

RESEARCH ARTICLE

Spatiotemporal trends and variability of rainfall across agro-ecologies in East Guji Zone, Southeast Ethiopia

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OPEN ACCESS

Citation: Sahilu M, Tekalign S, Mohammed Y, Sishaw T, Kedir H, Asfaw S (2024) Spatiotemporal trends and variability of rainfall across agro-ecologies in East Guji Zone, Southeast Ethiopia. *PLoS Clim* 3(3): e0000361. <https://doi.org/10.1371/journal.pclm.0000361>

Editor: Ahmed Kenawy, Mansoura University, EGYPT

Received: March 18, 2023

Accepted: January 14, 2024

Published: March 21, 2024

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Data Availability Statement: Since the data for the study was obtained from the third body the Ethiopian Metrological Institute with an agreement for using the data for the research purpose. Therefore, you can obtain the data from the organization using their e-mail address nma.datausers@mail.com.

Funding: We would like to acknowledge the Hossana College of Education and Haramaya University for funding the study. With collaboration both institution provided financial support for the

Abstract

Distribution and trends of rainfall reveal spatial and temporal variability that have a paramount effect on the life and livelihood of small-holder farmers. This study aimed to analyze spatial variability and temporal trends of rainfall distribution across the three Agro-Ecological Zones (AEZs) of East Guji. Time series gridded daily rainfall data (1990–2020) were collected from the Ethiopian Meteorological Institution. Different descriptive statistics, trend tests: Man Kendal and Sen's slope estimator, Inverse Distance Weighted Index and Precipitation Concentration Index (PCI) was used in the study. The finding demonstrated that altitude and rainfall decrease as one advances from the western (highland) to the eastern (lowland) direction in the study area where the highest rainfall was recorded in Solemo (highland) and the least in Negele (lowland). The study showed that as altitude increases annual rainfall also increases and rainfall variability decreases. Similarly the mean length of the growing season declines as one advance from the highlands to the lowlands. The PCI of the lowlands, midlands, and highlands AEZs was 19%, 17%, and 12% respectively. The PCI showed that those highlands had moderately concentrated rainfall but both lowlands, and midlands, had an irregular distribution of rainfall. The Coefficient of Variation (CV) indicated that highland areas had moderate variability in rainfall in all seasons except winter. In contrast, the low and midlands had shown high variability of rainfall (>30%) in all seasons. From a seasonal perspective, both CV and PCI revealed that the winter season showed more variability than others. Moreover, a significant increasing trend of annual rainfall was observed in the highlands AEZs (Bore 15.3mm/year and Solemo 14.6mm/year), lowland AEZs (Chembe 10.9mm/year, Dawa 8mm/year and Bitata 7.8mm/year) as well as midland AEZs (Kercha 14.5mm/year) at a significant level of 5%. Therefore, strategies should be designed to use additional water resources for irrigation; and provide short-cycle grown and drought-resistant crops in the rest of the midlands and lowlands AEZs.

corresponding author MS for the her completion of PHD work. The funders had no role in study design, data collection, analysis and interpretation, the writing of this manuscript, and in the decision to submit it for publication.

Competing interests: The authors have declared that no competing interests exist.

1. Introduction

Global climate change and climate variability increased erratic rainfall in many parts of the world [1]. Africa is a continent highly pretentious about the problem. Climate change caused increased rainfall variability in much of Sub-Saharan Africa (SSA) [2]. Rainfall variability has a significant effect on the welfare of the household and national production of agricultural-based economies [3]. The future social-economic development of the African community is determined by water acquired from highly variable rainfall [4]. In most parts of SSA, the amount of precipitation will decline by about 20% [5] while its variability will increase [6].

The remarkable spatial variability of rainfall will continue in the future [7–9]. Several factors from local to global level influence the distributions of rainfall in Ethiopia. In Ethiopia, a spatial variation of rainfall is observed across the different AEZs. The local variability of rainfall in Ethiopia is articulated by multifaceted topography which ranges from 4620m above sea level at Ras Dashen Mountain to the lowest at Afar Depression (Kobar Sink) 120m below sea level [10]. There is also temporal variability of rainfall from days to seasons and decades. Particularly, rainfall variability has great influences on the life and livelihood of smallholder farmers in Ethiopia. Ethiopia is the most vulnerable to the effects of rainfall variability. Since agriculture is the backbone of the Ethiopian economy it contributes about 40% of the GDP, 80% of total employment, and 90% of exports. Besides, 79% of the population depends on rain-fed agriculture for their income [11,12].

Besides global factors: such as the El Nino–Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and the Inter Tropical Convergence Zone (ITCZ) influenced the seasonal rainfall variability over Ethiopia [13,14]. El Nino weakens the high-pressure air mass in the South Indian and South Pacific Oceans that causes rainfall in Ethiopia [15]. Complete models on the impact of El Nino on Ethiopian climate variability are lacking because of the existence of different AEZs which resulted in many microclimate and a lack of meteorological data [16].

So far several studies have found that-complex trend of rainfall distribution in various parts of the country. [17–19] reported significant declines in the annual and summer (*kiremt*) rainfall totals in the eastern, southern, and southwestern, northern, north-central, north-western, and western parts of the country. However the study by Rosell & Holmer, [19] also indicated an increasing trend of annual rainfall at some locations in eastern Ethiopia as well as an increase in annual and summer (*kiremt*); a decrease in spring (*belg*) rainfall in central Ethiopia. Bayable et al. [20] reported the annual rainfall showed a non-significant decreasing trend over Western Harerge. Habte et al. [21] reported a declining trend of annual and March-May rainfall (long rain) or spring in the Guji Zone.

Further, the national-level study by Wagesho et al. [22] showed varied rainfall patterns in different parts of the country. Likewise, Mohammed et al. [23] reported a significantly increasing trend of summer rainfall in some of the stations and a declining tendency in spring rain in all studied stations in Southern Wollo. Abegaz & Mekoya, [24] also reported a significant decreasing trend in spring (*belg*) and winter (*bega*) rainfall and increasing annual and summer (*Kiremt*) rainfall in central Ethiopia. Likewise, Alemayehu et al. [25] showed significantly increasing trends of annual and seasonal rainfall totals in the western part of Ethiopia. Similarly, Belay et al. [26] reported an increasing trend of annual, summer (*Kiremt*) and winter (*Bega*) rainfall whereas the spring (*belg*) season rainfall showed a significant decreasing trend in southern Ethiopia. A recent study conducted by Worku et al. [27] demonstrates rainfall showed a significant increasing trend during August, October, and November and was extremely variable during December, January, and February in Borena, Southern Ethiopia.

Although topography is prominent in determining the distribution of rainfall in Ethiopia most of the existing studies were not AEZs centered except the study in Welayita [28] in North

Western Ethiopia [29] in Northern Shewa [30]. Since large-scale studies highly mask the spatial and temporal variability of rainfall, further AEZ based local-level investigation of variability and trends of rainfall events were suggested by many authors, [27,31–33]. Thus, the ongoing issue of rainfall variability requires current investigation across the AEZs due to the existence of diverse micro climates in the country. This study gives prior emphasis on the influences of AEZs in the spatial variability and temporal trends of rainfall distributions in Guji Zone.

Given the high dependence on rain-fed agriculture, it is important to precisely characterize the spatial variability, temporal trends, onset and secession, and distribution of rainfall in each AEZ. Hence, there is no previous investigation that has examined the spatial variability and temporal trends of spring and autumn rainfall in the three AEZs of the study area. The study fills gaps in knowledge of the spring (*belg*) and autumn (*meher*) seasons, spatial variability and temporal trends of rainfall in the different AEZs of the Guji zone. Thus, identifying rainfall variability at this micro-scale level provides relevant information which enables stakeholders to design context-specific adaptation strategies in different AEZs. Therefore, the objective of this study is to analyze spatial variability, temporal trends, onset and cessation, and distribution of spring and autumn rainfall across the three AEZs using long-time series rainfall data.

2. Descriptions of the study area

2.1 Location of the study area

This study was conducted in the East Guji Zone, in the Southern part of Oromia Regional State, Ethiopia. Geographically, the East Guji Zone is located between 4° 30' N–6° 30' N latitude and 38° 15' E–40° 5' E longitudes (Fig 1), and covers a total area of about 18,577 Km². It shares a border with Gedeo and Sidama on the North, Somali Regional State in the South, Bale Mountain on the East and Borena Zone on the West. The northern and eastern neighbors of the Eastern Guji zone mainly have highland AEZs that experience wetter microclimate [21]. The southern and the western adjacent land of the study area holds the lowland AEZs that experience relatively drier climate conditions [27]. Borena is mainly lowland which embraces a semiarid and arid climate and recently has been highly pretension by drought [34].

The total population of the area as projected by [35] was 1,499,013 in 2017. The Guji Oromo are the dominant Ethnic group which represented 95.57%, the Amhara https://en.wikipedia.org/wiki/Amhara_people 2.43%, and the Somali 2% [36]. They are predominantly pastoralists, agro-pastoralists and farmers [37]. Coffee is an important cash crop in the Guji zone [38].

2.2. The biophysical characteristics of East Guji

The study area is situated in the southern part of Ethiopia, which experienced bimodal rainfall cycles in spring (March–May) with a peak in April/May and autumn (October–November) [14]. The area is characterized by a bimodal rainfall pattern where the long rainy season (*Arfansa*) occurs from March to May and covers about 48% of the annual rainfall whereas the short rainy season (*Hagaya*) extends from September to November which shares about 36% of the annual rainfall. Thus, together spring (*belg* or *arfansa*) and autumn (*meher* or *Hagaya*) cover around 84% of rainfall in lowlands and midlands AEZs of East Guji (Fig 4). Besides, the mean rainfall in the midlands and lowlands for winter and summer was 6% and 10% respectively.

