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Climate Trends, variability, and impacts of ENSO on rainfall amount in Ethiopia: A Case study in Western Amhara National Regional State

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Abstract

Agricultural production in Ethiopia is predominantly rainfed. Variation in rainfall and El Niño Southern Oscillation (ENSO) affects the agricultural production system in the country. This needs a close study ontrends, variability of rainfall, and impacts of El Niño Southern Oscillation (ENSO) on rainfall amount to suggest possible adaptation strategies. The study was in Western Amhara of Ethiopia. Monthly rainfall data were collected from fifteen meteorological stations of Western Amhara and selected El Niño and La Niña years from National Oceanic and Atmospheric Administration (NOAA) from 1986 to 2015.Following data quality checking and inspection, the monthly rainfall data of the selected stations were arranged in Microsoft Excel Spread Sheet and analyzed using XLSTAT software. Coefficient of variation and the Mann Kendall non-parametric statistical test was applied to study trends and variability of rainfall and temperature in Western Amhara.Thelong-term recorded annual rainfall data indicated that there was an increasing trend from 1986 to 2015, but not significant. The rainfall variability was less (CV = 8.6%); also, the mean monthly rainfall of Western Amhara decreased during El Niño years and increased during La Niña years especially in the rainy season (JJAS) over30 years.

1. Background And Justification Of The Study

Rainfall is the basic meteorological phenomenon that has the greatest impact on human activities and the most important environmental factor limiting the development of the semiarid regions(Kipkorir 2002). Understanding rainfall variability is essential to optimally manage the scarce water resources that are under continuous stress due to the increasing water demands, increase in population, and economic development(Herath and Ratnayake 2004). Climate change is one of the critical global problems since the beginning of the industrial revolution(Shakhashiri and Bell 2014, Zandalinas et al. 2021) which has been attributed to the increasing trends of carbon dioxide and other greenhouse gases (GHGs) in the atmosphere.

The seasonal climate variability of Ethiopia, particularly rainfall, is influenced by weather systems of various scales; from mesoscales to the large scale, mainly El Nino-Southern Oscillation (ENSO) related phenomena(NMSA 1996).Based on the previous studies likeZeleke and Raes (1999);Merasha (1999);Tesfaye and Walker (2004),it has been also noted that the rainfall is highly variable in amount, and distribution and becomes unpredictable across regions and seasons.

El Niño Southern Oscillation (ENSO), a strong climatic driver, is active in the tropical regions with significant impacts on the climate and weather systems (Brönnimann 2007, Sarachik and Cane 2010, Zhang et al. 2016). This implies, it results from the ocean–atmosphere interactions occurred in inter-annual timescales. The ENSO pattern in the tropical Pacific can be in one of three states: El Niño, Neutral, or La Niña. El Niño (the warm phase) and La Niña (the cool phase) lead to significant differences from the average ocean temperatures, winds, surface pressure, and rainfall across parts of the tropical Pacific. Neutral indicates that conditions are near their long-term average(NOA 2021).

The trend of rainfall in Ethiopia is not uniform throughout the country. Recent studies likeHill and Porter (2017); and Asfaw et al. (2020)reported a decreasing trend in seasonal and annual rainfall. On the contrary, other studies like Gemeda (2019);Hundera et al. (2019);Tesfamariam et al. (2019); and Wedajo et al. (2019)have reported increasing trend in annual rainfall. Other studies like Cheung et al. (2008), and Omondi et al. (2014),Eshetu et al. (2018), Gebrechorkos et al. (2019),Degefie et al. (2019)found both an increasing and decreasing rainfall trend in different areas. This implies, the climate of a region or specific location depends on many factors including the amount of sunlight it receives, its height above sea-level, the shape of the land, how close to oceans and the equator as stated by the IPCC report Griggs and Noguer (2002). Thus, site specific study is vital for site specific solution. The general objective of this study is to analysesthe climate trends and variabilityandthe impact of ENSO on rainfall amount in Ethiopia in the case of Western Amhara.

2. Materials And Methods

2.1 Description of the study area

Western Amhara located in Amhara region of Ethiopia and it has five administrative zones:West Gojjam, East Gojjam, South Gondar, North Gondar and Awi. Each Zone is represented by three meteorological stations (Table 1).

Table 1
Description of the study meteorological stations

Zone	Station	Latitude(°)	Longitude(°)	Altitude(m)
East Gojjam	Debre-Markos	10.33	37.39	2446
	Motta	11.07	37.89	2417
	Debrework	10.65	38.16	2508
West Gojjam	Adet	11.28	37.49	2179
	BahirDar	11.60	37.36	1800
	Dembecha	10.74	37.61	2823
Awi	Dangila	11.43	36.85	2116
	Enjibara	11.00	36.19	2568
	Kidamaja	11.00	36.68	1928
S.Gondar	DebreTabor	11.87	38.00	2612
	NefasMewcha	11.81	38.36	3000
	Yifag	12.10	32.60	2020
N.Gondar	Debark	13.14	37.90	2836
	Gondar	12.52	37.43	1973
	Maksegnit	12.39	37.56	1912

2.2. Research design

2.2.1. Data type and source

The Long-term records of monthly rainfall data from 1986–2015 was used depending on data availability and by considering the most significant El Niño and La Niña years. It was collected from the National Meteorological Agency (NMA) of Ethiopia and/or from the archive of its branch offices found in Bahir Dar. The data was re-arranged as; El Niño; Neutral and La Niña years (NOAA) mean monthly rainfall data to assess the impact ofENSO.

ElNiñoyears are: 1987, 1991, 1993, 1994,1997,2002,2004,2006,2009&2015; Neutral years:1986,1989,1990,1992,1995,1996,2001,2003,2005,2008,2012,2013&2014 and LA Niña years: 1988,1998, 1999, 2000, 2007, 2010&2011) over each station in western Amhara.

To make ready for analysis, the row data series of meteorological stations should be stack. To do this, the row (Monthly rainfall) data series was entered to MS excel 2003, following day of a year entry format

(along columns observation year and in rows months and data observation), and stack using XLSTAT software. To stack successfully, the missed data must be filled.

Missing data is one of the main problems, which are often encountered in meteorological analysis. This may be due to the absence of observer, short interruptions in observations due to a large number of causes, the breakage or malfunction of instruments during a certain time period. When data are missing, it may be appropriate to complete these data sets from observations made in another nearby and reliable stations. So, an attempt was made in estimating missing data for study station with no complete rainfall data series. Regarding with missed data series, the most problematic areas were: Dangla (7 years monthly rainfall), and Debark (9 years monthly rainfall) and NefasMewucha(8 years monthly data) missing data series during observation year (1986–2015). The missed data have been estimated by using average method. The main reason to choose the first order/average method to fill the missing monthly rainfall data is to get more accurate analysis.

