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Article

Agroclimatic Zone Based Analysis of Long-Term Rainfall Trends and Variability in the Wabi Shebele River Basin, Ethiopia

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Abstract: Any change in the amount and annual distribution of rainfall causes a major socioeconomic and environmental problem where rainfed agriculture is predominant. For that reason, the objective of this study was to determine the long-term variability and trends of precipitation in the Wabi Shebele River Basin (WSRB), Ethiopia. The basin was discretized into 7 local agroclimatic zones (ACZ) based on annual rainfall and elevation. In this study, the coefficient of variation (CV) was used to check the variability of rainfall and modified Mann-Kendall (MK) and Innovative Trend Analysis (ITA) methods were used to detect rainfall trends. For each ACZ, stations with long-term records and less than 10 % missing data were selected for further analysis. The mean annual rainfall in the basin ranges from 227.2 mm to 1047.4 mm. The study revealed most of the ACZs showed a very high variation in Belg/Spring season rainfall (CV % > 30) than Kiremt/Summer and annual rainfall. Trend analysis revealed that no uniform trend was detected among ACZs at each temporal scale. But, most ACZ in the arid and semi-arid areas showed a non-significant decreasing trend. In comparison, a similar result was observed using MK and ITA methods.

Keywords: agroclimatic zone; trend analysis; modified MK; ITA; Wabi Shebele

1. Introduction

Climate change is already affecting every inhabited region across the globe with human influence contributing to many observed changes in weather and climate extremes [1]. Specifically, Agricultural production is already being adversely affected by rising temperatures, increased temperature variability, changes in amounts and frequency of precipitation, a greater frequency of dry spells and droughts, the increasing intensity of extreme weather events, rising sea levels, and the salinization of arable land and freshwater [2]. Africa, due to its low adaptive capacity and high sensitivity of socio-economic systems, is one of the most vulnerable regions highly affected and to be affected by the impacts of climate change [3]. Ethiopia relies on low-productivity rainfed agriculture for a majority of its national income; consequently, the importance of the timing and amount of rainfall that occurs in Ethiopia cannot be overstated [4].

Agricultural production in Ethiopia highly depends on rainfall and it is predominantly rainfed [5,6]. The country generates most of the energy needed from hydropower plants which rely on the amount of water stored in the reservoirs. Thus, Ethiopia is vulnerable to climate variability, and climate change is likely to increase the frequency and magnitude of disasters [7–9]. These have made the country most susceptible to famine usually caused by drought [8]. The government of Ethiopia is currently implementing large-scale investments in hydropower and irrigation projects along the major river basins [10]. As a result, climate variability and trend analysis at appropriate spatial and temporal scales are crucial for understanding and mitigating problems in hydrology and water resources, such as water resource development, environmental protection, and ecological balance [11–13].

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In the past three decades, climate variability and trend analysis in metro-hydrological time series has been conducted by many researchers using different methods, data sources, and spatial and temporal scales. The Mann–Kendall test [14] is the most widely used test for detecting monotonic upward or downward trends in hydro-meteorological and environmental data on the assumption that the observations in the time series are not autocorrelated. This test is mostly supported by Sen's slope estimator for estimating the magnitude of a trend in the time series [15]. Both tests are non-parametric tests that do not require the data set to be normally distributed. Numerous studies used this method to estimate temporal trends for different climatic variables [7,8,13,16–23,25]. Simulation experiments demonstrated that the existence of autocorrelation in the time series alters the Mann–Kendall (MK) statistics [26–29]. Accordingly, checking autocorrelation in the time series became a common practice before any analysis of trend detection is performed using the MK test.

Recently, [30] developed the innovative trend analysis (ITA) method to avoid all the restrictive requirements for the statistical test in the MK trend test. The basis of the approach rests on the fact that if two time series are identical to each other, their plot against each other shows scatters of points along 1: 1 (45°) line on the Cartesian coordinate system [30,31]. National and international researchers have used the ITA method in different parts of the world [31–35]. The main limitation of the ITA method is that it does not allow the determination of the differences between each point and the 1:1 line are statistically significant [35].

Even though, most of the researchers adapted commonly used MK tests the spatial discretization resolution (size, spatial scale) and data source used for trend analysis varies. Different studies used a different spatial frames for analysis including station [5,7,16, 18,20,21,32,35], agroecosystem zonation [17,24,36], temperature-based zonation [16], and subbasin [4,7,11,18]. Similarly, the sources of the data used for the trend analysis also vary based on availability and accessibility. Observed station data is the most common source of data in climatic variabilities and trend analysis studies [8,16,18,31,35–37] in recent years, reanalyzed gridded satellite climatic data have been used in different studies [5,7,11,17,20,24,38].

Numerous studies were conducted on climate variability and trends analysis in Ethiopia and abroad [13,16,17,31–33,36,39–43]. Some of the studies include, Abay basin [7,17,32,44,45], Awash basin [8,36,40,46,47], Omo Gibe basin [10,23,24], and Tekeze basin [21,37,48]. Those studies revealed that the variability and trends of precipitation vary at different localities. The precipitation amount showed a general statistically decreasing trend [7,8,16,17,21,38], insignificant trends [18,46], and increasing trend [11]. In general, these studies revealed that there is no uniform temporal and spatial rainfall pattern in the world and particularly in Ethiopia.

Although climate variability and change have location-specific impacts especially in Ethiopia due to spatial and temporal variation of rainfall and topography variation, few studies have been carried out regarding precipitation variabilities and trends in the Wabi Shebele River basin (WSRB). In the upper and middle part of the basin, [33] investigated the spatiotemporal distribution and variability of rainfall in seasonal and annual time series using station data in MK and ITA tests. In the northern district of middle WSRB, [20] investigated the spatiotemporal variability and trends of rainfall and its association with Pacific Ocean SST in the West Harerge Zone of eastern Ethiopia using satellite-based rainfall data and the Mann-Kendall Trend Test. Because of unevenly distributed rainfall recording stations in the basin, a study based on station data may not be sufficient for water resources planning and decision-making. Therefore, this study investigated variations and trends in maximum daily, rainy seasons and annual precipitation over time in the upper, middle, and lower part of WSRB, at each agro-climatic zone, using modified MK after checking serial autocorrelation and ITA methods.

