rainfall variabilities of the first categorized group based on the length of observation, i.e., 35 years (1983–2017). In this category, annual rainfall varied from 380 to 1191 mm at Adigudem and Hagereselam stations, respectively. The variability of catagory1 stations showed a similar increasing and decreasing pattern except for a few years with a tremendously high amount of rainfall. Thus, high rainfall amount was recorded at Hagere Selam and Abi-Adi in 1969

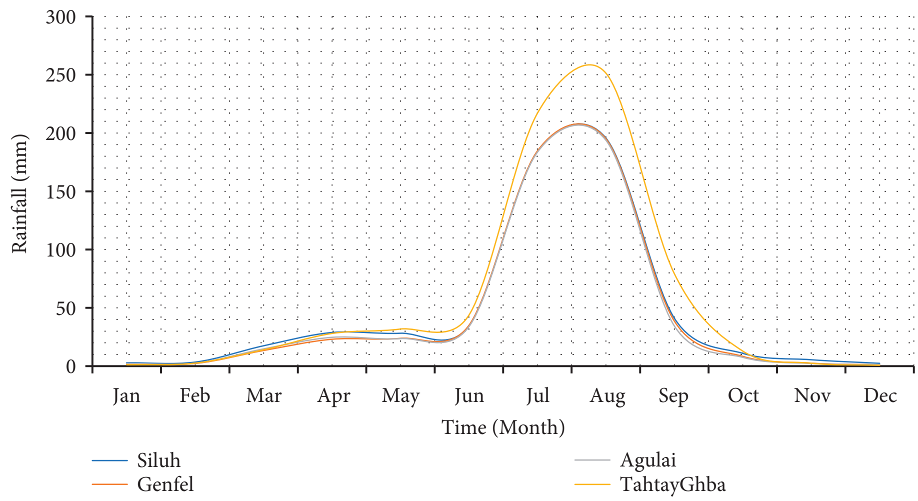

Figure 2: The mean monthly rainfall (mm) at Siluh, Genfel, Agulai, and Tahtay Ghba catchments.

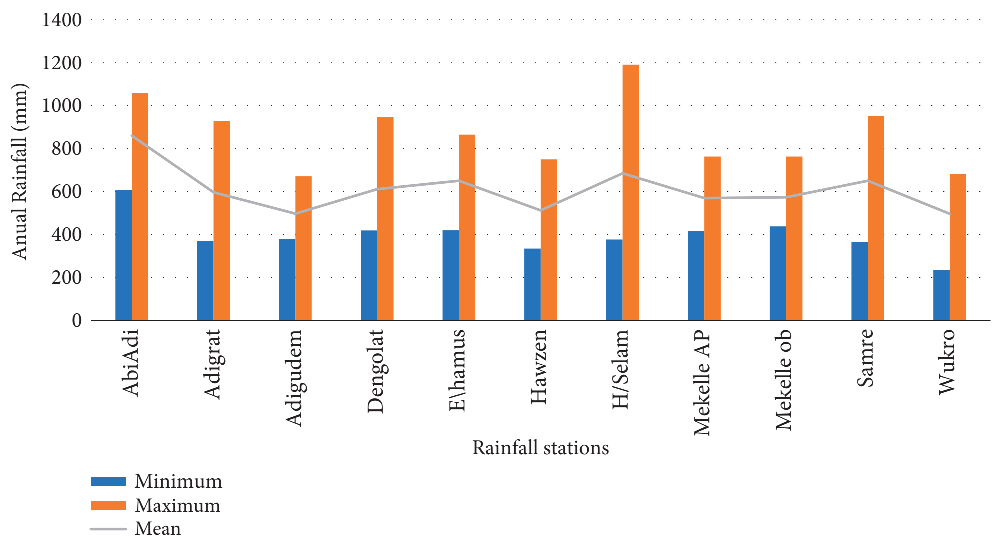

Figure 3: The annual rainfall for the 11 stations of the study area.

and 2016, respectively. In category-one stations; the annual rainfall pattern indicated a similar variability or no significant change as shown in Figure 4.

The chart in Figure 5 displays the annual and seasonal rainfall variability of the second categorized group based on the length of observation, i.e., from 43 up to 65 years, in total (1953–2017). The variability of rainfall in category two is shown in Figure 5; the annual rainfall varied from 280 mm at Wukro to 978 mm at Dongelat, while the annual temporal rainfall variability indicated a similar pattern of rise and fall in a majority of stations. However, there was no significant decreasing pattern in recent years in all stations.

The summary of descriptive statistical analysis for the 11 rainfall stations located in Ghba subbasin is given in Table 2. The annual skewness presented that 64% of the stations were approximately symmetrical while 26% were moderately symmetrical. Besides, all stations indicated a Z-score of skewness and kurtosis closer to zero, telling no significant difference from normality [82, 83]. The general indication of coefficient of variance (CV) is as follows: a CV of <20 has small or no variability, a CV of 20–30% has moderate variability, and a CV of >30% has high variability [84, 85]. In this study, some annual rainfall variability stations were detected in three stations: Hagere Selam, Samre, and Wukro. The seasonal variability was also tested in order to evaluate the full rainfall characteristics that occurred in the period 1952–2017. The two rainfall seasons selected were June–September (rainy season) and March–May (short rainy). The rainy season rainfall showed a slightly similar result as that of the annual rainfall variability. Out of eleven rainfall stations, around 73% of the stations showed the mean annual rainfall had a CV of less than 20%, while 27% of stations indicated a CV between 20 and 26%, as given in Table 2. Hence, this reviled in the annual time series eight stations showed no rainfall variability, and three stations showed a moderate variability. In the rainy seasonal period, except Abi-Adi station all stations are characterized by moderate variability. However, as given in Table 2, the period of dry season rainfall showed that 100% of the stations had a CV > 30 which indicates high variability.

