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Regional Scale Spatiotemporal Variations of Rainfall Over Agroclimatic Zones of Wollo Highlands, Northeastern Ethiopia

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ABSTRACT

Rainfall is one of the key climatic variables that affect spatiotemporal patterns of water availability and analyzing its trends and variability is important from both the scientific as well as socio-economic point of view. In this study, long-term rainfall trends were investigated in annual, seasonal and monthly scales based on 16 climate-stations in the Agroclimatic zones of Wollo highlands, Northeastern Ethiopia over the past 60 years. After testing homogeneity, Mann-Kendall and Sen's slope estimator tests were applied to detect trends of rainfall data and magnitude of changes over a time period. In order to detect the most probable change year, the Petit test was applied. Results of the study showed an increase in annual rainfall trend in northwest and northeast whereas decreasing trend detected in the northern, western and southeastern parts of Wollo highlands. The magnitude of significant increasing trends of annual rainfall vary up to 1.99 mm/year. Three seasons: Kiremt, Belg and Bega were used to compare seasonal variations. Kiremt rainfall variations were higher compared with those other two seasonal series with values varying from 2.14-3.98 mm/season. A noticeable decrease in Belg season was observed in all the regions except western parts of Wollo, besides no significant trends were detected in Belg and Bega rainfall series. This study's results also show an increasing trend from June to August, little or no trend from November to January and decreasing trends in the remaining months. The findings of this study could support the researchers to realize monthly, seasonal and annual variability of rainfall over agroclimatic zones of Wollo highlands and a groundwork for further studies.

Keywords: Rainfall. Mann-Kendall test. Sen's slope estimator. Spatiotemporal variations. Wollo highlands. Ethiopia

1. INTRODUCTION

Water resources availability, management and utilization within a watershed is primarily impacted by spatiotemporal variability of rainfall and water yield which may distress food and water security, agricultural production, economic development, societal statues and ecosystems and ecosystem services [1]. Rainfall is one of the most important variables in the field of climate sciences and hydrology frequently used to trace extent and magnitude of climate change and variability which is important for a variety of applications in hydrology and water resources management [2], [3].

Associated with global warming and climate change, changing rainfall patterns and their impact on surface water resources are important climatic problems facing societies recently [4]–[6]. Cheung et al.[7] emphasized that in countries where their economy is heavily dependent on low-productivity rain-fed agriculture, rainfall variability and trends are commonly cited leads to socioeconomic problems such as water scarcity and food insecurity. As a result, investigating the spatiotemporal dynamics of these meteorological variables is very crucial so as to provide input for policymakers and practitioners that help to make informed decisions.

Numerous studies showed that different statistical methods developed and used over the years in Ethiopia in order to detect the trends and shifts of trends in hydro-climatic variables [7]–[9]. There are various parametric and non-parametric tests used for identifying trends in hydro-meteorological time series. However, in recent studies, non-parametric tests are mostly used for non-normally distributed and censored data, including missing values, which are frequently encountered in hydro-climatological time series. The most commonly used non-parametric Mann-Kendall test [10], [11] has been applied to quantify the significance of monotonic trends of hydrometeorological time series [12]. However, the magnitude of the trend itself is not estimated by the Mann-Kendall test. For this purpose, another nonparametric method referred to as the Sen's slope estimator approach is very popular by researchers to quantify slope of the pattern (magnitude) [13], [14]. Though both Mann-Kendall and Sen's slope estimator methods cannot detect the duration or timing of changes, non-parametric Pettitt tests [15] widely used with rainfall data [16] were used.

Several recent studies on climatological trends conclude that trend in observed rainfall comprises a complex function of the climatic environment, precipitation intensity and season [17]. Relevant literatures on trend and variability analysis in rainfall time series across the globe were reviewed to identify the research gaps. These studies include trend analysis of climatic variables such as precipitation, temperature, and water yield in various parts of the world [12], [18], [19].

So far, several studies have been carried out to analyze rainfall variability and trend in specific locations in the Amhara region including Wollo [20]–[22] and covering different watersheds throughout Ethiopia. Several studies such as Cheung et al., Conway and Hulme, Mengistu et al., Selesh and Zanke, Wagesho et al., Onyutha and Willems [7], [23]– [27] have been undertaken to investigate the characteristics of rainfall patterns in different parts of Ethiopia. These studies concentrated on specific locations and few of them were concentrated on the rainfall variability of the country considering few stations with long records.

Seleshi and Zanke [25] analyzed the rainfall in different climatic zones of Ethiopia based on 11 key stations for a period of 1965-2002 using Mann-Kendal test and showed that there is no trend in the annual and seasonal rainfall totals over central, northern and northwestern Ethiopia. Cheung et al. [7] examined the changes in annual and seasonal rainfall using 134 stations for a period of 1960-2002 and concluded that there are no significant changes or trends in annual rainfall at the watershed level in Ethiopia. Wagesho et al. [26] investigated trends using gridded rainfall data for 1951-2000 in annual, seasonal and maximum 30-day extreme rainfall over Ethiopia and showed a decreasing trend for annual and summer season in the northern, northwestern and western parts whereas increasing annual rainfall trend in the eastern part of Ethiopia.

Menigstu et al. [24] analyzed the spatial and temporal variability and trends of rainfall over Upper Blue Nile basin in Northwestern Ethiopia for a period 1981-2010 and showed that annual and seasonal statically non-significant increasing trend except spring season which showed a declining trend in the north-east part of the basin. Bewket and Conway [22] characterized rainfall variability and trend in the drought prone Amhara regional state of Ethiopia and showed a complex picture of rainfall variability for both temporal and spatial scales. Conway and Hulme [23] reported decreasing annual rainfall in the Eastern Nile of Tekeze-Atbara and Blue Nile basins of north and northwestern Ethiopia resulting in a reduction of river flows between the years of 1945 and 1984.