2. Materials and Methods

2.1. Study Area

Wabi Shebele River Basin (WSRB) is one of the largest river basins in Ethiopia in terms of area coverage. The basin, which occupies a total area of 189,655 km2 comprising nearly 17 % of the country's total land area, lies between 4.91° – 9.59° N latitude and 38.69° – 45.33° E longitude Figure 1. The basin is characterized by a broad range of elevations varying from 179 m.a.s.l along the Ethio-Somalia border in the south to more than 4188 m.a.s.l in the northwest part of the Bale mountains. More than 80 % of the area has an elevation of less than 1500 m considered low land (arid and semi-arid) in the country. The basin, the upstream is characterized by steep valley slopes while the lowland has gentle slopes. Annual average precipitation over the state varies from 227 mm in the southeast to 1240 mm in the northwest with the average annual temperature ranging from 6.29 °C in the northwest to 35.98 °C in the southeast. Due to bimodal rainfall distribution in the basin, there are two rainy seasons, the main rainy season (Kiremt/summer) spans from June to September and the short rainy season (Belg/spring) extends from March to May. The dominant soil types are Gypsisols, Calcisols, and Leptosols covering 68 % of the basin. A large percentage of the population in the highlands depends on crop cultivation while the lowlanders, in general, are pastoralists.

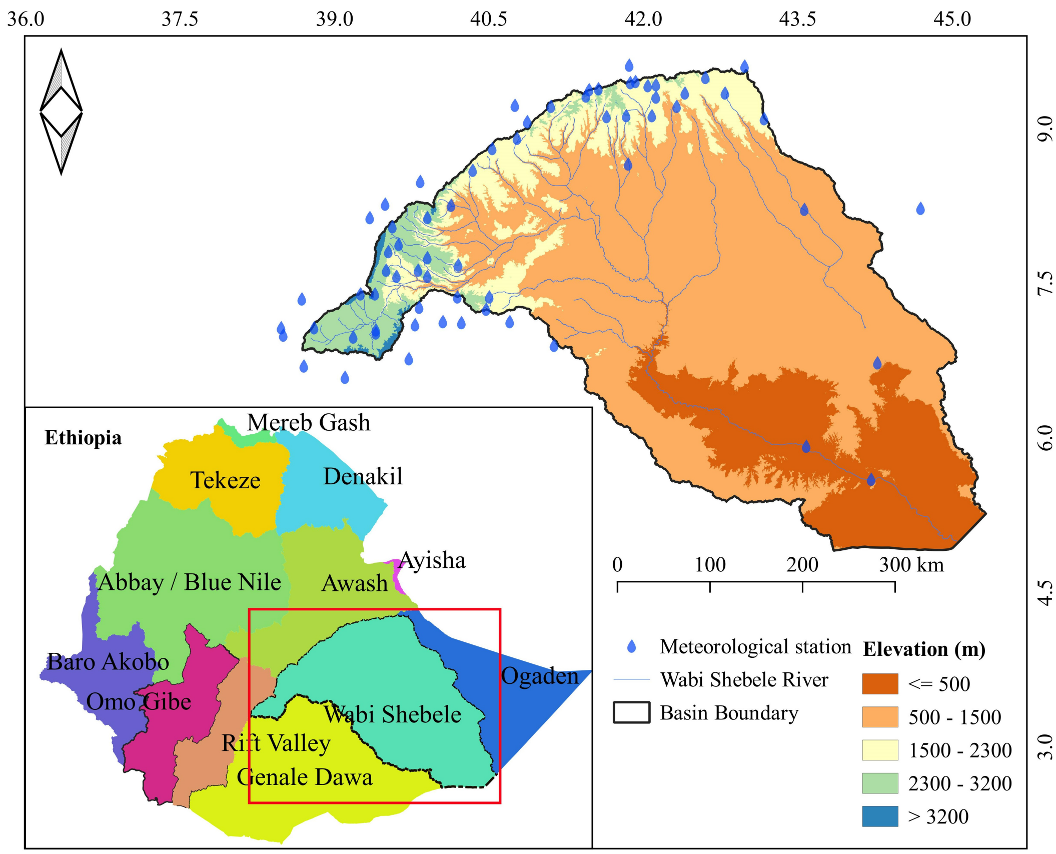

Figure 1. Location Map of Wabi Shebele River Basin (WSRB)

2.2. Methods

2.2.1. Data Preparation

For this study, observed daily rainfall data from 44 stations for the period from 1987 to 2016 was obtained from the National Meteorology Agency (EMA). Which was aggregated to seasonal and annual precipitation for analysis of rainfall distribution. The area is bimodal where two rainfall seasons are recorded March, April, and May (MAM) and June, July, August, and September (JJAS) as spring (light rainy) and summer (heavy rainy) seasons respectively Figure 2. But, in the low land area, spring is a heavy rain season than summer which is occurred in September, October, and November (SON). The major concern of this research was water resources-related climatic parameters such as maximum daily, Belg/Spring, Kiremt/Summer, and annual precipitation were considered in the analysis. The monthly values were summed up to prepare the seasonal precipitation and daily maximum data were extracted as required for the analysis. After local agroclimatic zonation, one station from each ACZs was selected based on the long-term availability of records and less percent of missing records. Even though 9 ACZs were identified in the basin, due to a lack of recording stations and less area coverage (less than 1 %) stations representing the two ACZs were not found so only 7 ACZs were considered in this study. The missing data were filled using TAMSAT satellite-based reanalyzed rainfall data because of the unpredictability of the climate in the tropical zone to use statistical methods. The details of the meteorological stations used in this study showed in Table 1.