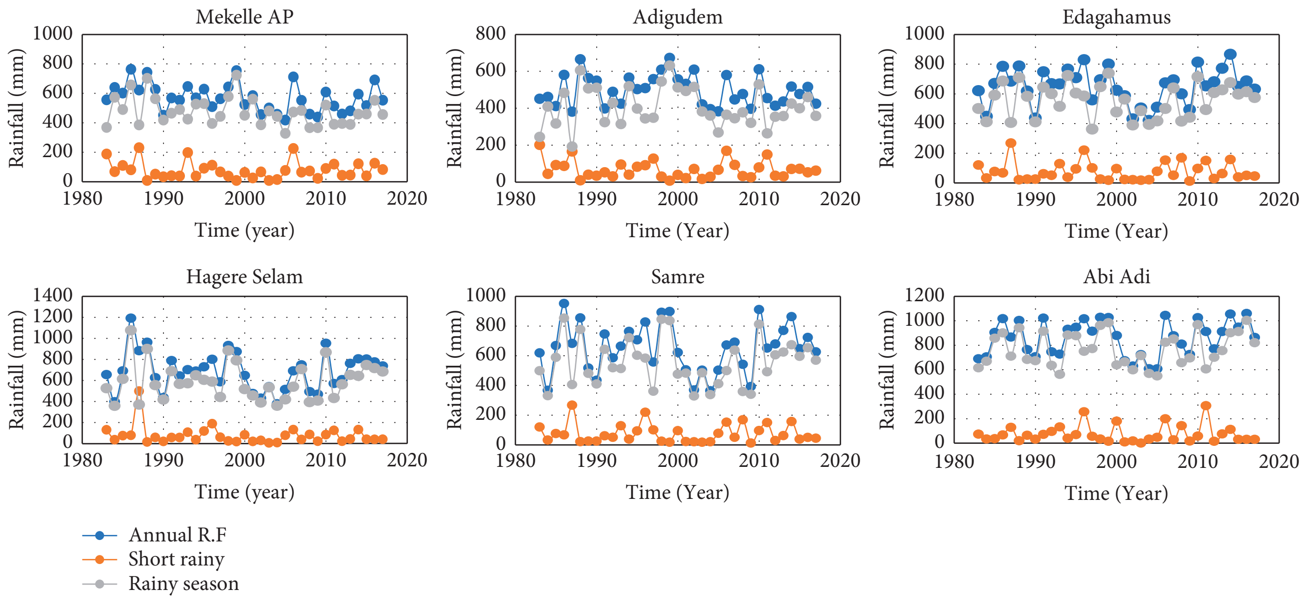

Figure 4: Seasonal temporal variability of rainfall (mm) in stations of 35 years of observation.

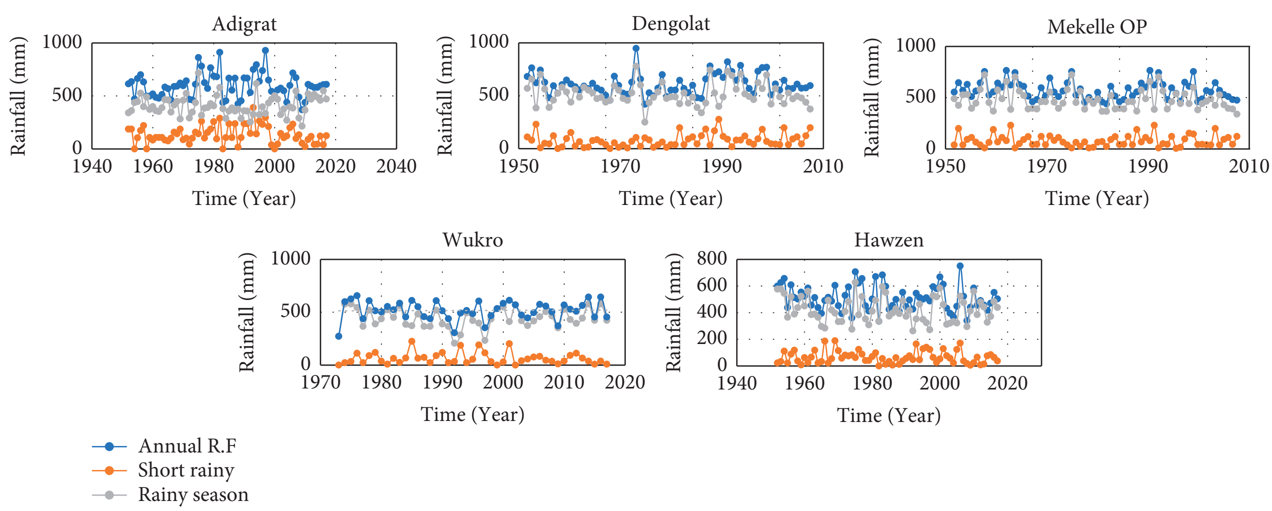

Figure 5: Seasonal temporal variability of rainfall (mm) in stations of 43–65 years of observation.

