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Analysis of Spatiotemporal Variability and Trends of Rainfall among the Agro-Climatic Zone of Abiya Watershed, Northwest Ethiopia

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Abstract

Studies like this have a paramount advantage in area where rain-fed agriculture is dominant. The objective of this study was to analyze the spatiotemporal variability and trends of rainfall among the agro-climatic zones of Abiya Watershed. The study employed 50 sample grid points from CHIRPS for the period 1981-2019 with a spatial resolution of 5 km × 5 km. Coefficient of Variation (CV), Precipitation Concentration Index (PCI), and Standardized Anomaly Index (SAI) were used to analyze rainfall variability. Mann Kendall’s (MK) and Sen’s slop have used to define the trends and magnitude of the changes in rainfall amount. The CV output shows low, moderate, and high variability of monthly and seasonal rainfall and low inter-annual variability. The PCI of the watershed showed uniform seasonal rainfall distribution (Summer and Spring), strong irregular seasonal rainfall distribution (Winter), and irregular annual rainfall distribution, and the SAI perceived the existence of inter-annual and inter-seasonal variability of rainfall with a greater negative anomalies percentage. The MK output presented, most of the months were increased and all increased in the annual and seasonal rainfall. The information obtained from this study was used as input for decision-makers to take appropriate adaptive measures in agricultural sectors.

Keywords: Agro-climatic zones; Rainfall trends; Rainfall variability; Upper Blue Nile basin

Introduction

Rainfall is a prominent climatic factor that affects agricultural production through its impact on the timing of agricultural operations. Notwithstanding non-climatic factors, rainfall dictates how land is used and the types of crops that are cultivated in a particular area [1]. Rainfall change and its threats to food security and sustainable development are stronger in poorer regions of the world. It is one of the main climatic variables that influence both the spatial and temporal patterns of water availability for agriculture and food security. In several African countries, more than 85% of the population is involved in rain-fed agriculture.

Previous studies highlighted that the variability in rainfall in the region is linked to large-scale climate variability, including the El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD). ENSO has shown various impacts in precipitation; warming of the ocean temperature leads to an upturn in rainfall and change in the bearing of the Inter-Tropical Convergence Zone (ITCZ). In common, variability in rainfall in East Africa, mainly the variability in inter-annually is modulated by large scale climate forcing and changes in sea surface temperature, which affects the rainfall amount by changing wind patterns and humidity fluxes.

Ethiopia is well-known for its high rainfall variability through space and time due to geographical locations and topographic complications. Furthermore, precipitation can be temporally wide-ranging from days to decades in terms of the direction and amount of rainfall trends over regions and seasons. The performance of the agricultural sector and the rainfall pattern show strong correlations. Rainfall shortage often leads to famines [2].

Specifically, rainfall is the greatest important meteorological parameter in Ethiopia, as around 85% of the Ethiopian labor force is employed in rain-fed agriculture which highly depends on low or high amounts of rainfall availability vital for crop production. Ethiopia is one of the states in Eastern Africa presenting variable climatic conditions. It has different agro-ecology zones which are characterized by a dazzling variety of microclimates and corresponding weather patterns. It has a tropical wet season climate characterized by extensive topographic-induced variations. Mean annual rainfall spreading ranges in the nation from more than 2000 mm over the Southwestern highlands to a minimum of below 300 mm over the southeastern and northwestern lowlands.

Rainfall distributions over the nation are also strongly uneven among diverse seasons. The yearly rainfall inconsistency in the maximum of the state remains exceeding 30%. In terms of cyclical production, the spring season suffers from more rainfall variability than the summer season, and most spring season growing areas (eastern, northeastern, and southern part of the country) are distressed from the random beginning of the season and numerous crop failures.

Precipitation in Ethiopia confirms high variability in crossways place and periods owing to the difficult topography fluctuating from 120 meters abovesea-level (m.a.s.l) to 4620 m.a.s.l. The risk related to climate variability poses a direct impact from the start of land preparation to the last harvest. The erratic rainfall patterns, including onset and pause dates and spreading of rainfall, govern crop yields and regulate the choice of the crops to grow [3].