Therefore, the review of these previous studies in different parts of Ethiopia showed different findings and conclusions for the existence of trend primarily due to the use of different reasons like arbitrary division of the study area, the quality of the available data, data gap filling, periods of analysis and other factors [7], [25]. Furthermore, researchers included the limited number of rainfall stations located in the highlands of Wollo for their work. As a result, it is crucial to include high number of rainfall stations to analyses the spatial and temporal variability of rainfall patterns which are crucial in adaptation planning for agroclimatic zones of Wollo highlands, as rain-fed agriculture not only accounts for around 83% of the Gross Domestic Product (GDP) but also constitutes 90% of the total employment of this region.

A deeper understanding of the characteristics and distribution of rainfall patterns over time and space will support water resources management, agricultural development and disaster management and planning in Ethiopia in the context of global climate change [28], [29]. Agroclimatic zones of Wollo Highlands in particular are affected by consequent droughts [22], [25], [30]. Hence, the purpose of this study is to investigate the rainfall variability and trends based on the highland watersheds of Wollo in sub regional scale and contribute to the existing literature on local scale trends and variability of rainfall where a detailed previous study does not exist in the study region.

2. MATERIALS AND METHODS

2.1 Description of the study area

The study area situated roughly from 10.15^0 - 12.39^0 N latitude and 38.42^0 - 40.21^0 E longitude which covers the agroclimatic zones in the Wollo highlands. The agroclimatic zones of Wollo highlands (Figure 1) is located in the Northeastern part of Ethiopia covering an approximate drainage area of 31,569 km2. The area is characterized by complex topography with a broad range of elevations varying from 4248 meter above sea level (masl) in the central mountainous area to 913 masl in the george areas of the eastern and western lowland parts (Figure 1).

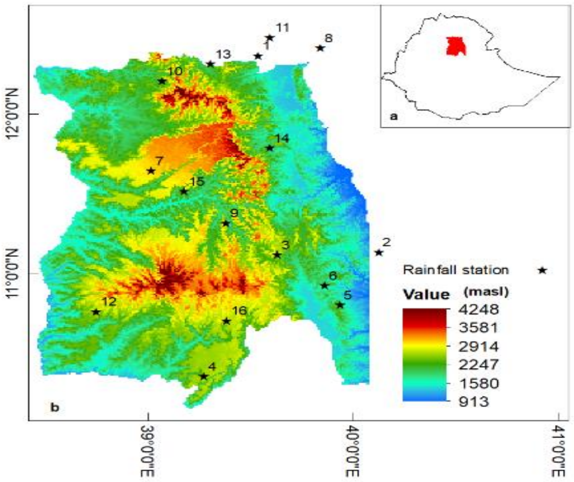

Fig.1 Location and terrains of the study area. (a) Location of agroclimatic zones of Wollo Highlands in Ethiopia; (b) the terrain of agroclimatic zones of Wollo Highlands (elevation in meter above sea level (masl) denoted by the pathed colors) and 16 rainfall stations used in this study (for details see Table 1).

The variation of rainfall in the study area is driven by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) [25] and complex topography. This affects the spatial and temporal variation of rainfall amount [31]. Three seasons controlling the amount of rainfall over Wollo highlands: main rainy season from June to September locally known as Kiremt, the dry season or “Bega” from October to February and short rainy season or “Belg” from March to May. The annual average rainfall over the study area varies from 1688 mm in the central highlands to 700 mm in the eastern lowland parts. As a whole, the rainfall increases with altitude.

The economy of Wollo highlands is mainly based on low productivity rain-fed agriculture, like the rest of Ethiopia rural areas. The study area agricultural systems are dependent on natural rainfall and dominated by small scale farmers [22]. The agricultural sector of this area is highly susceptible to the amount and distribution of rainfall and associated recurrent droughts which leads to food shortages and famine.

2.2 Kombolcha's geographical data and rainfall details

There are now more than 50 rainfall recording stations located within the highlands of Wollo and surrounding areas. However, for hydro-climatic studies a few stations have continuous records. The stations used in this study were selected based on several criteria, which included length of the data, completeness, and the spatial and geographic distribution of the stations. Based on this criteria, daily rainfall data for more than 58 rainfall gauging stations having relatively good quality and long records (>30 years) over different climatic zones of Wollo were provided by the Ethiopian National Meteorological Services Agency (NMSA). Close scrutiny of the data has shown that only sixteen stations with a reasonably good geographic distribution to cover the study area (Figure 1; Table 1) have daily rainfall data with less than 10% missing values in any given year used for this study.

Station records are from the early 1950s to the late 2010s with varying record length of each station. During field visit, it is observed that station histories are not known, but it is likely that some have incurred some changes in location and observation practices with implications for homogeneity of their records. All records were scanned for discontinuities, outliers and obvious errors – where possible/appropriate these were cross-checked with records from nearby locations and removed if judged erroneous. The three steps visualization, comparison to the nearest station within the same zone and regression will be taken for verifying these selected stations data used in this research. The remaining 27 stations' data that have relatively good quality were used for infilling missing data at the 16 stations selected, whereas others were rejected.

Table 1. Rainfall stations used in this study

S.No.	Station	Latitude (^{O}N)	Longitude (^{O}E)	Altitude (m)
1	Alemata	12.31	39.41	1580
2	Bati	11.13	40.13	1660
3	Dessie	11.06	39.38	2500
4	Jama Degolo	10.26	39.15	2550
5	Kemissie	10.43	39.5	1450
6	Kombolcha	11.07	39.44	1903
7	Kone Abo	11.41	38.57	3000
8	Korem	12.31	39.31	3000
9	Kutaber	11.16	39.32	2700
10	Lalibela	12.31	39.03	2500
11	Maichew	12.48	39.32	2400
12	Mekane Selam	10.61	38.76	2620
13	Nefas Mewucha	11.44	38.27	3000
14	Sirinka	11.33	39.37	2000
15	Wegeltena	11.36	39.13	3000
16	WereElu	10.35	39.27	2690

2.3 Methodology

This study revealed the spatiotemporal characteristics of rainfall variations in the agro climatic zones of Wollo highlands in Northeast Ethiopia from 1952 to 2016. As a first step of analysis, basic statistical parameters like mean, standard deviation, kurtosis, coefficient of variation and skewness coefficient were computed from the rainfall data of each station. In general, many hydro-climatic time series data are not normally distributed, non-parametric tests were preferred over parametric tests. This study performed a trend analysis using non-parametric statistical tools such as Mann–Kendall test [10], [11], Sen's slope estimator [32] and Petit test [15] to determine significance trends, trend magnitudes and detecting change point, respectively. The upward and downward trends with statistical significance are also shown by Mann-Kendall test method. In this paper, annual and seasonal data series were used for trend analysis. Monthly rainfall trends also have been analyzed separately.

