Spatial Rainfall Variability of Oromia Region, Ethiopia

Arragaw Alemayehu[*1], Molla Maru[2] and Woldeamlak Bewket[2]
[*1]Department of Geography & Environmental Studies
Debre Berhan University
[2]Department of Geography & Environmental Studies
Addis Ababa University
Molla Maru - Email: mollamaru@gmail.com
Woldeamlak Bewket - Email: woldeamlak.bewket@aau.edu.et
Corresponding author: Email: arragawalex@gmail.com

ABSTRACT

Rainfall over Ethiopia shows high spatial and temporal variability and has significant effects on Ethiopia's economy in general and on the agriculture sector in particular. This study describes the rainfall climatology of Oromia Region of Ethiopia using over the past 30 years (1983-2016) of monthly rainfall data from 20,475 points of 4km×4km grids. The data are created by blending station records with meteorological satellite estimates and were obtained from the National Meteorological Agency of Ethiopia. Methods of analysis used include calculation of longterm averages and indices of variability, and detection of trends over the period of observation. We found that mean annual areal rainfall over Oromia Region is 1009 mm, varying from 816 mm in the lowlands (locally known as Kolla, <1500 m asl) agroecological zone to 1240 mm in the midlands (locally known as Weyna-Dega, 1500–2300 m asl) agroecological zone. Inter-annual rainfall variability is generally low, and its intra-annual variability is characterized by moderate to high concentration. Annual rainfall shows statistically non-significant increasing trend. March-May (Belg) rainfall shows statistically non-significant decreasing trend except for Weyna-Dega agroecological zone where there is no clear trend. June-September (Kiremt) rainfall shows statistically significant increasing trend in Weyna-Dega and Dega (>2300 m asl) agroecological zones at p=0.05 level; and at p=0.1 level in the entire Oromia Region. The October-February (Bega) rainfall shows increasing trend in the Kolla agroecological zone at p=0.1 level. February and September show statistically significant increasing trends at p=0.05 level. The correlation between altitude and rainfall in Oromia

Region is positive and statistically significant at p = 0.01 except in the Dega agroecological zone which showed statistically significant negative correlation at p=0.01 level. We present results by agroecological zones, and we believe this gives useful insights for development of context-specific agricultural planning, climate risk management and water resource management strategies in this topographically and climatologically diverse Region.

***Keywords**: rainfall climatology, agroecological zone, Oromia Region, Ethiopia*

1. INTRODUCTION

Rainfall shows high spatial and temporal variablity over Ethiopia (Seleshi and Zanke, 2004; Wagesho et al., 2013; Suryabhagavan, 2017; Asfaw et al., 2018) and the country's economy has been affected by long-term changes in rainfall amount and distribution where the country has witnessed frequent incidents of both excessive and deficient rainfalls (Washington et al., 2006; Korecha, 2013; Zeleke et al., 2017). Studies have shown that rainfall variability has significant effects on Ethiopia's economy in general and on the agriculture sector in particular (Admassu, 2004; Lemi, 2005; World Bank, 2006; Bewket, 2009; Conway and Shipper, 2011; Bewket, 2012; Robinson et al., 2013; Wagesho et al., 2013; Bezabih et al., 2014; Eshetu et al., 2015; Alemayehu and Bewket, 2016). Rainfall is the most important weather variable in Ethiopia affecting various sectors (Washington et al., 2006). More than 80% of Ethiopians are engaged in subsistence rain-fed agriculture and this shows the extent of socioeconomic stress rainfall variability causes in the country. Climate change is greatly exacerbating this situation (Bewket, 2009; Conway and Shipper, 2011; Gebrehiwot and van der Veen, 2013; Alemayehu and Bewket, 2016). A better understanding of trends and variability of rainfall is an important component in the study of climate variability (Nicholson, 2014) as rainfall shortages or changes in seasonal pattern led to food shortages or even famines in Ethiopia (Alemayehu and Bewket, 2017).

There are many studies on variability and trends of rainfall over Ethiopia covering different temporal and spatial scales. The conclusions from these studies indicate that rainfall did not show clear trends for the country as a whole. In the northern part, declining trends of annual and seasonal rainfalls were reported by Gebre et al. (2013), Wagesho et al. (2013), Gebremedhin et al. (2016) and Berhane (2020). In the southwest, Seleshi and Zanke (2004) and Wagesho et al. (2013) observed declining trends. Jury and Funk (2013) reported contradictory trends; increasing trend in the lowlands and declining trend over the highlands. On the other hand, Viste et al. (2013) reported increasing trends. While Kebede and Bewket (2009) and Degefu and Bewket (2014) reported the absence of significant trends. In the central part of the country, declining trends were reported by Osman and Sauerborn (2002), Rosell and Holmer (2007), Alemayehu and Bewket (2017) and Asfaw et al. (2018). Northwestern part of the country was covered by Bewket and Conway (2007), Ayalew et al. (2012), Mengistu et al. (2013), Wagesho et al. (2013), Addisu et al. (2015) and Ademe et al. (2020). Bewket and Conway (2007), Ayalew et al. (2012), Mengistu et al. (2013) reported mixed trends while Wagesho et al. (2013), Addisu et al. (2015) and Ademe et al. (2020) observed declining trends. Urgessa (2013) covered the south, east and southeast part of the country and noted declining trends. However, the above studies are generally consistent with each other in reporting declining trends in the *Belg* rainfall in their respective study areas and periods.

This complex spatio-temporal variability of rainfall over Ethiopia is attributed to the large variations in altitude (Gamachu, 1988) varying from the lowest point at the Danakil depression (120 m bsl) to the highest peak in the Simien Mountains (4620 m asl) (Reda et al., 2015), the north-south oscillation of the Inter Tropical Convergence Zone (ITCZ) (Kassahun, 1987), the El Niño-Southern Oscillation (ENSO) phenomena (Camberlin, 1997; Shanko and Camberlain, 1998; Seleshi and Zanke, 2004; Gleixner et al., 2017; Solomon et al., 2019), fluctuations in sea surface temperatures (SSTs) over the Indian, Pacific and Atlantic Oceans (Shanko and Camberlin, 1998; Gissila et al., 2004; Segele and Lamb, 2005; Korecha and Barnston, 2007; Segele et al., 2009a, b; Viste and Sorteberg, 2013; Jury and Funk, 2013; Degefu et al., 2017; Weldegerima et al., 2018; Solomon et al., 2019), and the inter-seasonal and inter-annual variation of the strength of the monsoon over the Arabian Peninsula (Segele and Lamb, 2005; Segele et al., 2009a, b). The studies on spatial and temporal variability of rainfall and links to ENSO and SSTs (Camberlin, 1997; Shanko and Camberlain, 1998; Seleshi and Zanke, 2004; Shanko and Camberlin, 1998; Gissila et al., 2004; Segele and Lamb, 2005; Korecha and Barnston, 2007; Segele et al., 2009a, b; Jury and Funk, 2013; Viste and Sorteberg ,2013; Degefu et al., 2017; Gleixner et al., 2017; Weldegerima, et al. 2018; Solomon et al., 2019) concluded that annual and seasonal rainfall signals are sensitive to these large scale climate drivers.