2.2.2 Data analysis techniques

The coefficient of variation (CV) was computed as the ratio of standard deviation (SD) to the mean in a given time-series as used by Ademe et al. (2020) to quantify the extent of variability, which is expressed as a percentage. The CV values are classified as follows: if CV < 20% it is low variability, if 20%< CV < 30%, it is moderately variability, if CV > 30%, it is strong variability(Hare 2003).

The non-parametric Mann-Kendall test statistics ‘S’ developed by Mann (1945)was adopted to analyze the climate trend and calculated using the following equation.

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

Where S is the Mann-Kendall's test statistics: x_i and x_j are sequential data values for the time series data of length n.

$$sgn\left(x_j - x_k\right) = \begin{cases} +1, if\left(x_j - x_k\right) > 0 \\ 0, if\left(x_j - x_k\right) = 0 \\ -1, if\left(x_j - x_k\right) < 0 \end{cases}$$

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, ifS > 0 \\ 0, ifS = 0 \\ \frac{S+1}{\sqrt{var(S)}}, ifS < 0 \end{cases}$$

A positive Zs value indicates an increasing trend, while a negative Zs value shows a decreasing trend as used by Shi et al. (2013),Deng et al. (2018),Adeyeri et al. (2019), and 0 values indicate no trend. In this

study, both the null hypothesis (H_o) and the alternative hypothesis (H_1) were used to check a trend in the time series. The H_o indicates that there is no trend (random variables) in thetime seriess, while the H_1 states that, there is a possibility of bi-directional changes(Li et al. 2012). In this study, H_o is rejected if Zs value is > 1.96 ($\alpha = 0.05$) at 5% significant level.

3. Results And Discussion

West Gojjam Zone

The extreme maximum (ext max) and extreme minimum (ext min) annual total rainfall has been recorded 1904.1mm (Dembecha) and 914.7 mm (Adet) respectively. When we see rainfall variability of these stations, all have less variability over the past 30 years (Table 2).

Table 2
Descriptive statistics of rainfall for selected station in West Gojjam for 30 years

Station	Ext Max	Ext Min	Range	Mean	Variance	STD	CV (%)
Adet	1685.1	914.7	770.4	1227.0	37506.2	193.7	15.8
BahirDar	1711.6	1076.5	635.1	1398.6	27669.3	166.3	11.9
Dembecha	1904.1	944.7	959.4	1393.8	44748.4	211.5	15.2

The mean monthly rainfall of West Gojjamis decreased during El Niño years and increased during La Niña years as compared to the mean especially during rainy season (JJAS).It gets highest mean monthly rainfall in July during El Niño, Neutral and La Niña years (Fig. 3).

The general trend of west Gojjam zone annual average rainfall has a decreasing trend in 30 years. It has an extreme maximum and minimum annual total rainfall of 1727.1mm and 1208.9 mm respectively. This shows that, the value oscillates between 1727.1 and 1208.9 mm. It has less Rainfall Variability (CV = 9.42%) over 30 years(Table 3).

Table 3
Descriptive statistics of rainfall for West Gojjam for 30 years.

Ext Max	Ext Min	Range	STD	CV (%)
1727.1	1208.9	518.2	126.2	9.42

East Gojjam

The extreme maximum and extreme minimum annual total rainfall has been recorded 1620.7mm (Debremarkos) and 593 mm (Debre Work) respectively. When we see these stations, D/work has moderate rainfallvariability. WhereasDebremarkos and Motta have less rainfall variability over the past 30 years (Table 4).

Table 4
Descriptive statistics of rainfall for selected station in East Gojjam (1986–2015)

Station	Ext Max	Ext Min	Range	Mean	Variance	STD	CV (%)
Debremarkos	1620.7	1059.4	561.3	1332.8	18422.5	135.7	10.2
Motta	1485.6	876.8	608.8	1201.9	28319.1	168.3	14.0
Debrework	1332.3	593.0	739.3	883.7	36185.0	190.2	21.5

The general trend of East Gojjam zone annual average rainfall has been an increasing trend in 30 years (Fig. 4). It has an extreme maximum and minimum annual total rainfall of 1317.4 mm and 984.4 mm respectively. This shows that, the graph oscillates between 1317.4 and 984.4 mm. It has less rainfall variability (CV = 9.8%) over 30 years (Table 5).In most months especially in rainy season (JJAS), East Gojjam has high mean monthly rainfall duringLa Niña years and low mean monthly rainfall in El Niño years(Fig. 5).

Table 5
Descriptive statistics of rainfall in East Gojjam (1986–2015).

Ext Max	Ext Min	Range	STD	CV(%)
1317.4	984.4	333.0	111.9	9.8

Awi zone

The study shows that the extreme maximum and extreme minimum annual total rainfall recorded 2828.6 mm (Enjibara) and 1192.8 mm (Dangla) respectively. All stations have less rainfall variability over the past 30 years because all have CV < 20% (Table 6).

Table 6
Descriptive statistics of rainfall for selected stationin Awi for 30 years.

Station	Ext Max	Ext Min	Range	Mean	Variance	STD	CV
Dangila	2008.6	1192.8	815.8	1628.9	43423.4	208.4	12.8
Enjibara	2828.6	1950.6	878.0	2358.9	45283.0	212.8	9.0
Kdamaja	2693.3	1507.7	1185.6	2202.4	57545.7	239.9	10.9

The general trend of Awi zone annual average rainfall has been an increasing trend in 30 years (Fig. 6). It has an extreme maximum and minimum annual total rainfall of 2429.3 mm and 1742.2 mm respectively. This shows that, the graph oscillates between 2429.3mm and 1742.2 mm. It has less rainfall variability (CV = 8.9%) over 30 years (Table 7).

Table 7
Descriptive statistics of rainfall in Awi zone for 30 years.

Ext Max	Ext Min	Range	STD	CV(%)
2429.3	1742.2	687.0	182.8	8.9

In most months, the mean monthly rainfall during La Niña years, Neutral and El Niño years have nearly the same with long mean monthly rainfall. This indicates that ENSO condition has no significant effect on rainfall amount of Awi zone. This may be due to local factors like many forests in the area (Fig. 7).

South Gondar Zone

The extreme maximum and extreme minimum annual total rainfall has been recorded 1928.4mm (DebreTabor) and 741.6 mm (NefasMewcha) respectively. When we see these stations, all have less rainfall variability over the past 30 years (Table 8).

Table 8
Descriptive statistics of rainfall for selected station in South Gondar for 30 years.