1)Mann-Kendall Test: This method is a ranked non-parametric test which has been widely used to analyze trends in hydro-meteorological time series [12] and highly recommended by the World Meteorological Organization (WMO) [33]. Since the Mann-Kendall test statistics depend on positive or negative signs, the trends in this test not significantly affected by the outliers and skewness occurred in the data series.

The Mann-Kendall test statistics S is calculated with the variance for a series y1, y2, …., yn as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(y_j - y_k\right) \quad (1)$$

Where yk is ranked from k = 1, 2, …, n-1 and yj is ranked from k+1, 2, …., n and n is the length of the data set.

The data values of each yk is used as a reference point to compare with the data values of yj is given by:

$$\operatorname{sgn}(y_j - y_k) = \begin{cases} +1 \; if \; y_j - y_k > 0 \\ 0 \; if \; y_j - y_k = 0 \\ -1 \; if \; y_j - y_k < 0 \end{cases} \quad (2)$$

Where yk and yj are the data values in time series k and j (j>k), respectively and sgn(yj-yk) is the sign function. For a sample size n ≥ 10, Mann-Kendall test is then characterized by normal distribution with the mean E(S) = 0 and variance is calculated as:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)\right] \quad (3)$$

Where m is the number of tied groups in the time series and ti is the number of ties in the ith tied group.

The standardized Mann-Kendall test statistics (Z) can be estimated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, \; if \; S > 0 \\ 0, \; if \; S = 0 \\ \frac{S-1}{\sqrt{Var(S)}}, if \; S < 0 \end{cases} \quad (4)$$

In this research, at a significance level α (=0.05), the null hypothesis that no trend exists should be rejected if absolute value of Z > Z1-α/2 (= 1.96) which is commonly used in the Nile and Tekeze Basins hydro-climatic trend analysis [8], [34]. A positive value of Z indicates an increasing trend while a negative value of Z reflects a decreasing trend. A positive Z value larger than 1.96 denotes a significant increasing trend, whereas a negative Z value lower than -1.96 shows a significant decreasing trend.

2)Sen's Slope Estimator: The magnitude of the trend in the time series was determined using Sen's estimator which has been widely used in hydro-meteorological time series [12], [35]. Sen [32] developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Q_i = \frac{y_j - y_k}{j-k} \quad for \; i = 1,..., N, \quad (5)$$

Where Qi is Sen's slope, yj and yk are the data values at times j and k (j > k), respectively.

If there is only one datum in each time period, then $N = \frac{n(n-1)}{2}$; where n is the number of time 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 slope estimator are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as:

$$\theta = \begin{cases} Q_{[(N+1)/2]}, & if \; N is odd \\ \frac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2}, & if \; N is even \end{cases} \quad (6)$$

The sign of θ shows whether the trend is decreasing or increasing.

3)Pettit test: This test, developed by Petit [15] is a non-parametric test, which is useful for evaluating the occurrence of abrupt changes in hydrological and climatic records with continuous data. One of the reasons for using this test is that it is more sensitive to breaks in the middle of the time series and mostly used changes point detection in climatic records [34]. This method detects a significant change in the mean of a time series when the exact time of the change is unknown.

The test uses a version of the Mann-Whitney statistic Ut,N. Let t be the most likely change point year of a time series (Y1, Y2, . . ., YN) with a length of N. Two partial time series (Y1, Y2,. . ., Yt) and (Yt+1, Yt+2,. . ., YN), can then be derived by dividing the time series at time t. The test statistic Ut,N is given by:

$$U_{tN} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} \operatorname{sgn}\left(Y_i - Y_j\right) \qquad (7)$$

A continuous increase in the value of UtN when plotted with t will indicate absence of change point but when the value of |UtN| increases initially and then decreases after a point, it will indicate the presence of change point. The point where maximum value of Ut obtained is considered as the most probable change point.

$$K_N = \max_{1 \le t \le N} \left|U_{tN}\right| \qquad (8)$$

The change points of the rainfall series located at KN, provided that the statistic is significant.

3. RESULTS AND DISCUSSIONS

3.1 Spatiotemporal variations in rainfall series

The rainfall data screened and comparisons between stations were made using the statistical metrics like mean, standard deviation (STD), coefficient of variation (CV), skewness (Cs), and actual excess kurtosis (Ku).

Noticeable basic statistical properties of the rainfall time series of sixteen rainfall stations in the highlands of Wollo given in Table 2 and Figure 2.