Studies on variability and trends of rainfall in Ethiopia are generally carried out at different spatial scales such as, river catchment scale (e.g., Mengistu et al., 2013; Degefu and Bewket, 2014; Addisu et al., 2015; Bekele et al., 2017; Asfaw et al., 2018; Mulugeta et al., 2019; Ademe et al., 2020), and national or sub-national scales (e.g., Seleshi and Zanke, 2004; Cheung et al., 2008; Jury and Funk, 2013; Urgessa, 2013; Wagesho et al., 2013; Gummadi et al., 2017). Bewket and Conway (2007) is perhaps the first Regional level climatology study. Recently, Solomon et al. (2019) investigated monthly to inter-decadal rainfall variability of the Southern Regional Sate of Ethiopia. There is no study conducted so far as it is known to authors which examined the rainfall climatology of Oromia Region. However, there are attempts to investigate rainfall variability of the region at district, zonal and watershed scales (e.g., see Feke et al., 2021; Bayable et al., 2021; Bekuma et al., 2022; Teshome et al., 2022; Worku et al., 2022). The objective of this study is therefore to describe the rainfall climatology of Oromia Region using over 30 years (1983-2016) of monthly rainfall data from 20,475 points of 4km×4km grids. The paper is organized in four sections. In the following section, we present a brief description of materials and methods of the study. Section 3 presents the results and discussion, and conclusions are presented in section 4.

2. MATERIALS AND METHODS

2.1 Description of the study area

Oromia is the largest National Regional State of Ethiopia covering over 350,000 km^2, which is over 34% of the country's area (CSA, 2007) (Fig. 1). Topography varies from high rugged mountain ranges and undulating plateaus to panoramic gorges and deep incised river valleys, and rolling plains. The highest peak is 4607 m asl (Mt Batu in the Bale mountains). According to the traditional agroecological zonation system which considers altitude, the Region has 51% of its area in *Kolla* (less than 1500 m asl) zone, 36% in the *Weyna-Dega* (1501-2300 m asl) zone and 13% in *Dega* (>2300 m asl) zone (Fig. 2). Areal mean annual rainfall over Oromia Region is 1009 mm. Mean annual temperature is 20.4 ^{0}C. The mean annual minimum and maximum temperatures are 13.6 ^{0}C and 27.1 ^{0}C, respectively.

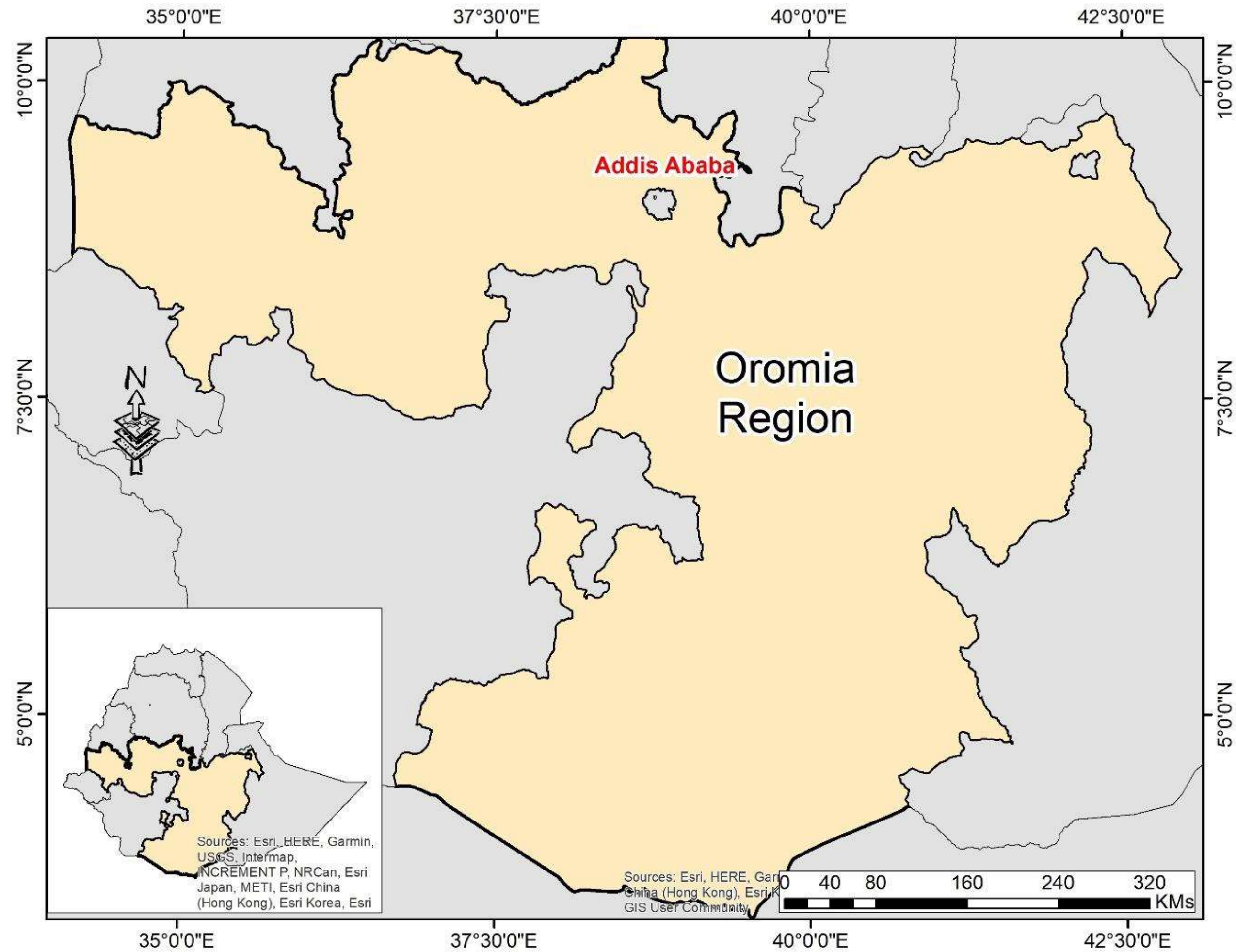


Figure 1. Location of the study area

According to CSA (2013), the population of Oromia Region was 35,467,001 out of which 17,788,003 were males and 17,678,998 were females. Of the total population, about 15% resides in towns and the remaining 85% lives in rural areas, directly deriving livelihoods from agriculture and pastoralism. The Region accounts for nearly half of crop production, 45% of the area under annual crops, and 38% of the total livestock population of the country (CSA, 2007; Tilahun and Schmidt, 2012; JICA, 2018). The major crops grown in the Region are coffee, maize, wheat, barley, *tef*, sorghum, peas, bean and oil seeds. Coffee is the main cash crop. The average land holding per household in the Region is 1.14 ha, compared to the national average of 1.0 ha (FDRE, 2018).