The chart in Figure 6 displays the SAI of the annual rainfall for sample rainfall stations in the Ghba subbasin. This figure shows that the negative anomaly varied from 42% to 71% of the total number of observations at Edaga Hamus and Mekelle AP, respectively. On seasonal time series, short rainy (MAM) and the rainy season (JJAS) showed a negative anomaly between 45% to 67% and 45% to 65% of the observations, respectively. The short rainy (MAM) rainfall displayed a higher negative anomaly at Abi-Adi, whereas the rainy season (JJAS) showed a higher negative anomaly at Mekelle AP. In some stations (e.g., Hagere Selam and Samre) a negative anomaly was observed in consecutive years.

3.3. Monthly and Seasonal Streamflow Characteristics. The mean monthly streamflow of the four catchments of the Ghba subbasin is shown in Figure 7 where Ghba 1 and Ghba 2 hydro stations are located in the Tahtay Ghba catchment. The Ghba River discharge was low from mid-October to mid-February but started to increase in the short rainy season (May) as shown in Figure 7. The highest flow was recorded in July at all stations except in Ghba 1 where the highest flow was recorded in August. The maximum streamflow was 53.6 cubic meters per second (m^3/s) in August at Ghba 1, while the minimum was 0.04 m^3/s in the dry season in October at Genfel station. The results from all of the stations in the subbasin showed a low flow during the dry season (October–February) but the increase started in the short rainy season (March) and slightly declines from May to June and starts to increase in the end of June, as shown in Figure 7.

3.4. Interannual and Temporal Streamflow Variability. The annual streamflow of 6 stations in the Ghba subbasin is shown in Figure 8. The annual flow varied from a minimum of 0.5 m^3/s at Ilala station to a maximum of 19.14 m^3/s at Ghba 1 station.

Table 2: Summary of descriptive statistical analysis of rainfall stations.

S/N	Station	Analyses period	Annual					Rainy season		Short rainy	
			Mean (mm)	SD	CV (%)	Skewness	Kurtosis	Mean (mm)	CV (%)	Mean (mm)	CV (%)
1	Abi-Adi	1983–2017	860	142	16	−0.236	−1.257	766	18	70	96
2	Adigrat	1970–2017	597	115	19	0.646	0.506	409	22	134	61
3	Adigudem	1983–2017	498	81	16	0.366	−0.888	406	25	66	70
4	Dengolat	1975–2017	612	98	16	0.779	0.813	516	20	77	77
5	E/hamus	1983–2017	651	118	18	−0.339	−0.616	553	20	76	81
6	Hawzen	1971–2017	512	92	18	0.355	−0.415	422	22	65	70
7	H/Selam	1983–2017	685	180	26	0.412	0.129	589	29	74	113
8	Mekelle AP	1983–2017	570	92	16	0.372	−0.605	476	20	77	75
9	Mekelle Ob	1953–2017	574	87	15	0.573	−0.381	479	20	78	70
10	Samre	1983–2017	650	161	24	−0.053	−0.749	553	27	61	81
11	Wukro	1973–2017	497	98	20	−0.592	0.080	428	23	49	88

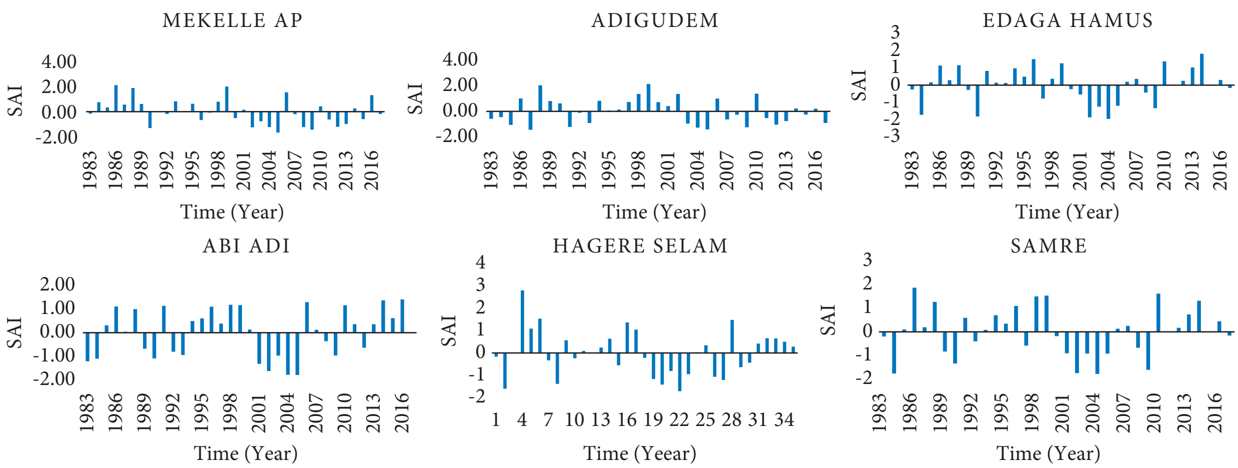

Figure 6: The annual standardized anomaly index (SAI) of rainfall stations in the subbasin.