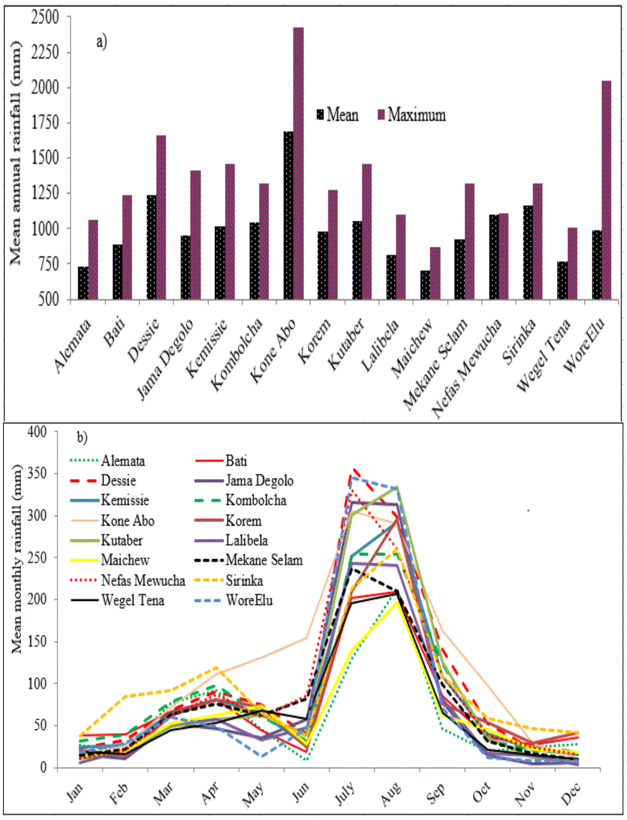

Fig. 2 (a) Mean annual and maximum rainfall, and (b) mean monthly rainfall in the 16 stations of Wollo highlands from 1952-2016

The highest mean annual rainfall was recorded in Kone Abo (1687.94 mm) and the lowest mean was registered in Maichew (700.18 mm). Kone Abo station also recorded the maximum (355.39 mm) but Mekane Selam recorded the minimum (155.36 mm) STD. However, as shown in Figure 2a maximum rainfall (2428.10 mm) is seen for Kone Abo while minimum (866.10 mm) is indicated for Maichew. The Highlands of Wollo are-characterized by heavy rainfall in the months of July and August Figure 2b.The study area received the maximum mean monthly rainfall in July (358.00mm), July (345.25mm), and August (333.93mm) in the central and south-eastern parts of Wollo at Dessie, WereElu and Kutaber stations, respectively. The minimum mean rainfall was observed in December (2.89mm), November (5.03mm) and December (6.84mm) in the stations of Lalibela, Jama Degolo and Kutaber, respectively.

The skewness (Cs), which is a measure of asymmetry in a frequency distribution around the mean, varied between -1.07 and 1.63. Six stations are positive skewness indicating that annual rainfall during the period is asymmetric and it lies to the right of the mean. Excess kurtosis (Ku) is a statistic describing the peakedness of a symmetrical frequency distribution, it varied from -0.68 to 6.14 (Table 2).

Table 2. Descriptive statistics of the annual rainfall data over the study stations

Station	Mean	STD	CV	Cs	Ku
Alemata	734	195.62	0.27	-0.52	0.36
Bati	885	156.95	0.18	-0.07	1.54
Dessie	1242	263.09	0.21	-1.07	3.24
Jama Degolo	950	196.24	0.21	-0.20	1.40
Kemissie	1020	222.42	0.22	0.59	0.14
Kombol-cha	1045	159.57	0.15	-0.49	0.33
Kone Abo	1688	355.39	0.21	-0.07	-0.21
Korem	981	221.52	0.23	-0.39	0.29
Kutaber	1050	215.85	0.21	-0.07	0.32
Lalibela	812	203.79	0.25	-0.30	-0.38
Maichew	701	176.58	0.25	-0.45	-0.68
Mekane Selam	924	155.36	0.17	0.44	0.83
Nefas Mewucha	1103	281.61	0.26	0.92	4.17
Sirinka	1164	323.38	0.28	1.63	6.14
Wegeltena	771	173.69	0.23	1.38	5.68
WereElu	992	373.26	0.38	1.35	1.86

For time series data to be considered normally distributed, the value of Cs and Ku must be equal to 0 and 3, respectively. Table 2 indicates that the rainfall data are partly positively skewed and not normally distributed. The CV, a statistical measure of the dispersion of data points in a data series around the mean, was computed for all stations to investigate spatial pattern of inter-annual variability of annual precipitation over the study area. CV varied between 0.15 (Kombolcha) and 0.38 (WereElu). Table 2 shows that stations found in the Northeastern and Eastern part of the highlands of Wollo (Maichew, Alemata, Korem, Sirinka, Bati, Kemissie and Kombolcha) have a more inter-annual variability of rainfall than the stations observed in the west and southwest part of the study area. It can be concluded from the results that the areas of usually having heavy rainfall are the zone of least variability and areas of lowest rainfall are the zone of highest variability.

3.2 Trends in rainfall

The spatiotemporal heterogeneity in rainfall across the study area was characterized by using statistical analysis and annual anomalies. The rainfall data sorted and arranged in Excel then the homogeneity checked using the standard normal homogeneity test. The data are found to be homogeneous and rainfall trends and variability are analyzed in the annual, seasonal and monthly scales for 1952 to 2016 time periods in all 16 stations. The results of each time scales of all stations spatiotemporal variation are discussed below:

3.2.1 Annual rainfall trends

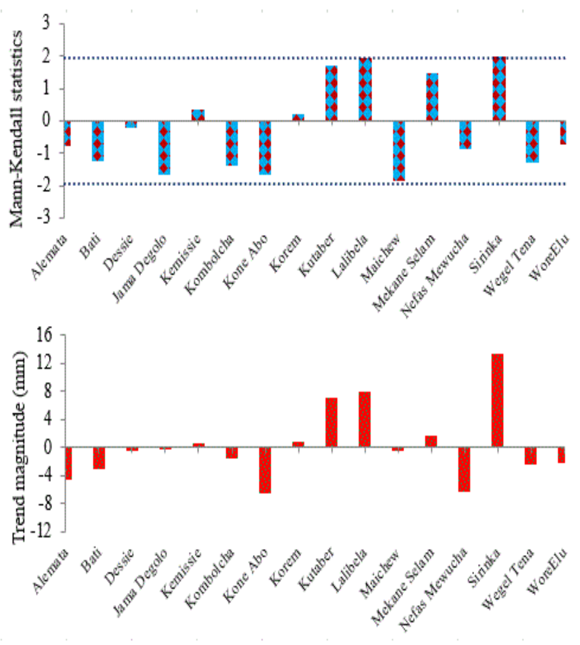

Fig. 3 Graphical illustrations of the trend tests for annual time series of the Wollo highland stations (the 95% confident intervals are marked with dotted lines in the top figure)