Station	Ext Max	Ext Min	Range	Mean	Variance	STD	CV (%)
DebreTabor	1928.4	1096.7	831.7	1489.2	36560.3	191.2	12.8
NefasMewcha	1265.5	741.6	523.9	1057.6	19331.6	139.0	13.1
Yifag	1305.9	743.0	562.9	1040.2	22396.0	149.7	14.4

The general trend of South Gondar zone annual average rainfall has been an increasing trend in 30 years (Fig. 8). It has an extreme maximum and minimum annual total rainfall of 1362.1 mm and 960.2 mm respectively. This shows that, the graph oscillates between 1362.1 mm and 960.2 mm. It has less rainfall variability (CV = 9.5%) over 30 years (Table 9).

The mean monthly rainfall of South Gondar is negatively affected (decreased) during El Niño years and increased in La Niña years compared with long mean especially during rainy season (JJAS). However, in March, May and December, its mean monthly rainfall is increased in El Niño years (Fig. 9).

Table 9
Descriptive statistics of rainfall in South Gondar for 30 years.

Ext Max	Ext Min	Range	STDEV	CV (%)
1362.1	960.2	401.9	114.0	9.5

North Gondar Zone

The extreme maximum and extreme minimum annual total rainfall has been recorded 2006.7mm (Debark) and 1258.7mm(Gondar) respectively. Maksegnt has high rainfall variability (CV = 30.3%) whereas Gondar and Debark have less rainfall variability over the past 30 years (Table 10).

Table 10
Descriptive statistics of rainfall for selected station in North Gondar for 30 years.

Station	Ext Max	Ext Min	Range	Mean	Variance	STD	CV (%)
Debark	2006.7	702.4	1304.3	1128.8	75098.7	274.0	24.3
Gondar	1258.7	843.8	414.9	1074.9	11108.3	105.4	9.8
Maksegnt	1677.8	640.8	1037.0	1015.1	94596.5	307.6	30.3

The general trend of North Gondar zone annual average Rainfall has been an increasing trend in 30 years (Fig. 10). It has an extreme maximum and minimum annual total rainfall of 1349.5 mm and 786.7 mm respectively. This shows that, the graph oscillates between 1349.5 and 786.7 mm. It has less rainfall variability (CV = 15.8%) over 30 years(Table 11).

Table 11
Descriptive statistics of rainfall in North Gondar zone for 30 years.

Ext Max	Ext Min	Range	STD	CV (%)
1349.5	786.7	562.8	169.7	15.8

The mean monthly rainfall of North Gondar zone is decreased during El Niño years and near to long mean in La Niña and neutral years compared to long mean especially in rainy seasons (JJAS). However, in May and December, its mean monthly rainfall is increased in El Niño years than neutral and La Niña years. Whereas during neutral years March mean monthly rainfall is above El Niño and La Niña years (Fig. 11).

Western Amhara

The extreme maximum and extreme minimum annual total rainfall was recorded 2828.6 mm (Enjibara) and593.0 mm (DebreWork) respectively. When we see these stations, Maksegnt has more rainfall variability (CV = 30.3%) whereas Debarkhas moderately less rainfall variability (CV = 24.3%) and the rest stations have less rainfall variability over the past 30 years (Table 12).

Table 12
Descriptive statistics of rainfall for selected stationin Western Amhara (30 years).

Station	Ext Max	Ext Min	Range	Mean	Variance	STD	CV (%)
Debremarkos	1620.7	1059.4	561.3	1332.8	18422.5	135.7	10.2
Motta	1485.6	876.8	608.8	1201.9	28319.1	168.3	14.0
Debrework	1332.3	593.0	739.3	883.7	36185.0	190.2	21.5
Adet	1685.1	914.7	770.4	1227.0	37506.2	193.7	15.8
BahirDar	1711.6	1076.5	635.1	1398.6	27669.3	166.3	11.9
Dembecha	1904.1	944.7	959.4	1393.8	44748.4	211.5	15.2
Feresbet	2784.6	655.8	2128.8	1744.5	191786.7	437.9	25.1
Dangila	2008.6	1192.8	815.8	1628.9	43423.4	208.4	12.8
Enjibara	2828.6	1950.6	878.0	2358.9	45283.0	212.8	9.0
Kidamaja	2693.3	1507.7	1185.6	2202.4	57545.7	239.9	10.9
DebreTabor	1928.4	1096.7	831.7	1489.2	36560.3	191.2	12.8
NefasMewcha	1265.5	741.6	523.9	1057.6	19331.6	139.0	13.1
Yifag	1305.9	743.0	562.9	1040.2	22396.0	149.7	14.4
Debark	2006.7	702.4	1304.3	1128.8	75098.7	274.0	24.3
Gondar	1258.7	843.8	414.9	1074.9	11108.3	105.4	9.8
Maksegnt	1677.8	640.8	1037.0	1015.1	94596.5	307.6	30.3

Annual Average rainfall of Western Amhara

Table 13
Descriptive statistics of rainfall in Western Amhara for 30 years.

Ext Max	Ext Min	Range	STD	CV(%)
1539.1	1202.2	336.9	109.9	8.6

Man-Kendall test shows that the general annual rainfall trend of Awi, East Gojjam, South Gondar, North Gondar and the Western Amhara have increasing trend but not significant. The annual average rainfall of West Gojjam has a decreasing trend in 30 years (Table 14). It has an extreme maximum and minimum annual total rainfall of 1539.1 mm and 1202.2 mm respectively. This shows that, the graph oscillates between 1539.1mm and 1202.2 mm (Fig. 12).Western Amhara has less Rainfall Variability over 30 years (CV = 8.6%).The mean monthly rainfall of Western Amhara is decreased during El Niño years and

increased during La Niña yearsin rainy season (JJAS). It gets highest mean monthly rainfall inJuly during Neutral and La Niñaandalso in August duringElNiñoyears.

Table 14
Mann-Kendall annual rainfall trend analysis (1986–2015).

Zone	Z	p
Awi	1.18	0.24
East Gojjam	0.96	0.34
West Gojjam	-1.07	0.29
South Gondar	0.89	0.38
North Gondar	0.36	0.72
Western Amhara	**0.61**	**0.55**

4. Conclusion And Recommendation

In general, the overall rainfall trend in Western Amhara showed an increasing trend during the observation period (1986–2015), but not significant. The mean monthly rainfall of Western Amhara is decreased (below normal) during El Niño years and increased (above normal) during La Niña years in rainy season (JJAS). These will affect the agricultural practices in the study area.Western Amhara has less Rainfall Variability over 30 years. The highest and lowest annual rainfall was found to be 2828.6mm(Enjibara) and 593.0 mm (DebreWork) respectively. It is imperative to adjust the agriculture activity to the variability situation and design planned climate change adaptation strategiesto enhance the adaptive capacity and resilience of rain fed dependent smallholder farmers. At the same time, the concerned government and partners should address the ENSO forecast for communities to safeguard the environment and maintain their agricultural practices.