Therefore, four seasons have been identified in the study area namely; the major dry season winter or *bega* (Dec–Feb), the long rainy period named spring or *belg* (Mar–May), summer or *kiremt* (June–August) and the short rainy period is autumn or *meher* (Sept–Nov). The winter

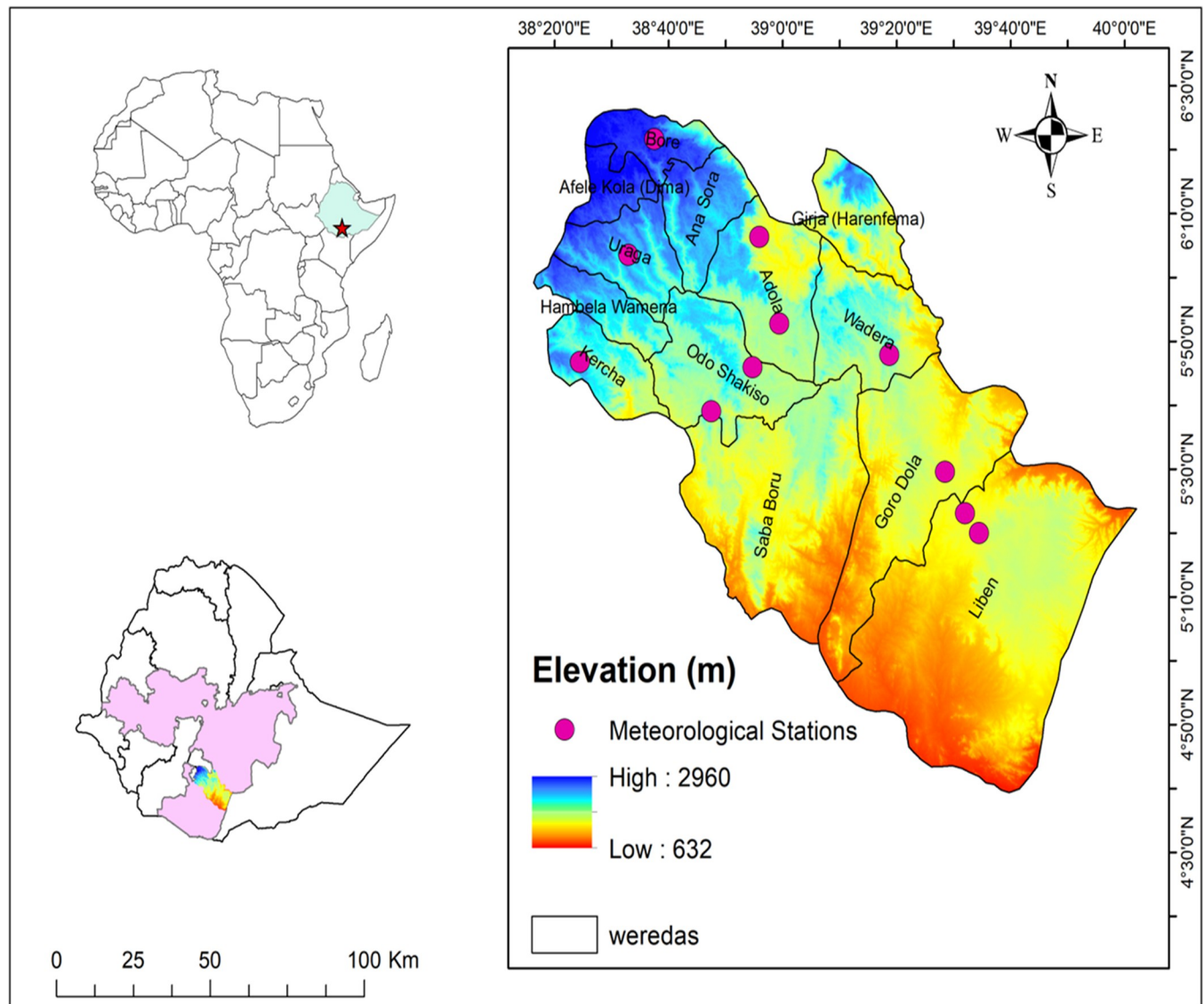


Fig 1. Location map of the study area. Source: Projection WGS_1984_UTM_Zone_37°. The map is produced using ArcGIS 10.8: Ethiopia GeoPortal -Free access to Shape file. (<https://ethiopia.africageoportal.com>).

<https://doi.org/10.1371/journal.pclm.0000361.g001>

(*Bega*) and summer (*Kiremt*) are relatively dry seasons except for the highland area which receives better rainfall in the summer season. Thus, the highlands part of Eastern Guji receives almost the corresponding amount of rainfall in the three seasons: spring (34%), summer (30%), and autumn (29%).

The elevation of the study area ranges from 632m to 2960m above sea level, and is categorized under the three AEZs. They are: lowlands (*Kola*) 500m-1500m, midland (*Woina Dega*) 1500m-2300m, and highland (*Dega*) 2300m-3200m based on [39] which; covers about 27.3%, 51.5%, and 21.2% of the total area, correspondingly. The mean annual rainfall in the Guji Zone for lowlands, midlands, and highlands is 747mm, 932mm, and 1232mm respectively (Table 6). The mean temperature records were 22.1°C, 19.4°C, and 15.8°C in the lowlands, midlands and highlands AEZs correspondingly.

As a result of a multiplicity of AEZs and soil set up in the area; a variety of vegetation cover: dense natural forests, planted trees, acacia, and scrubs are major land cover in Guji. The dense forest resource of the Eastern Guji Zone comprises the Bore-Anferara National Forest Priority Area and the Anferara-Wadera National Forest Priority area. These areas are among the 58 Priority Forest Areas (PFAs), which have been so designated to protect biodiversity and conserve forest resources in Ethiopia.

3. Materials and methods

3.1. Research design

The study followed a quantitative research design. Quantitative research is selected because the study is grounded on observed (recorded) statistical data. A standardized procedure was followed to analyze the data. Thus, the output of the study can be replicated and generalized to a similar study. It is a non-experimental, descriptive and observational research. Non-experimental quantitative research design refers to there is no manipulation of variables in the study. The research described the spatial variability and temporal trends of rainfall across the three AEZs in the Eastern Guji. Gridded rainfall data (0.04° by 0.04°) of the sample stations were taken from Ethiopian Meteorological Institutions (EMI) to detect, quantify and generalize variability and trends of rainfall over the studied period (1990–2020). The gridded rainfall data was chosen over meteorological station data since the latter has more missing values and short time series data. Gridded time series rainfall data of eleven stations were assessed quantitatively to analyze spatial variability, temporal trends, onset and cessation and distribution of rainfall. Some descriptive statistics such as, statistical, and spatial analysis tools, were used in the study. Finally, results were systematized on tables and figures followed by proper discussions.

3.2. Sampling procedure

Probability and non-probability sampling procedure was used to select an appropriate sample for the study. Guji Zone was selected through purposive sampling as it represents three AEZs such as lowlands, midlands and highlands which can be used to show the spatial dimensions of rainfall variability in the area. A stratified random sample procedure was applied to select the required groups or strata for the study. AEZs are considered as strata for the study. A random sample is selected from each stratum based on the percentage of each AEZs embraced. Lowland, midland and highland AEZs cover about 27.5%, 51.2% and 21.3% of the total area, respectively. By considering the distributions of AEZ in the study area, five, four, and two stations from midland, lowland, and highland AEZs respectively were randomly assigned. Accordingly, the randomly chosen stations (grid cells) include: Chembe, Dawa, Negele, Bitata, Oddo Shakiso, Adola (Kibre Mengist), Harekello (Goro Dola), Wadera, Kercha, Solemo (Uraga), and Bore (Table 1).

3.3. Methods of data analysis

Several methods exist to estimate the variability of the date of rain onset and cessation of the growing season. For the study onset and cessation date was determined using Walter's formulation as modified by [40]. The method was selected because it used a threshold value of 51mm accumulated rainfall to determine the onset. Since about 80% of the locality comprises midland and lowland. Relatively, low rainfall coupled with high temperature and evapotranspiration distinguishes the locality. Consequently, ample precipitation is required for planting in the area. Thus, the method is minimized considering false onset days which result in early departure of the rainy period. By this method, the onset date of the rain is the time a place

Table 1. Location of study stations and length of rainfall series (31 years).

Agro-Ecological Zones	Stations	Elevation in Meter(m)	Latitude In degree(°)	Longitude In degree(°)	Years of Observation
Lowlands (Kola) (632m-1500m)	Chembe	1025m	6°	38°55'	1990–2020
	Dawa	1177m	5°33'	38°48'	1990–2020
	Negele(Liben)	1439m	5°41'	39°36'	1990–2020
	Bitata	1473m	5°30'	39°25'	1990–2020
Midlands (Weinadega) (1500m -2300m)	Oddo Shakiso	1620m	5°45'	38°56'	1990–2020
	Adola (Kibre Mengist)	1680m	5°54'	38°58'	1990–2020
	Hare kello(Goro Dola)	1708m	5°25'	39°28'	1990–2020
	Wadera	1750m	5°46'	39°18'	1990–2020
	Kercha	2036m	5°46'	38°25'	1990–2020
Highlands (Dega) (2300m-2960m)	Solemo (Uruga)	2362m	6°05'	38°34'	1990–2020
	Bore	2712m	6°25'	38°36'	1990–2020

Data Source: EMI.

<https://doi.org/10.1371/journal.pclm.0000361.t001>

receives an accumulated amount of rainfall over 51mm and not the first day the rain falls. Cessation date: is the date after which not 51mm of rain is expected. The method is expressed as: [41].

$$\text{Onset/End} = \frac{DM}{TM} \times (51 - AP) \tag{Eq(1)}$$

Where, DM = number of days in the month containing the onset; TM = total rainfall for the month in which accumulated rainfall exceeds 51mm; AP = accumulated rainfall of previous months just before the month in reference; 51mm = the threshold of rainfall for both Onset/End months. Where such an onset date was followed by rainfall amount less than 51 mm, the next rain date that is up to 51mm or more will be chosen [42]. The length of the growing season, under rain-fed conditions, is defined as the period from the date of the onset of the rainy season to its cessation.

The study employed Mann-Kendal’s test and Sen’s slope estimators to identify long-term rainfall trends and the rate of change in monthly, seasonal and annual time steps in three AEZs of the study area respectively. The Man Kendall test is highly recommended for general use by the WMO [43]. It is chosen for trends test in a time series data since it doesn’t request for normality or linearity, is less sensitive to outliers or is robust against the influence of extremes [44,45].

When the Z value exceeds either of the confidence limit lines, it shows a significant trend at a given significance level (< 0.05). Hence, H₀ is rejected and in place, H₁ is accepted. Where, n is the number of data points; x_j and x_i are the time series observations in year j and i, j>1. The Mann-Kendall statistic S of the series x is obtained by the following Equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(X_j - X_i) \tag{Eq(2)}$$

$$\text{Sign of } (X_j - X_i) = \begin{cases} +1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \tag{Eq(3)}$$

Sign $(X_j - X_i)$ means the individual sign capability that takes on the values [1, 0, or -1]. A positive S value indicates an ever-increasing trend, and a negative value indicates a downward trend. Compute the variance of S as follows:

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

Where: n is the data point's number, g is the zero difference between compared values number, t_p is the number of data points in the p^{th} group. A standardized measure of test statistics (Z_{MK}), determined using the following equation:

$$Z_{MK} = \begin{cases} \frac{s - 1}{\sqrt{VAR(S)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{S + 1}{\sqrt{VAR(S)}} \text{ if } S < 0 \end{cases} \tag{Eq(5)}$$

The magnitude of the change in the time series was detected by a simple non-parametric procedure developed by [46]. This test computes the linear rate of change (slope) and the intercept as shown in Sen's method [46]. The magnitude of the trend is calculated by using Sen's slope estimator in the following equation:

$$\beta = Median \left(\frac{x_j - x_i}{j - i} \right), j > i \tag{Eq(6)}$$

Where β is Sen's slope estimate $\beta > 0$ indicates an upward trend in a time series. Otherwise the data series presents a downward trend during the period.

The precipitation concentration index (PCI) defined by [47] is a powerful indicator of temporal precipitation distribution. PCI is generally used for evaluating seasonal precipitation changes to investigate the heterogeneity of monthly rainfall data. In the study, PCI was used to analyze the monthly and annual variability of precipitation. The calculation is described as follows:

$$PCI = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} p_i)^2} \times 100 \tag{Eq(7)}$$

Where: P_i = the total rainfall of i^{th} month

As indicated by [47], PCI values are categorized as uniform (<10) presents a uniform distribution of rainfall, (11–15) indicates moderate, (16–20) shows irregular, and (> 21) shows a strong irregular monthly rainfall distribution.