Table 3. Annual and seasonal rainfall properties using Mann-Kendal test in Wollo highlands (Numbers in bold are statistically significant)

Station	Annual		Kiremt		Bega	Belg		
	Sen's Slope (θ)	Z	θ	Z	θ	Z	θ	Z
Alemata	**-4.57**	-0.81	0.16	1.02	0.00	0.00	-0.18	-1.82
Bati	-3.23	-1.28	0.21	0.53	0.00	0.00	-0.17	-1.15
Dessie	-0.57	-0.25	0.00	0.02	0.00	0.00	-0.05	-0.95
Jama Degolo	-0.32	-1.69	0.01	0.02	0.00	0.00	-0.09	-1.29
Kemissie	0.66	0.37	0.05	0.45	0.00	0.00	-0.09	-2.20
Kombolcha	-1.67	-1.39	0.04	0.25	0.00	0.00	-0.05	-0.72
Kone Abo	**-6.65**	-1.68	-0.08	-0.33	0.00	0.00	-0.19	-1.34
Korem	0.99	0.21	0.32	3.42	0.44	4.10	0.00	0.00
Kutaber	**7.22**	1.72	0.35	1.57	0.00	0.15	-0.06	-1.12
Lalibela	**8.12**	1.96	**0.45**	2.14	0.00	0.00	0.08	1.36
Maichew	-0.66	-1.89	0.33	3.00	-0.05	-3.43	0.00	0.00
Mekane Selam	1.80	1.49	0.12	0.54	0.00	-0.82	-0.16	-1.56
Nefas Mewucha	**-6.50**	-0.91	**1.52**	3.98	-0.27	-5.27	0.39	4.20
Sirinka	**13.46**	1.99	0.43	1.27	0.08	1.85	-0.45	-2.44
Wegeltena	-2.60	-1.30	0.11	0.72	0.00	0.00	-0.16	-2.43
WereElu	-2.20	-0.76	0.04	0.38	0.00	0.00	-0.05	-2.03

The results of the non-parametric Mann-Kendall test for the annual rainfall trend are presented in Table 3 and Figure 5. The mean annual rainfall over 62 % of the stations in the Wollo highlands showed a long-term decreasing trend whereas 38% (six stations such as Kemissie, Korem, Kutaber, Lalibela, Mekane Selam and Sirinka) showed an increasing trend (Table 2; Figure 5a). Only 13 % of the stations showed a significantly increasing trend (Figure 5b).

The Mann-Kendall test statistics and magnitude of the trend determined using the Sen estimator in the time series of each station showed in Table 2 and Figure 3. The stations Kutaber, Lalibela and Sirinka showed a significant increasing trend with values 7.22, 8.12 and 13.46 mm/year, respectively.

The results of this study based on Sen's slope estimator showed that the highest decreased in annual rainfall observed in Nefas Mewucha with a value of (-) 6.50 mm/year whereas the highest increase in annual rainfall observed at Sirinka with a value of (+) 13.46 mm/year. Based on the results, it is evident that significant long-term changes have occurred in the rainfall quantity across the regions of Wollo highlands (Figure 4a). Analysis based on annual data suggests that there is an observed decrease in rainfall across most of the Central regions of Wollo (Wegeltena, Kone Abo and Dessie), Northern region (Alemata and Maichew) and Eastern regions (Bati and Kombolcha). Moreover, increasing trend observed in some stations located in Southern and Central regions (Mekane Selam and Kutaber) and Western region (Lalibela).

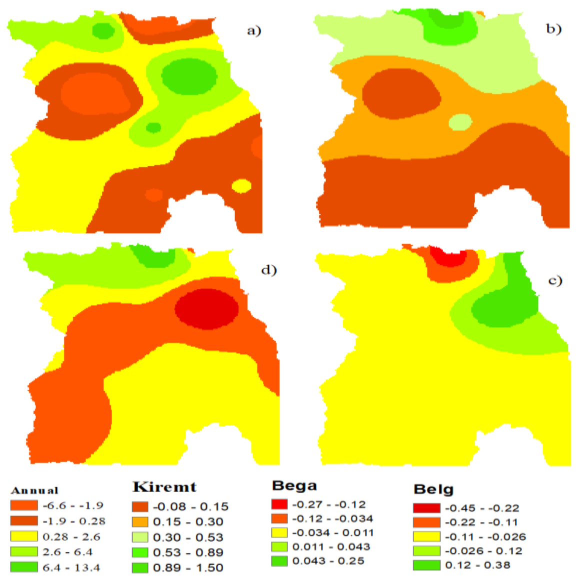

Fig.4 Spatial distribution of rainfall trends in the highlands of Wollo a) Annual b) Kiremt c) Bega and d) Belg seasons

Figure 4(a-d) showed spatial increasing and decreasing trends of annual and seasonal rainfall distributions over agroclimatic zones of Wollo highlands. Figure 4a indicated an increase in annual rainfall trend detected in the northwest and north east areas whereas decreasing trend in annual rainfall detected in the northern, western and south east of Agroclimatic zones of Wollo highlands.

3.2.2 Seasonal rainfall trends

To investigate the changes in rainfall for different seasons, a year was divided into three seasons: Kiremt (June-September), Belg (February–May), Bega (October–January). Rainfall analysis was carried out for all the seasons as well as the whole year separately.

In Kiremt (Wet season) rainfall, 94% of the stations and 6% of the stations show increasing and decreasing trends, respectively (Figure 5a). Only 25% of the stations are found with significant increasing trends and none with decreasing (significant negative) trends (Figure 5b) while the remaining 75% of the stations showed a non-significant (either increasing nor decreasing) trend. These significant positive (increasing) trends were located at Korem, Maichew, Lalibela and Nefas Mewucha found in the North and Western parts of Wollo. Generally, it can be said that the Kiremt season has been experiencing mild increasing precipitation trends over the past 60 years in the whole Wollo regions (Figure 6).