Inconsistent rainfall patterns and repeated extreme events such as droughts, floods, and irregularities in cyclical rainfall quantity and distribution are among the main climate-related calamities that have severe consequences for food security and fiscal growth. The start and end of the rain, seasonal rainfall patterns of rainfall circulation, occurrence, and the chance of the length of a dry spell in the growing season are vital factors that affect the preparation, establishment, and management of crops in Ethiopia.

There is a paucity of studies at local places and differentiated by Agro-Climatic Zone (ACZs). Mekonen and Berlie, showed that the trends and spatiotemporal variations in rainfall remain unknown in several localities of Ethiopia [4]. Studies that scientifically investigate long-term and local scale fluctuations in these climate parameters are seriously lacking in many parts of the country. Abiya watershed is found in the Amhara region that contains various ACZs and has high climate variability such as rainfall variability. Due to this, local farmers were faced various problems. The present study is designed to analyze the spatial variability and temporal trends of rainfall among the ACZs of the watershed, to fill the spatial gap by considering different ACZs.

Materials and Methods

Description of the study area

The investigation is carried out in the Abiya watershed, which is found in northwest Ethiopia within 10°43′0″ to 11°15′0″N latitude and 37°25′0″ to 37°55′0″E longitude, upper Blue Nile basin, Ethiopia (Figure 1). The watershed covers an area of 1819 km^2. Its elevation ranges from 1,500 to 4,084 meters. Following MoA, this study adopted the traditional ACZs grouping approach [5]. By using the digital elevation model, the ACZs of the watershed consist of midland, highland, and cold-highland zones. The temperature of the watershed has a mean minimum of 10.7°C and a mean maximum of 23.7°C annually. The mean annual rainfall was 1324 mm.

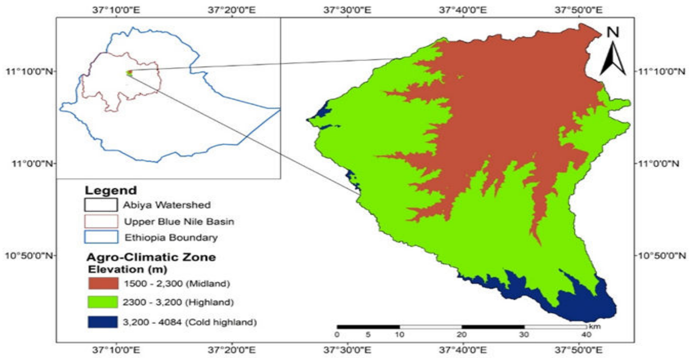

Figure 1: Location map of the agro-climatic (elevation) zones of the Abiya watershed.

Geographically, the watershed is characterized by its highly undulating topography, which consists of mountains, deep gorges, escarpments, and plateaus. Most of the residents in the watershed were involved in mixed agriculture, which includes both crop cultivation and livestock rearing. In the Amhara region, where they consider the location to be arranged, the average family size is anticipated to be 4.6 individuals, whereas the population density is expected to be 189.4 people km^{-2}. Based on this, it is better to project the total population inhabiting the watershed, and the aggregate population of the area is 344,572.

Methods and approaches

Data type and source: A digital elevation model with (30 m × 30 m resolution) was used for this study. It was accessed from the United States Geological Survey (USGS) for generating ACZs and calculating their area coverage (Table 1).

ACZs	Midland	Highland	Cold-highland	Watershed
Elevation (meters)	1500-2300	2300-3200	3200-4084	1379-4084
Area (ha)	77,057	95,527	9,344	181,928
%	42.4	52.5	5.1	100

Table 1: Areal coverage of the ACZs of the Abiya watershed.

CHIRPS satellite data: The rainfall station databases of Ethiopia have many missing values, do not have adequate data records to support trend analysis; and do not make available well-timed and sufficient rainfall pattern data due to the scattering of observations, uneven allocation, and data gaps in the original dataset, accordingly it became mandatory to employ an alternative rainfall data source. Nowadays, there are several satellite-based precipitation datasets with varying spatiotemporal resolutions that are viable alternatives to rain gauge data. CHIRPS is a comparatively new rainfall dataset with good spatial (0.05°) and temporal (daily) resolution. The dataset is derived from multiple data sources covering 50°S and 50°N from 1981 to the present.