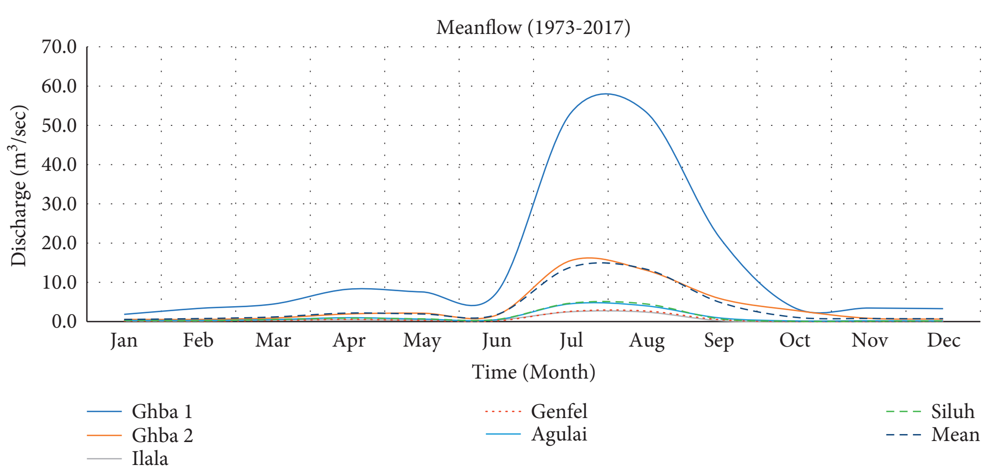

Figure 7: The mean monthly river discharge at six stations in the Ghba subbasin.

The chart in Figure 9 displays the annual streamflow variability of the subbasin at six stations. The hydrographs had a similar pattern on annual, rainy (JJAS) and short rainy (MAM) seasons river discharge. There were a few years when the high flow was recorded. Extreme streamflow was recorded at the Ghba 1, Ghba 2, and Ilala stations in 2001, 1996, and 1984, respectively. As identified by the graphical and linear trend on annual streamflow shown in Figure 9, a hydrology regime change in flow reduction was detected in all stations except in Agulai and Siluh stations. However, the temporal streamflow variability with decreasing pattern shown in Figure 9 was exhibited in all stations.

The summary of descriptive statistics of the six streamflow stations in Table 3 showed the annual streamflow in all the stations indicated a Z-score of skewness and kurtosis not closer to zero, indicating a significant difference

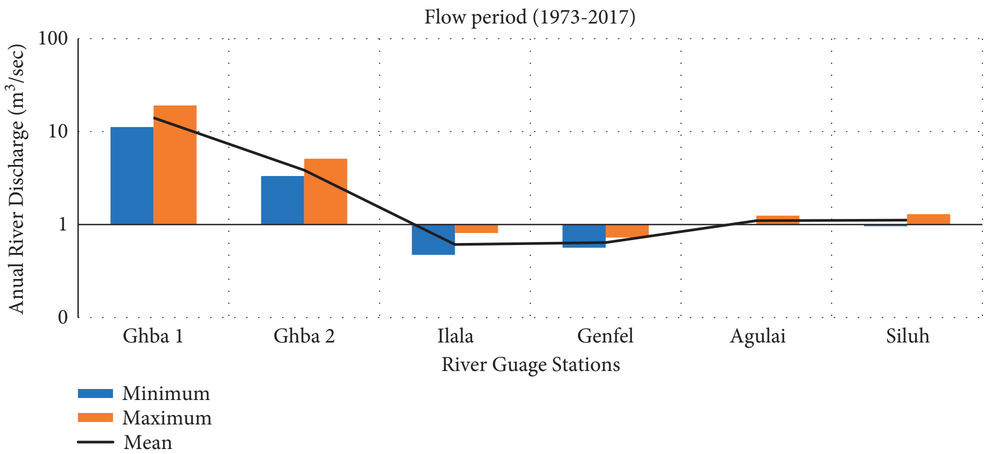

Figure 8: The annual river discharge of Ghba subbasin at six stations.

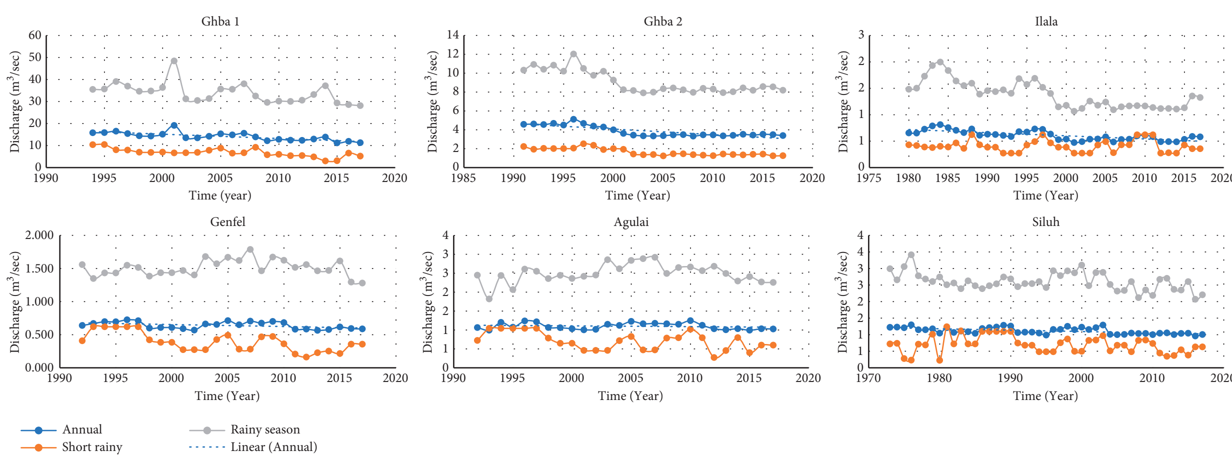

Figure 9: The temporal variability in the annual and seasonal streamflow in the subbasin.

from normality, i.e., positively skewed showed us the decreasing trend of the data series or somehow a change in the hydrology regime.

In this study, as can be seen in Table 3, all the stations in the annual and rainy season (JJAS) variability test showed normal (CV < 20), whereas the streamflow variability test in the short rainy season (MAM) showed a high CV from 23.2% to 36.5% in all the stations. Only two stations showed moderate variability, with a CV of 23.2% and 27% at Ghba 1 and at Ghba 2, respectively.