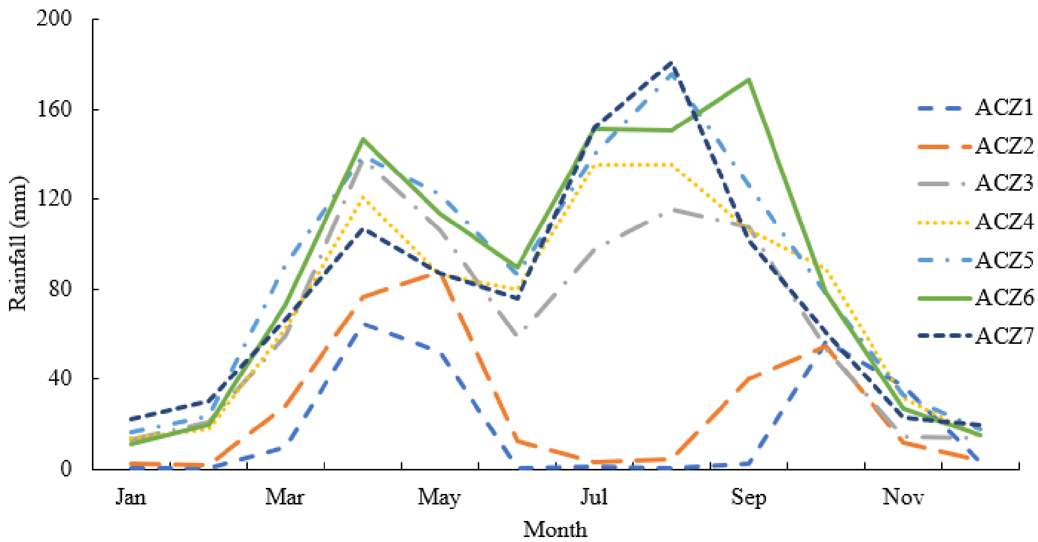

Figure 2. Rainfall Monthly Distribution in WSRB in each agroclimatic zone

2.2.2. Agroclimatic Zonation

There are 17 local agroclimatic zones (ACZs) in Ethiopia based on the annual average rainfall (AARF) amount and elevation of the area [51]. DEM of 30 m grid size was used to classify the basin into 5 elevation classes and 2 rainfall zone. The annual average rainfall spatial distribution map was prepared using an interpolation algorithm in the QGIS environment. The basin consists of 9 out of 17 ACZs detail presented in Table 1 and Figure 3. The arid and semi-arid area covers 81.29 % of the basin whereas only 18.79 % of the basin is considered as humid. This makes the basin very vulnerable to climatic-related issues, especially rainfall. ACZ1, ACZ2, ACZ3, and ACZ 4 are further categorized as dry regions whereas ACZ5, ACZ6, and ACZ7 are categorized as humid regions. On other hand, ACZs are categorized as Low land (ACZ1, ACZ2, and ACZ5), Mid-Highland (ACZ3 and ACZ6), and Highland (ACZ4, ACZ8, ACZ7, ACZ9) based on altitude range.

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Table 1. Agro-climatic Zones and Selected stations

ACZ: Agroclimatic Zones	MAR (mm)	Elevation (m)	Area		Selected station			
			Km^2	%	Site	Latitude	Longitude	Elevation (m)
ACZ1: Dry Bereha (Hot-lowlands)	Less than 900 (Dry= Arid and Semi-Arid)	< 500	42113.71	22.20	Gode	5.92	43.58	290
ACZ2: Dry Kolla (Lowlands)		500-1500	104350.7	55.00	Degahabour	8.22	43.56	1070
ACZ3: Dry Weyna Dega (Midlands)		1500-2300	11973.94	6.31	Gursum	9.35	42.4	1900
ACZ4: Dry Dega (Highlands)		2300-3200	795.35	0.42	Indeto	7.57	39.9	2416
ACZ8: Dry Wurch (Frost zones)		3200-3700	37.46	0.02	Not Available			
ACZ5: Moist Kolla (Lowlands)	Greater than 900 (Moist= humid)	500-1500	7599.37	4.01	Gololcha	8.26	40.13	1372
ACZ6: Moist Weyna Dega (Midlands)		1500-2300	12489	6.59	Bedessa	8.91	40.77	1703
ACZ7: Moist Dega (Highlands)		2300-3200	9335.57	4.92	Arsi Robe	7.88	39.62	2441
ACZ9: Moist Wurch (Frost zones)		3200-3700	960.6	0.51	Not Available			
Total Area			**189655.7**	**100**				

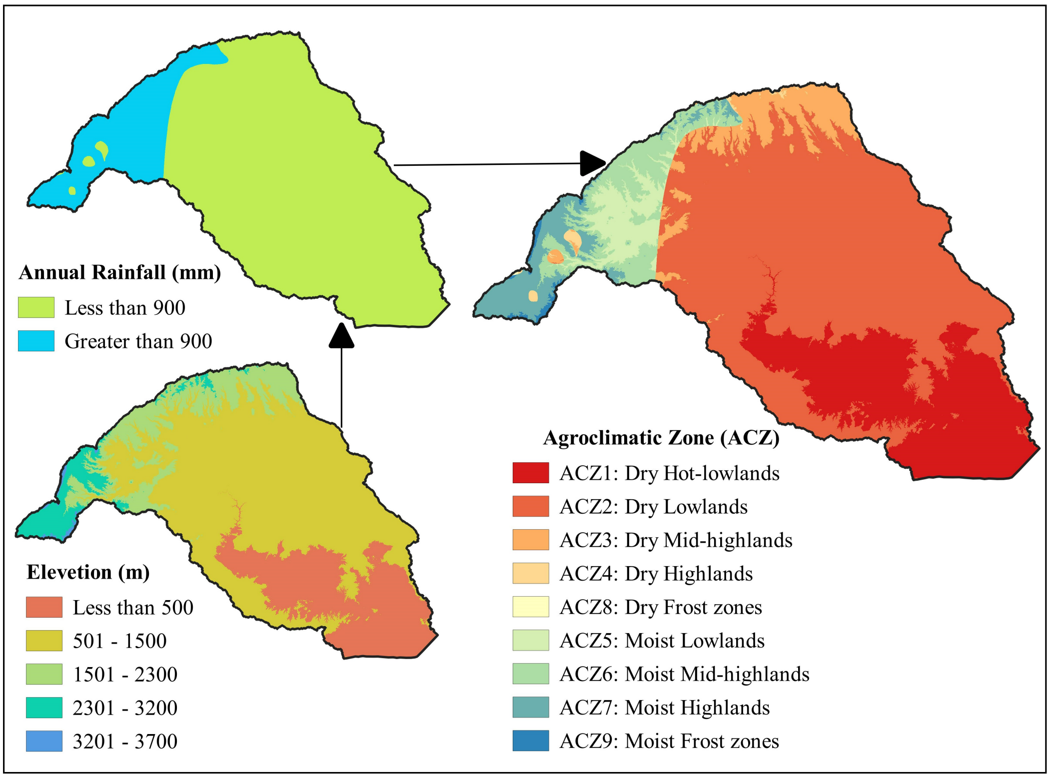

Figure 3. Agroclimatic Zone map

2.2.3. Precipitation Seasonal and Annual variability

For each ACZ and period, descriptive statistics for the long-term temporal data were computed using standard statistical procedures using Microsoft excel including mean, minimum, maximum, variance, standard deviation (SD), and Coefficient of Variation (CV). The CV is a statistical measure of the inter-annual variation of rainfall in the data series. In this study, the coefficient of variation (CV) was calculated on annual basis for daily maximum, rainy seasons, and annual precipitation, to investigate the inter-annual variability of rainfall distribution. Greater values of CV indicate larger variability and vice versa. The CV (%) value for each series can be computed as follows:

$$CV = \frac{\sigma}{\mu} * 100 \quad (1)$$

wwhere σ is the annual precipitation standard deviation and μ is the mean annual precipitation. The degree of variability of rainfall events classified as low (CV < 20), moderate (20 < CV < 30), and high (CV > 30) [7,17,55].