The performance of the CHIRPS dataset was validated by Dinku, et al. in contrast to 1200 reference rain gauge measurements from Ethiopia, Kenya, and Tanzania and informed that CHIRPS was better than most high-resolution satellite products of rainfall data in several regions of East Africa [6]. Likewise, in our country CHIRPS has been available widely and has confirmed strong performance when assessed at station locations across the country such as Lemma, et al. in Ethiopia, Taye, et al. in Upper Blue Nile basin, and Alemu and Bawoke in Amhara region, respectively [7-9]. The study area also found under the former validation showed, therefore in this study the CHIRPS rainfall data have used without validation.

A record of daily rainfall data for this study was taken 50 sample grids points (each representing areas of 5 × 5 km) to study from the CHIRPS dataset. All of the grids points (Figure 2) cover the period between 1981 and 2019 and the grids points were stratified into three ACZs (21 grids points from midland, 26 grids points from highland, and 3 grids points from cold highland) purposively to represent the rainfall conditions of each ACZs of the study area, respectively.

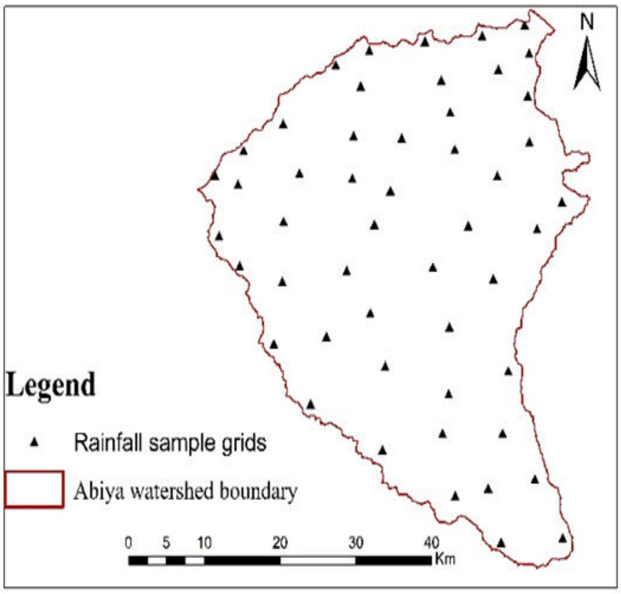

Figure 2: Sample grids were considered for collecting rainfall datasets in the Abiya watershed.

Data analysis

Coefficient of Variation (CV): Rainfall variability analysis: The CV measures the overall variability of the rainfall in the area of concern. A higher value of CV indicates a rainfall with greater variability and vice versa, it is calculated using the formula:

$CV = \sigma/\mu \times 100$

Where CV is the coefficient of variation, σ is the Standard Deviation (SD) and μ is the mean rainfall for the chosen temporal scales. CV values <20%, 20%-30%, and >30% corresponded low variable, moderately, high variability variable. CV was employed to compare the level of rainfall variability among the ACZs of the study watershed. On account of this advantage, these tools have extensively been employed in previous studies.

Precipitation Concentration Index (PCI): PCI is a measure of comparative distribution. It is a means to signify the spatial variability of rainfall patterns. PCI implies rainfall concentration in terms of distribution and variability and is worked out using the following equations. The same methodology was also used by previous studies [10].

$$PCI_{annual} = \frac{\sum_{i=1}^{12} Pi^2}{(\sum_{i=1}^{12} Pi)^2} * 100$$

$$PCI_{seasonal} = \frac{\sum_{i=1}^{4} Pi^2}{(\sum_{i=1}^{4} Pi)^2} * 33$$

Oliver, found that PCI values <10 denote uniform precipitation distribution, if (11<PCI<15), the rainfall concentration is moderate, if (16<PCI<20), an irregular distribution, and A strong irregular precipitation distribution PCI is above 21.

Standardized Anomaly Index (SAI): Standardized Anomaly Index (SAI) was used as an indicator of rainfall variability and it describes the number of standard deviations that a rainfall event deviates from the average of the considered years. It was also used to determine the frequency of dry and wet years in the observed and used to assess the frequency and severity of droughts. It indicates the departure from the long-term mean with negative values representing periods of below-normal rains (droughts) while positive values reflect above normal rains (food risk). It is calculated as:

$$SAI_i = \frac{X_i - \bar{X}}{\sigma}$$

Where X_i is the annual rainfall of the particular year; $\bar{X}$ is the long-term mean annual rainfall throughout observation and σ is the standard deviation of annual rainfall throughout the observation. SAI was also calculated for the seasonal scale, SAI value is classified as extremely wet (SAI>2), very wet ($1.5 \leq SAI \leq 1.99$), moderately wet ($1 \leq SAI \leq 1.49$), near normal ($-0.99 \leq SAI \leq 0.99$), moderately dry ($-1.49 \leq SAI \leq -1$), severely dry ($-1.99 \leq SAI \leq -1.5$) and extremely dry ($SAI \leq -2$), respectively. The same methodology was also used by.