Variability of rainfall is computed using the coefficient of variation (CV) [48], Coefficient of variation (CV) provides a measure of year-to-year variation in the data series. As documented by Hare [48], the degree of rainfall variability is classified as high ($CV > 30$), moderate ($20 < CV < 30$) and low ($CV < 20$).

$$CV = \frac{\sigma}{\mu} \times 10 \tag{Eq(8)}$$

Where: CV = coefficient of variation σ = standard deviation μ = Mean rainfall (mm)

Inverse distance weighted (IDW) is a spatial analysis tool used to illustrate the spatial trends of observed rainfall. The IDW is a measure between neighboring stations for time series. An inverse distance interpolation is one of the simplest and most popular interpolation

techniques. It combines the proximity concept with the gradual change of the trend surface. An inverse distance (ID) weighted interpolation is defined as a spatially weighted average of the sample values within the search neighborhood [49]. The spatial distributions of annual and seasonal rainfall (spring and autumn) were mapped using IDW interpolation in arc GIS.

4. Results and discussions

4.1. Agro ecology-based spatial distribution of rainfall in the study area

The section clarifies the spatial distribution of rainfall across the three AEZs of the Eastern Guji. Accordingly, the highlands (*Dega*), midlands (*Waina Dega*), and lowlands (*Kola*) AEZs account for 27%, 51.5% and 21.2% of the total area respectively (Fig 2). AEZs clearly articulated the spatial distribution of rainfall in the study area. The western part of the study area is the highland (*Dega* AEZ) where the highest intensity of annual rainfall (1273mm) was recorded in Solemo (Uraga) (Fig 3). The central and eastern part of the study area is mainly midland (*Waina Dega*) AEZ. The south eastern part of the study area is predominantly lowland (*Kola*) where the lowest rainfall (624mm) was recorded in Negele (Liben) (Fig 3). As one advances from the western (highlands) to eastward (lowlands) direction in the study area both altitude and rainfall decline (Fig 2). The spatial distribution map of rainfall also denotes that maximum rainfall was recorded in the spring (*belg*) season followed by autumn (*meher*). The peak of spring rainfall was recorded around Adola and Shakiso (midlands), autumn rainfall was highest around Chembe (lowland); summer and annual rainfall was greatest in Bore and Solemo in the highland AEZ (Fig 3).

Finally, the spatial variability of rainfall in the study area was expressed through contrasting reality observed across the highlands, midlands, and lowlands AEZs in the study area. Primarily, the onset and cessation also resulted in LGP diminishing from the highlands to the lowlands and midlands AEZs. Single and long LGP was witnessed in the highland AEZ whereas a dual growing period with short LGP was observed in the lowlands and midland AEZs of the study area. Besides, the seasonal distribution of rainfall in the three AEZs of the study area revealed that the highlands received almost the same amount of rainfall in three seasons except winter (Fig 3). In contrast, the lowlands and midlands gain rainfall maxima in the spring and autumn seasons whereas summer and winter are relatively dry seasons (Fig 3). In addition, a significant increasing trend of the annual and autumn rainfall was observed mainly in the highlands, most of the lowlands and in some of the midlands AEZ.

On the other hand, the rest stations in the mid and lowlands AEZs have an insignificant increasing trend of the annual rainfall. Furthermore, relatively higher PCI & CV values were observed in the lowlands (*Kola*) and midlands (*Weynadega*). In contrast, it was lower for the highlands (*Dega*) AEZ. To conclude, 78.8% of the study area is enclosed with the midlands and lowlands which received scarce rainfall. The implication is that midlands and lowlands faced severe problems of variability in the onset and end, short LGP and lack of significant trend on monthly and seasonal rainfall. Consequently, scarcity of rainwater for agriculture prevailed in the mid and low lands AEZ of the study area.

4.2. Variability of onset and cessation of rainfall in the study area

The distribution of variability of the onset and cessation of rainfall and its temporal trends in East Guji from 1990–2020 was discussed in this section. Accordingly, the lowlands and midlands of the study area have two distinct onset and cessation periods in the autumn and spring seasons (Table 2). Thus, they are familiar with dual growing seasons. The average onset date of spring rainfall in the highland AEZs was April 18 and ends on November 2. Hence, the highland AEZ of the study area has a single growing period as well as an onset and cessation period.

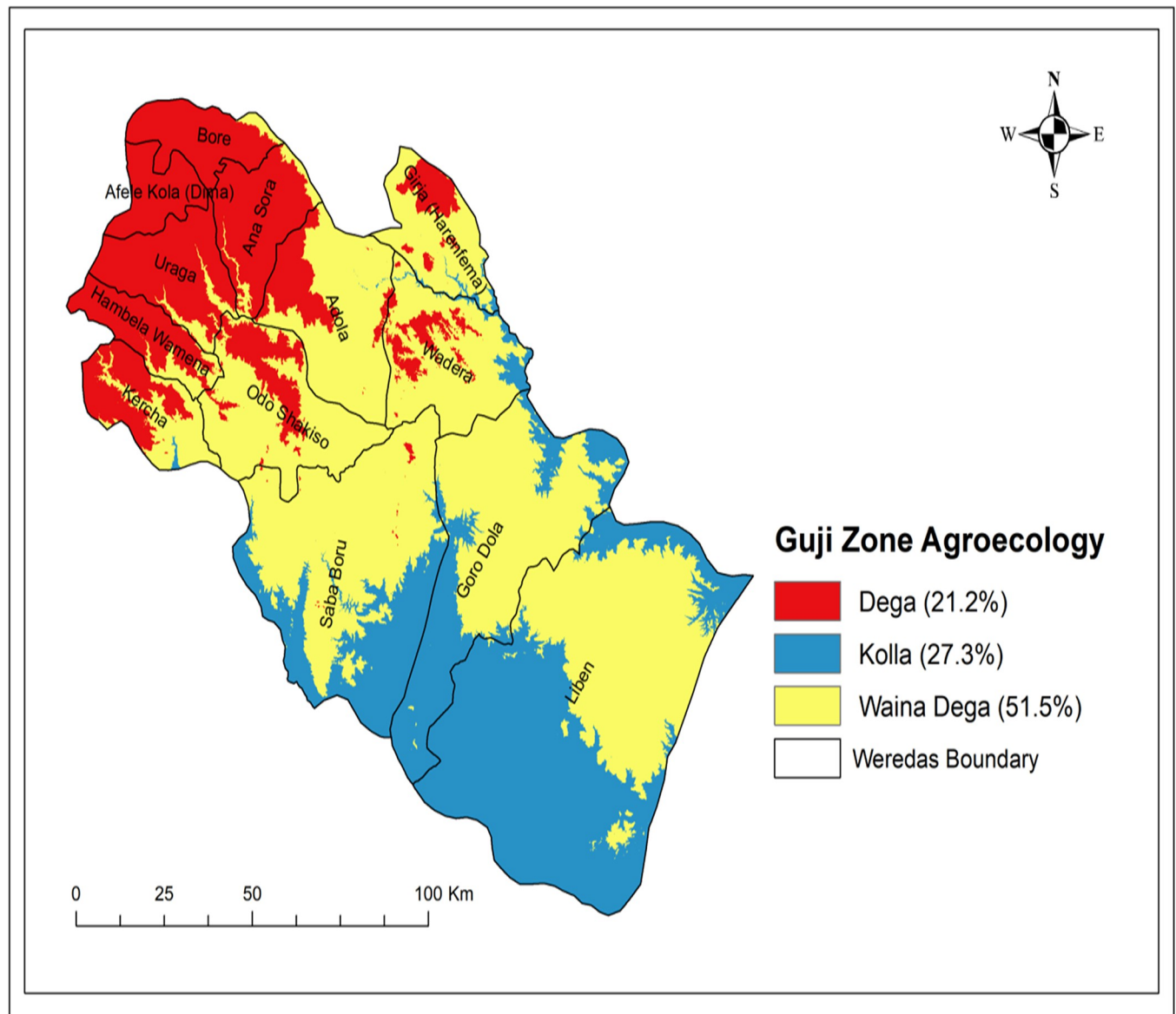


Fig 2. Distributions of AEZs in the study area. The map is produced using ArcGIS 10.8: Ethiopia GeoPortal—Free access to Shape file. (<https://ethiopia.africageoportal.com>).

<https://doi.org/10.1371/journal.pclm.0000361.g002>

Presently, the smallholders farmers in the highlands started using the spring season (April–May) for short season growing vegetables such as Potato, Tomato and Onion. They cultivate cereal crops such as Barley, Wheat, Maize, Peas and Bea using the summer and autumn rainfall (June–November).

In the midland AEZ the spring rainfall begins on April 20 and terminates on 24 May, the autumn rainfall starts on October 13 and ceases on November 10. Consequently, the mean length of growing period (LGP) in the midlands for the spring and autumn seasons was 35 and 27 days respectively. Further, spring rainfall arrives on 25 April and halts on May 18 in the lowlands. Besides, autumn rainfall starts on October 15 and ends on November 7 in the lowlands. Moreover, in the lowland LGP were 23 and 16 days for the spring and autumn seasons