The chart in Figure 10 displays the SAI of the annual streamflow for all hydro stations in the Ghba subbasin. The figure shows that the negative anomaly varied from 51% to 69% of the total number of observations. Most of the negative anomalies are in a consequent year giving signals of a possible change in the hydrology regime.

3.5. Independence, Stationarity, and Homogeneity Tests. The results of the von-Neumann independence, Wald–Wolfowitz stationarity, and Mann–Whitney homogeneity tests applied on the daily rainfalls (in millimeters) and flow discharge (in m^3/sec) series recorded were analyzed using standardized variates, Skewness, Kurtosis, and Z-value. The critical values of the Z-score were ±1.645, ±1.96, and ±2.576 at 0.1, 0.05, and 0.01% significance level, respectively. For a probability of 0.1, 0.05, and 0.01% significance level, the series was independent at 11 rainfall and six hydro stations because the von-Neumann's Q statistic test results were greater than the critical values. For the same significance level, the Wald–Wolfowitz stationarity test shows not stationary for 11 rainfall and six hydro stations because the standardized variates test results were less than their tail probability. Finally, the Mann–Whitney homogeneity test was conducted and the tail probability of the series for 11 rainfall and six hydro stations was homogeneous because the Mann–Whitney homogeneity test statistic result was greater than the critical values. Thus, out of 16 rainfall and six hydro stations, the trend analyses were performed for the homogeneous, nonstationary, and independent 11 rainfall and six hydro stations.

3.6. Hydroclimatic Trend Analysis

3.6.1. Rainfall Data Series. Annual and seasonal trend analysis was performed for the selected homogeneous rainfall data series. A summary result of the Mann–Kendall

Table 3: Summary of descriptive statistical analysis of streamflow stations.

S/N	Station	No. of observations	Annual					Rainy season		Short rainy	
			Mean (m^3/sec)	Sd	CV (%)	Skewness	Kurtosis	Mean (m^3/sec)	CV (%)	Mean (m^3/sec)	CV (%)
1	Ghba 1	24	14.10	1.81	12.9	0.579	0.459	33.9	13.0	6.8	27.0
2	Ghba 2	27	3.84	0.56	14.6	0.765	−1.025	9.0	12.9	1.7	23.2
3	Ilala	26	0.64	0.05	8.0	0.087	−1.478	1.5	8.1	0.4	36.5
4	Genfel	26	0.64	0.05	8.0	0.087	−1.478	1.5	8.1	0.4	36.5
5	Agulai	26	1.10	0.08	7.5	0.341	−1.308	2.5	9.8	0.7	32.6
6	Siluh	45	1.12	0.10	8.6	0.267	−1.246	2.6	10.3	0.7	36.3

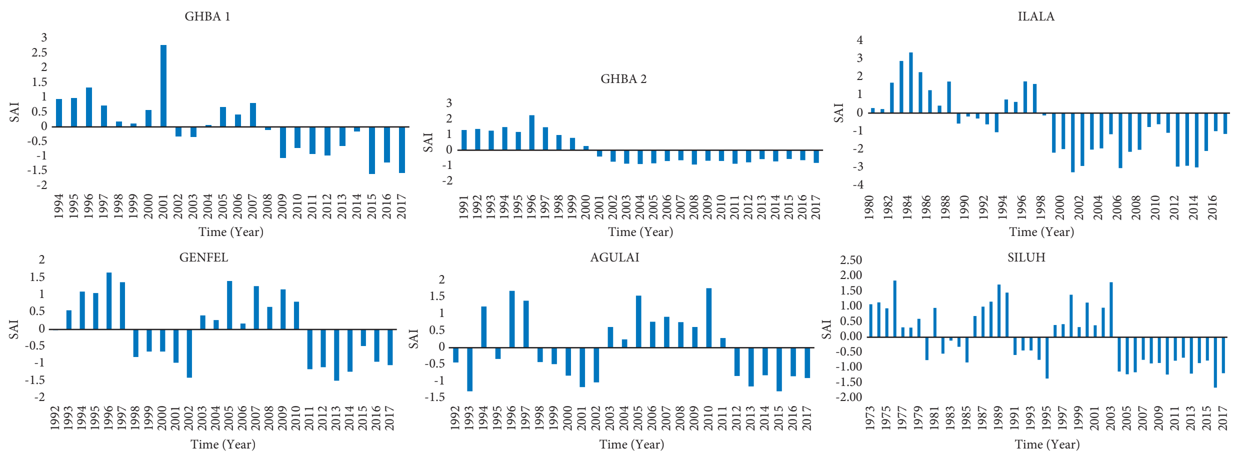

Figure 10: The annual standardized anomaly index (SAI) of streamflow stations in the subbasin.

(MK), Spearman's rho (SR), and Sen's slope (Q) tests of seasonal, and annual rainfall of 11 stations is given in Table 4. The analysis was checked against 1%, 5%, and 10% significant levels and is marked with bold and its P values (in brackets). The annual and seasonal rainfall trend at all stations has not shown a significant trend except at Dengolat (5% significant level) in the short rainy season and Mekelle AP (10% significant level) at annual rainfall, while five of the stations showed a decreasing (negative) trend and six an increasing trend at annual and rainy season. In the short rainy season, seven stations showed a decreasing trend while four stations showed a positive increasing trend. The dry season indicated no significant trend at all stations, while 10 of the stations showed a positive increasing trend and one decreasing trend. Moreover, a negative *Zs* and *SR* value was detected in about 45%, 63.63%, 45%, and 9.1% of the stations in annual, short rainy (MAM), rainy (JJAS), and dry seasons, respectively.