2.2.4. Precipitation Trend analysis

In this study, two non-parametric methods (Mann-Kendall and Sen's slope estimator) and the ITA method were used to detect the rainfall temporal trend in the study area. The detail of these methods presented in consecutive sections.

Modified Mann-Kendall (MK) test

The Mann–Kendall test [14] is perhaps the most widely used non-parametric test for detecting trends in hydro-meteorological and environmental data. It is a nonparametric test for monotonic trends where data is either consistently increasing or decreasing over time. It does not assume the data to be normally distributed and is flexible to outliers in the data. The test assumes a null hypothesis, H_O, of no trend and an alternate hypothesis, H_A, of

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increasing or decreasing monotonic trend. The mathematical equations for Mann-Kendall Statistics S, V(S), and standardized test statistics Z are as follows [14,16,28].

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_i) \tag{2}$$

$$sgn(x_j - x_i) = \begin{cases} +1, & \text{if } (x_j - x_i) > 0 \\ 0, & \text{if } (x_j - x_i) = 0 \\ -1, & \text{if } (x_j - x_i) < 0 \end{cases} \tag{3}$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \tag{4}$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{V(S)}}, & \text{if } S < 0 \end{cases} \tag{5}$$

In these equations, x_i and x_j are the time series observations in chronological order, n is the length of the time series, t_p is the number of ties for p^{th} value, and q is the number of tied values. A positive (negative) value of Z indicates that the data tend to increase (decrease) with time. The strength of the trend is proportional to the magnitude of the Mann–Kendall Statistic. The null hypothesis of no trend is rejected if the absolute value of Z is higher than 1.65, 1.96, and 2.58 at 10 %, 5 %, and 1% significance levels respectively.

Sen's slope estimates

Sen developed a more robust and non-parametric procedure for estimating the magnitude of a trend in the time series [15]. The slopes of data value pairs were calculated to get the Sen's slope estimate Q_i by the relationship:

$$Q_i = \frac{x_j - x_k}{j-k}, \text{for } i = 1,2,3...N \tag{6}$$

where x_j and x_k are the data values at times j and k (j > k). If there is only one datum in each time period, then $N = \frac{n(n-1)}{2}$, where n is the number of periods. If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$, where n is the total number of observations.

The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope (Q_{med}) estimator is computed as:

$$Q_{med} = \begin{cases} Q_{\left[\frac{(N+1)}{2}\right]}, & \text{if N is odd.} \\ \frac{Q_{\left[\frac{(N)}{2}\right]} + Q_{\left[\frac{(N+2)}{2}\right]}}{2}, & \text{if N is even.} \end{cases} \tag{7}$$

Positive/negative values of Q_{med} indicate an increasing/decreasing trend, respectively, while its value indicates the steepness of the trend.

Simulation experiments demonstrated that the existence of serial correlation alters the variance of the estimate of the Mann–Kendall (MK) statistic; and the presence of a trend alters the estimate of the magnitude of serial correlation [29]). Several modifications in the MK test have been proposed by different authors to remove the influence of the autocorrelation procedure including variance correction [27], effective sample size [52], and trend-free pre-whitening (TFPW) [28,29]. In this study for the time series where serial correlations were detected in the data, [27] procedure was applied to eliminate the autocorrelation before performing Mann- Kendall trend tests and Sen slope estimation. Serial

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autocorrelation was calculated with an autocorrelation function (modifiedmk package) [53] using R software. Detrending was performed for some analysis and was applied as a simple removal of the linear trend calculated over the full period of record. Numerous researchers have also used this approach to eliminate serial correlation in time series data [8,16,19].

Innovative Trend Analysis (ITA)

Recently, [30] developed ITA method to avoid all the restrictive requirements for a statistical test such as the MK trend test. In this trend analysis method, graphs are used as templates. The basis of the approach rests on the fact that if two time series are identical to each other (no trend), their plot against each other shows scatters of points along 1 : 1 (45°) line on the Cartesian coordinate system [30,31]. First, the time series is divided into two equal parts, which are separately sorted in ascending order. Then, the first and the second half of the time series are located on the X-axis and the Y-axis, respectively. If data are located on the upper triangular area of the no trend line, an increasing trend in the time series exists. If data are accumulated in the lower triangular area of the no trend line, there is a decreasing trend in the time series [30,34]. In this research, the ITA method was applied to the seasonal, and annual precipitation data between (1987 -2016) to investigate the trend in data series using R (i.e. package used 'trendchange::innovtrend (X)') as developed by [54]. Besides, to illustrate graphically the distance of the data points from the 1 : 1 line, in this paper, two confidence bands (0.1 and -0.1, 0.05 and -0.05) have been added/plotted using Matlab; this is to help the reader to better realize the differences between the data points and the trendless line, without any statistical implications [31].

3. Results

3.1. Statistical Analysis of Rainfall Variability

The descriptive analysis of precipitation for this study included computing the mean, standard deviation, and coefficient of variation in the annual precipitation time series for each ACZ. Table 2 presents these statistical parameters for the 30 years studied (1987–2016). According to the rainfall data analysis, the mean annual rainfall ranges from 1047.4 mm in ACZ6 in the northwest part and less than 350 mm in ACZ1 and ACZ2 in the south and southeastern lowland parts of the WSRB. Seasonal analysis showed Belg is the main rainfall period in ACZ1 and ACZ2 whereas summer is the heavy rainfall period in ACZ3 to ACZ7. Daily maximum rainfall is high in low elevation zones than in high elevation zones.

Based on the value of CV estimated, Belg/spring rainfall showed the highest inter-annual variability in all ACZs. But the maximum inter-annual variability was detected in summer rainfall in ACZ1 (87.4 %) and ACZ2 (68.9 %). Relatively, minimum CV was found in all ACZs using annual average rainfall.