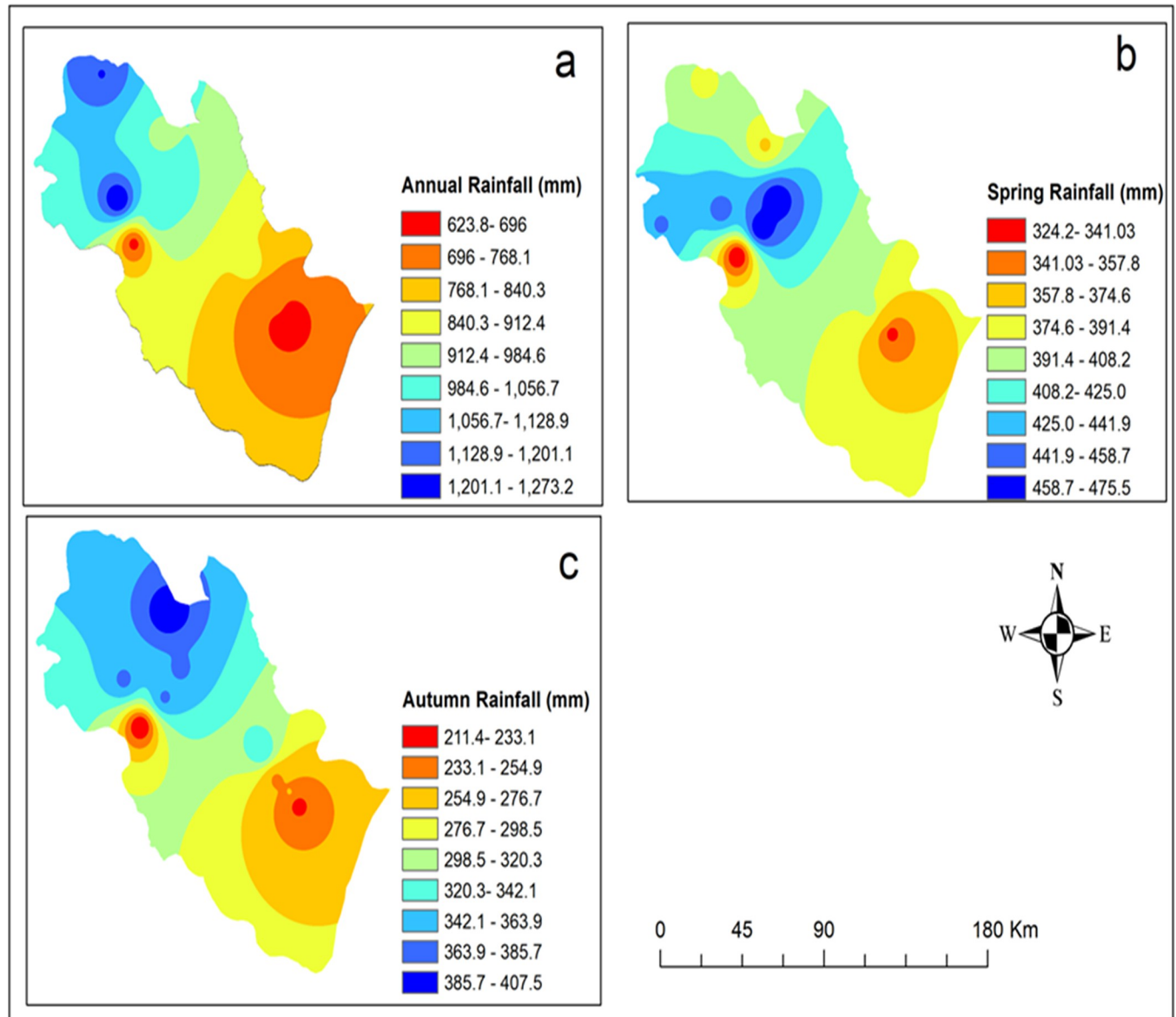


Fig 3. Spatial distribution of rainfall using Inverse Distance Weighted Interpolation (IDWI). The map is produced using ArcGIS 10.8: Ethiopia GeoPortal-Free access to Shape file. (<https://ethiopia.africageoportal.com>).

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respectively. Thus, as one moves from highlands AEZs to lowlands and midlands in the study the LGP declines.

CV is a useful measure of variability in the length of the growing season; because particularly in short LGP, relatively small changes in LGP have important consequences. High CV is dominant in areas with relatively short growing seasons, while low CV value corresponds to long growing periods. Similarly, the highland AEZs had long LGP which is 198 days and witnessed low CVs 16% and 6% for the onset and cessation periods respectively. The finding implies the highland of the study area relishes long wet spells from April to November. Hence rainfall distribution in the highlands was regular. However, in the midlands and lowlands practicing rain-fed agriculture with such a short LGP has been puzzling.

Table 2. Onset and cessation of rainfall in the study area.

AEZs	Stations	Spring Onset			Spring Cessation				Autumn Onset			Autumn Cessation			
		Mean	CV	DOY	Mean	CV	DOY	LGP	Mean	CV	DOY	Mean	CV	DOY	LGP
Lowlands	Chembe	115	13	April,25	142	40	May, 22	27	271	9	Sep,28	295	12	Oct,22	24
	Dawa	115	43	April,25	146	37	May, 26	31	297	34	Oct,24	311	50	Nov,7	14
	Negele (Liben)	117	15	April,27	132	36	May, 12	15	307	30	Nov,3	313	32	Nov,9	6
	Bitata	112	11.5	April,22	132	20.5	May,12	20	299	25	Oct, 26	318	48.5	Nov,13	19
Midlands	Shakiso	109	20	April,19	147	21	May,27	38	289	7	Oct, 16	315	38	Nov,10	26
	Adola (KM)	107	20	April,17	146	26.5	May,26	39	285	26	Oct, 12	317	35	Nov,13	32
	Hare Kello	115	13	April,25	139	32	May,19	24	296	19	Oct, 23	317	44	Nov,13	21
	Wadera	112	17	April,22	137	39	May,17	25	289	6	Oct, 16	314	40	Nov,10	25
	Kercha	107	24	April,17	151	45	May,31	44	259	43	Oct, 9	309	26	Nov,5	50
Highlands	Solemo	107	16	April,17	NA	NA	NA	NA	NA	NA	NA	306	5	Nov,2	199
	Bore	108	16	April,18	NA	NA	NA	NA	NA	NA	NA	306	7.5	Nov,2	198

Data Source: EMI NA = Not Applicable DOY = Days of the Year LGP = Length of Growing Period.

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The CV for the onset of spring rainfall in lowland and midland was 21% and 19% whereas; for the autumn season was 24% and 20% respectively. The CV for the cessation of spring and autumn rainfall in both low and midland is 33% and 36% respectively. Thus, very high CV (>30) in the cessation of the spring and autumn rainfall together with short LGP was detected in the lowlands and midlands AEZs of the study area. As demonstrated in Table 2, more variability of rainfall was observed in lowlands and midlands in the cessation period than in the onset period. Therefore the ending date for both spring and autumn rainfall is erratic. The contrasting result was obtained by [50] who found the presence of more variability in the onset of the spring (*Belg*) rains than the cessation period.

Table 3 demonstrates the spatial-temporal trends of the onset and cessation of seasonal rainfall in the Guji Zone. There was no statistically significant trend in the onset of spring season rain in all AEZs of the study area. Yet, an insignificant declining trend was detected at the onset of spring rainfall in most parts of the study area. Besides, an insignificant trend was

Table 3. Trends of onset and cessation of rainfall in the study area.

AEZs	Stations	Spring Onset			Spring End			Autumn Onset			Autumn End		
		MKT	S	P	MKT	S	P	MK	S	P	MKT	S	P
Lowlands (kola)	Chembe	0.03	13	0.83	-0.21	-95	0.11	-0.24	-94	0.07	-0.02	-11	0.86
	Dawa	-0.14	-63	0.29	0.15	70	0.24	-0.04	-14	0.77	0.02	9	0.88
	Negele	-0.05	-21	0.73	0.04	18	0.78	0.09	40	0.51	0.007	3	0.97
	Bitata	-0.14	-65	0.27	0.06	30	0.62	0.09	46	0.44	0.11	48	0.39
Midlands (Weinadega)	Shakiso	0.08	37	0.54	-0.13	-47	0.33	-0.19	-85	0.13	0.13	43	0.35
	Adola	0.05	25	0.68	-0.15	-73	0.22	-0.32	-152	0.01*	0.15	73	0.22
	Harekello	-0.10	-49	0.41	-0.03	-12	0.85	-0.23	-101	0.07	0.30	139	0.01*
	Wadera	0.07	28	0.61	0.27	125	0.03*	-0.04	-19	0.75	0.13	60	0.31
	Kercha	0.14	65	0.27	0.096	44	0.46	-0.04	-18	0.77	0.26	107	0.05*
Highlands (Dega)	Solemo	-0.02	-7	0.92	NA	NA	NA	NA	NA	NA	0.17	77	0.196
	Bore	-0.006	-3	0.97	NA	NA	NA	NA	NA	NA	0.114	53	0.38

Data Source: EMI NA = Not Applicable.

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detected in the cessation date of spring rainfall in all AEZs except the midland (Wadera) where the ending date of the spring rainfall was significantly increased. Nevertheless, a significant declining trend (delay) in the onset of autumn rainfall was observed in the midlands (Adola). Moreover, an insignificant decline in the onset of autumn rainfall was observed in all except in the lowlands (Negele and Bitata). Whereas, a significant increase in the end date of autumn rainfall was observed in the midland (Harekello and Kercha). Except for the above-mentioned stations there was no statistically significant trend in the onset as well as the termination of autumn rainfall in all AEZs of the study area.

The implication is that both spring and autumn seasons' rainfall began and terminated with divergent dates. Therefore, as Tables 2 and 3 illustrate inconsistency in the beginning and termination of both spring and autumn season rainfall was common in lowland and midland AEZs of the study area.

In a nutshell, as one moves from highlands to lowlands in the study area the LGP declined, the reliability of rainfall weakened and rainfall variability increased (Table 2). Therefore, too short LGP, and erratic rainfalls are great challenges for smallholder farmers in the lowlands and midlands part of the study areas. As a result, crops will suffer from a lack of moisture which leads to insufficient crop production. Since delay in planting due to late onset and early departure of rain may result in reduced yield, planting following a "false" onset of the growing season may lead to failure and the need for expensive replanting [51,52].

4.3. Agro ecology-based distribution of rainfall in the study area

The section explains monthly, seasonal and annual spatial and temporal distribution of rainfall in the three AEZs of the East Guji Zone. The distribution of mean monthly rainfall (MMR) in East Guji is summarized in Fig 4 and mean seasonal at Fig 5 and the mean annual distribution at Fig 7. Accordingly, considerable spatial and temporal variations were observed in the three AEZs. Hypothetically, March, April, May, and September, October, and November are expected wet months of the year in the southern and south eastern part of Ethiopia. However, as a result of the perceived variability of rainfall, disparate realities were discovered in the study area. March and September remained as dry months. It was also affirmed in Fig 4 that April, May, and October were the three wettest months of the year in the lowlands and midlands AEZs. It is also noted that April to November was wet and December to March were dry months in the highlands AEZs.

The output of PCI also confirmed the variability of monthly rainfall distribution (Table 4). Moderately concentrated precipitation was observed in the highland and irregular distribution of rainfall was distinguished in the lowland and midland part of the study area.

In the lowlands and midlands AEZs rainfall occurs in two seasons which are after and before the beginning of the dry seasons. Particularly, lowlands and midlands AEZs receive rainfall during spring (*belg*) and autumn (*meher*) seasons with spring maxima (Fig 5). Moreover, little amount of precipitation was obtained in the summer and winter seasons in the study areas except in the highlands. In the southern and southeastern parts of Ethiopia, the ITCZ passes two times which results in a bi-modal pattern of rainfall. This bi-modal pattern results in a rainy season in March-May when the convergence zone travels north, and another rainy season when the zone migrates south in September-November. However, summer is a dry season [12,14,53].