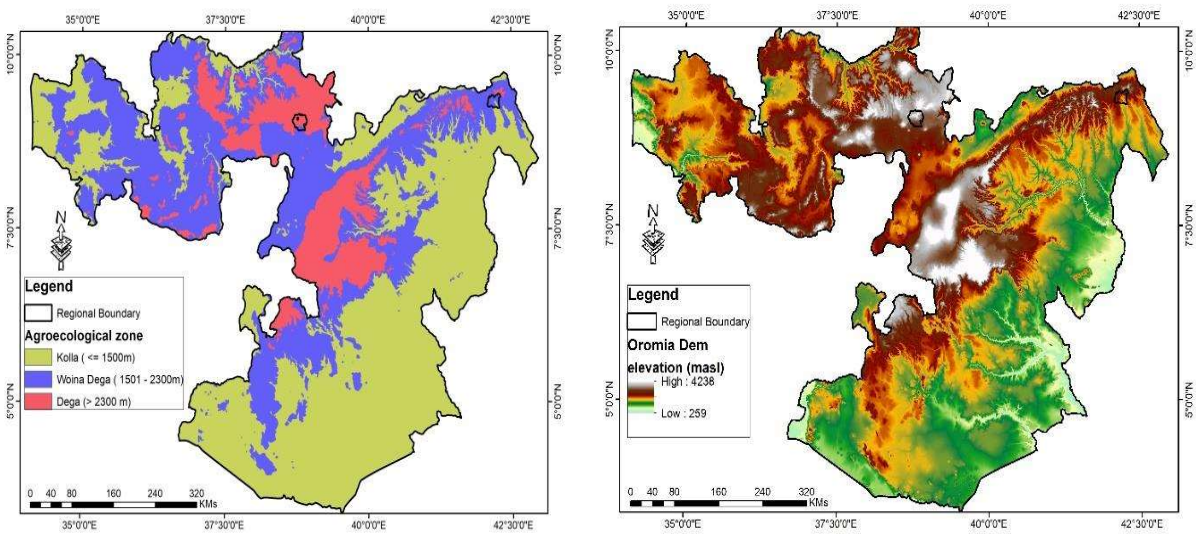


Figure 2. Elevation (right) and Agroecological zone (left) in the Oromia Region, Ethiopia

2.2 **Data and methods**

Over 30 year of monthly rainfall data for 20,475 points of 4km×4km grids reconstructed from weather stations and meteorological satellite estimates were obtained from the National Meteorological Agency of Ethiopia for the period 1983-2016. Out of the 20,475 points, 10,461 are found in the *Kolla*, 7,393 are found in the *Weyna-Dega* and 2,621 of the points are found in the *Dega* agroecological zones.

Spatial and temporal variability in rainfall using the 20,475 points were determined using statistics such as mean, standard deviation, Precipitation Concentration Index (PCI), Standardized Rainfall Anomaly (SRA) and Coefficient of Variation (CV). The CV measures year-to-year variation in the data series. According to NMA's (1996) classification, CV less than 0.20 is less variable, CV between 0.20 and 0.30 is moderately variable, and CV greater than 0.30 indicates high variability. The PCI values measure extent of seasonality of rainfall, and it is given as indicated in De Luis et al. (2000);

$$PCI = 100 \times [\sum Pi^2/(\sum Pi)^2] \qquad (1)$$

where: Pi = the rainfall amount of the i^{th} month; and ΣPi^2 = summation over the 12 months. PCI values of less than 10 indicate uniform monthly distribution of rainfall, values between 11 and 15 indicate moderate concentration, and values above 15 indicate high concentration.

SRA is commonly used as a simple index to characterize drought at different time scales, or to identify abnormal wetness or dryness (Guttman, 1999). SRA values are given as;

$$SRA = (Pt - Pm)/\ \sigma \qquad (2)$$

where SRA = standardized rainfall anomaly, Pt = annual rainfall in year t, Pm = is long-term mean annual rainfall over a period of observation and σ = standard deviation of annual rainfall over the period of observation. According to Agnew and Chappel (1999), SRA values indicate extreme drought (SRA < -1.65), severe drought (-1.28 > SRA > -1.65), moderate drought (-0.84 > SRA > -1.28), and no drought (SRA > -0.84).

The non-parametric Mann–Kendall test (Mann, 1945; Kendall, 1975) was applied to assess the existence of significant trends in the rainfall data over the study period. The Mann-Kendall test statistic S is calculated as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \qquad (3)$$

Where, *n* is the length of the data set, x_j and x_k are the annual values in years *j* and *k, j>k*, respectively, and

$$\operatorname{sgn}(x_j - x_k) = \begin{bmatrix} 1 & if\ (x_j - x_k) > 0 \\ 0 & if\ (x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{bmatrix} \quad (4)$$

If n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall. For samples greater than ten the normal approximation test is used (Salmi et al., 2002). First the variance of S is computed by the following equation that takes ties into account:

$$\operatorname{var}(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right] \quad (5)$$

Here q is the number of tied groups and t_p is the number of data values in the p^{th} group. The standardized test statistic Z was calculated using S and var(s) values as follows:

$$Z = \begin{bmatrix} s - 1/\sqrt{\operatorname{var}(s)} & if > 0 \\ s + 1/\sqrt{\operatorname{var}(s)} & if < 0 \\ 0 & if = 0 \end{bmatrix} \quad (6)$$

The value of Z in the Mann-Kendall test statistics follows standard normal distribution with mean of zero and variance of one. The presence of a statistically significant trend is evaluated using the Z values. Positive (+) values indicate an increase over time while, negative (-) values indicate decrease. Analysis was done from the final model and for the variables that were found statistically significant at p=0.01, p=0.05 and p=0.1 levels.

The slope of the linear trend is estimated using Sen's estimator in order to calculate the magnitude of the significant trends. It is given as;

$$Y = mx + b \tag{7}$$

where y is dependent variable which is a continuous monotonic increasing or decreasing function of time, m is the slope, x is independent variable and b is the constant.

To examine the relationship between altitude and rainfall, bivariate correlation and linear regression analyses are used. For each 4km×4km grid of rainfall, altitude data is generated from Digital Elevation Mode (DEM). The DEM is extracted from Shuttle Radar Topography Mission (SRTM) which accesses elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth.

The correlation between altitude and rainfall in the Region and across agroecological zones is mapped and analyzed. Rainfall surface maps are generated using simple kriging interpolation technique with the help of ArcGIS 10.7. Simple kriging interpolation technique was preferred over the other interpolation techniques as it takes into account the spatial correlation pattern with the least interpolation error (Beck et al., 2005). Using the dense network of grids, surface maps are generated for annual and seasonal rainfalls at agroecolological zone level to identify local patterns. Moreover, maps showing annual and seasonal rainfall trends, PCI, SRA and CV are generated to display their spatial patterns using simple kriging interpolation technique. To compare standardized rainfall anomalies with the occurrence of El Niño and La Niña episodes, the El Niño and La Niña episodes for the country are obtained from Solomon et al. (2019).

3. RESULTS AND DISCUSSION

3.1 Monthly rainfall

The monthly rainfall distribution shows August and May are the wettest months, with similar amounts of rainfall. May is a dry month in most parts of the country, but one of the rainiest here as the eastern and southern parts of the Region receives its main rain during the *Belg* season (Fig. 3). December and January are the driest months, with similar amounts of rainfall. In the Weyna Dega zone, July and August are the wettest months, while in the Dega zone the wettest months are September and October. In the Kolla zone, the wettest months are April and May. Hence, there is difference in the intra-annual distribution of rainfall across the three agroecological zones.