Rainfall trend analysis

Serial autocorrelation test: Trend detection in time series requires data that is random and persistence-free Ngongondo, et al. to solve the confounding effect of serial dependence when interpreting the results [11]. To avoid the influence of serial autocorrelation on the Mann-Kendal (MK) trend test, serial autocorrelation should be checked before applying the MK trend test. Therefore, in this study, the rainfall time series for each ACZs was tested for randomness and independence using autocorrelation function as described in von Storch as follows [12]:

$$r_k = \left[\frac{1}{n-1}\sum_{i=1}^{n-k}(X_i - \bar{X})(X_{i+k} - \bar{X})\right] / \left[\frac{1}{n}\sum_{i=k}^{n}(X_i - \bar{X})^2\right]$$

Where r_k is the lag–k autocorrelation coefficient, $\bar{X}$is the mean value of a time series X_i, n is the number of observations, and k is the time lag. Random series have autocorrelations near zero for all time-lag separations, except the zero-lag coefficient, which is always one. In that case, statistical tests are directly applied to the series. Non-random series have one or more significantly non-zero autocorrelation values, and statistical tests, in this case, are applied to a pre-whitened series to account for the non-randomness.

Mann–Kendall test (MK): MK test is a non-parametric statistical test that is a widely functional and the most effective way to define whether a time series has a monotonic ascending or descending trend. It is also a lesser amount of sensitivity to outliers or robust against the influence of extremes. MK test is used to ascertain the presence of a statistically significant or non-significant trend in rainfall and temperature variability. It measures rainfall variability on both annual time scales (inter-annual variability and seasonal scales (inter-seasonal variability). Following the MK test, the study tested the null hypothesis (H_0) of no trend, which means the measurements x_i are randomly ordered in time, against the alternative hypothesis (H_1), where it is a monotonic (decreasing or increasing) trend in the time series data being tested. It is recognized in the MK statistic S, the variance statistic Var (σ), and the consistent standard normal test statistic Z could be considered as follows:

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

Where n is the length of the dataset, x_i and x_j are two elements of the measured time series at the time step i and j, respectively, and

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

If the dataset is identically and independently distributed, then the mean of S is zero and the variance of S is given by

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) \right]$$

Where n is the length of the dataset, m is the number of tied groups (a tied group is a set of sample data having the same value) in the time series and t_i is the number of data points in the i^{th} group.

The Z statistics are computed using the formula

$$Z = \begin{cases} \dfrac{S+1}{\sqrt{\mathrm{Var(S)}}} & for\ S < 0 \\ 0 & for\ S = 0 \\ \dfrac{S-1}{\sqrt{\mathrm{Var(S)}}} & for\ S > 0 \end{cases}$$

A negative (positive) Z value indicates a downward (upward) trend. A significant level α is used to test the monotonic trend. The obtained trend is statistically significant at the 99% confidence level (α=0.01) if |Z|>2.58, at the 95% confidence level (α=0.05) if |Z|>1.96 and at the 90% confidence level (α=0.1) if |Z|>1.65 [13].

Sen's slope estimator: It is a non-parametric procedure used to quantify trend magnitude in time series data. It is a more robust estimator than others because of its relative insensitivity to extreme values. Sen's slope estimator has been commonly used for determining the trend magnitude in hydro-meteorological time series. It limits the influence of missing values or outliers on the slope as compared with linear regression. For a given time series $X_i=x_1, x_2, x_3, \ldots, x_n$, having N pairs of data, the slope is computed as

$$\beta_i = \left(\frac{x_j - x_i}{j - i}\right), i = 1, 2, 3, \ldots N, j > i,$$

The Sen's slope β represents the median of the slope values β_i and is calculated as

$$\beta = \begin{cases} \beta_{\frac{N+1}{2}}, & if\ \ N\ is\ odd \\ \left(\dfrac{\beta_{\frac{N}{2}} + \beta_{\frac{N+2}{2}}}{2}\right), & if\ N\ is\ even \end{cases}$$

The sign of β reflects the data trend direction, whereas its value indicates the steepness of the trend.