Besides the spring and autumn precipitation, the highlands in the study area gain additional rainfall in the summer season; the same is true for most parts of the country. Hence, summer, spring and autumn are wet seasons in the highlands. They experienced long wet spells for most months of the year. As to EPCC [7] topographic highs play a major role in releasing the

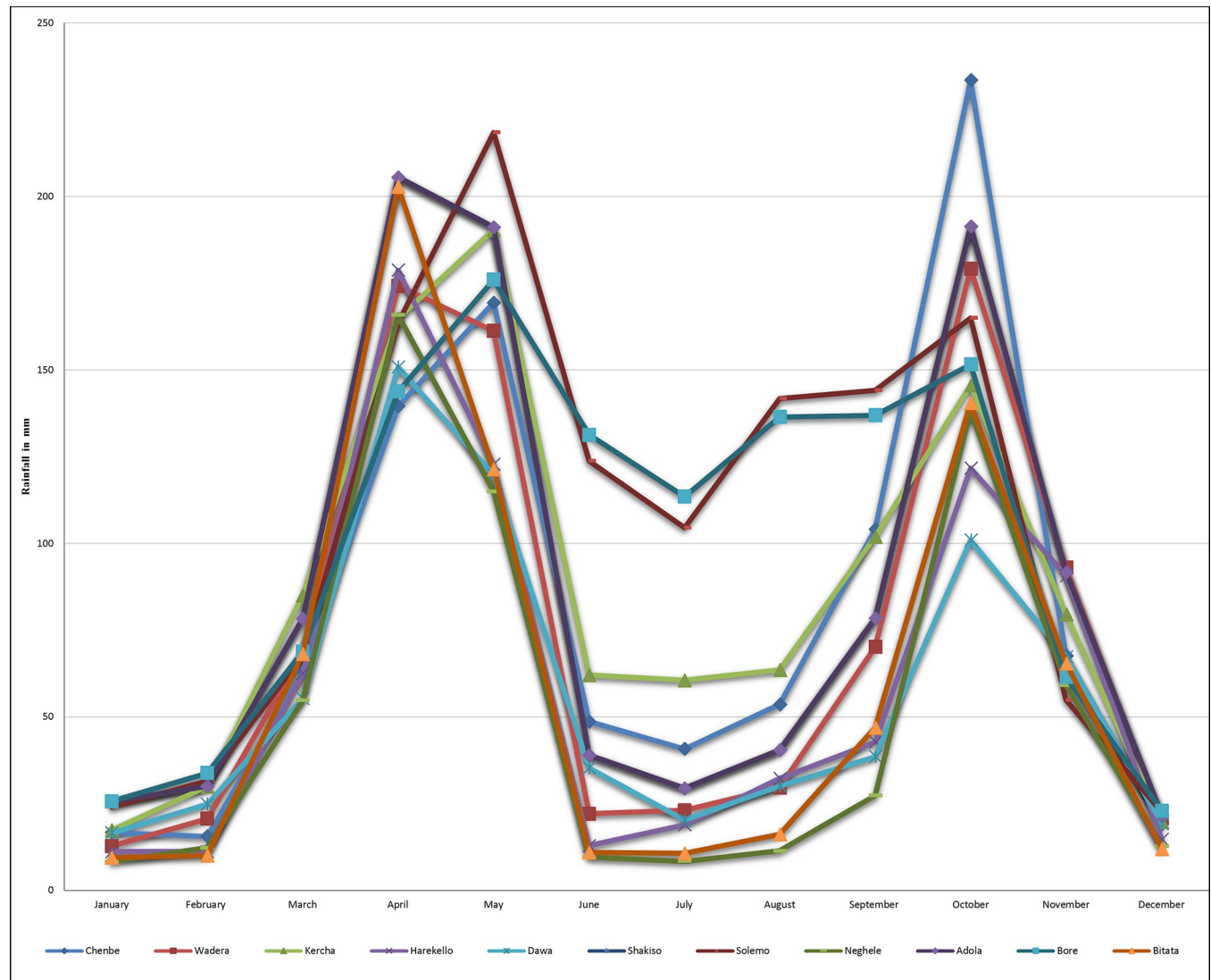


Fig 4. Distribution of mean monthly rainfall in the study area. Data Source: EMI.

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conditional thermodynamic instabilities of the moist incoming air into the country strengthening convective developments.

Consequently, the contributions of seasonal rainfall to total annual rainfall varied among the highland, midlands and lowland AEZs. The midlands and lowlands receive (84%) of precipitation in the spring and autumn seasons (Fig 5). Moreover, almost all areas found in mid and lowland AEZs except Chembe received their rainfall peak in the spring (*belg*) season (Fig 5). Chembe received the greatest rain of the autumn season. As a result, the three major AEZs in the study area reveal a substantial difference in the distribution of annual rainfall (Fig 6). Accordingly, the highest mean annual rainfall was observed in the highland Solemo (1262mm) and the smallest in the lowland Negele (624mm) during the studied period. Therefore, the highland AEZ acquires the highest whereas the lowlands obtain the least amount of rainfall (Fig 7). There was spatial and temporal variability in the distribution of monthly, seasonal and annual rainfall in the study area (Figs 4,5,7 and 8).

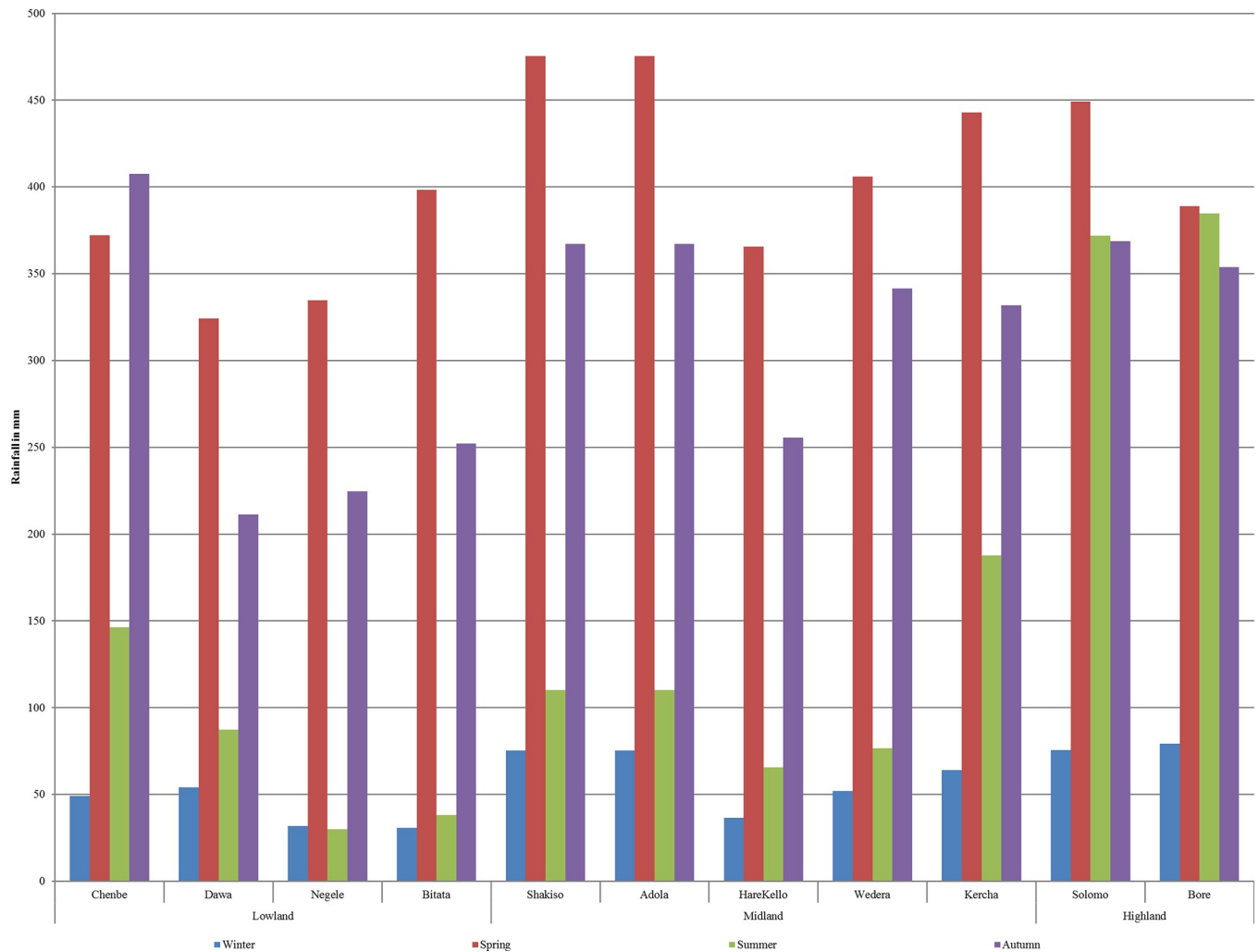


Fig 5. Distribution of mean seasonal rainfall in the study area. Data Source: EMI.

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4.4. Agro ecology-based rainfall variability in the study area

Analysis of the variability of rainfall has been done using PCI and CV. PCI is a prominent indicator of rainfall variability. It clearly shows the level of uniformity or concentration in the distribution of rainfall across the months of the year. PCI value revealed the presence of inconsistent monthly rainfall distribution in the East Guji zone. Accordingly, there was no place in the study area with a uniform distribution of rainfall throughout months of the year ($< 10\%$ PCI). Thus, the mean PCI value of the lowlands, midlands, and highlands AEZs was 19%, 17%, and 12% respectively. As a result, lowlands and midlands acquired irregular rainfall distribution but highlands have moderately concentrated precipitation. Likewise, the year-to-year variability of rainfall denoted 27%, 21%, and 19% CV in the lowlands, midlands, and highlands correspondingly. Thus, the highland part of the study area holds low; whereas, moderate year-to-year variability of rainfall was detected in the low and midlands (Fig 9). Therefore, relatively higher PCI & CV values were observed in the lowlands (*Kola*) and midlands (*Weynadega*). In contrast, it was lower for the highlands (*Dega*) AEZ. Hence, based on PCI & CV there was a significant difference in the level of rainfall variability across the AEZs. As one

Table 4. Magnitude and trend of monthly rainfall distribution.

AEZs	Centers	Sen's Slope (Magnitude)		MKT (Trends)	
		Months with Positive (S)	Months with Negative (S)	Trend	No trend
Lowlands	Chembe	January, April, June, August, September, November, December	February, March, May, July, October		All Months (AM)
	Dawa	January, March, April, May, August, September, October, December	February, June, July, November		AM
	Negele	January, April, May, August, September, November	February, March, June, July, October, December		AM
	Bitata	April, September, October, November, December	January, February, March, May, June, July, August	September	11 Months
Midlands	Shakiso	March, May, June, July, August, September, November, December	January, February, April, October		AM
	Adola	March, May, June, July, August, September, November, December	January, February, April, October		AM
	Hare Kello	January, April, August, September, November, December	February, March, May, June, July, October		AM
	Wadera	January, February, June, July, August, September, November, December	March, April, May, October		AM
	Kercha	January, March, April, May, June, July, September, October, November, December	February and August	October	11 Months
Highlands	Solemo	January, March, April, May, August, September, November, December	February, June, July and October	September	11 Months
	Bore	January, April, May, July, August, September, November, December	February, March, June, and October		AM

Data Source: EMI AM = Refers to All Months of the year.

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advances from highlands to lowlands in the study area; altitude and rainfall decrease and inter-seasonal and annual variability of precipitation increases. The finding of the study corresponds with the studies of [31,54] which stated that as annual and seasonal rainfall increases; PCI values decrease.

According to Fig 10, the CV in the lowlands and midlands AEZs in the spring and autumn seasons was high ($CV > 30$). Both PCI and CV have assured the existence of high seasonal variability of rainfall distribution in the mid and lowland AEZs. As NMA (55) [55] rainfall variability greater than 30% CV is risky for farmers who rely on rain-fed agriculture. Therefore, the detected higher CV resulted in lesser dependability of the seasonal rainfall for agricultural activities in the lowland and midland AEZs.

In contrast, the CV in the highland implies moderate variability of rainfall ($CV < 30\%$) which was 28%, 30%, and 29% in the spring, summer and autumn seasons respectively. The trend and magnitude showed a non-significant declining trend in winter rainfall in all AEZs. Besides, very high CV was observed in the winter season 102%, 99%, and 68% in lowlands, midlands, and highlands AEZs respectively. The observed extremely high CV was an expression of extremely high rainfall variability in the winter season in the study area. Likewise, both PCI and CV are highest in the winter season which reveals greater rainfall variability in the study area. Similar results were reported by [21,27] whereby extremely high variability ($CV > 90\%$) of winter season rainfall was noticed in Borena and Guji Zones respectively. Winter rain is the smallest in amount but contributes to humidity and pasture to grazing land. According to [56] significant dry periods during the winter season may have impacts if the deficiency continues into the growing season, resulting in low soil moisture recharge and deficient soil moisture at spring planting.