3.6.2. Temperature Data Series. Annual and seasonal trend analysis was performed for the selected homogeneous temperature data series. A summary result of the Mann–Kendall (MK), Spearman's rho (SR), and Sen's slope (Q) tests of seasonal, and annual temperature of 11 stations is given in Table 5. The analysis was checked against 1%, 5%, and 10% significant levels and is marked with bold and its P values (in brackets). The annual and seasonal temperature trend at eight stations has not shown a significant trend, whereas at Abi-Adi and Mekelle AP (5% significant level) in all seasons and at Adigudem (10% significant level) in all seasons except in dry season has shown a significant trend. Moreover, only one of the stations showed a decreasing (negative) trend and 10 stations showed an increasing trend during annual and seasonal periods. Moreover, a negative *Zs* and *SR* value was detected in about 9.1%, of the stations in annual, short rainy (MAM), rainy (JJAS), and dry seasons.

3.6.3. Discharge Data Series. Annual and seasonal trend analysis was performed for the selected homogeneous streamflow data series. A summary result of the Mann–Kendall (MK), Spearman's rho (SR), and Sen's slope (Q) tests of seasonal, and annual streamflow of 6 stations is given in Table 6. The analysis was checked against 1%, 5%, and 10% significant levels and is marked with bold and its P -values were all at a 5% significant level. Moreover, a negative *Zs* and *SR* value was detected in all stations either at annual, short rainy (MAM), rainy (JJAS), and dry seasons or all as given in Table 6.

As can be seen in Figure 11, the overall significant trend is on hydroclimatic data with increasing (+), decreasing (-), and no change (0) trends on annual rainfall, temperature, and streamflow.

3.7. Relationship between Rainfall and Streamflow. As shown in Figure 12 , the annual rainfall and streamflow at six hydro gauging stations were evaluated and induced a positive correlation coefficient which varied from 0.18 to 0.67. The

Table 4: Summary of the rainfall trend test using Mann–Kendall, SR, and Sen's slope.

N	Station	Annual			Rainy season			Short rainy			Dry season		
		Zs	SR	Sen's slope	Zs	SR	Sen's slope	Zs	SR	Sen's slope	Zs	SR	Sen's slope
1	Abi-Adi	0.12	0.11	1.75	0.09	0.08	1.76	−0.09	−0.08	−0.25	−0.01	−0.01	0.00
2	Adigrat	0.02	0.02	0.16	0.03	0.03	0.21	−0.02	−0.02	−0.06	0.02	0.01	0.03
3	Adigudem	−0.06	−0.05	−0.78	−0.01	−0.01	−0.18	−0.08	−0.07	−0.39	0.05	0.04	0.11
4	Dengolat	0.05	0.04	0.34	−0.08	−0.07	−0.54	0.18 (0.03)	0.17	0.68	0.02	0.02	0.00
5	E/hamus	0.02	0.02	0.31	0.06	0.07	0.62	−0.03	−0.02	−0.11	0.12	0.11	0.25
6	Hawzen	−0.12	−0.11	−0.80	−0.10	−0.10	−0.78	−0.02	−0.02	−0.06	0.02	0.02	0.00
7	H/Selam	−0.44	−0.45	−0.01	0.07	0.06	1.99	−0.04	−0.05	−0.59	0.09	0.08	0.23
8	Mekelle AP	−0.23 (0.05)	0.22	−3.42	−0.17	−0.18	−1.83	0.01	0.01	0.05	0.11	0.12	0.21
9	Mekelle Ob	−0.13	−0.12	−0.86	−0.13	−0.14	−0.65	0.01	0.01	0.00	0.03	0.02	0.00
10	Samre	0.03	0.04	0.40	0.06	0.05	1.07	−0.03	−0.02	−0.11	0.11	0.12	0.25
11	Wukro	0.13	0.12	0.88	0.07	0.06	0.58	0.08	0.07	0.22	0.07	0.06	0.03

Table 5: Summary of temperature trend test using Mann–Kendall and Sen's slope.

S/N	Station	Annual			Rainy season			Short rainy			Dry season		
		Zs	SR	Sen's slope	Zs	SR	Sen's slope	Zs	SR	Sen's slope	Zs	SR	Sen's slope
1	Abi-Adi	0.46 (0.02)	0.53	0.02	0.36	0.35	0.01	0.40	0.41	0.03	0.29	0.28	0.02
2	Adigrat	−0.09	−0.10	0.16	−0.07	0.06	0.00	−0.04	0.05	0.00	−0.04	0.03	0.00
3	Adigudem	0.20 (0.09)	0.19	0.02	0.26	0.24	0.02	0.35	0.36	0.03	0.08	0.09	0.01
4	Dengolat	0.03	0.02	0.00	0.01	0.02	0.00	0.00	0.00	0.68	0.01	0.01	0.00
5	E/hamus	0.06	0.07	0.00	0.01	0.01	0.00	0.04	0.05	0.00	0.06	0.05	0.00
6	Hawzen	0.06	0.05	0.00	0.04	0.06	0.00	0.04	0.04	0.00	0.06	0.07	0.00
7	H/Selam	0.4	0.06	0.00	0.04	0.05	0.00	0.01	0.01	0.00	0.01	0.01	0.00
8	Mekelle AP	0.49 (0.02)	0.51	0.03	0.42	0.44	0.02	0.38	0.37	0.03	0.36	0.35	0.02
9	Mekelle Ob	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00
10	Samre	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00
11	Wukro	0.08	0.07	0.00	0.02	0.02	0.01	0.02	0.00	0.22	0.07	0.06	0.00

Table 6: Summary of the streamflow trend test using Mann–Kendall and Sen's slope.