Results and Discussion

Rainfall variability

Coefficient of variation of monthly, seasonal, and annual rainfall: There was a spatial variation in the mean annual rainfall of the study area. The variation was ranged from a mean annual rainfall of 1207.41 mm with 115.6 mm standard deviation in the midland, highland experienced 1336.07 mm with 119.82 mm standard deviation, and cold highland received 1428.96 mm with 120.44 mm standard deviation. Generally, the mean annual total rainfall varies in each ACZ, and the highest annual rainfall values were observed in the highest elevation area and the lowest rainfall value was recorded in the lowest elevation area. This implies that the rainfall amount was increased toward elevation. The result agreed with the findings of previous studies conduct by.

The rainfall variability showed low inter-annual variability (CV<20%) as shown by the coefficient of variation. It varied from 9.57 at midland zone, 8.93 highland, and 8.43 at cold highland zone, respectively. The areas with low mean annual rainfall show more inter-annual variability in the study area. This result agrees with the findings of Dawit, et al. that revealed the inverse relationship between rainfall variability and mean annual rainfall in the Guna Tana Watershed, Upper Blue Nile basin of Ethiopia, and Bayable, et al. also report the same result in West Harerge Administrative Zone, Eastern Ethiopia [14,15].

The variability of the summer season was similar to annual (CV<20%). Summer precipitation was a smaller amount variable in the watershed matched to the other season. This finding was supported by earlier studies. Additionally, the annual total rainfall was dominated by the main rain season. For this reason, annual rainfall and main rain (summer) season rainfall show a similar CV across all ACZs.

The highest values of the CV in the spring and winter seasons were recorded (CV>30%) in most areas, respectively, which implied more inter-annual variability of winter and spring than summer. The result of this study agrees with the findings of who reported that less variability of rainfall was observed in the summer season than other seasons in different parts of Ethiopia. Similarly, the months of July, August, and September had less rainfall variation and the remaining months experienced high rainfall variation. This finding was also in line with previous studies.

In each ACZs the three-month July, August, and September had high contributions that contributed the greatest share to the annual rainfall. These results also agree with the findings of. Much of the rainfall was concentrated in the summer season (Table 2). The summer season was the main rainy season in all ACZs. Its contribution to the annual total ranged around 72% in each ACZs, whereas the contribution of spring rainfall to the annual total ranged from 14% at midland and to 17% at cold highland, and winter rainfall contributes between 10 to 11% to annual rainfall. Viste, et al. their study also reported that summer was the main rainy season in the north and northwest of the country, and this season contributes more than 70% of the annual precipitation [16]. Other studies revealed that the summer season contributes the highest (64-85%) while the spring season contributes much lower (5-30%) of the total annual rainfall across many parts of Ethiopia.

ACZs	Midland zone				Highland zone				Cold highland zone			
Month	Mean	SD	CV	(%)	Mean	SD	CV	(%)	Mean	SD	CV	(%)
Jan	6.48	3.67	56.64	0.54	8.78	3.93	44.76	0.66	10.85	4.39	40.46	0.75
Feb	13.34	6.92	51.87	1.10	15.82	7.72	49	1.18	18.12	8.53	47.08	1.27
Mar	33.49	18.79	56.10	2.77	43.31	23.08	53.29	3.24	53.81	27.08	50.33	3.77
Apr	46.7	22.57	48.33	3.87	57.27	26.77	46.74	4.29	69.42	30.44	43.85	4.86
May	85.13	45.58	53.54	7.05	100.14	51.92	51.84	7.5	111.21	56.47	50.78	7.78
Jun	126.02	35.65	28.29	10.44	146.55	37.26	25.42	10.97	159.76	37.89	23.71	11.18
Jul	310.10	51.89	16.74	25.7	340.16	57.37	16.87	25.46	358.91	60.15	16.75	25.12
Aug	279.7	36.29	12.97	23.17	308.57	38.17	12.37	23.09	328.36	39.14	11.92	22.97
Sep	169.98	32.61	19.18	14.07	178.99	34.13	19.07	13.4	186.10	34.98	18.79	13.03
Oct	103.83	52.62	50.68	8.6	100.80	49.28	48.89	7.54	96.00	47.30	49.27	6.72
Nov	22.87	13.91	60.82	1.89	23.39	15	64.13	1.75	21.79	14.54	66.72	1.52
Dec	9.77	5.50	56.29	0.8	12.29	6.50	52.89	0.92	14.63	7.84	53.58	1.03
Spring	178.66	64.6	36.15	14.8	216.54	72.05	33.27	16.2	252.56	75.56	29.91	17.7
Summer	885.8	84.6	9.55	73.36	974.27	91.93	9.44	72.92	1033.13	97.66	9.45	72.3
Winter	142.95	59.03	41.29	11.84	145.26	57.30	39.45	10.87	143.27	54.96	38.36	10
Annual	1207.41	115.6	9.57	100	1336.07	119.82	8.97	100	1428.96	120.44	8.43	100