Declarations

Authors Contributions: ZerihunYohannes Amare, BelaynehBirkuGeremew, Nigatu MeliseKebede, SisaynewGetahunAmera worked on data extraction, data analysis, result interpretation and write-up. All authors have read and agreed to the published version of the manuscript

Declarations: conceived and extract the data; performed the analysis; and interpreted the data; contributed literature materials, and wrote the manuscript

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Figures

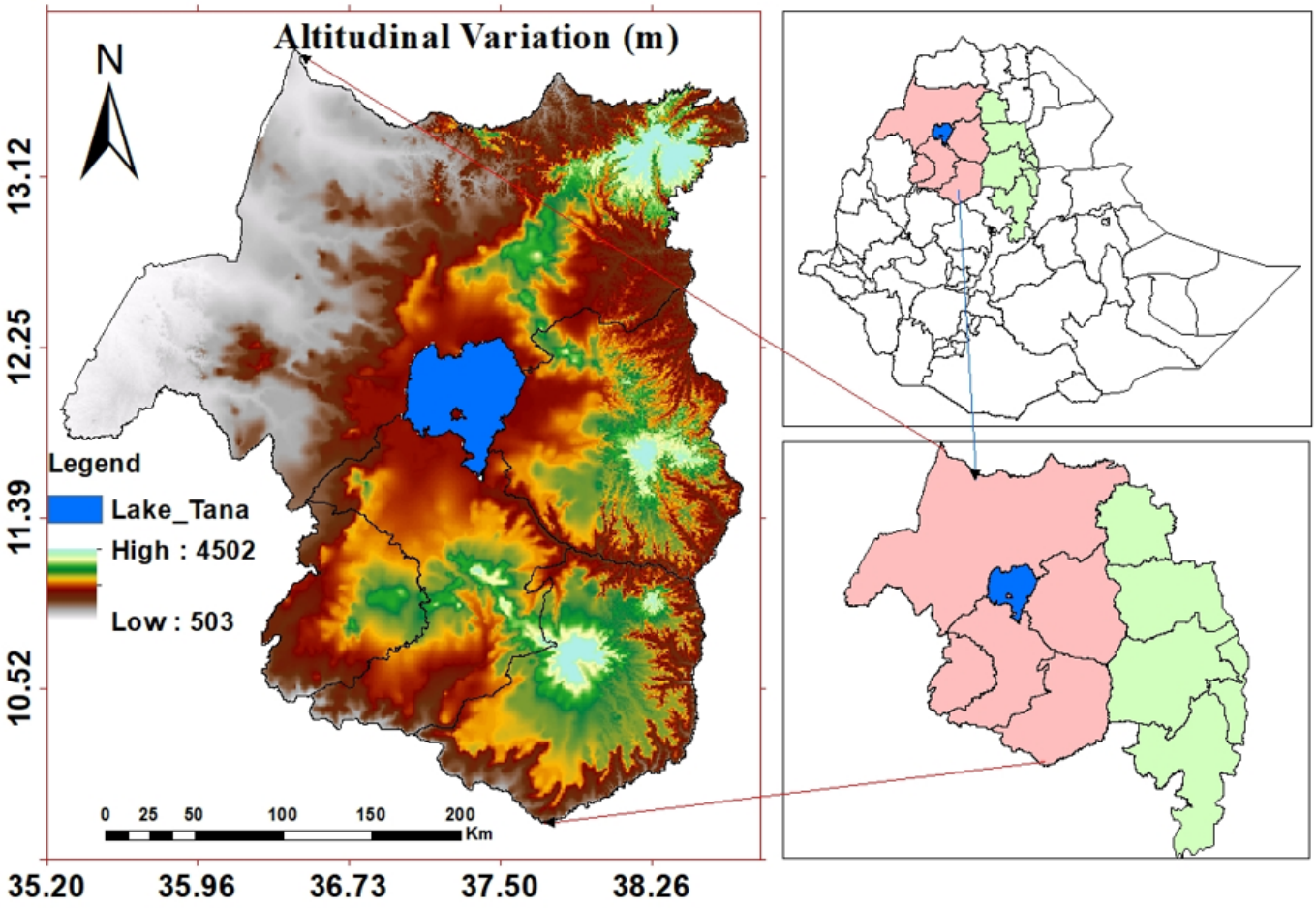


Figure 1

Location of Study area using ArcGIS 10.1

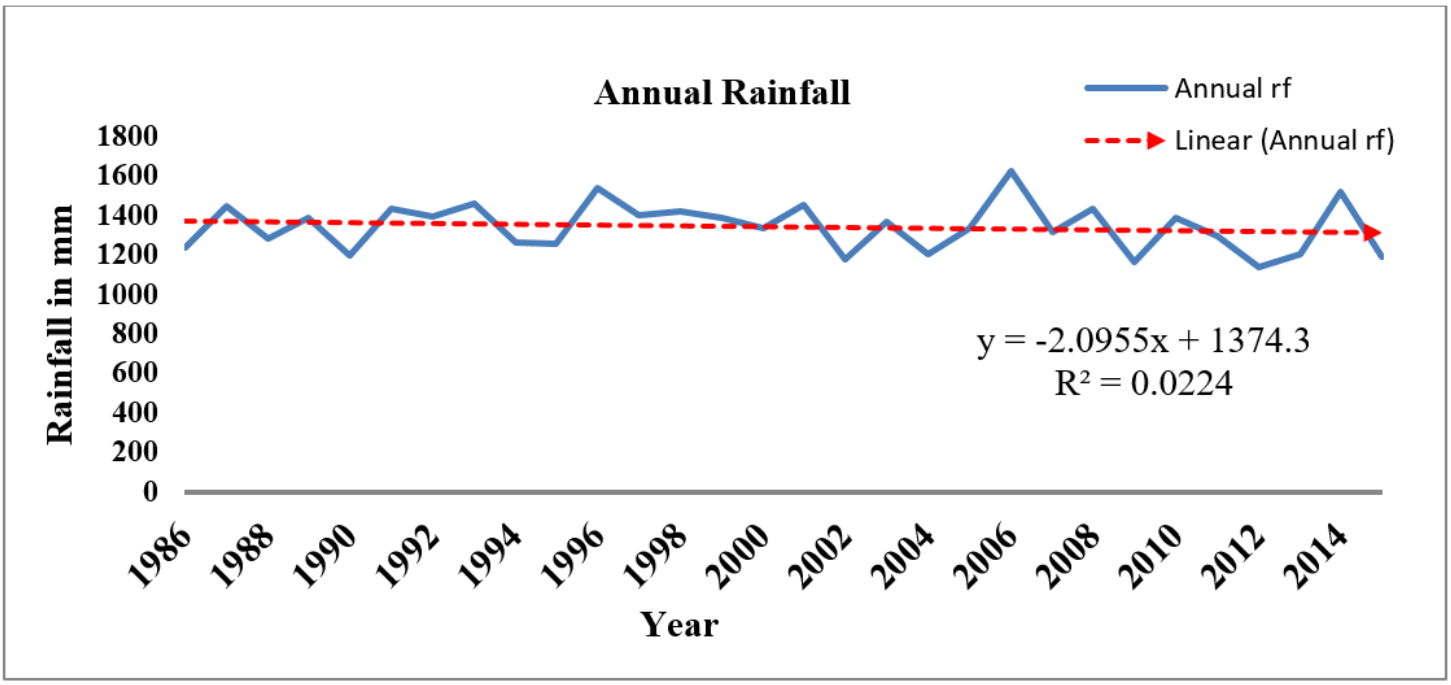


Figure 2

Trend of Annual average Rainfall of West Gojjam in mm from 1986-2015.

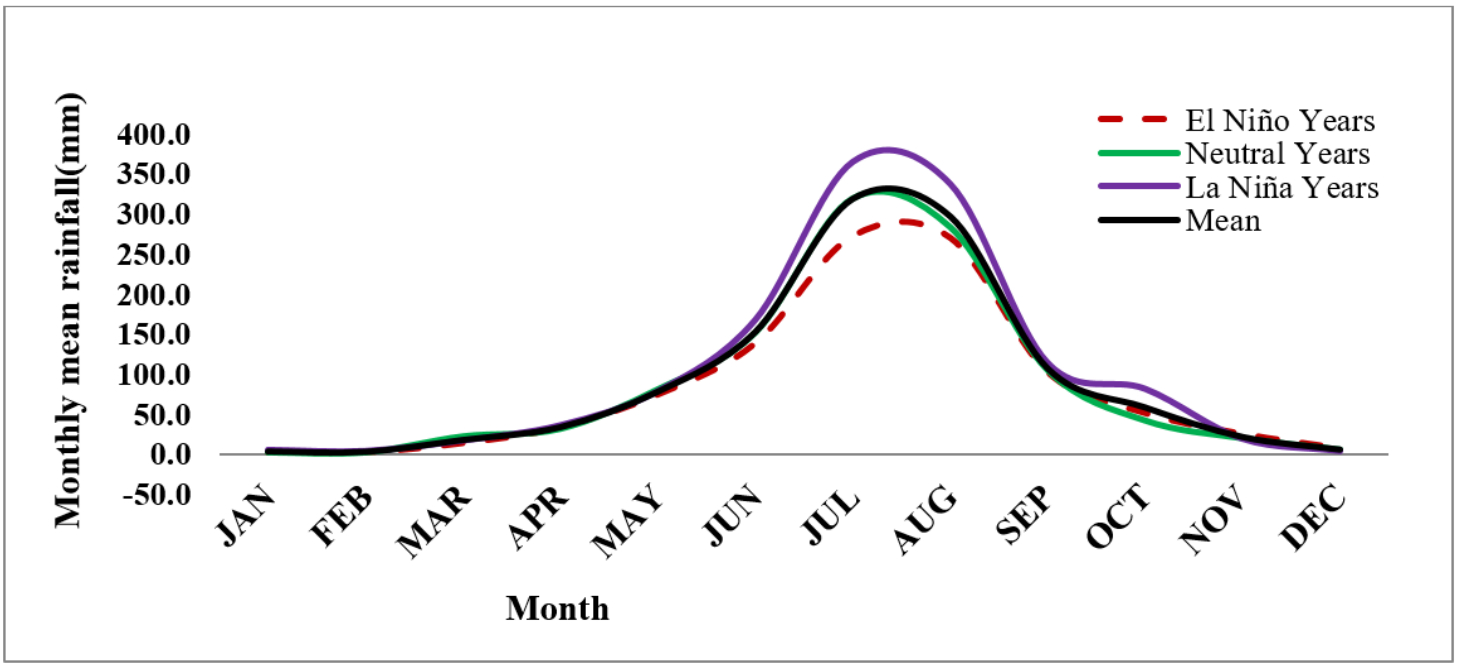


Figure 3

Mean monthly rainfall of West Gojjam in mm since 1986-2015.

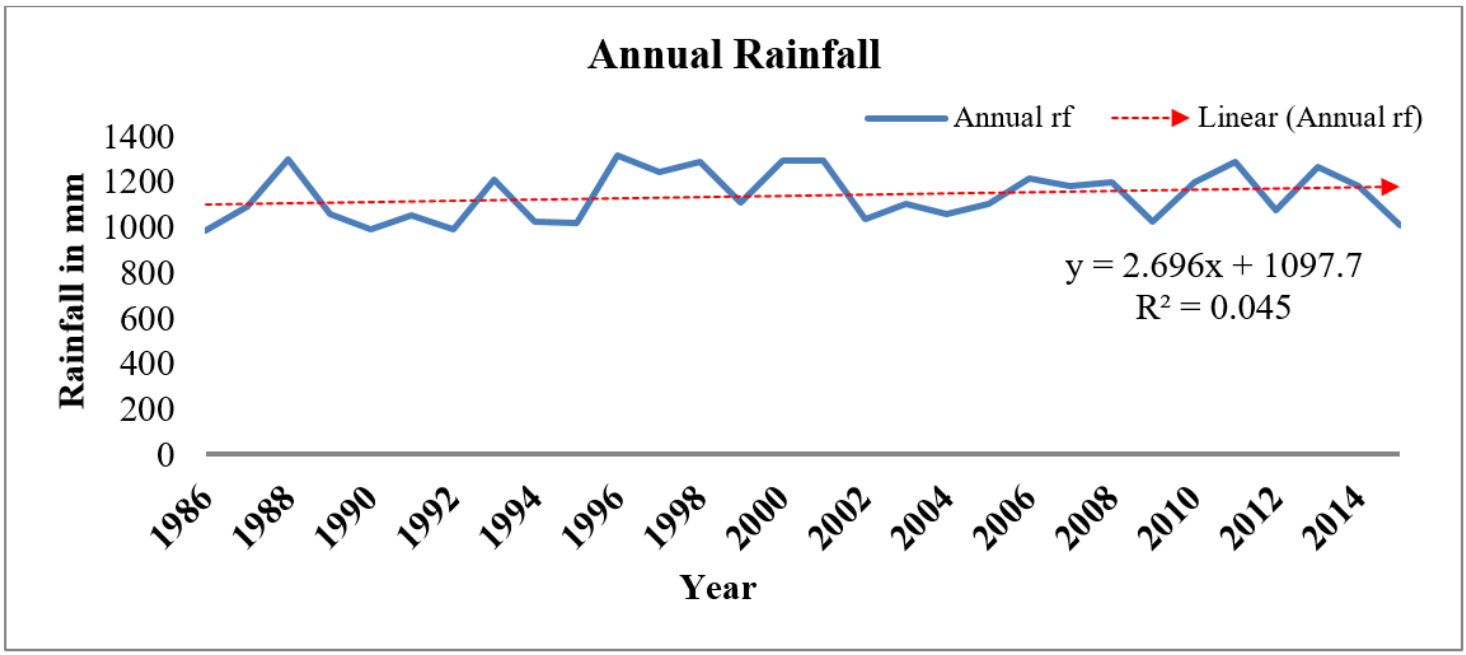


Figure 4

Annual average rainfall of East Gojjam in mm from 1986-2015.