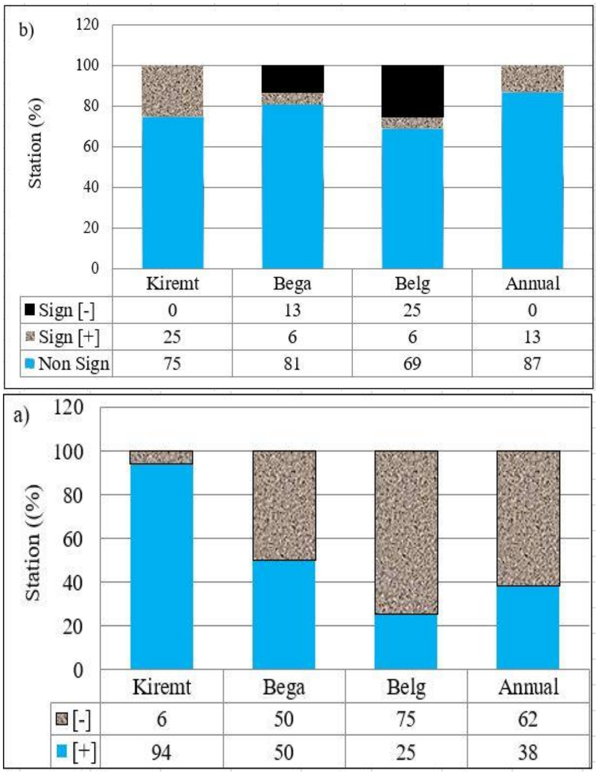

Fig. 5 Percentage annual and seasonal trend test results a) Overall negative and positive trends b) significant positive and negative trends at 95% confidence level

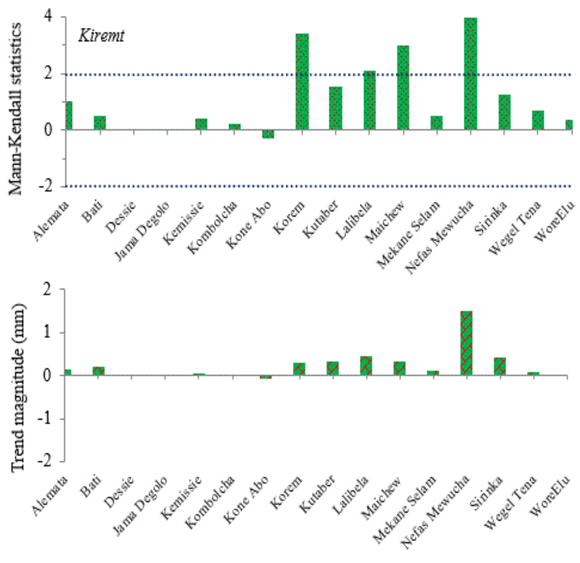

Fig. 6 Results of the trend tests for Kiremt season time series of Wollo highland stations
(the 95% confident intervals are marked with dotted lines in each top figure)

The rainy season (Kiremt) rainfall over Wollo showed a long term significant increasing trends for Korem, Lalibela, Maichew and Nefas Mewucha stations with a value of 0.32, 0.45, 0.33 and 1.52 mm/season, respectively. According to the Sen's slope estimator the highest increasing significant trend are 1.52 mm/season and 0.45 mm/season for Nefas Mewucha and Lalibela stations, respectively (Table 2 ; Figure 6).

The spatial analysis in Figure 4b indicated that Kiremt season trend analysis detected an increasing trend in rainfall in the northern and northwestern parts of Wollo. However, the rainfall trend decreased towards the southern parts of Wollo.

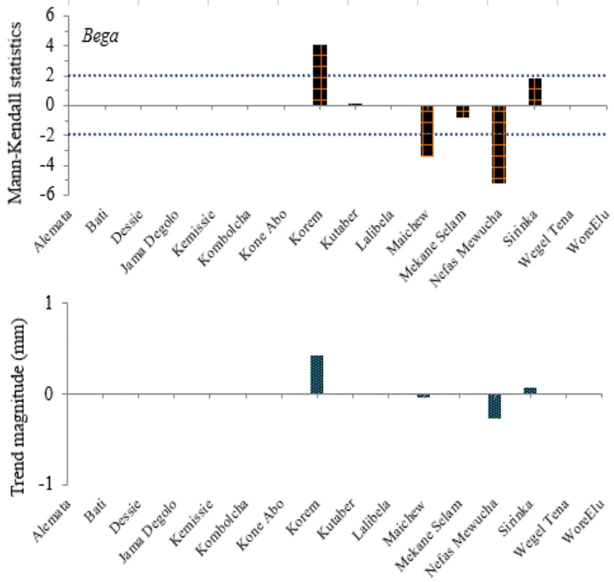

Fig.7 Results of the trend tests for Bega season time series of Wollo highland stations
(the 95% confident intervals are marked with dotted lines in each top figure)

In the Bega (dry) season Mann-Kendall test found that most of the stations in Wollo with non-significant trends (81%) (Figure 5b). The magnitude of significant variation for about ten stations was almost nil (zero). However, 13% of stations (Maichew and Nefas Mewucha) were found to have significant negative (decreasing) trend and only Korem station was significant for positive (increasing) trend (Table 2 and Figure 7). In general, Bega season has been found to experience region wide neither increasing nor declining precipitation trends over the past 60 years (Figure 7). The analysis of seasonal precipitation showed a mix of positive and negative trends.

In the Bega season (Table 2; Figure 7) no slopes are prevalent in all the parts of Wollo. This relates most of the stations not detected trends in rainfall in the months of October, November, December and January (Table 3).