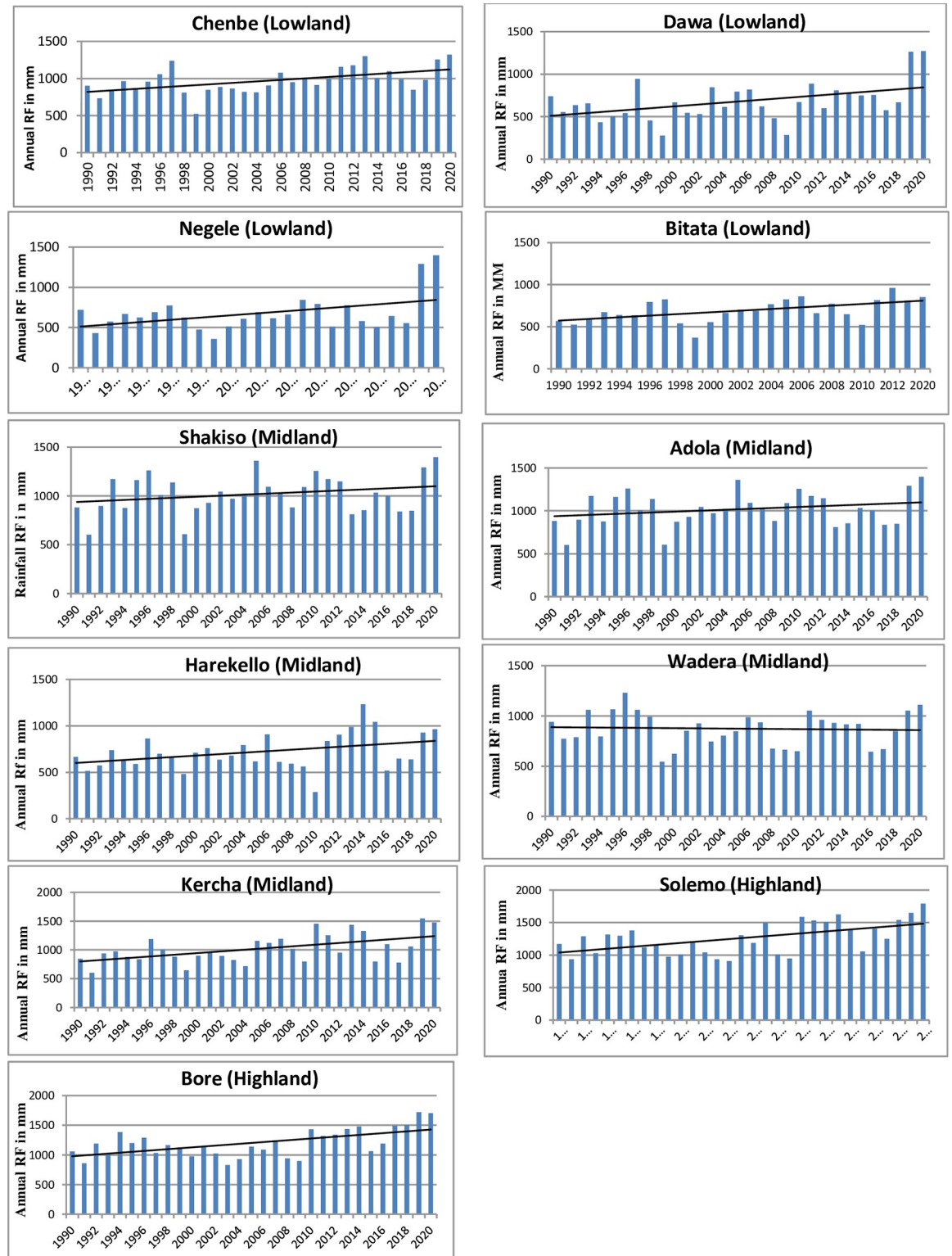


Fig 6. Annual rainfalls of stations in the study area. Data Source: EMI.

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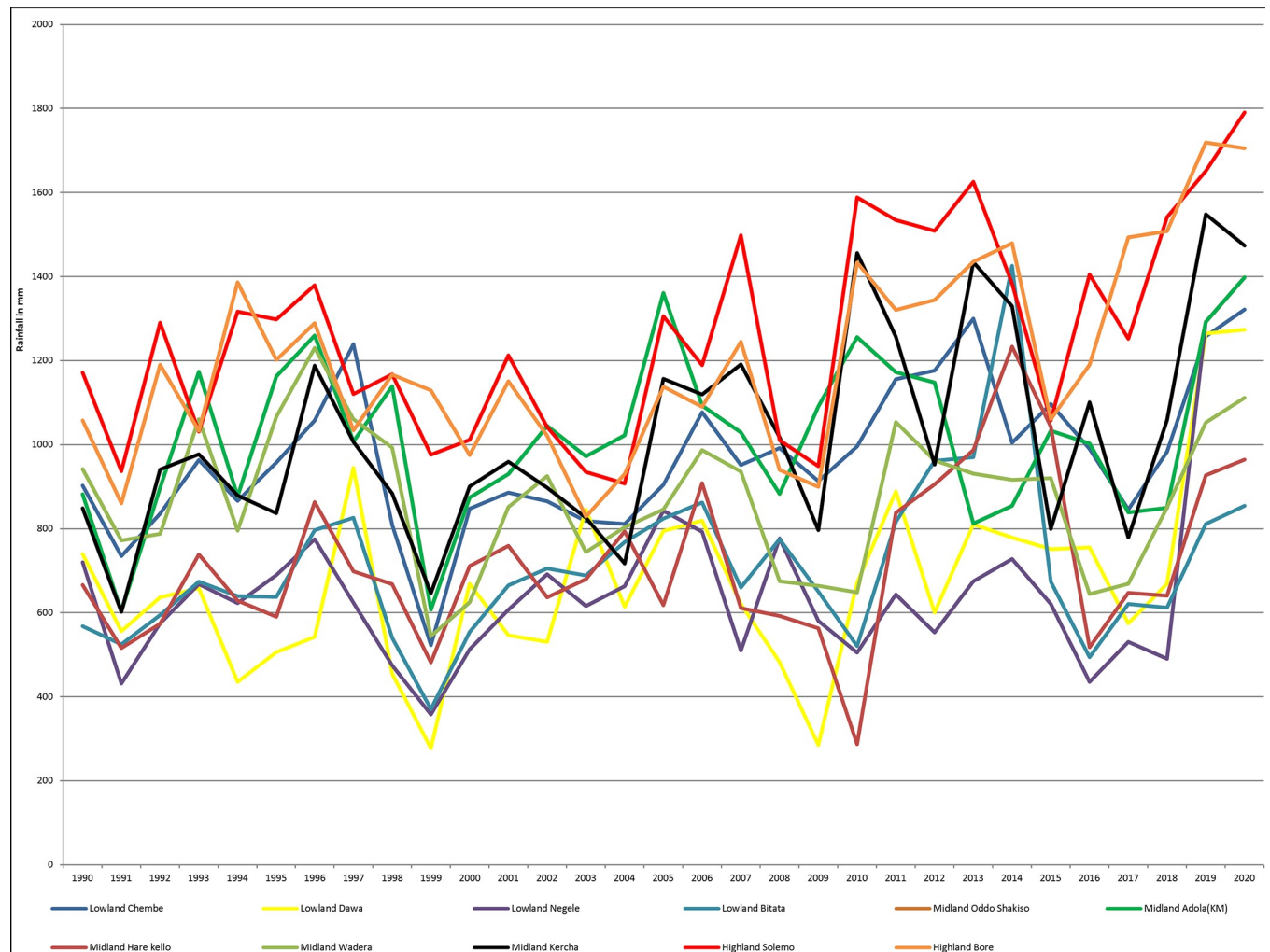


Fig 7. Annual distribution of rainfall in the study area. Data Source: EMI.

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4.5. Agro ecology-based trends of rainfall in the study area

The trends and magnitudes of changes in mean monthly rainfall (MMR) across the three AEZs of the study area were summarized in Table 4. The magnitude of the change in rainfall across different months was disparate. Accordingly, Sen's slope denotes positive and negative magnitudes in the distribution MMR. It revealed that a negative slope or declining magnitude of MMR distribution covered 38% of the studied months or periods. However, 62% of the studied months hold a positive magnitude of MMR distribution. The implication is an escalation in the magnitude of rainfall in the study area.

As shown in Table 4 the monthly rainfall lacked statistically significant trends in almost all months of the year. Exceptionally, a statistically significant increasing trend of rainfall was observed in Solemo (highland AEZ) and Bitata (lowland AEZ) in September at a significant level of ($P < 5\%$). Similarly, in Kercha (midland AEZ) October rainfall showed statistically significant positive trends. As shown in Table 4, except for September and October, there were no significant trends in monthly rainfall distribution across all AEZs.

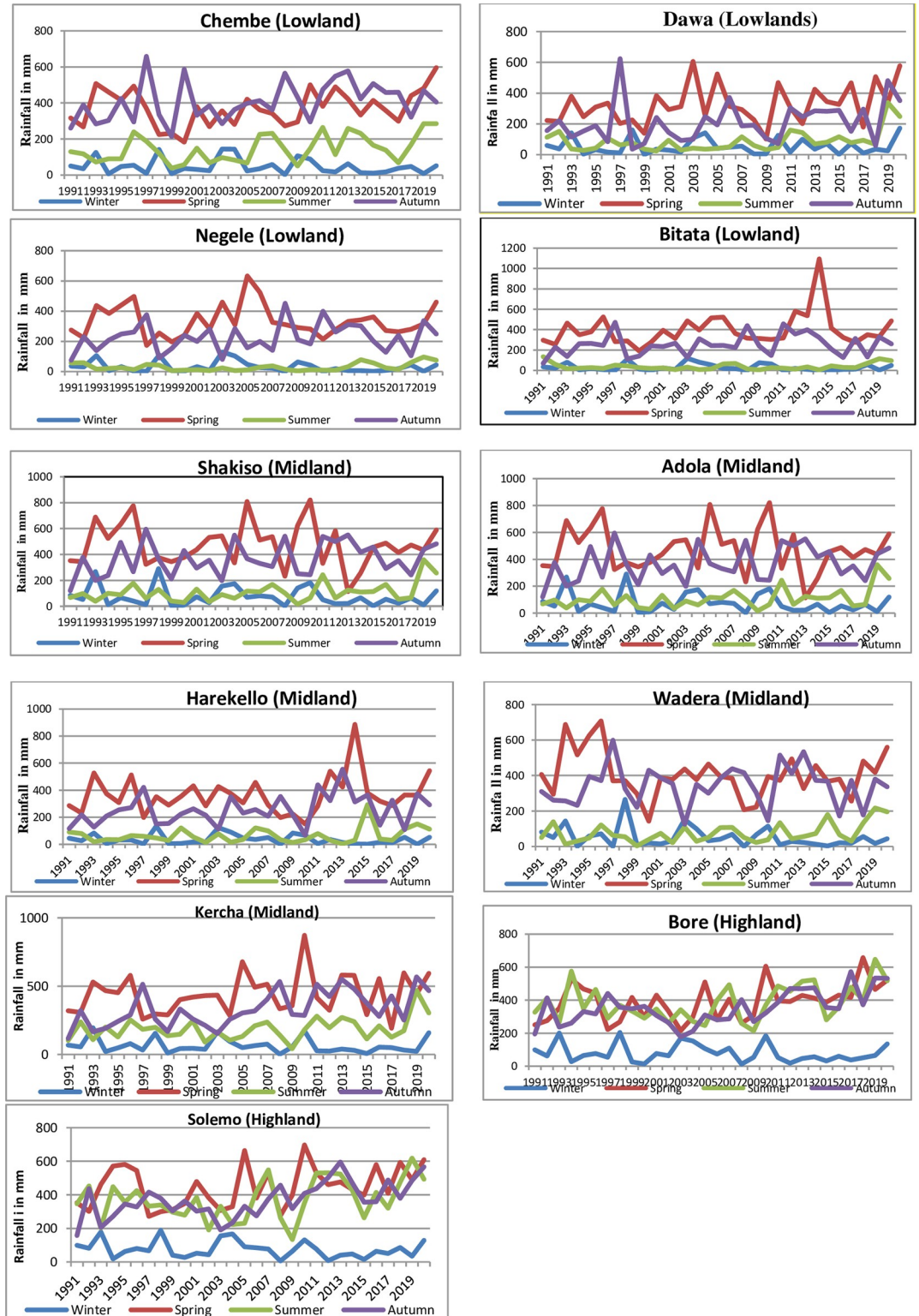


Fig 8. Seasonal distribution of rainfall of individual stations in the study area. Data Source: EMI.