3.2. Trend analysis

3.2.1. MK and Sen's slope Test

Serial autocorrelation was checked for the data series of daily maximum, Belg (short rainy season), Kiremt (heavy rain season), and annual precipitation. Then, the precipitation trend at the selected period scale has been analyzed using the MK test and the magnitude of change using the Sen slope estimator [14,15]. Finally, the presence of decreasing or increasing trends in the data series has been investigated.

Results of MK and Sen slope analysis on the daily maximum precipitation, spring season precipitation, summer season precipitation, and annual precipitation data for each ACZ in the basin are shown in Table 3. The spatial and temporal trends in selected time series revealed a nonuniform trend in the basin. From the analysis result, daily maximum rainfall has shown the most significant increase in ACZ1, ACZ5, and ACZ6, an insignificant increase in ACZ4 and ACZ7, and an insignificant decrease in ACZ2 and ACZ3.

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Table 2. Statistical summary on annual daily maximum, rainy seasons, and annual rainfall

Temporal Scale	Spatial Zone	Minimum	Maximum	Mean	Variance	SD	CV (%)
Daily Max	ACZ1	19.2	106.6	47.0	485.7	22.0	46.9
	ACZ2	24.0	110.0	49.8	324.1	18.0	36.1
	ACZ3	32.3	104.0	58.8	289.7	17.0	29.0
	ACZ4	24.7	84.0	49.2	182.8	13.5	27.5
	ACZ5	23.1	90.6	48.4	379.8	19.5	40.3
	ACZ6	25.1	95.0	51.5	291.2	17.1	33.2
	ACZ7	28.9	129.6	50.0	385.2	19.6	39.2
Spring	ACZ1	26.9	300.4	126.4	3378.2	58.1	46.0
	ACZ2	59.9	374.8	192.1	5597.7	74.8	39.0
	ACZ3	172.7	620.8	302.9	11528.2	107.4	35.4
	ACZ4	94.3	620.1	269.6	12519.6	111.9	41.5
	ACZ5	176.7	568.1	352.4	13764.8	117.3	33.3
	ACZ6	160.0	818.4	333.3	17183.4	131.1	39.3
	ACZ7	115.0	429.0	260.3	7020.0	83.8	32.2
Summer	ACZ1	0.0	338.8	95.5	6966.1	83.5	87.4
	ACZ2	16.7	299.3	106.7	5397.0	73.5	68.9
	ACZ3	154.8	631.7	379.4	11143.4	105.6	27.8
	ACZ4	275.9	851.3	456.0	15727.2	125.4	27.5
	ACZ5	334.0	1009.7	527.8	17850.9	133.6	25.3
	ACZ6	181.5	882.2	563.7	23640.9	153.8	27.3
	ACZ7	205.3	801.4	510.2	12350.2	111.1	21.8
Annual	ACZ1	100.1	535.3	227.2	11275.1	106.2	46.7
	ACZ2	161.4	564.3	326.3	12731.6	112.8	34.6
	ACZ3	459.1	1538.4	797.2	45085.9	212.3	26.6
	ACZ4	646.1	1505.2	892.0	29667.9	172.2	19.3
	ACZ5	778.4	1440.3	1047.2	33181.4	182.2	17.4
	ACZ6	732.4	1667.5	1047.4	42891.4	207.1	19.8
	ACZ7	576.9	1326.3	926.0	23943.1	154.7	16.7

Note: ACZ= Agroclimatic Zone, SD = Standard Deviation, CV = Coefficient of Variation

As depicted in Table 3, the declining trend of belg/spring rainfall is not statistically significant in all ACZs except ACZ4 whose rainfall is statistically significant decreasing by -4.11 mm/annual. In Kiremt/Summer precipitation, only one ACZ showed a significantly decreasing trend at a 5 % significance level, on the contrary, the remaining ACZs showed a statistically insignificant increase. The analysis of annual precipitation showed a statistically insignificant decrease (ACZ2 and ACZ4) or increase (ACZ1, ACZ5, ACZ6, and ACZ7) in the trend. ACZ3 which is a dry middle elevation zone showed a nonsignificant decrease in daily maximum and Belg/Spring rainfall, a significant decreasing trend in Kiremt/Summer, and annual average rainfall.

3.2.2. ITA method

In this research, the ITA method was applied to daily maximum, rainy seasons, and annual precipitation data between (1987 -2016). The time-series data were divided into two sub-series 1987-2001 (the first half) and 2002 -2016 (the second half). Then, the sub-series data were sorted and plotted on the Cartesian coordinate system first-half sub series (FHS) on the horizontal axis and the second half sub series (SHS) on the vertical axis according to the graphical template [30]. The increasing or decreasing trend was evaluated based on the position of the data point relative to the trendless line. Figure 4-7 show the results of the ITA approach applied to the seven ACZ of the research area at daily maximum, Belg/Spring, Kiremt/Summer, and annual period respectively. For the interpretation of these figures,

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Table 3. Mann- Kendall trend analysis results for different time series

No	Zones	Daily Max		Spring		Summer		Annual	
		Z-Value	Sen's Slope	Z-Value	Sen's Slope	Z-Value	Sen's Slope	Z-Value	Sen's Slope
1	ACZ1	**2.78****	1.02	-0.82	-1.00	1.53	3.27	0.46	0.85
2	ACZ2	-1.62	-0.53	-0.62	-0.85	0.14	0.16	-0.29	-0.59
3	ACZ3	-0.66	-0.28	-1.03	-2.38	**-2.00***	-3.97	**-8.59****	-12.30
4	ACZ4	0.80	0.15	**-2.32***	-4.11	1.46	3.36	-0.86	-1.96
5	ACZ5	**2.66****	0.72	-0.25	-0.47	1.46	3.33	0.21	0.97
6	ACZ6	**3.28****	0.52	-0.36	-1.10	1.36	5.84	0.77	3.73
7	ACZ7	0.57	0.18	-0.86	-2.22	1.61	3.65	0.32	1.54

Note: * and ** statistically significant at 0.05 and 0.01 alpha levels

0.05 bands have been added, and divide the precipitation into three categories are "low", "medium", and "high". The intention of these bands is only to help the reader to better appreciate the offset of the points from the trendless line, without any statistical meaning.