Station	Annual			Rainy season			Short rainy			Dry season		
	Zs	SR	Sen's slope	Zs	SR	Sen's slope	Zs	SR	Sen's slope	Zs	SR	Sen's slope
Ghba 1	−0.62	−0.61	−0.19	−0.45	−0.44	−0.32	−0.58	−0.53	−0.08	−0.65	−0.64	−0.17
Ghba 2	−0.48	−0.51	−0.05	−0.44	−0.42	−0.10	−0.59	−0.55	−0.04	−0.58	−0.56	−0.02
Ilala	−0.51	−0.49	−0.01	−0.57	−0.53	−0.02	−0.07	−0.08	0.00	0.02	0.02	0.00
Genfel	−0.28	−0.27	0.00	0.09	0.07	0.00	−0.47	−0.48	−0.02	−0.15	−0.13	0.00
Agulai	−0.17	−0.15	0.00	0.09	0.08	0.00	−0.32	−0.33	−0.02	−0.15	−0.14	0.00
Siluh	−0.39	−0.37	0.00	−0.30	−0.29	−0.01	−0.20	−0.19	−0.01	0.08	0.07	0.00

correlation coefficient was 0.18, 0.27, and 0.67 at Agulai, Siluh, and Ghba 1, respectively. By comparison, the correlation was very low in one station at Agulai (0.18), and low in four stations: Siluh (0.27), Ilala (0.29), Ghba 2 (0.30), and Genfel (0.32). While one station at Ghba 1 showed relatively higher a positive correlation of 0.67. Hence, the current finding revealed the existence of a positive correlation relationship in a different time series of the tested stations.

4. Conclusion and Recommendations

The current study presents a full statistical analysis of the presence of trends and point changes in rainfall, temperate, and streamflow in the Ghba basin. The analyses were done for 11 rainfall and temperature stations as well as six streamflow monitoring stations. Linkages between the trends in rainfall, temperature, and streamflow across the whole subbasin were cautiously surveyed at different scales. Annual and seasonal trend analysis for rainfall, temperature, and discharge was performed at each station. To meet the main objective of this study, i.e., to understand the hydroclimatic variables trend, characterization, the Mann–Kendall test, SR, and Sen's slope test estimator were employed. Following these analyses, the main driving force for streamflow reduction over the subbasin was assessed.

The finding of this study indicated the occurrence of temporal rainfall variability. Out of eleven rainfall stations, around 73% of the stations showed the mean annual rainfall had a CV of less than 20%, while 27% of stations indicated a CV between 20 and 26%. Hence, this reviled in the annual time series eight stations showed no rainfall variability and three stations showed a moderate variability. In the rainy