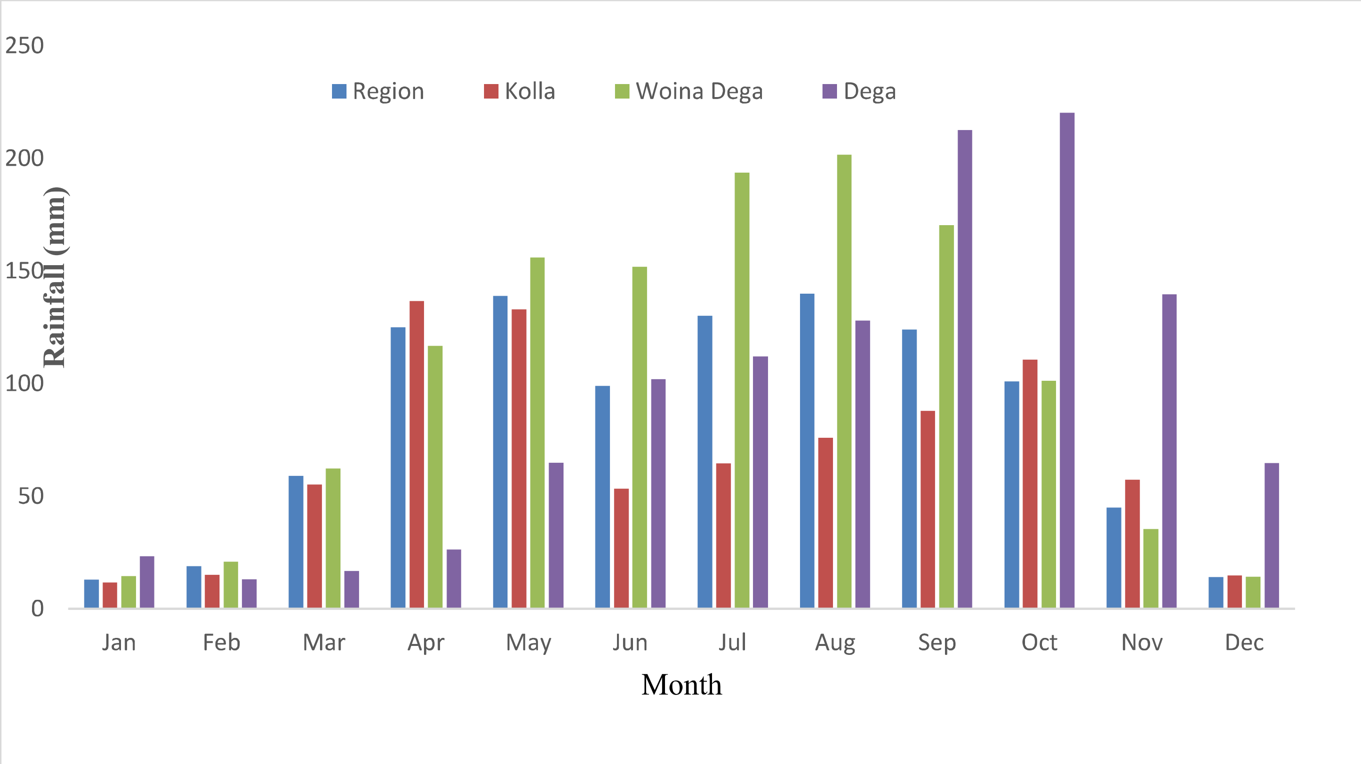


Figure 3. Monthly rainfall distribution in Oromia Region, Ethiopia

3.2. Annual rainfall

Mean annual rainfall of over Oromia Region is 1009 mm. It varies from 816 mm in the *Kolla* agroecological zone to 1240 mm in the *Weyna-Dega* agroecological zone (Table 9). About 60% of the Region receives < 1000 mm. The majority of the *Kolla* agroecological zone (79%) receives < 1000 mm. About 31% of the *Weyna-Dega* agroecological zone receives > 1501mm. In the *Dega* agroecological zone, close to 49% of the area receives 1000-1500 mm (Table 1 and Fig. 4).