With regards to daily maximum rainfall ITA result in Figure 4, the precipitation points indicated an increasing trend in all precipitation categories in ACZ1 and ACZ5. Contrary, maximum daily precipitation points showed decreasing trend in all precipitation categories in ACZ2. The rest showed different patterns in different precipitation categories. All wet ACZs show that most data points fall above the trendless line, implying an overall increasing trend. But, dry ACZs indicated increasing in ACZ1 and decreasing in ACZ2 and ACZ4 trends. Whereas, ACZ3 showed a decreasing trend in low and an increasing trend in high rainfall categories.

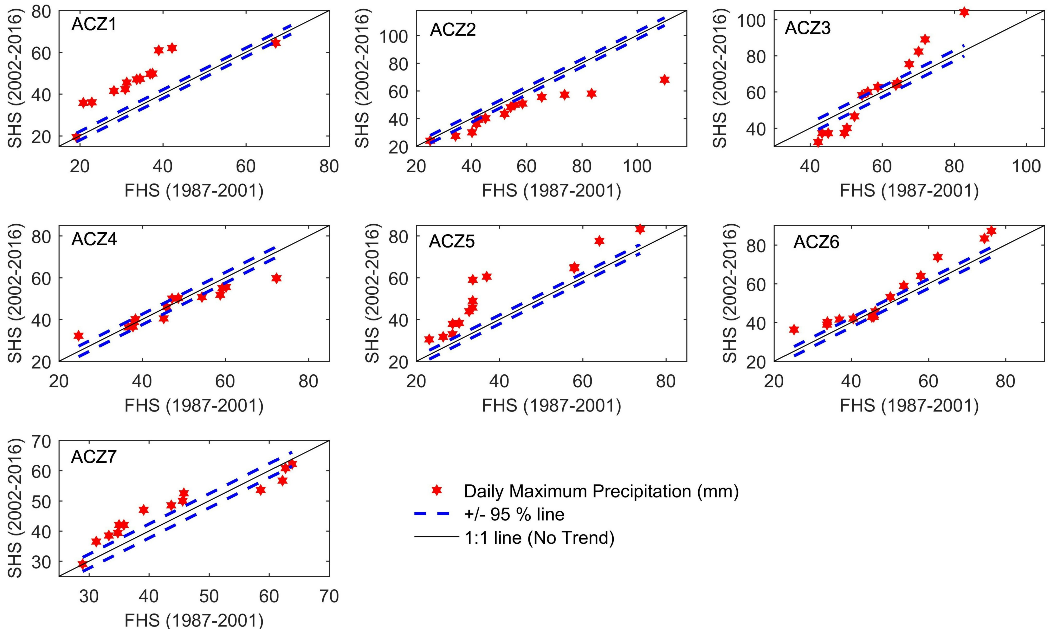

Figure 4. Daily maximum rainfall trend using the ITA method

In a short rainy season, an increasing or decreasing trend was estimated based on the sum of precipitation in March, April, and May Belg/Spring rainfall data Figure 5. A decreasing trend was found in ACZ1, ACZ3, and ACZ4 in all categories of rainfall. No clear trend was detected in ACZ2, ACZ5, and ACZ7. In ACZ6, negative patterns were detected, but only for the "low" and the "high" precipitation values. In this time scale, a negative pattern was observed in all ACZs due to the majority of the data value located in the lower triangle of no trend line following the ITA procedure.

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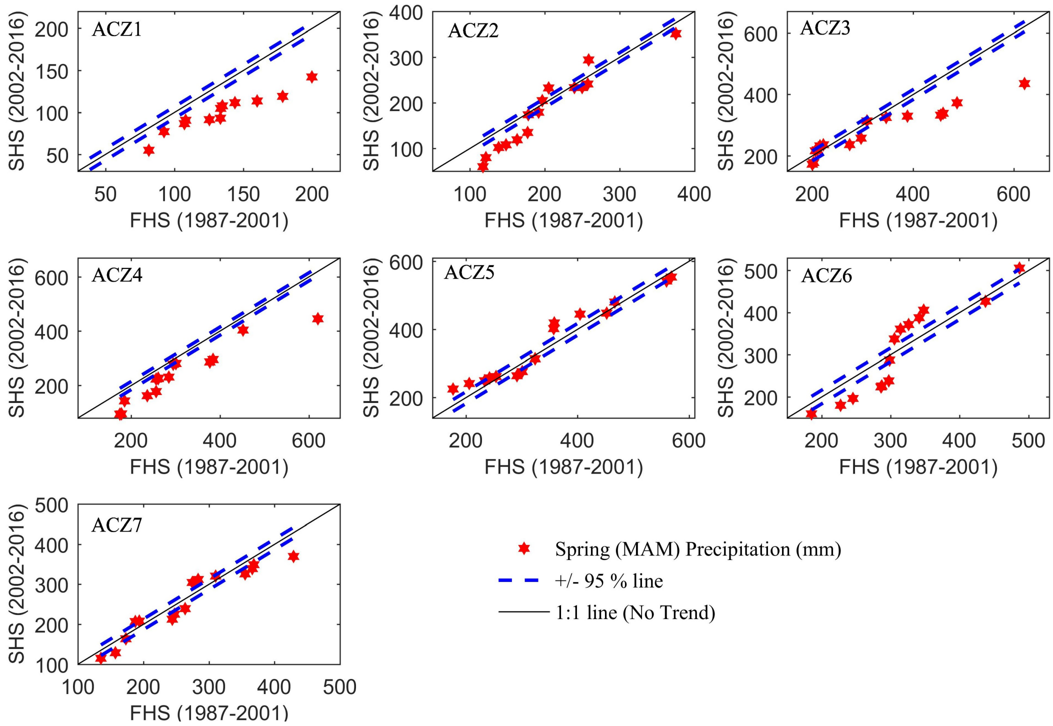