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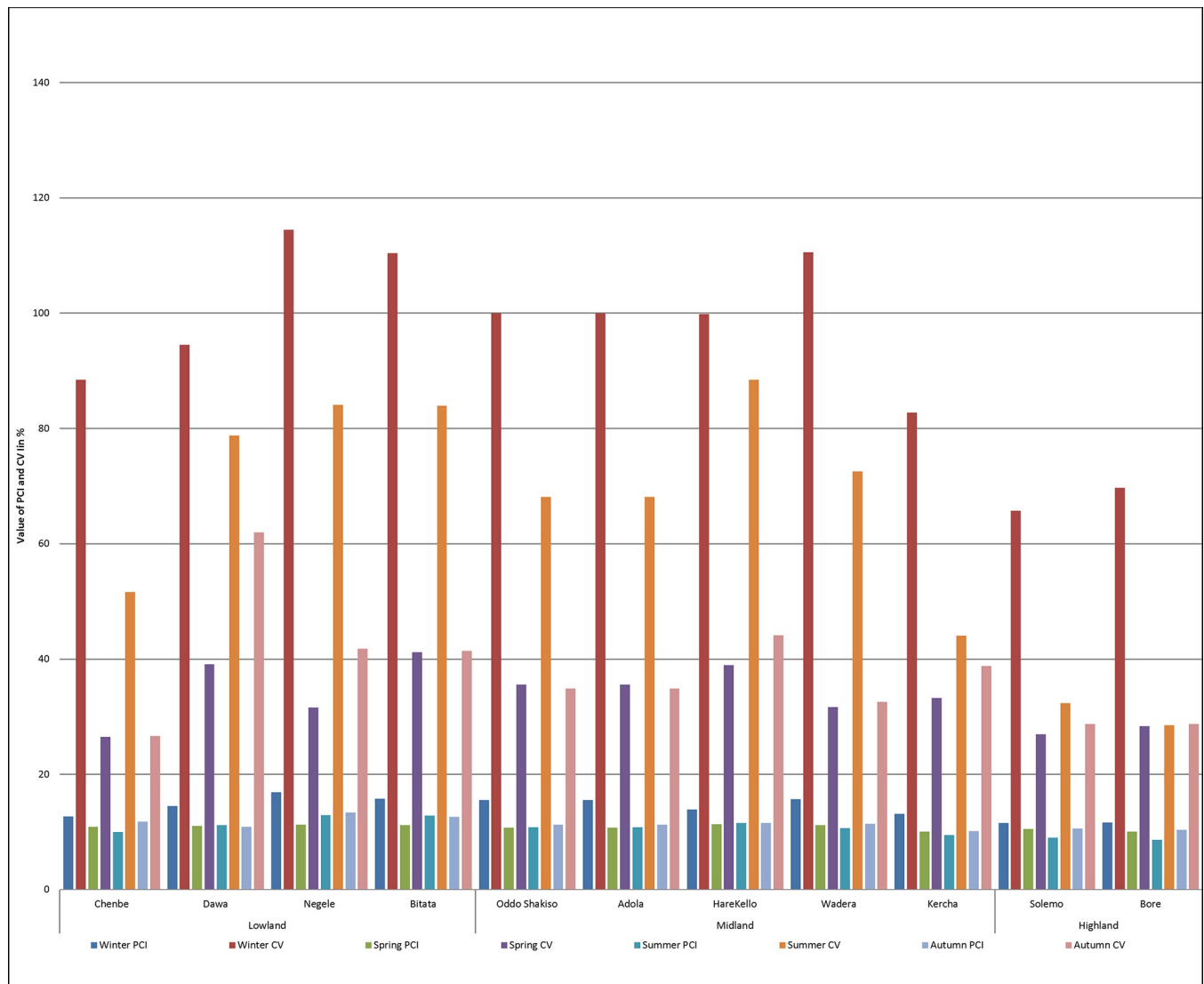


Fig 9. Annual rainfall variability using PCI and CV. Data Source: EMI.

<https://doi.org/10.1371/journal.pclm.0000361.g009>

Likewise, there were no statistically significant trends of seasonal rainfall distribution except in the autumn season. A non-significant declining trend of spring season rainfall was observed in: Adola, Shakiso, Wadera (midlands) and Negele (lowland) during the study period. Therefore, spring (long rainy period) rainfall showed an insignificant decreasing trend at Adola, Shakiso, Wadera and Negele. The findings of decreasing trend of spring rainfall agree with the result of [21,23,24,26] who reported decreasing trend of spring or *belg* (March–May) season rainfall in different parts of the country. Similar results were also reported [57–61] in Eastern Africa in the “long rains” season in (March–May) which denoted a long-term decline. Consequently, an insignificant increase of annual rainfall was observed at the above-mentioned specific localities. La Niña affects MAM precipitation and leads to deficit rainfall in Southern Ethiopia [62].

Nevertheless, a non-significant increasing trend was detected in the rest of a great number of stations in the spring or *belg* rainfall. Thus, the highlands, most Lowlands: Chembe, Dawa

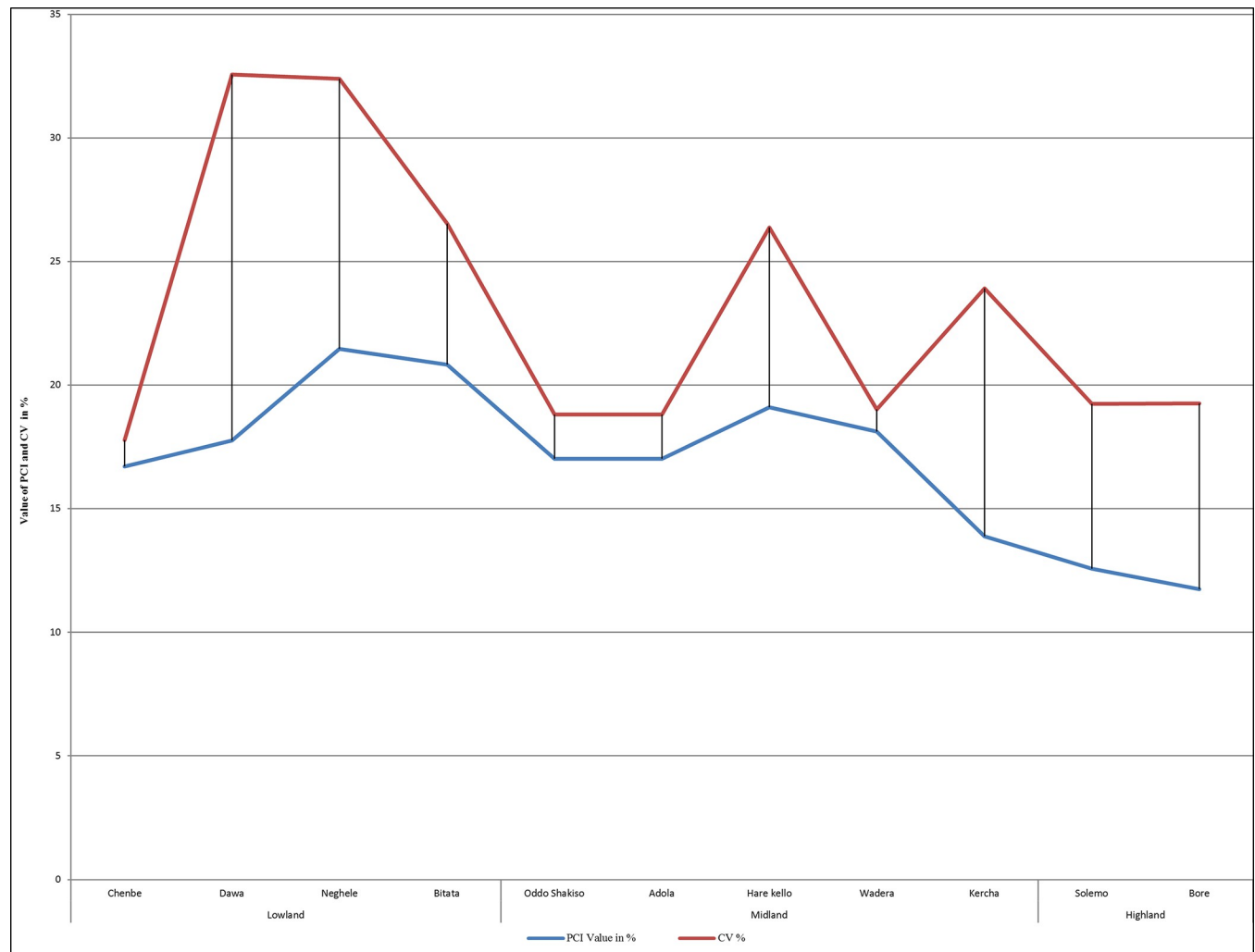


Fig 10. Seasonal variability of rainfall using PCI and CV. Data Source: EMI.

<https://doi.org/10.1371/journal.pclm.0000361.g010>

and Bitata (lowland) and Harekello (midland) had shown a non-significant increasing trend of spring rainfall (Table 5). Besides, the value of Sen's slope denoted a non-significant decline in the magnitude of spring rainfall in the Kercha (midland). Likewise, an insignificant decline in summer rainfall was detected in the lowlands (Bitata, Negele) and midlands (Harekello) stations.

The highland AEZs experienced a non-significant increasing trend in summer and spring but a statistically significant increase in autumn rainfall. Remarkably, autumn rainfall revealed a significant increasing trend in Bore and Solemo, (highlands), Chembe (lowland) as well as in Kercha (midland) stations at a significant level of 5%. This is in line with the studies of [21,27] who reported a significantly increasing trend of rainfall during the autumn season (short rainy period) in Borana and Guji zones correspondingly. Studies also confirmed that in S-Ethiopia there has been a rainfall deficit for the main rainfall season (MAM) and excessive rainfall for the Small Rainfall season (ON) [13,63,64].