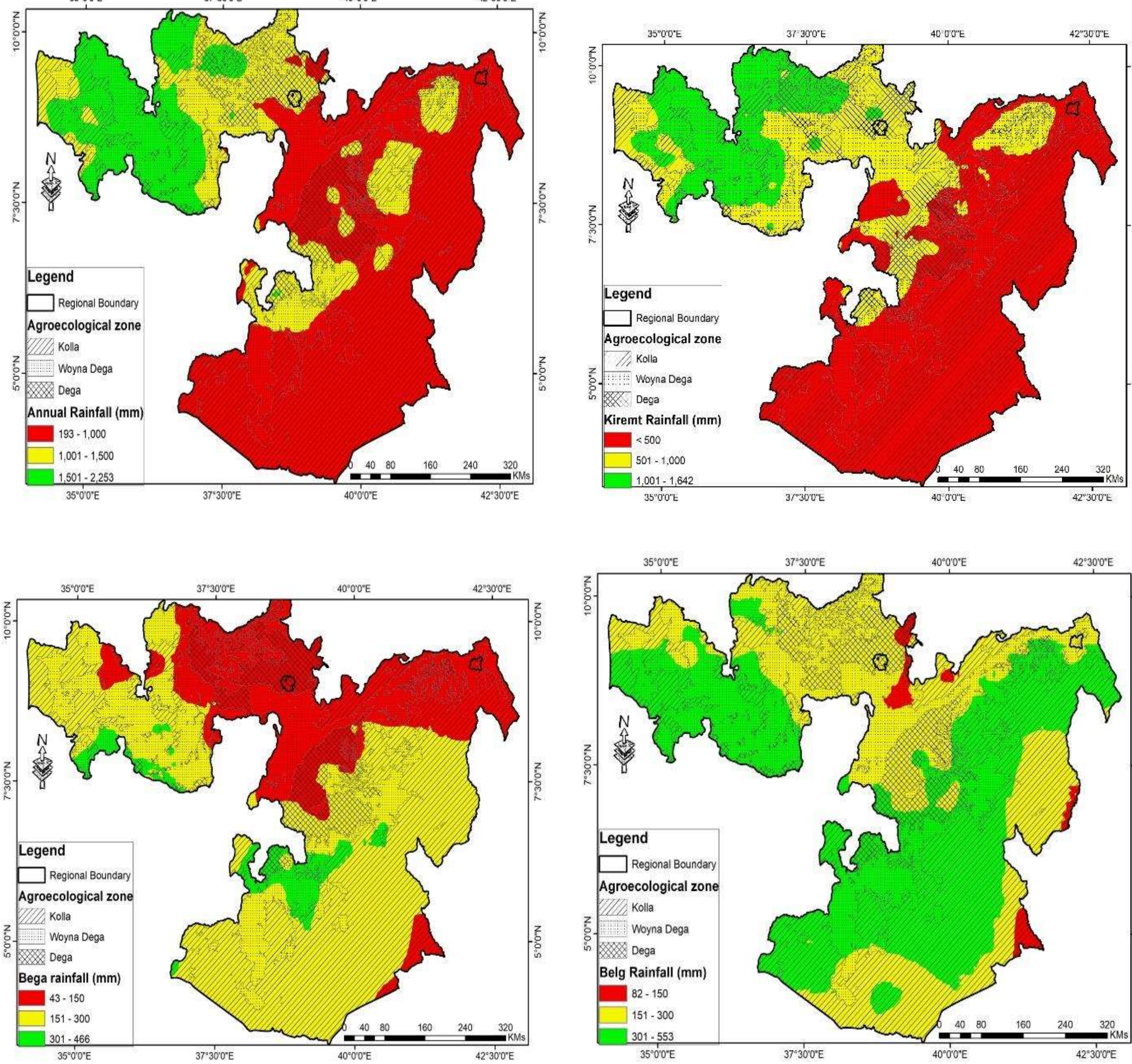


Figure 4. Spatial distribution of annual and seasonal rainfall in Oromia Region, Ethiopia

Annual rainfall in the Region shows less variation in large part of the area (74%). Rainfall shows less variation in more than 90% of their respective areas in the *Weyna-Dega* and *Dega* agroecological zones. Rainfall shows less variation in 54% of the area in the *Kolla* agroecological zone (Table 2 and Fig. 6).

Table 1. Annual and seasonal rainfall distribution by agroecological zones in Oromia Region (% areas), Ethiopia

Seasonal rainfall	Agroecological zone			Oromia Region
	Kolla	*Weyina-Dega*	*Dega*	
Kiremt season				
< 500 mm	79	39	43	60
500-1000 mm	13	29	49	24
> 1000 mm	8	31	8	16
Belg season				
< 150 mm	3	2	4	2
150-300 mm	39	42	69	44
> 300 mm	58	56	27	54
Bega season				
< 150 mm	18	43	67	33
150-300 mm	79	47	28	61
> 300 mm	3	10	5	6
Annual				
< 1000mm	79	39	43	60
1000-1500 mm	13	29	49	24
> 1500 mm	8	31	8	16

The PCI shows that rainfall in Oromia Region is generally characterized by moderate to high monthly concentration. Only the *Dega* agroecological zone showed a non-significant trend in PCI, towards greater rainfall concentration (Table 6).

Table 2. Distribution of annual rainfall variability by agroecological zones in Oromia Region, Ethiopia

Agroecological zone	CV class (based on NMA 1996)							
	CV < 20%		20% <= CV<= 30%		CV>=30%		Total	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Kolla	98305	54.4	68832	38.1	13652	7.6	180789	100
Weyna-Dega	119648	92.1	10247	7.9	0	0.0	129895	100
Dega	44721	98.9	489	1.1	0	0.0	45210	100
Region	262674	73.8	79567	22.4	13652	3.8	355893	100

Intra-annual variability of rainfall in the Region shows high concentration in large part of the area (71%). Moderate intra-annual variability of rainfall is observed in 55% and 42% of areas in the *Dega* and *Weyna-Dega* agroecological zones, respectively. Large part of the area in the *Kolla* agroecological zone (87%) shows moderate concentration (Table 3 and Fig. 6).

Table 3. Distribution of intra-annual rainfall variability by agroecological zones in Oromia Region, Ethiopia

Agroecological zones	PCI classes (based on De Luis et al. 2000) 10% < PCI < 15% (Moderate concentration)		PCI > 15% (High concentration)		Total	
	SqKm	%	SqKm	%	SqKm	%
Kolla	23036	12.7	157990	87.3	181025	100
Weyna-Dega	54621	42.0	75381	58.0	130001	100
Dega	24903	55.1	20320	44.9	45223	100
Region	102559	28.8	253691	71.2	356249	100

The year 1997 was the wettest year for *Bega* rainfall. The year 1987 was the wettest year for *Belg* rainfall and the driest year for *Kiremt* rainfall. Similarly, the year 1984 was the driest year for annual and *Bega* rainfalls. Unexpectedly, the year 1984 which is the worst drought year in the country including the Oromia Region is the wettest year for *Kiremt* rainfall in the *Kolla* agroecological zone (Table 4).

Table 4. The driest and wettest years and seasons in Oromia Region, Ethiopia

Parameter	Wettest				Driest year			
	Annual	*Kiremt*	*Belg*	*Bega*	Annual	*Kiremt*	*Belg*	*Bega*
Region	1997	2007	1987	1997	1984	1987	1984	1984
Kolla	1997	1984	1987	1997	1984	1987	2011	1984
Weyna-Dega	2012	2012	1996	1997	1984	1987	1995	1984
Dega	2006	2007	1987	1997	1984	1987	2009	1984

3.2.1. Annual rainfall and altitude

Annual rainfall increases with increase in altitude up to 2300m asl, which then shows declining pattern. The correlation between altitude and annual rainfall for the Region as a whole is positive and statistically significant at p=0.01 level (Table 5 and Fig. 5). An increase in altitude by 1m increases rainfall by 0.3 times. Similarly, correlation between altitude and rainfall across agroecological zones was computed. Results reveal that altitude and rainfall have statistically significant positive correlations at p=0.01 level in the *Kolla and Weyna-Dega* agroecological zones. An increase in altitude by 1m increases rainfall by 0.221 and 0.013 times in the *Kolla and Weyna-Dega* agroecological zones, respectively. In the *Dega* agroecological zone, altitude and rainfall have statistically significant negative correlation at p=0.01 level. An increase in altitude by 1m decreases rainfall by 0.052 times. Large part of the *Dega* agroecological zone is found in the Arsi and Bale areas which are located in the eastern part of the Region. These areas are basically under the influence of the easterly and southeasterly winds which produce *Belg* rains. Conversely, the moist westerly winds which carry large moisture during *Kiremt* season which extends from West Africa through Ethiopia towards India are less efficient in the area because of the leeward effect of the western highlands.