Figure 5. Belg/Spring rainfall trend using the ITA method

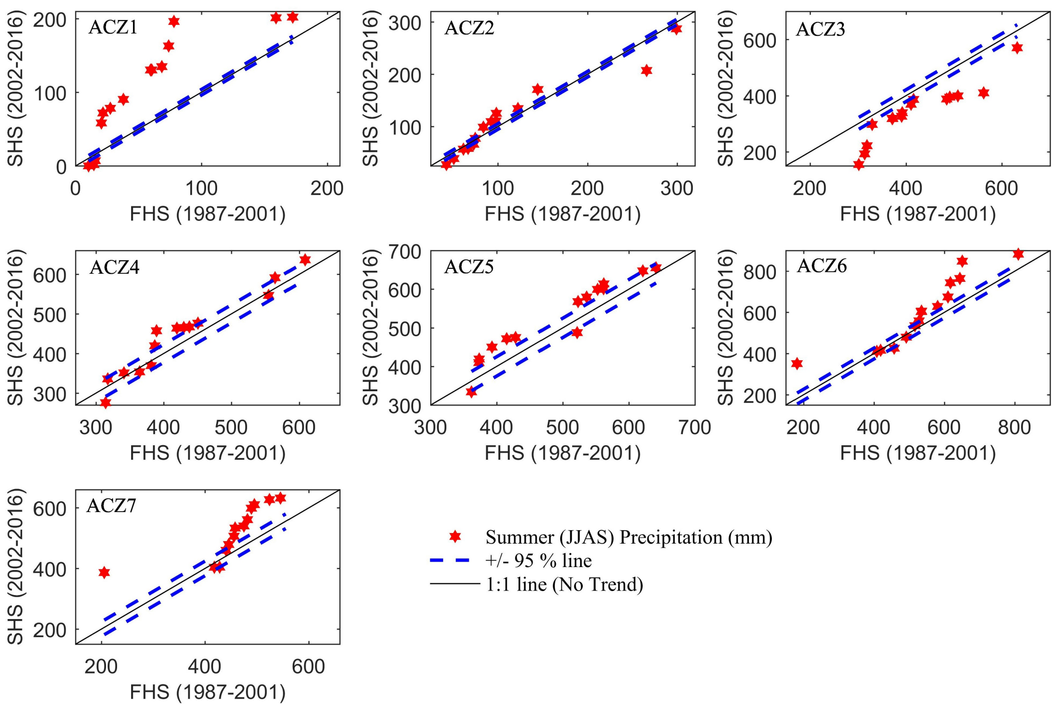

Figure 6. Kiremt/Summer rainfall trend using the ITA method

Application of ITA in a main rainy season rainfall (Kiremt/Summer) Figure 6, at all rainfall categories clear negative trend was observed in ACZ3 with all the values positioned out of the 0.05 relative band limit. In ACZ1, ACZ6 and ACZ7, the data points show an increasing trend in medium and high rainfall categories whereas decreasing in low rainfall categories. A contrasting pattern was found in ACZ2 and ACZ5, in ACZ2 medium rainfall categories showed an increasing trend whereas low and high rainfall categories showed a decreasing pattern. The opposite pattern was detected in ACZ5. Overall, an increasing trend was detected in dominant ACZs WSRB in Kiremt/Summer rainfall.

On an annual temporal scale Figure 7, a prevailing negative trend for all categories of rainfall (low, medium, and high) has been detected in ACZ3 and ACZ4 with almost all values exceeding the 0.05 relative band limit. In ACZ2 and ACZ6, medium rainfall categories showed decreasing trend whereas low and high rainfall categories showed an increasing trend. In ACZ5, the data points show an increasing trend in medium and high rainfall categories whereas decreasing in low rainfall categories. Relatively, ACZ7 showed constant with the value concentrated within the 0.05 band limit.

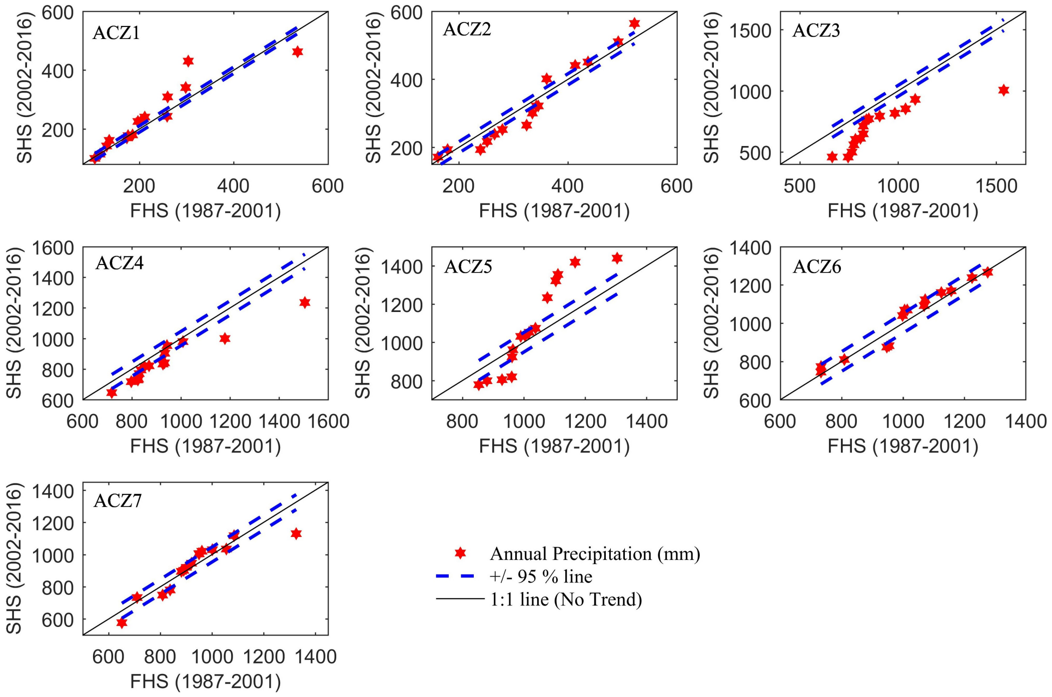

Figure 7. Annual rainfall trend using the ITA method

4. Discussion

4.1. Rainfall variability in the basin

The statistical analysis revealed that the seasonal and annual distribution of rainfall depends on the elevation of the area. From the monthly distribution of annual rainfall, Kiremt/Summer rainfall is the main rainfall season for the area with an elevation greater than 1500 m.a.s.l. On the contrary belg/spring rainfall is the main rainfall season in the area less than 1500 m.a.s.l. Spatially, higher rainfall distribution is recorded in the northwest and northern part of the basin whereas very small rainfall amounts are recorded in the south and southeast part of the basin. Relatively, most of the ACZs in higher elevations showed lower inter-annual variation (CV < 20 %) whereas ACZs in lower elevations showed moderate to high variation (CV > 20 %). Higher inter-annual variability of maximum daily and belg rainfall was observed in all ACZs. The results of this study are generally consistent with other research results which were conducted in different parts of the country and reported that rainfall in belg/spring exhibits higher inter-annual variability than Kiremt/summer rainfall [5,32,46,55]. Less than 20 % CV is observed in annual rainfall of higher elevation climatic zones which implies that there is low variability of rainfall in the annual time series. But, lower elevation zones (ACZ1 and ACZ2) showed higher inter-annual variability with CV ranging from 34.6 % to 87.4 % in the time series that was considered in this study. In this study, the analysis of rainfall variability revealed that low rainfall areas tend to experience high rainfall variability. Similarly, previous studies found that the areas with high rainfall amounts exhibit a low coefficient of variations at different time series [4,17,24,33,46,55].