Table 2: Summary statistics results of rainfall in the midland zone, highland zone and cold highland zone.

Distribution of seasonal and annual rainfall: Table 3 depicts the annual and seasonal PCI values by ACZs for the years ranging from 1981 to 2019.

ACZs	PCI (%)			
	Annual	Summer	Spring	Winter
Midland zone	16.55[a]	9.3[b]	7.48[b]	55.99[c]
Highland zone	16.29[a]	9.19[b]	10.86[b]	51.83[c]
Cold highland zone	16.02[a]	10.56[b]	9.18[b]	48.83[c]
Note: [a]: An irregular distribution; [b]: Uniform precipitation distribution; [c]: Strong irregular precipitation distribution				

Table 3: PCI value of annual and seasonal in each ACZs with their description.

It shows irregular distributions in the annual rainfall pattern at all ACZs. This finding is also consistent with recent studies by. Similarly, Gebrechorkos, et al. also observed that there was a tendency for irregular rainfall patterns in Ethiopia, Kenya, and Tanzania [17]. The table also illustrates a uniform precipitation distribution pattern in summer; spring shows moderate rainfall concentration at all ACZs and a strong irregular precipitation distribution in the winter season in each year.

Seasonal and annual rainfall anomaly: Figure 3 shows annual and seasonal standardized rainfall anomalies in the three ACZs for the period 1981-2019. The upward bar and the downward bar illustrate positive and negative anomalies, respectively. There was noticeable inter-annual and inter-seasonal variability of rainfall. During those most years, annual and seasonal rainfall was below average. The reduced rainfall, shown in the below figure as negative rainfall anomalies, has a critical implication on rural livelihoods in general and food security in particular, and positive rainfall anomaly illustrates for years in each ACZs during the study period and this implies that during those years annual rainfall was above average in each belt. anomaly due to the occurrence of the El Niño which affected the main livelihood of the rural people in different parts of Ethiopia.

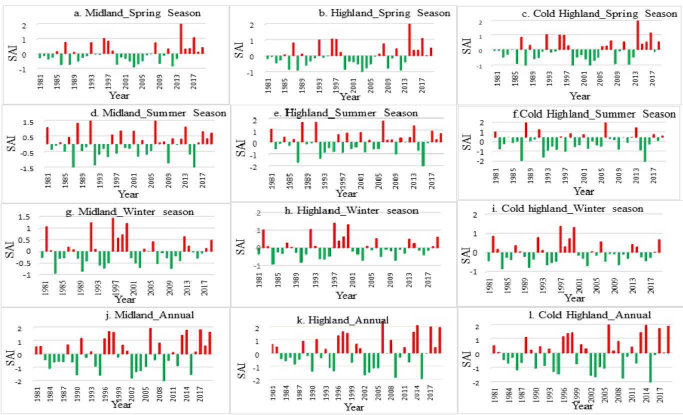

Figure 3: Annual and seasonal SRA value by ACZs of the Abiya watershed.

The SRA value for mean annual in the study area ranges from +2.81 in 2006 to -2.48 in 2015 in the cold highland zone, from +1.86 in 2006 to -1.93 in 2015 in the highland zone, and from +1.95 in 2006 to -2.16 in 2009 in the midland zone. Except for the cold highland zone, the driest and wettest years were 2009 and 2006, respectively. Other studies also found in the central highlands of Ethiopia and in the Amhara region. The year 2015 experienced the highest negative anomaly due to the occurrence of the El Niño which affected the main livelihood of the rural people in different parts of Ethiopia.