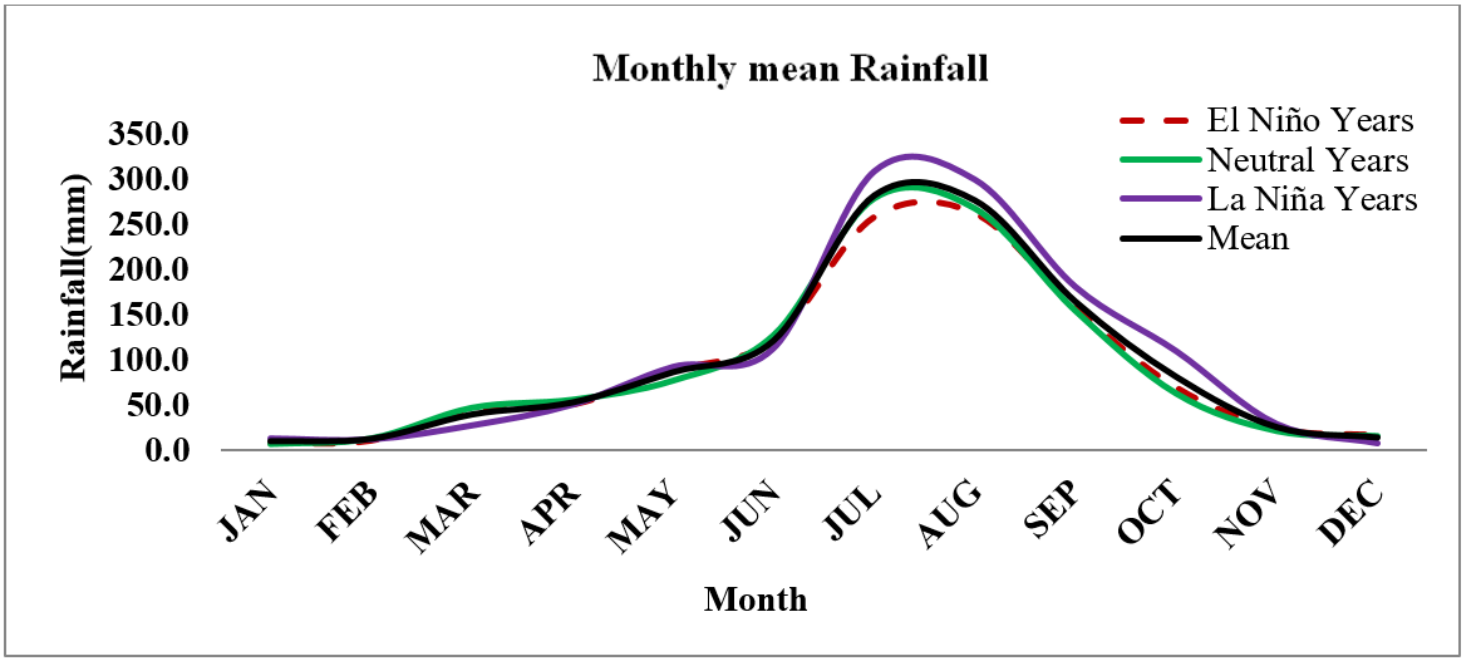


Figure 5

Mean monthly rainfall of EastGojjam in mm from 1986 to2015.

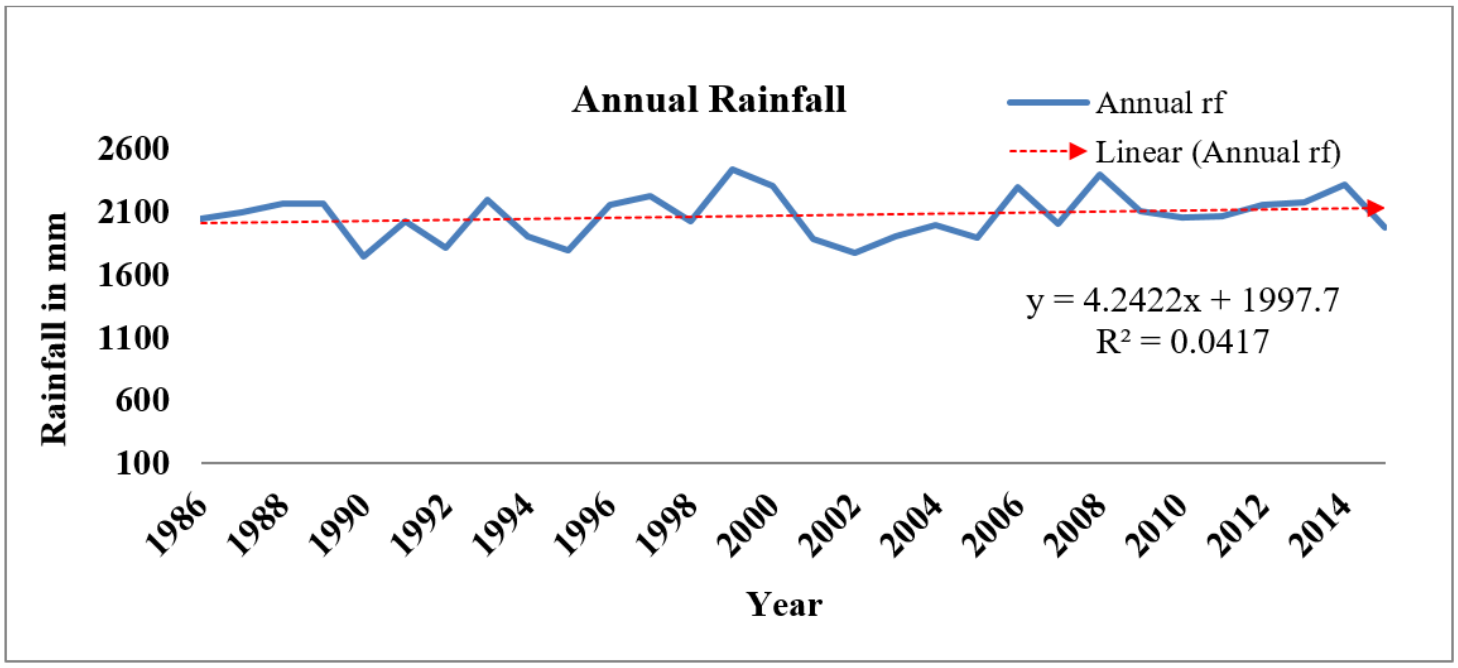


Figure 6

Annual Total Rainfall of Awi in mm from 1986-2015.