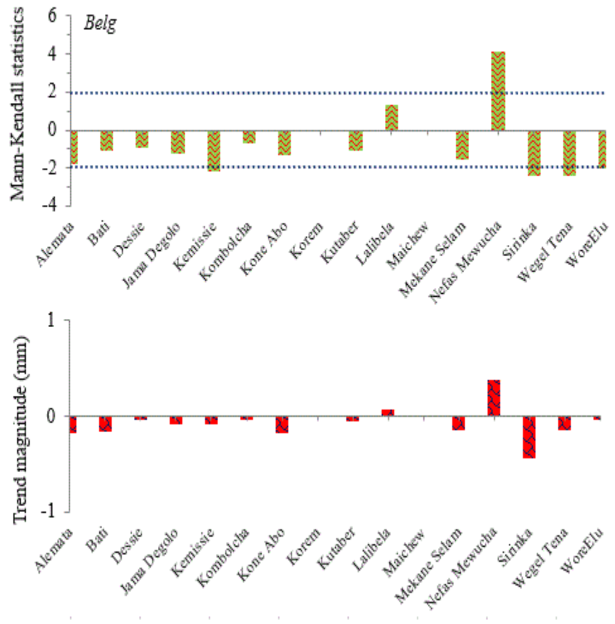

Fig. 8 Results of the trend tests for Belg season time series of Wollo highland stations
(the 95% confident intervals are marked with dotted lines in each top figure)

However, only two stations such as Sirinka and Kutaber showed increasing trend with values 0.08 to 0.44 mm/season, respectively. Also, two stations such as Maichew and Nefas Mewucha detected decreasing trends with values -0.05 and -0.27 mm/season, respectively. According to the results of Bega season spatial rainfall trends shown in Figs. 4c there is no trend detected in more than 80% of the parts of Wollo for the past 60 years. However, the north tip of Wollo showed a decreasing precipitation trend and some northeast parts detected an increasing trend.

In the Belg (small rainy) season, most of the rainfall trends were decreasing accounting for about 75% and the remaining 25% of the stations showed increasing (Figure 5a). The result of the analysis also showed that

25% of the stations showed a significant decreasing trend whereas 6 % of the station showed a significant increasing trend (Fig 5b). According to these results, a mix of increasing and decreasing trends in Belg rainfall series experiences for the last 60 years (Figure 8). In the Belg season (Table 2; Figure 4d) decreasing slopes are prevalent in all the parts of the highlands of Wollo. This relates to the decrease in rainfall in the Belg season months of February, March, April and May (Table 3). The decrease in magnitude varied from -0.05 to -0.45 mm/season. This decreasing Belg season rainfall affects the livelihood of the rural farmers living in the highlands of Wollo as well as the economy of Amhara region in particular and the country Ethiopia in general. However, Western part of Wollo (Nefas Mewucha and Lalibela stations) showed a positive trend which varied from 0.08 to 0.39 mm/season.

The spatial rainfall variation results as observed in Figure 4d, indicates that the rainfall trend in the Belg season detected a decreasing trend in the eastern, central and southwestern parts of Wollo. Moreover, the spatial variations of rainfall trend slightly decreased in the southeastern parts of Wollo. In contrast, the trend analysis results spatial variation detected an increasing trend in the northern parts of Wollo. This complex Belg season spatial variations of rainfall increasing and decreasing trends in various parts of Wollo has some implications for water resources, managers, decision makers and rural farmers.

3.2.3 Monthly rainfall trends

Monthly analysis of rainfall distribution and trends showed a mix of increasing and decreasing trends at different stations in the highlands of Wollo for the study periods. Table 4 shows the variations of rainfall time series for each month in the area of Wollo highlands. All the stations in the months of November, December, January and February detected non-significant mixed trends. In some stations such as Alemata, Bati, Korem, Kutaber, Lalibela, Mekane Selam, Sirinka and Wegeltena detected a significant increasing trend in the months of July and August with values varied from 1.98 – 8.62 mm/month.

The highest increasing significant trend was detected at Sirinka whereas the lowest significant increasing trend detected at Bati station. The significant decreasing trends were detected in some stations such as Alemata, Jama Degolo, Kone Abo, Mekane Selam, Nefas Mewucha, Sirinka and Wegeltena in the months of March, April and May. The highest significant decreasing trend was marked at Kone Abo in the western parts for May (-4.06 mm/month), Jama Degolo for March (-3.04mm/month) whereas the minimum significant trend was observed at Alemata for May (-2.01 mm/month) north eastern parts of Wollo highlands.

In general, on an all-Wollo highland stations basis, June, July and August experienced increasing rainfall, whereas February, March, April, May and September showed decreasing rainfall. The months of January, November and December showed little or no change in rainfall.

3.2.4 Rainfall change point detection

Pettitt test is used to identify a change point in a time series (Equation 8), and assumes that the observations form an ordered sequence [15]. Table 5 shows the results from Pettitt tests that reveal statistically significant shifts for seasonal rainfall at the significance level of 0.05 to detect the change points of transitional years. For annual precipitation, there is no change point year that could be detected at 95% confidence level as most of the stations (87%) annual precipitation showed non-significant trend. In most stations the decreasing shifts occurred around 1983/84, and increasing shifts occurred more around 1986-1991 and 1998. Moreover, variations in seasonal shift periods were observed in 1976-1979 at Maichew and Sirinka, 2000-2007 at Bati, Kutaber and Wegeltena stations (Table 5).

Table 4. Sen estimator of slope, θ (mm/month) for monthly rainfall for all stations used in this study.