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4.2. *Precipitation Trend*

Trend: MK and Sen's slope estimator

From MK analysis, daily maximum rainfall detected a statistically significant increasing trend in ACZ1, ACZ5, and ACZ6 with increases of 1.02, 0.72, and 0.52 mm/year, respectively. In addition, seasonal and annual trend tests showed a mix of increasing and decreasing trends at different ACZs. Analysis of Belg rainfall indicated that all of the ACZ in the study basin showed a decreasing trend over the last 30 years (1987-2016). The maximum rate of change in Belg/Spring rainfall was -2.22, -2.38, and -4.11 mm/year in ACZ7, ACZ3, and ACZ4, respectively. The Kiremt/Summer season however showed a non-significant increasing trend in rainfall for all ACZs except ACZ3 showed a significantly decreasing trend at a 0.05 significance level. The analysis also revealed that three ACZs (ACZ2-4) depicted decreasing trends of annual rainfall, while ACZ3 is statistically significant. The maximum annual decreasing rate was observed in ACZ2, ACZ4, and ACZ3 at -0.59, -1.96, and -12.3 mm respectively between 1987 and 2016. In the highland area, ACZ6 showed the maximum increase of annual rainfall with 3.73 mm/year.

In the WSRB, no uniform trend was detected among ACZs that were considered at different temporal scales using the MK method. The finding agrees with previous studies conducted in the different river basins of the country [32,33,36,40,46,47,55].In Lake Tana Sub-basin, [7] revealed a general decreasing trend in annual precipitation. [17] reported dominantly decreasing trends in small and main rain seasons and annual rainfall in the Choke Mountain Watersheds (1981–2016). [46] found an increasing trend in the Kiremt season and annual rainfall in most of the stations investigated however the Belg season rainfall showed a non-significant declining trend in four of the five representative stations in Modjo River Watershed, Awash River Basin of Ethiopia. Similarly, [21] reported a decreasing trend in all stations located in the semi-arid areas of Western Tigray, Ethiopia. [33] found a mixed result of increasing and decreasing seasonal and annual rainfall in the Upper Wabe Shebelle River Basin, Ethiopia. Kiremt and annual period, most rainfall stations showed increasing trends, while in the Bega season rainfall showed decreasing trends. On the contrary, [11] found annual and seasonal rainfall totals showed increasing trends in the Alwero watershed, western Ethiopia.

Trend: ITA method

In this study, the ITA method was also applied to investigate the existence of a statistical trend in maximum daily rainfall, rainy season rainfall, and annual rainfall. The advantage of ITA over the MK method is that detailed trend evaluation can be made by dividing the rainfall into three categories that are "low", "medium", and "high". Strong trends of extreme ("high" and "low") precipitation are associated with floods and drought [31]. Uniform trends were not detected in all ACZs using categorized rainfall data. Except for ACZ2, all ACZs showed more points above the no trend line implying an overall increasing trend of daily maximum rainfall. On seasonal rainfall, a decreasing trend was detected in ACZs based on the percentage of data points located below the no trend line. On other hand, Kiremt rainfall showed a generally increasing trend in all ACZs except for ACZ3. Similarly, ACZ3 showed decreasing trend in annual rainfall in low, middle, and high categories. In the annual time series, the data points are concentrated within the + 0.05 band line. Even though a limited document was found on trend analysis using the ITA method, the find of this study is consistence with previous studies that are a nonuniform result [31,33,35].

MK and ITA method Comparison

Results of the ITA have been compared with the ones obtained through the MK method applied on the series checked for autocorrelation through the application of a pre-whitening

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procedure. In this study, all statistically significant increasing or decreasing trends at 0.05 % of the level of significance using the MK method showed a similar trend in all categories of rainfall using the ITA method. On the contrary, even though most of the data points fall above the no trend line in all categories, there is no significant increasing and decreasing trend detected in the time series data using the MK method. In general, a similar result was observed using the MK and ITA method but an in-depth assessment of rainfall at the low, middle, and high categories was only possible using the ITA method. Because of the higher variability of rainfall in the basin, the ITA method is more complex to decide the existence of a trend at a different time than the statistical method. The data points are very scattered in the plot. Even though ITA has the advantage of estimating hidden trends at three categories of the data point, in this study, it was found that the boundary of low, middle, and high data values is not as simple as stated in the initial work [30].

5. Conclusions

For the countries, rainfed agriculture is a major source of income generation and employment opportunities, any change in the amount and distribution of rainfall causes a major economic, environmental, social, and political failure. Understanding spatial and temporal variability and trends of rainfall in the WSRB remain a challenge to assess. This is due to a combination of complex topography, higher climatic variation, and low spatial coverage of observation stations. Therefore, this study investigated agroclimatic zone-based variability and trend in maximum daily, rainy seasons, and annual time series of rainfall in the Wabi Shebele River basin over a 30-year study period (1987–2016) using MK and ITA methods. From the agroclimatic zonation of the WSRB, arid and semi-arid cover 81 % of the area whereas only 19 % is considered as humid. This study shows the annual rainfall distribution in the basin is entirely bimodal. In this study, low land and low rainfall areas tend to experience high rainfall variability than highland and higher annual rainfall areas. The trend tests found decreasing in Belg/Spring precipitation, an insignificant increase in Kiremt/Summer precipitation, and a decreasing trend in annual precipitation in ACZs covering more than 70 % of the basin. In line with this, agricultural practices in Belg/Spring season will be affected if a similar trend continues especially in low land areas where Belg is the main rainy season. In general, the amount of water resources shows a decreasing trend with higher inter-annual variability. Coupling with climate change, a decreasing trend of rainfall severely impacts the livelihoods of the rural communities relying on subsistence rainfed agriculture.

In general, the findings of this study provide valuable information on the characteristics and variability of rainfall in the WSRB essential for planning and designing sustainable water management strategies and minimizing the impact of extreme climate events. Further study should be conducted to project the future pattern of the rainfall in the basin using a climate model appropriate for the basin under different projection scenarios.

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