Table 5. Correlation between annual rainfall and altitude in Oromia Region, Ethiopia

Agroecological zone	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	T	Sig.
Kolla	0.593	0.011	0.471	54.544	0.000
Weyna-Dega	0.215	0.022	0.115	9.969	0.000
Dega	-0.211	0.018	-0.227	-11.938	0.000
Region	0.300	0.004	0.428	67.676	0.000

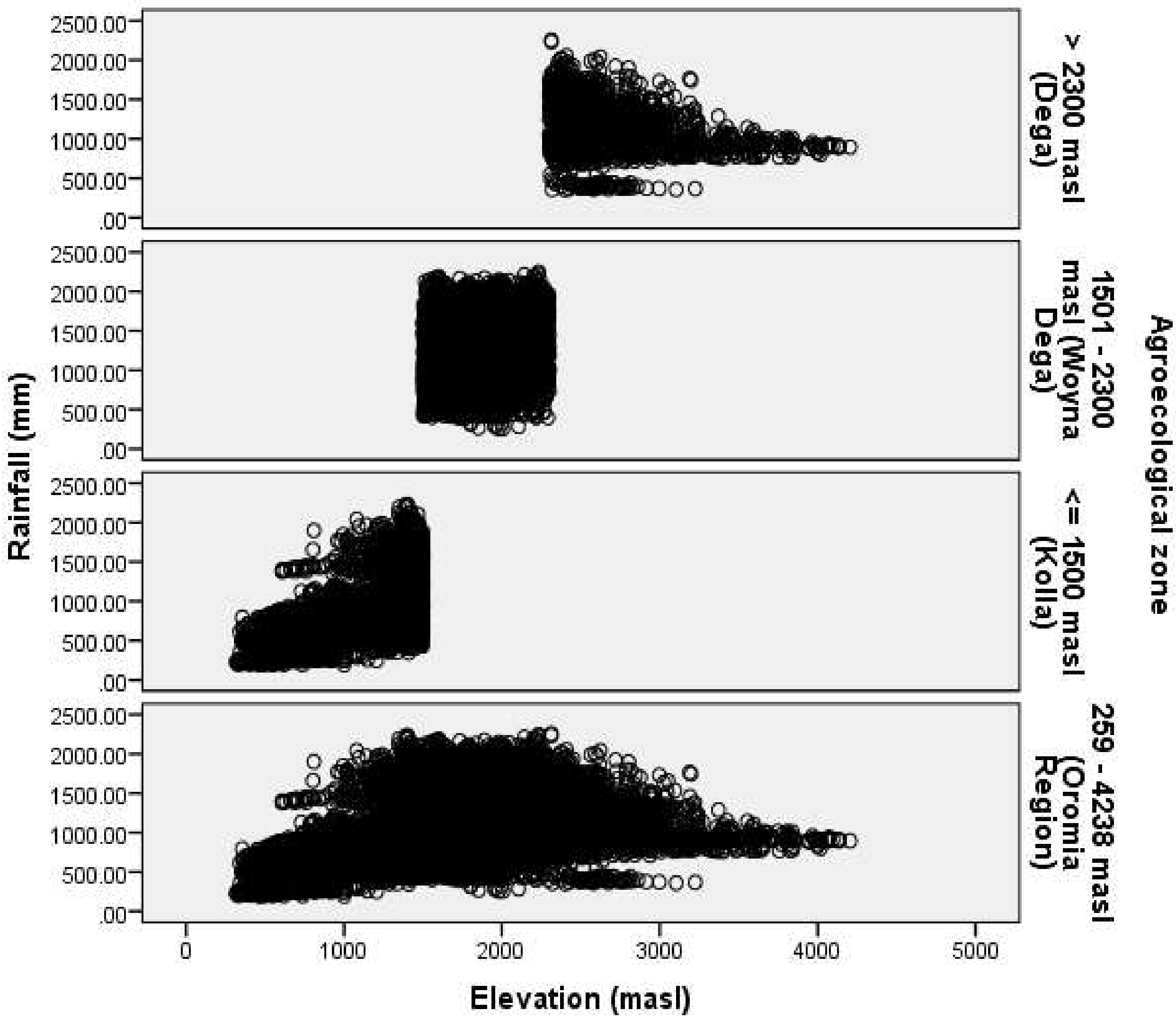


Figure 5. Correlation between annual rainfall and altitude in Oromia Region, Ethiopia

3.3. Seasonal rainfall

Over the Region, the mean *Kiremt* rainfall is 493 mm. At grid cell (4kmx4km) level, the lowest amount of *Kiremt* rainfall is recorded in the *Kolla* agroecological zone (10 mm); this amount is equivalent to the mean monthly rainfall of the driest month. The highest amount of *Kiremt* rainfall on the other hand is recorded in the *Weyna-Dega* agroecological zone (> 1600 mm). The mean *Belg* rainfall over Oromia Region varies from 279 mm (in the *Dega* agroecological zone) to 335 mm (in the *Weyna-Dega* agroecological zone) with overall mean of 323 mm. The mean *Bega* rainfall over Oromia Region is 193 mm, varying from 144 mm (in the *Dega* agroecological zone) to 210 mm (in the *Kolla* agroecological zone) (Table 1 and Fig. 4).

The *Kiremt* rainfall contributes the largest to the annual rainfall, i.e., 49% to 62% except for the *Kolla* agroecological zone where it contributes 34% of annual rainfall. In this agroecological zone, the contribution from *Belg* rainfall is large (40%). Large proportion of *Bega* rainfall is observed in *Kolla* agroecological zone (26%). The highest monthly rainfall, which is also a measure of rainfall concentration shows that it accounts for about 23% in the *Dega* and 31% in the *Kolla* agroecological zones (Table 6).

Table 6. Average contribution of the three seasons, Highest Monthly Rainfall (HMR) contribution, precipitation concentration index and trends of precipitation concentration index in Oromia Region, Ethiopia

Parameter	PCI (%)	Trend of PCI	HMR (%)	*Kiremt*	*Belg*	*Bega*
Region	11	-0.2	26	49	32	19
Kolla	11	-0.3	31	34	40	26
Weyna-Dega	12	-0.1	24	58	27	15
Dega	13	0.2	23	62	25	13

Standardized rainfall anomalies for annual and seasonal time series are calculated for each of the three agroecological zones and the Region. Annual and seasonal rainfall exhibit similar year-to-year fluctuations. The percentage of positive standardized rainfall anomalies is high (57%) in the decade 2010-2016 and low (35%) in the decade 2000-2009 (Table 7). Standardized rainfall anomalies are examined in relation to the occurrence of moderate to high El Niño and La Niña episodes. Standardized rainfall anomalies were negative in the different El Niño periods since the last four decades. For example, in all the moderate to very strong El Niño periods (1983/84, 1986/87, 1987/88, 1991/92, 1994/95, 1997/98, 2002/03, 2009/10 and 2015/16) negative rainfall anomalies are observed in the Region, indicating the association between annual rainfall of the Region and El Niño events. On the other hand, the major La Niña years are 1988/89, 1995/96, 1998/99, 1999/00, 2007/08, 2010/11 and 2011/12. However, the association between positive standardized rainfall anomalies and the different La Niña events is less clear. This shows that the association between positive standardized rainfall anomalies and La Niña periods is not symmetric; overlapping of wet years with La Niña events is not observed.