The drought incidents in Ethiopia negatively affected the livelihoods of millions of people. The major droughts in Ethiopia recorded in the last three decades were related to ENSO events. In Ethiopia, El Niño events in 1987, 1991, 2001, 2009, and 2015 coincided with an extended drought condition from April to November, which covers the main cropping season of the country. The annual rainfall anomaly was computed and drought years in the study area detected negative anomalies of 1984, 1985, 1986, 1987, 1990, 1994, 2002, 2009, 2012, 2015, 2016 which are coinciding with the El Niño events. The results are supported by the recent studies on the effect of El Niño events on Ethiopian rainfall distribution and its outcomes.

Rainfall trend

Rainfall autocorrelation: All autocorrelations fell within 5% significance levels, and there was no apparent pattern (e.g. positive autocorrelations followed by negative autocorrelations). This means the yearly rainfall time series for all ACZs did not show any significant serial correlation at all lags. The rainfall data were not correlated with each other (Figure 4).

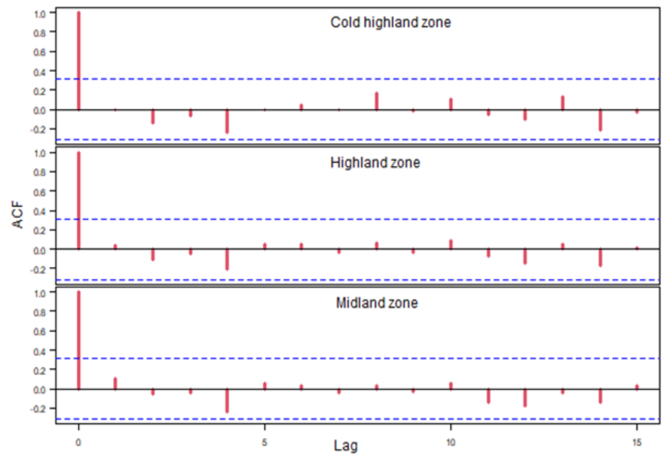

Figure 4: The correlation coefficient of the annual rainfall at different lags in three ACZs.

These time series were therefore random, meeting the independence distribution criteria. As shown by earlier studies, and come up with the same result noted that there was no constant persistence in the observed rainfall series data for the Amhara region of Ethiopia.

However, this non-association was the essence of randomness. In short, adjacent observations did not "correlate" (the areal average annual rainfall data indicated that no dependency or periodicity existed in this time series and suggested that areal average annual rainfall quantities are entirely independent of one year to the next). In general, there was no significant ongoing correlation by whole lags at the 5% significance level when the Autocorrelation Function (ACF) for annual rainfall in all ACZs was examined. Therefore, the analysis of the trends in the characteristics of the rainfall did not need any further data manipulation; the MK test was carried out directly. Outcomes from the serial correlation test, the MK test, and Sen's slope predictor should be applied to the rainfall data from 1981-2019 for the Abiya watershed in all ACZs.

Monthly, seasonal, and annual rainfall trends: The MK test and the trend's slope were performed on the rainfall time-series 1981-2019 for the three ACZs were presenting (Table 4).

ACZs	Midland zone			Highland zone			Cold highland zone		
Month	Mean	MK	Trend	Mean	MK	Trend	Mean	MK	Trend
Jan	6.48	-2.00**	-0.09	8.78	-1.68*	-0.07	10.85	-1.24	-0.045
Feb	13.34	0.28	0.01	15.82	0.16	0.01	18.12	-0.21	-0.12
Mar	33.49	0.27	0.07	43.31	-0.01	-0.01	53.81	0.00	0.00
Apr	46.7	0.60	0.14	57.27	0.39	0.16	69.42	0.27	0.09
May	85.13	1.6	1.19	100.14	1.55	1.38	111.21	1.11	1.67
Jun	126.02	1.00	0.43	146.55	0.82	0.56	159.76	0.88	0.56
Jul	310.10	1.14	0.68	340.16	0.77	0.46	358.91	0.44	0.39
Aug	279.7	-0.22	-0.07	308.57	-0.50	-0.26	328.36	-0.96	-0.59
Sep	169.98	-0.65	-0.40	178.99	-0.42	-0.25	186.10	-0.33	-0.15
Oct	103.83	0.20	0.12	100.80	0.00	0.00	96.00	0.08	0.08
Nov	22.87	1.08	0.23	23.39	1.21	0.24	21.79	1.28	0.23
Dec	9.77	0.74	0.05	12.29	0.45	0.03	14.63	0.12	0.00
Spring	178.66	1.52	1.09	216.54	1.35	1.24	252.56	1.15	1.34
Summer	885.8	0.68	1.00	974.27	0.58	0.78	1033.13	0.6	0.86
Winter	142.95	0.59	0.44	145.26	0.69	0.49	143.27	0.46	0.48
Annul	1207.41	0.11	2.05	1336.07	0.87	2.07	1428.96	0.92	2.00
Note: * is statistical significance at 0.1; ** is statistical significance at 0.05									