As with the long rains, these regional-mean long-term linear trends are punctuated with periods of pronounced anomalous rainfall, including 1997–1998 and 2019–2020 when short

Table 5. Trends of seasonal rainfall in the study area.

Seasons	AEZs	Centers	Mean	STD	CV	MKT	Slope	P- Value
Winter	Lowlands	Chembe	49	43.4	88.5	-0.071	-1.439	0.707
		Dawa	54.2	51.2	94.5	-0.095	0.194	0.599
		Negele	32	36.5	114.5	-0.190	-3.306	0.259
		Bitata	31	34	110.4	-0.190	-2.145	0.260
	Midlands	Shakiso	75.2	75.2	100	-0.167	-8.163	0.329
		Adola	75.2	75.2	100	-0.167	-8.163	0.329
		Hare Kello	37	36.5	100	-0.167	-1.614	0.329
		Wadera	52	57.5	111	-0.167	-5.866	0.329
		Kercha	64	53	83	-0.143	-3.036	0.409
	Highlands	Solemo	75.5	50	66	-0.262	-6.464	0.115
Bore		79.3	55.3	70	-0.286	-6.095	0.084	
Spring (long rain)	Lowlands	Chembe	372.1	98.5	26.5	0.143	14.047	0.408
		Dawa	324.2	127	39.1	0.261	10.104	0.115
		Negele	335	106	31.6	-0.071	1.0346	0.707
		Bitata	398.4	164.3	41.2	0.214	11.96	0.202
	Midlands	Shakiso	475.5	169.1	35.6	-0.166	6.559	0.328
		Adola	475.5	169.1	35.6	-0.166	6.558	0.328
		Hare Kello	366	143	39	0.000	1.982	1.000
		Wadera	406	129	32	-0.095	1.678	0.599
		Kercha	443	147.4	33.3	0.119	-0.832	0.499
	Highlands	Solemo	449.3	121	27	0.143	13.43	0.408
Bore		389	110.5	28.4	0.119	13.33	0.499	
Summer	Lowlands	Chembe	146.3	75.5	51.6	0.214	8.650	0.201
		Dawa	87.4	69	78.7	0.261	6.214	0.115
		Negele	30	25.2	84.1	0.000	-0.513	1
		Bitata	38.2	32.1	84	-0.071	-1.07	0.707
	Midlands	Shakiso	110.1	75	68.1	0.166	2.147	0.328
		Adola	110.1	75	68.1	0.166	2.147	0.328
		Hare Kello	65.5	58	88.4	-0.071	-0.324	0.707
		Wadera	77	54	72.6	0.095	6.982	0.201
		Kercha	188	83	44.1	0.095	0.656	0.599
	Highlands	Solemo	372	120.3	32.3	0.071	6.40	0.707
Bore		385	110	28.5	0.071	2.69	0.707	
Autumn (short rain)	Lowlands	Chembe	407.5	109	26.7	0.357	31.677	0.029*
		Dawa	211.4	131	62	0.166	14.132	0.329
		Negele	225	94	42	0.166	10.189	0.328
		Bitata	252.1	104.5	41.4	0.214	23.17	0.202
	Midlands	Shakiso	367.2	128.1	35	0.166	18.508	0.329
		Adola	367.2	128.1	35	0.166	18.507	0.328
		Hare Kello	255.5	113	44.1	0.214	17.831	0.202
		Wadera	342	111.3	33	0.095	8.915	0.599
		Kercha	332	129	39	0.357	33.029	0.029*
	Highlands	Solemo	369	106.1	29	0.404	27.674	0.013*
Bore		354	102	29	0.404	21.468	0.013*	

Data Source: EMI Level of Significant at = 5%.

<https://doi.org/10.1371/journal.pclm.0000361.t005>

Table 6. Trends of annual rainfall in the study area.

AEZs	Centers	Minimum	Maximum	Mean	CV	MKT	Slope	P-value
Lowlands (<i>kola</i>)	Chembe	523.15	1321.7	971.8	18.1	0.393	10.86	0.002**
	Dawa	277.51	1273.6	679.4	32.8	0.264	8.13	0.038**
	Negele	357.65	843.1	623.8	19.5	0.045	0.75	0.73
	Bitata	370.31	1425.6	714.1	26.8	0.247	7.82	0.05**
Midlands (<i>Weinadega</i>)	Shakiso	603.14	1398.02	1022.2	19.5	0.101	4.86	0.43
	Adola	603.14	1398.02	1022.2	19.5	0.101	4.86	0.43
	Hare Kello	287.02	1233.6	720.7	26.6	0.226	8.36	0.07
	Wadera	544	1230.6	875.9	19.7	-0.045	-0.70	0.73
Highlands (<i>Dega</i>)	Kercha	602.19	1548.1	1020.4	24.2	0.333	14.46	0.008**
	Solemo	908	1790.7	1262.3	19.6	0.354	14.63	0.005**
	Bore	829	1719.1	1202.5	19.6	0.376	15.33	0.003**

Data Source: EMI Level of Significant at 5%.

<https://doi.org/10.1371/journal.pclm.0000361.t006>

rains totals were 2–3 times higher than climatological values. Indeed, rainfall anomalies of 100–250 mm year⁻¹ are observed in 1997, 2006, 2012, 2015 and 2019, linked to variability associated with ENSO and corresponding interactions with the IOD [13,61,65–67]. The short-term variability, driven by changes in ENSO and the IOD, and unequal warming across the Indian Ocean [68]. Likewise, in the study areas also these were wet years: 1993, 1996, 2001, 2005, 2006, 2012, 2013, 2014, 2015, 2018 and 2020. The short rain has shown an increase in the same years in the study area.

The observed increase in the autumn rainfall in parts of the study area resulted in a subsequent increase in the trend in annual rainfall for highlands, midlands and lowlands except Wadera (Fig 8). Significant positive change in annual rainfall was observed in the highlands (Bore 15.3mm/year and Solemo 14.6mm/year), lowlands (Chembe 10.9mm/year, Dawa 8mm/year and Bitata 7.8mm/year), as well as midland (Kercha 14.5mm/year) stations at a significant level of 5% (Table 6). Besides, a non-significant increasing trend of annual rainfall was observed in the remaining midlands (Adola, Shakiso and Harekello) and lowlands (Negele) except for Wadera (midland) stations which holds an insignificant declining trend of annual rainfall.

To conclude, around half of the stations in the study area were experiencing a significantly increasing trend of annual rainfall (Table 5). However, the rest of them except Wadera had shown a non-significant increasing trend in annual rainfall. In general, portions of the study areas experienced a significant increase in the trend of annual rainfall. The finding coincides with studies of [19,20]; [24–26] who reported an increasing trend of annual rainfall in different parts of the country. The study also coincides with [63–64,69,70] who reported a notable increase in East African rainfall. Similar findings also explained that the increases in annual rainfall in the study area are largely a result of an increasing in the ‘short’ rainfall (OND) season in the area [63]. Therefore, at the mentioned locality most of the statistically significant increases in annual rainfall are directly related to the observed significant increase in trend in autumn (*meher*) rainfall.

However, the finding of increasing annual rainfall contradicts the studies made [19–21,43] that found a decreasing trend of annual rainfall in a different part of the country. Hence, the diverse trend was observed in different AEZs of the study area, ensuring varied spatial-temporal trends in rainfall distributions in Ethiopia. Moreover, [14] confirmed that a cold Gulf of Guinea leads to a strengthening of the TEJ and a suppressed ITCZ, in turn giving rise to increased rainfall in southern Ethiopia with a reduction in the north and central regions. This disparity has sometimes been called the East African climate paradox [57].

Besides, the choice of study period strongly influences the results of trend analysis of rainfall seriously due to the effects of temporal variability [31]. Previous studies made by Habte et al. [21] in the Guji Zone from 1986–2017 showed a declining trend of annual rainfall in the study area. A similar finding was reported by [61] in Eastern Africa the long rains exhibited consistent negative trends from 1985 to 2017. Notable declines occurred in 1999 and 2010–2011 in Eastern Africa the long rains.

In contrast, as observed in Figs 5 & 8 the wetness of the study area was enhanced during the ending period of the present study (2019 & 2020). In other words, the perceived increase in rainfall was recorded after the earlier study was already conducted in the study area. The study of [61] supported the finding of the current study by explaining the recovery of very wet long rains in 2018 and 2020 in Eastern Africa. Therefore, a comparable declining trend of long rainfall was observed in East Africa from 1985–2017 but the wetness was restored in 2018–2020. Thus, contrasting results obtained in the current study might be due to the chosen study periods which already determine the output of the trend analysis. Therefore, the temporal variability of rainfall in the study area is articulated by the period during which the study was conducted. Whereas, the observed spatial variability of rainfall in Guji zone was due to the diverse AEZ ranging from 632m -2960m (Fig 2).

5. Conclusions

Identifying the variability of rainfall in space and time, onset and cessation, and distributions across AEZs is essential since rain-fed agriculture is the mainstay of smallholder farmers in the study area. The finding denotes the presence of spatial and temporal variation in the distribution of rainfall in the three AEZs of the study areas. Midlands and lowlands experience bimodal rainfall, two distinct onset and cessations and dual LGP in the autumn and spring seasons. Whereas, highlands obtain a considerable amount of rainfall in spring, autumn and summer. Furthermore, variability in the days of onset and departure of rainfall was observed in the three major AEZs of the study area. Complex trends in the distribution of rainfall had been found in the area. Insignificant, increasing trends of spring rainfall had been discovered in most parts of the study area. Partially, there was a significant increase in autumn rainfall in the study area. Likewise, the annual rainfall had shown an insignificant increasing trend in some parts of the study area, a significant increasing trend was observed in the highlands (Bore and Solemo); lowlands (Chembe, Dawa and Bitata) as well as in the midland (Kercha) stations.

Thus, the PCI value decreases with increasing altitude and rainfall. As one moves from the highlands to the lowlands in the study area; rainfall decreases and the inter-annual variability of precipitation will increase. Therefore, moderate year-to-year variability was detected in the low and midlands whereas the highlands exhibited lesser year-to-year variability of rainfall. High monthly and seasonal variability together with the late onset and early termination of the spring and autumn rainfall in the midlands and lowlands parts of the study was a challenge for the small-holder farmers. Although rainfall variability was discovered as a problem its magnitude varies across the different AEZs in the study area. The erratic nature of rainfall resulted in shortage of water for rain fed agriculture in the mid and lowlands AEZ. Thus, more consideration should be given to the lowlands and midland AEZs of the study areas.

Therefore, selecting and providing appropriate short-cycle grown and drought-resistant crops to the midlands and lowlands AEZs of the study area is critical. Furthermore, additional support to strengthen the use of water resources for (irrigation/water harvesting) agricultural activities should be done for smallholder farmers in the midlands and lowlands AEZs. Accurate, reliable, and timely information about the onset and end of rainfall should also be

provided for the community to avoid planting crops on the false onset date. Due to limitations of time and resources the study was done at the scope of “*Spatiotemporal Trends and Variability of Rainfall*”. Further investigation of the spatial distribution and temporal trends of temperature together with an assessment of the rate of evaporation across the three AEZ in the study area is vital to understanding the micro climate of the area. So that the result will alleviate the issues related to the livelihood of smallholders.

Author Contributions

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