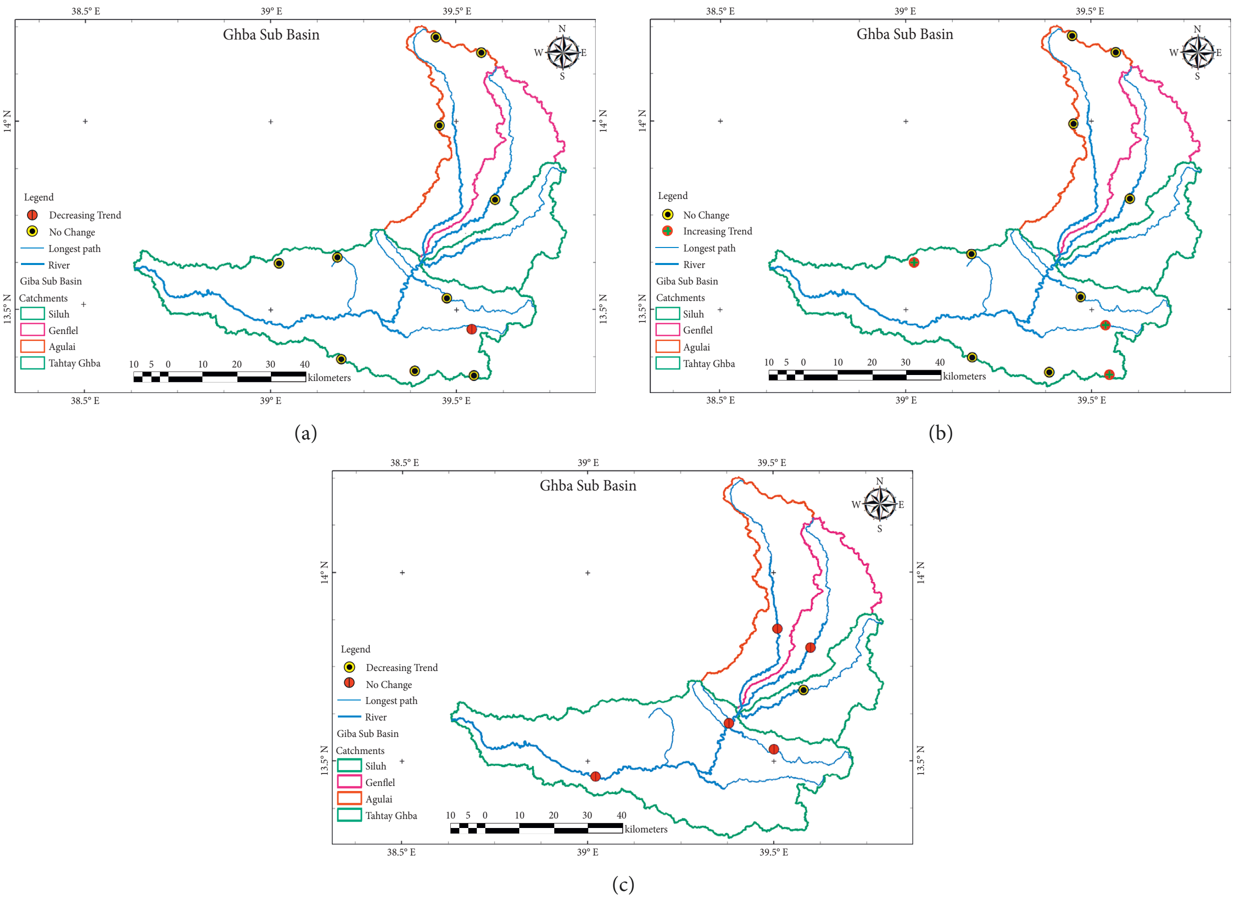

FIGURE 11: Location of hydroclimatic stations with increasing (+), decreasing (−), and no change (0) trends on annual rainfall (a), temperature (b), and streamflow (c).

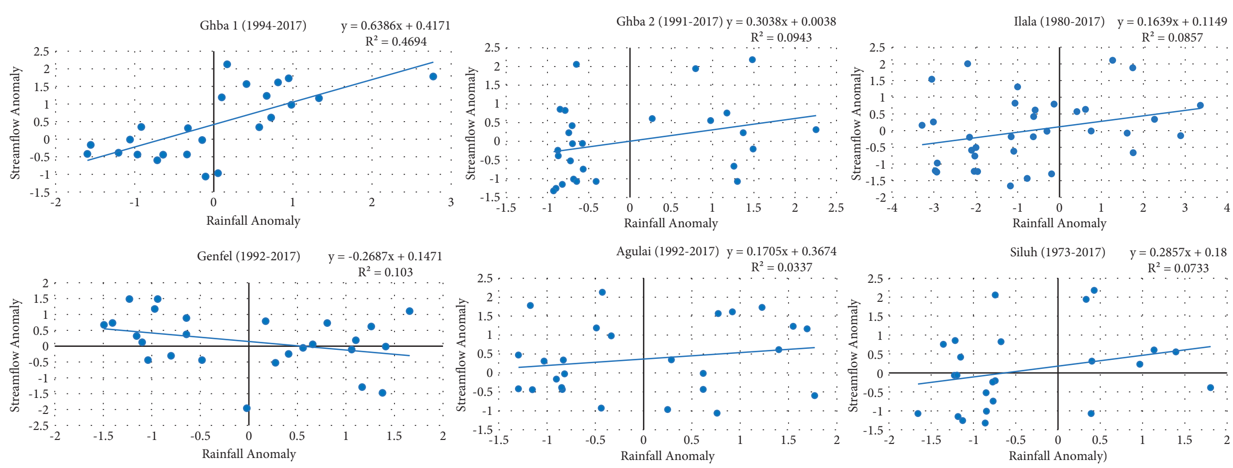

FIGURE 12: Relationship between rainfall and streamflow trend in the Ghba subbasin.

seasonal period, except Abi-Adi station all stations were characterized by moderate variability. However, during the period of the dry season rainfall showed that 100% of the stations had a CV > 30 which indicates high variability. Understanding this variability trend is key to the water allocation plan in the subbasin.

In order to understand the seasonal comparison of changes in hydroclimatic variables, the analyses were done for three seasons: rainy, short rainy, and dry.

The SAI in annual and seasonal time series indicated a negative anomaly. On seasonal time series, short rainy (MAM) and the rainy season (JJAS) showed a negative anomaly between 45% to 67% and 45% to 65% of the observations, respectively. Furthermore, the SAI result showed that most of the years exhibited negative anomalies in discharge, indicating a drier period. Moreover, a lot of large and small-scale irrigation schemes are found in Ghba subbasin [86, 87], especially in the Agulai and Genfel catchments, which could be directly affected by low water availability during short rainy (MAM). The occurrence of high streamflow variability combined with the expansion of irrigation in the subbasin influences agriculture and crop productivity, which aggravates the prevalence of food insecurity and drought in the subbasin.

The results of MK, Spearman's rho (SR), and Sen's slope tests showed a statistically significant decreasing annual discharge trends for all the stations, while no significant decreasing trend in annual rainfall was observed. Similar studies found the same result [6, 27]. The majority of rainfall stations exhibited no change trend in the mean annual rainfall for rainy and short rainy seasons. But, only one station at Mekelle AP showed a decreasing trend. The study found also a positive significant trend in the temperature of three stations. In general, the trends exhibited higher variability of discharge during the annual, rainy, short rainy, and dry seasons opposite to the rainfall trends. A weak relationship between rainfall and streamflow leads to assessing other factors of catchment characteristics change, catchment management interventions, and water abstractions upstream.

Based on the prior results and discussion, it can be decided that decreasing and increasing levels of rainfall, discharge, and temperature throughout the stations showed the change in hydroclimatic variables. This would propose that any climate and hydrological studies need to understand the variability and trends of a given dataset before applying for any future impact assessment.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The study described in this manuscript has been funded by MG Water Resource Consultancy Firm. The authors are extremely grateful to the Ethiopian National Meteorological Services Agency for providing climate data and the Ministry of Water and Energy (Ethiopia) for providing water resource data.

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