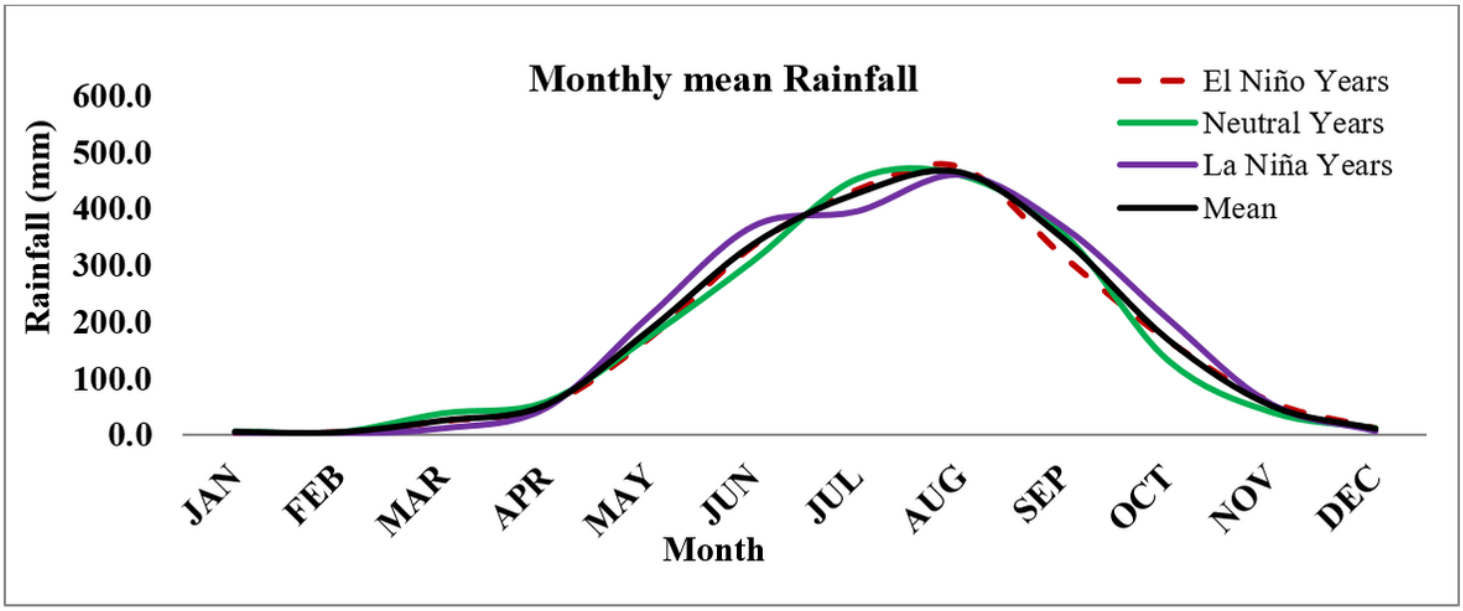


Figure 7

Mean monthly rainfall of Awi in mm since 1986-2015.

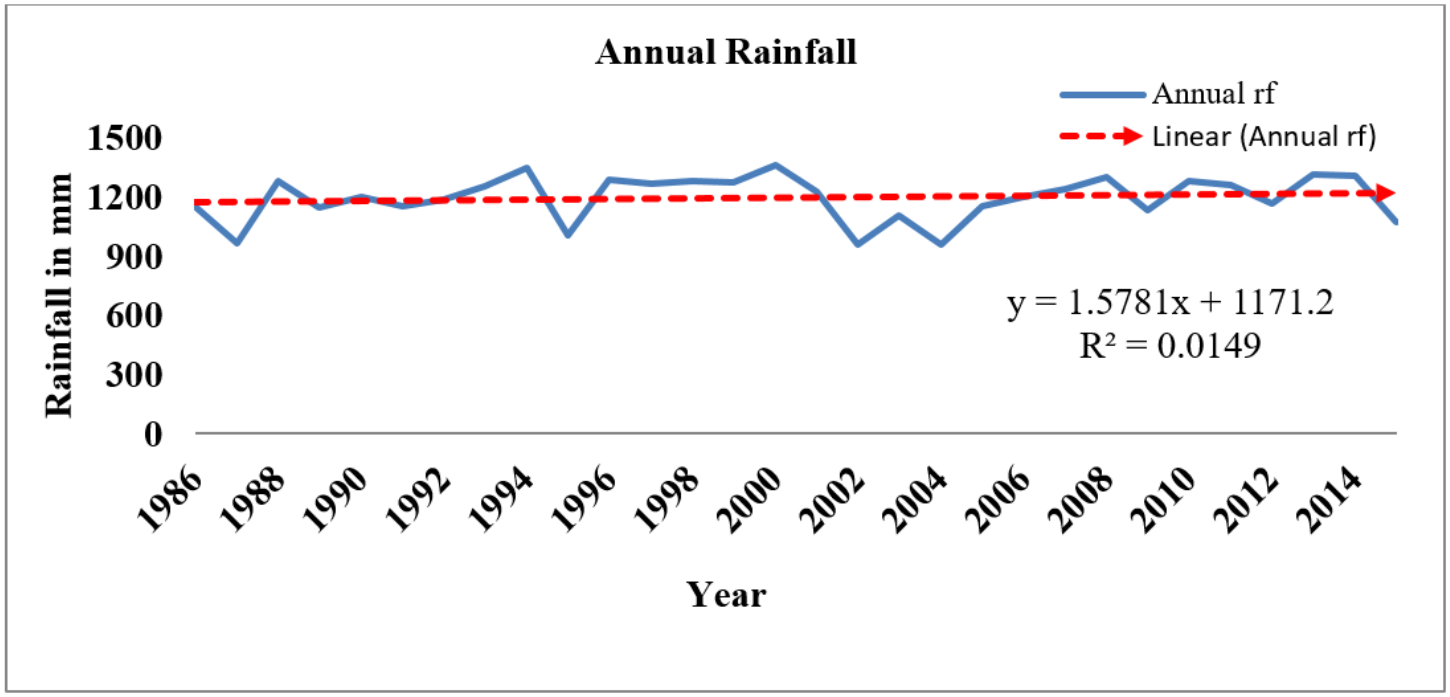


Figure 8

Annual average Rainfall of South Gondar in mm from 1986-2015.