Table 4: MK test and Sen's slope of monthly, seasonal, and annual rainfall by ACZs.

From the results, monthly rainfall data had shown a statistically significant decreasing trend for January at a 5% significance level in the midland and a 10% significance level in the highland zone. Correspondingly, a statistically significant declining trend for January was also shown by recent studies. Non-significant upward trends for February (except cold highland zone), March (in the midland zone), April, May, June, July, October, November, and December at any level of significance in all ACZs, respectively. A non-significant decreasing trend was perceived for the months, January (in the cold highland zone), March (in the highland and cold highland zone), August, and September in all ACZs, respectively.

A statistically non-significant upward trend was observed for winter, summer, and spring rainfall at any significance level in each ACZs. Similarly, the annual rainfall has shown a non-significant upward signals trend at any significance level. Likewise, previous studies in varied parts of Ethiopia also did not find a statistically significant trend in the yearly rainfall such as reported that annual rainfall exhibits statistically insignificant increasing trends in most areas in the Upper Blue Nile basin, and Alemu and Bawoke stated that annual rainfall shows statistically insignificant increasing trends in the Amhara region, all which includes the watershed. Similar non-significant increasing trend Eshetu, et al. was reported in Gatira, southwestern Ethiopia [18]. An increasing trend of annual rainfall Gedefaw, et al. was observed in the Amhara region specifically in Gondar, Bahir Dar, and Motta [19]. Contradict studies were reported by Mulugeta, et al. a non-significant decreasing trend of annual rainfall in the Awash River basin (1902-2016), and Bayable, et al. also resport the same result in West Harerge Administrative Zone (1983-2019), Eastern Ethiopia [20].

Conclusion

The study has presented a detailed analysis of the spatial variability and temporal trends of rainfall among the ACZs of the Abiya watershed. The mean annual and seasonal rainfall of the watershed increased towards higher elevation, from midland to cold highland in the watershed. On the other hand, the mean annual rainfall and summer season rainfall decreased from southwest to the northeast of the watershed. The main rainfall period was found to be the summer season that ranging from June to September. The CV shows low inter-annual variability, low inter-seasonal (Summer) variability, high inter-seasonal (Spring) variability at midland and highland and medium inter-seasonal (Spring) at cold highland, and high inter-seasonal (Winter) variability was observed in all ACZs. SAI was also observed that inter-annual and inter-seasonal variability of rainfall in all ACZs with highest negative anomalies. The PCI shows the watershed had irregular rainfall distribution in annual and uniform seasonal (for Summer and Spring) rainfall distribution in all ACZs, and strong irregular rainfall distribution for the winter season in all ACZs. There was an overall increase in the annual and seasonal rainfall with different magnitudes in the decades: Yet there were no significant trends in statistical terms at any level in annual and seasonal trends. This all the characteristics of annual and seasonal rainfall might have leads risky in the future. Since the annual rainfall had irregular distribution, the seasonal rainfall reveal uniform and strong distribution, low, moderate and high variability, and the trends were increased, therefore adaptive measures shall be applied.

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Data Availability Statement

All relevant rainfasll data are available online. A record of daily rainfall data for this study was taken from 50 sample grids points (each representing areas of 5 × 5 km) to study from the CHIRPS dataset, which was accessible online at http://climexp.knmi.nl/select.cgi?field=chirps_20_25.

Conflict of Interest Statement

The authors declare no conflict of interest.

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