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alemata	0.00	0.00	0.00	-0.04	**-2.01**	0.00	**3.29**	0.58	-1.36	0.00	0.00	-0.59
Bati	-0.10	-1.66	-0.41	-0.30	-1.00	1.22	**1.98**	1.39	-0.95	0.19	0.00	0.00
Dessie	0.00	-0.25	-0.60	-0.39	0.35	0.00	1.69	1.28	-0.64	0.19	0.00	0.00
Jama Degolo	-0.29	0.00	**-3.04**	-0.79	0.26	0.15	-1.16	1.30	1.15	0.00	0.00	0.00
Kemissie	0.00	-0.48	-0.19	-0.56	0.24	0.00	1.04	1.16	-0.29	-0.28	0.00	0.00
Kombolcha	-0.06	-0.03	0.30	0.72	1.06	-0.22	**-2.22**	-0.58	-0.05	0.03	0.00	0.00
Kone Abo	-0.19	-0.37	-0.19	-1.22	**-4.06**	1.82	-1.00	0.40	-1.81	-0.18	-0.17	0.02
Korem	0.06	0.00	-0.11	0.47	-0.87	0.29	**8.60**	**-2.96**	**-2.30**	-1.00	0.39	-0.85
Kutaber	0.01	-0.32	0.71	-0.25	-0.98	0.35	**5.00**	1.73	-0.24	-0.12	0.00	0.00
Lalibela	0.00	-0.31	-0.11	-0.19	-0.17	0.56	**2.47**	**5.62**	0.22	0.60	0.07	0.00
Maichew	0.00	0.00	0.00	0.39	-0.46	-0.41	1.17	0.86	0.00	-0.09	0.00	0.00
Mekane Selam	0.00	-0.53	-0.59	**-2.09**	1.20	0.44	**2.07**	1.37	-0.53	-0.01	-0.02	-0.05
Nefas Mewucha	0.00	-0.50	-0.96	-1.62	**-3.24**	1.90	1.74	**6.81**	-0.98	-0.15	-0.34	-0.07
Sirinka	0.02	-1.61	-1.70	**-2.97**	-0.70	0.00	**5.72**	**8.62**	0.85	**2.21**	0.00	0.10
Wegeltena	0.00	-0.35	-0.50	0.01	**-2.22**	1.21	**5.27**	-1.86	-0.75	-0.01	0.00	-0.14
WereElu	0.00	-0.05	-0.36	-0.28	-0.09	-0.13	0.39	0.54	0.34	-0.13	0.00	0.00

[1]Bold values indicate statistical significance at 95% confidence level as per the Mann-Kendall test (+ for increasing and - for decreasing)

Table 5. Results of the Petit test reported at the station level in the regions of Wollo

S. No	Station Name	Pettit test results	
		Change point (year)	Shift
1	Alemata	Sept 2005	Downward
2	Bati	July 1983 & April 2000	Downward
3	Dessie	Sept 1974 & July 1983	Downward
4	Jama Degolo	Sept 2007	Downward
5	Kemissie	Sept 1986	Upward
6	Kombolcha	Sept 1983	Downward
7	Kone Abo	Oct 2001	Downward
8	Korem	Feb 1991	Upward
9	Kutaber	Sep 1984 & Sept 2007	Upward
10	Lalibela	Jan 1983	Upward
11	Maichew	Feb 1976	Upward
12	Mekane Selam	Oct 1998	Upward
13	N/Mewucha	Jun 1988 & Oct 1998	Upward
14	Sirinka	Sep 1979	Downward
15	Wegeltena	Sep 1983 & Sept 2007	Downward
16	WereElu	Sep 1983	Downward

This is mainly due to the major drought years of 1973, 1983/84 and 2001 which hit the whole of Ethiopia. This result confirmed the study of Bewket and Conway [22], Conway [30] and Seleshi and Zanke [25], during the late 1970s to mid-1980s near-minimum rainfall, recorded confirming the unusually low rainfall received by Ethiopia during those years and the significant shift occurred.

In general, the finding of the results discussed in the above result and discussion sections indicated that there may be considerable direct or indirect effects of the observed rainfall trends in Wollo highlands. Annual rainfall series showed a mix of non-significant increasing and decreasing trends. Both increasing and decreasing trends observed in seasonal rainfall. The trends in Belg were mostly decreasing, while trends in Kiremt season were generally increasing and no trends observed in the Bega season. Moreover, the seasonal variation is more complicated as compared to annual variation. All the above points discussed will have a tremendous impact on agricultural production and hence, food security of Wollo. Hence, the results of above analysis will be helpful to the managers, planners and agricultural scientists to work out irrigation and water management options for woreda level planning in the regions of Wollo to improve the life of rural farmers. The findings of this research can also provide information to the government and community on the variability of rainfall for future planned water supply, hydropower and irrigation projects in the region. Such information also used for policy makers and managers within the context of water resource management, hydrology, agriculture, and ecosystem in the other Ethiopian river basins that have similar characteristics

4. CONCLUSION

The prime focus of this study was to evaluate the spatiotemporal variation of rainfall in the highlands of Wollo during the period from 1952 to 2016 using in situ rainfall data from sixteen stations. In this study, non-parametric statistical indices have been applied: Mann Kendall and Sen's method for trends and their direction and magnitude, and the Pettit test for shift detections. Overall, this study showed that no significant changes or trends were detected in annual rainfall series over the entire region except in some eastern parts of Wollo highlands that detected a significant increasing trend. As a result, seasonal and monthly spatial variation results indicated a mix of increasing and decreasing rainfall trends are of paramount importance for agriculture, water supply and another sector. Seasonal rainfall variation is higher throughout Kiremt and Belg seasons while in Bega no trend was detected in most parts of Wollo highlands. In the monthly time scale, increasing rainfall trends were detected in the months from June-August, little or no trend detected from November to January, and the remaining months detected a decreasing trend. This study showed that the most probable year in changing rainfall (shift) was detected in the 1980s and 2000s which was confirmed with historical droughts hit the region. Knowing the rainfall variability on the seasonal and monthly basis may help to increase the livelihood of rain-fed agriculture based rural farmers in the region. The findings presented here are also used for policy makers and managers within the context of agriculture, hydrology, water resources management and environment in the four Ethiopian major river basin watersheds located in the highlands of Wollo and other river basins that have similar characteristics. Nevertheless, further studies would be attractive to examine more rainfall characteristics like frequencies of high precipitations or low precipitations, increase or decrease in the number of rainy days, rainfall concentration index, standardized anomalies of annual rainfall and changes in dry-spell length.

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AUTHOR CONTRIBUTIONS

F.Fikru Abera designed the technical route of the study, analyzed the data and wrote the manuscript. Asalf Shumete provided observed data and proposed suggestions to improve the quality of the manuscript. The author has read and agreed to the published version of the manuscript

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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