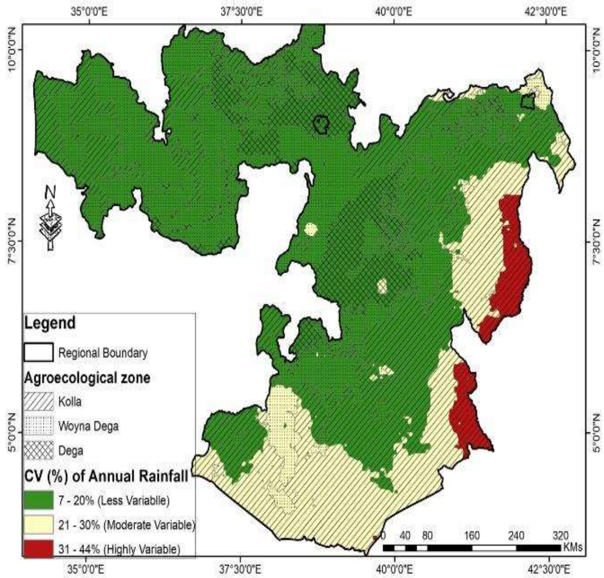
Table 7. Percentage of positive SRA and trends in Oromia Region, Ethiopia

Parameter	Percentage of positive SRA					Trend
	1980-1989	1990-1999	2000-2009	2010-2016	1983-2016	
Region	57	30	40	57	44	0.3
Kolla	57	30	20	57	38	0.2
Weyna-Dega	57	50	40	71	56	0.3
Dega	43	50	40	44	44	0.1
Average	54	40	35	57	46	

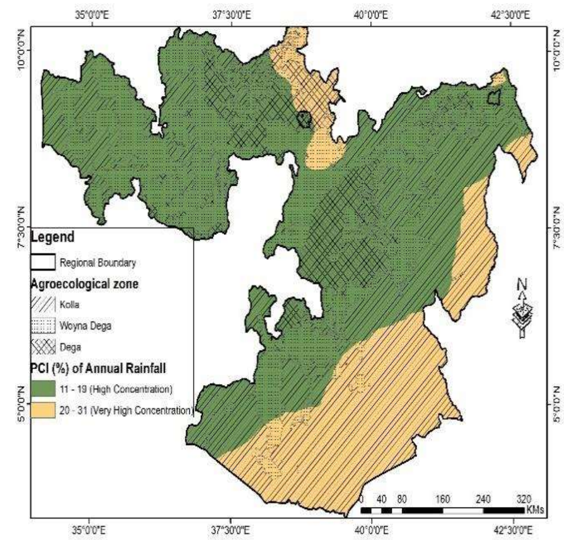
As indicated by the values of SRAs (Table 8 and Fig. 6), all parts of the *Dega* agroecological zone are drought free. This is followed by the *Weyna-Dega* agroecological zone where 97% of the area is drought free. About 38% of the *Kolla* agroecological zone is experiences different drought categories. About 79% and 17% of the Region are under moderate and severe drought vulnerability category.

Table 8. Distribution of SRA by agroecological zones in Oromia Region, Ethiopia

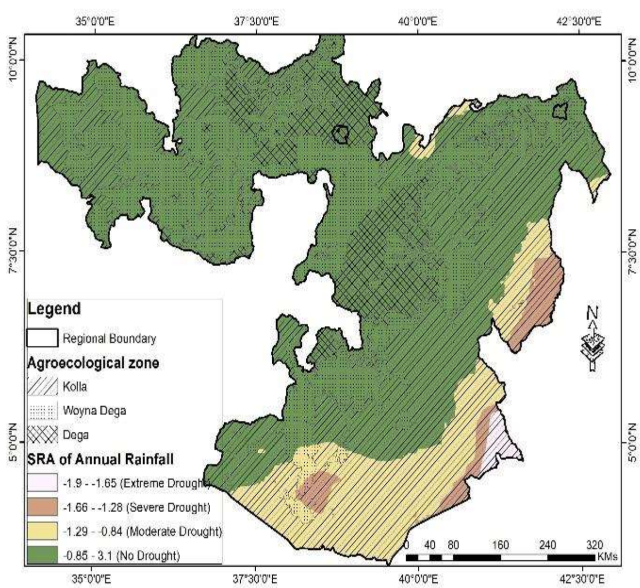
SRA values based on Agnew and Chappel (1999)										
Agroecological zones	SRA < -1.65 (Extreme Drought)		-1.28 < SRA <= - 1.65 (Severe Drought)		-0.84 < SRA <= - 1.28 (Moderate Drought)		SRA >= 0.84 (No Drought)		Total	
	SqKm	%	SqKm	%	SqKm	%	SqKm	%	SqKm	%
Kolla	3060.5	1.7	11997	6.6	54305	30.0	111663.5	61.7	181025	100
Weyna-Dega	0	0.0	423	0.3	3255	2.5	126323.8	97.2	130001	100
Dega	0	0.0	0	0.0	3	0.0	45220.0	100.0	45223	100
Region	3060.5	4.2	12419	17.0	57562	78.8	0.0	0.0	73042	100



a)



b)



c)

Figure 6. Spatial distribution of PCI (a), CV (b) and SRA (c) in Oromia Region, Ethiopia

3.4. Trends in monthly, seasonal and annual rainfall

April, October and November rainfall show statistically significant increasing trends at p=0.01 level in the *Kolla* agroecological zone. In *Weyna-Dega* agroecological zone, November and February rainfall shows statistically significant increasing trends at p=0.01 and p=0.05 levels, respectively. November also shows statistically significant increasing trend at p=0.01 in the *Dega* agroecological zone. Over Oromia Region as a whole, April and November show statistically significant increasing trends at p=0.01 level. In addition, September shows statistically significant increasing trend at p=0.05 level. In general, decreasing trends in the monthly rainfall are mostly found in the *Kolla* (50%) and some parts of the *Weyna-Dega* agro ecological zones (25%).

Table 9 presents variability in seasonal rainfall by agroecological zones. It is shown that inter-annual rainfall variability is generally low in the Region. *Kiremt* rainfall shows relatively high inter-annual variability in the *Kolla* agroecological zone (11%). The lowest and highest *Belg* rainfall CV is observed in *Weyna-Dega* (5%) and *Kolla* agroecological zones (23%), respectively. *Bega* rainfall shows high inter-annual variability in all agroecological zones (>29%).

Table 9. Annual and seasonal rainfall (mm), coefficient of variation and trends in Oromia Region, Ethiopia

Parameter	Annual			*Kiremt*			*Belg*			*Bega*		
	Amount (mm)	CV	LT	Amount (mm)	CV	LT	Amount (mm)	CV	LT	Amount (mm)	CV	LT
Region	1009	8	23	493	8	13*	323	20	-6	193	29	17
Kolla	816	12	21	282	11	42	325	23	-6	210	35	25*
Weyna-Dega	1240	8	30	718	7	20**	335	5	-	187	33	10
Dega	1124	8	11	701	9	20**	279	23	-14	144	39	1

* = Significant at 0.1 level; ** = Significant at 0.05 level; LT = linear trend (mm /10yr)

Annual rainfall shows statistically non-significant increasing change. *Kiremt* rainfall shows statistically significant increasing trends in *Weyna-Dega* and *Dega* agroecological zones and the Region as a whole at p = 0.05 level. *Belg* rainfall shows statistically non-significant decreasing trends except for *Weyna-Dega* agroecological zone where there is no clear trend. *Bega* rainfall shows statistically significant increasing trend in the *Kolla* agroecological zone at p=0.1 level (Table 9). We further investigated the spatial pattern of rainfall variability and trends and its area coverage by agroecological zones (Table 10 and Fig. 7).

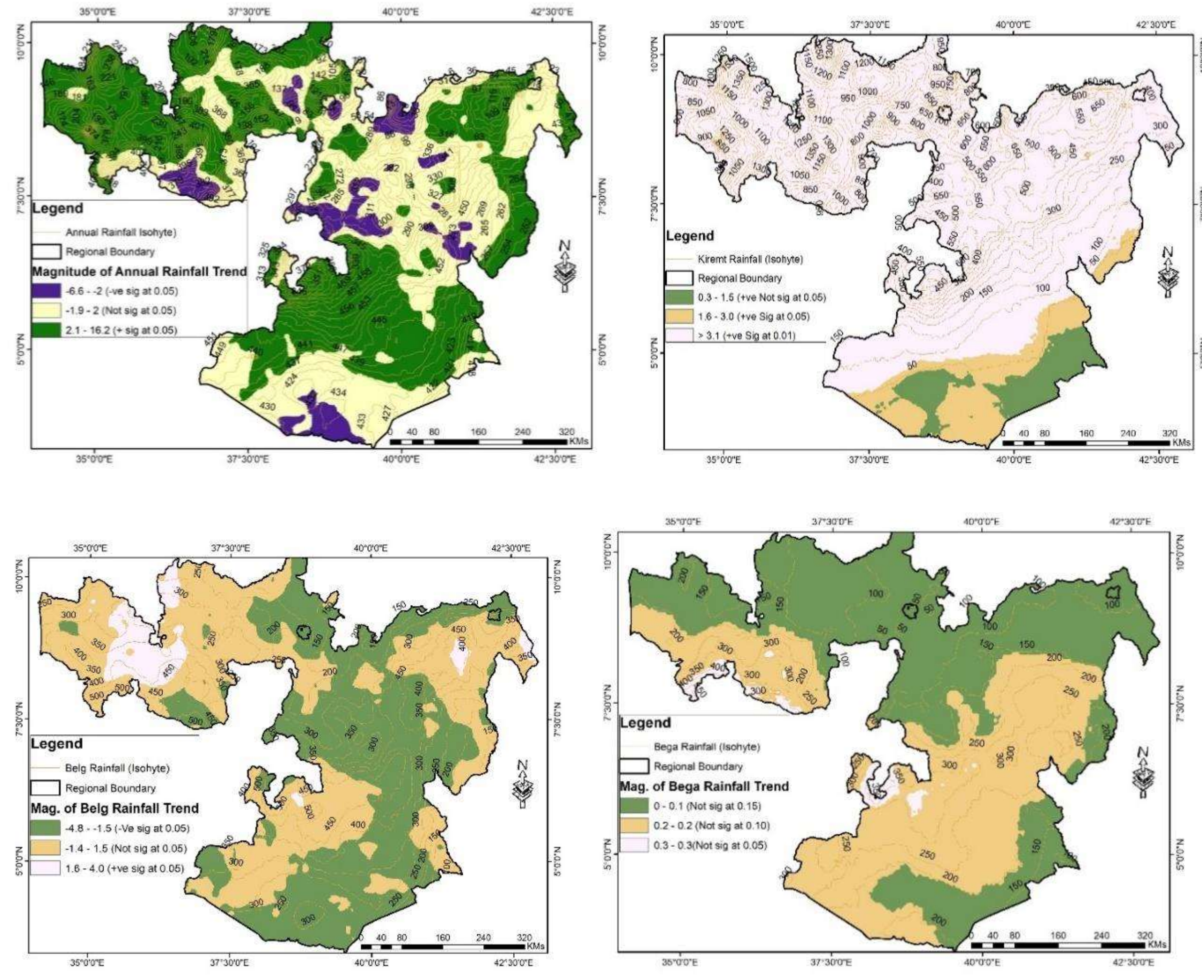


Figure 7. Spatial distribution of annual and seasonal rainfall trends in Oromia Region, Ethiopia

Spatially disaggregated, trend analysis for annual rainfall revealed that half of Oromia Region showed a significant increasing trend at p=0.05 level. Analysis of trends by agroecological zones indicated that 50% and 58% of the *Kolla and Weyna-Dega* agroecological zones showed significant increasing trend at p=0.05 level. About 7% and 6% of the *Kolla and Weyna-Dega* agroecological zones revealed significant decreasing trend at p=0.05 level. About 33% of the *Dega* agroecological zone showed a significant increasing trend at p=0.05 level (Table 10 and Fig. 8).

Table 10. Distribution of annual rainfall trends by agroecological zones in Oromia Region, Ethiopia

	Annual rainfall trend and magnitude of significant level							
	-6.6 < B < - 2 (-ve sig at p= 0.05)		-1.9 < B < 2 (Not sig at p= 0.05)		B >= 2 (+ve sig at p= 0.05)		Total	
Agroecological zones	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Kolla	12357	6.8	78988	43.7	89607	49.5	180952	100
Weyna-Dega	7197.25	5.5	47219	36.3	75530	58.1	129946	100
Dega	7660.5	16.9	22501	49.7	15070	33.3	45232	100
Region	27214.75	7.6	148708	41.8	180207	50.6	356130	100

Trends in rainfall anomaly generally indicate a tendency towards wetter conditions. Unlike other parts of the country where the 1990s are the wettest compared with the preceeding and the succeeding decades, the 1980s are dry in the Region. Interestingly, the number of El Niño episodes in this decade is greater than La Niña episodes. This shows that the impacts of El Niño on rainfall variability are location specific. Despite the proportion of positive SRAs are greater than 50% of total observations except for *Weyna-Dega* agroecological zone, non-significant increasing trends are observed in the SRA in the Region as a whole and the three agroecological zones (Table 7).

4. CONCLUSIONS

This study describes the rainfall climatology of Oromia Region using over 30 years (1983-2016) of monthly rainfall data from 20,475 points of 4km×4km grids. Mean annual rainfall over Oromia Region is 1009 mm. It varies from 816 mm in the *Kolla* agroecological zone to 1240 mm in the *Weyna-Dega* agroecological zone. About 60% of the Region receives < 1000 mm. The mean *Kiremt* rainfall over Oromia Region is 493 mm. The mean *Belg* and *Bega* rainfalls are 323 mm and 193mm, respectively. The monthly rainfall distribution shows there is difference in the intra-annual distribution of rainfall across the three major traditional agroecological zones; i.e., *Kolla*, *Weyna-Dega* and *Dega*. The correlation between altitude and rainfall in Oromia Region as a whole and *Kolla and Weyna-Dega* zones is positive and statistically significant at p=0.01 level, but statistically significant negative correlation is observed in the *Dega* agroecological zone at p=0.01 level. Inter-annual rainfall variability is generally low, and its intra-annual variability is characterized by moderate to high concentrations. Regarding trends, annual and *Belg* rainfalls show no significant change. The *Bega* rainfall shows increasing trend in the *Kolla* agroecological zone. The *Kiremt* rainfall shows statistically significant increasing trend except in the *Kolla* agroecological zone. Trends in rainfall anomalies show a tendency towards wetter conditions. February, April, September, October and November rainfall show statistically significant increasing trends. While our study provides a useful description of the rainfall climatology of the Region, it does not provide meteorological explanations to the observed temporal and spatial patterns of rainfall. This needs to be tackled by a future research.

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