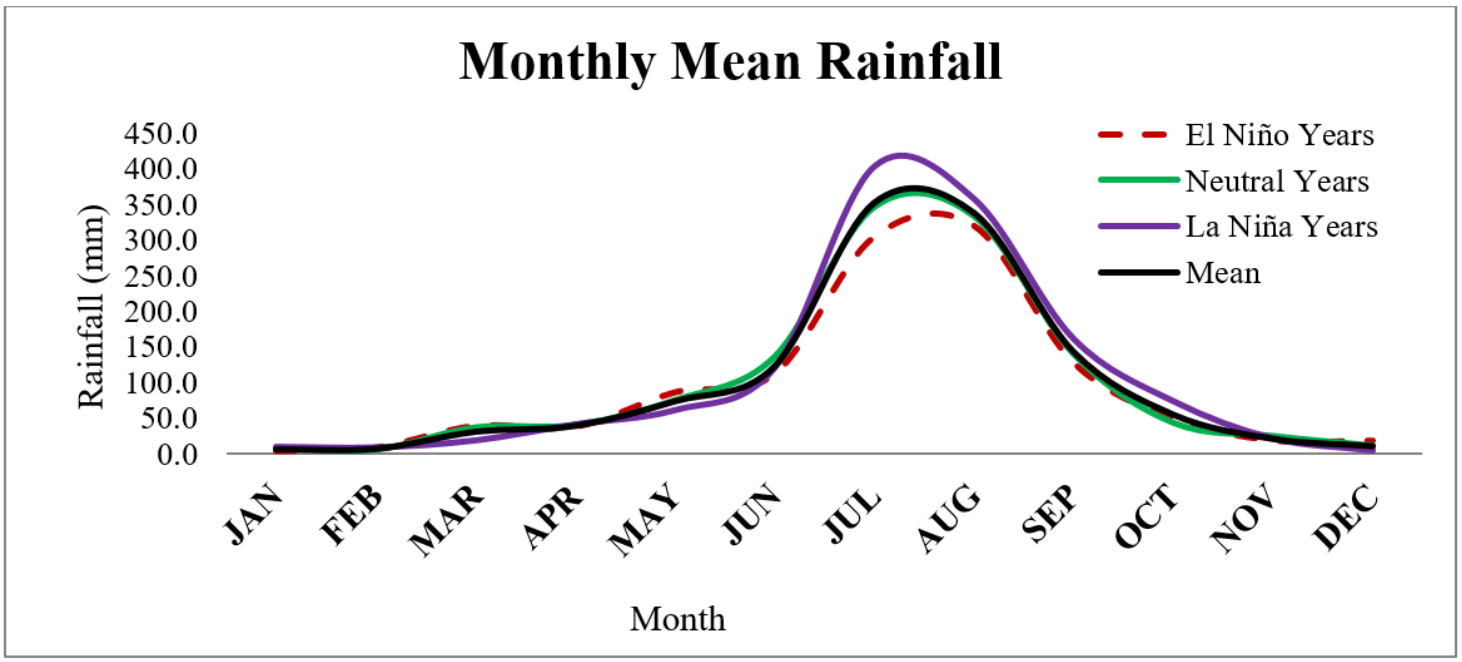


Figure 9

Mean monthly rainfall of South Gondar in mm since 1986-2015.

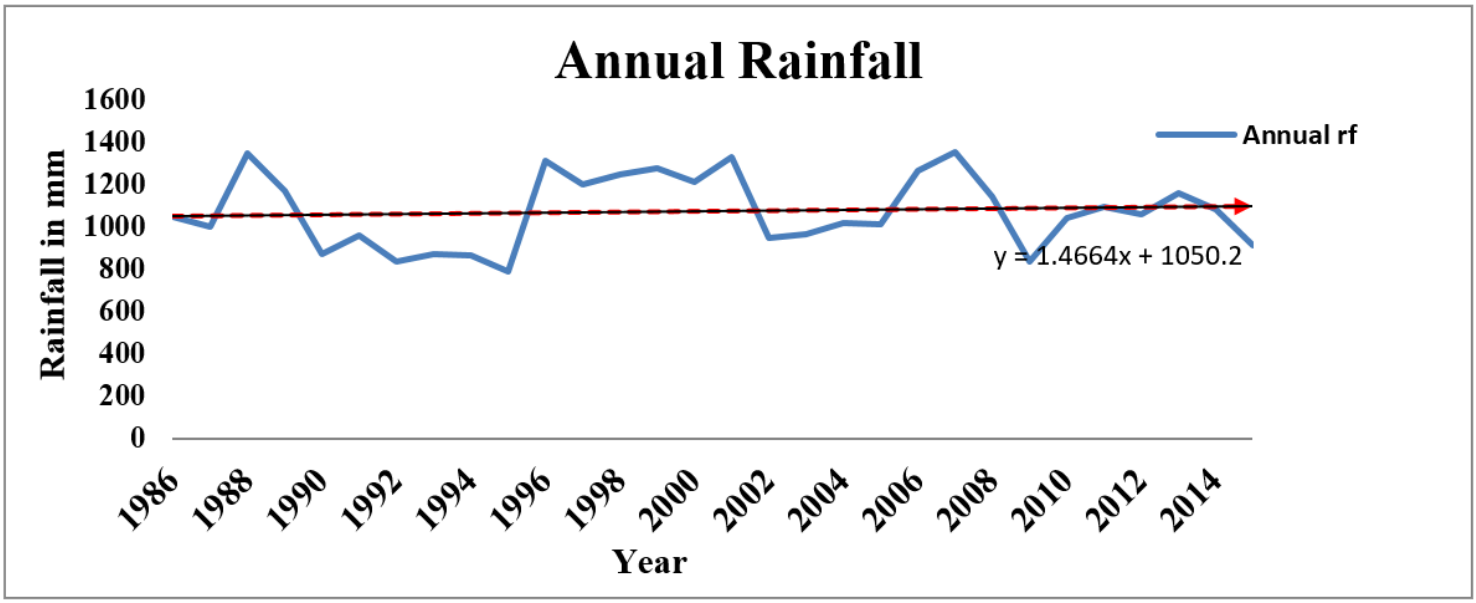


Figure 10

Annual average Rainfall of North Gondar in mm (1986-2015)

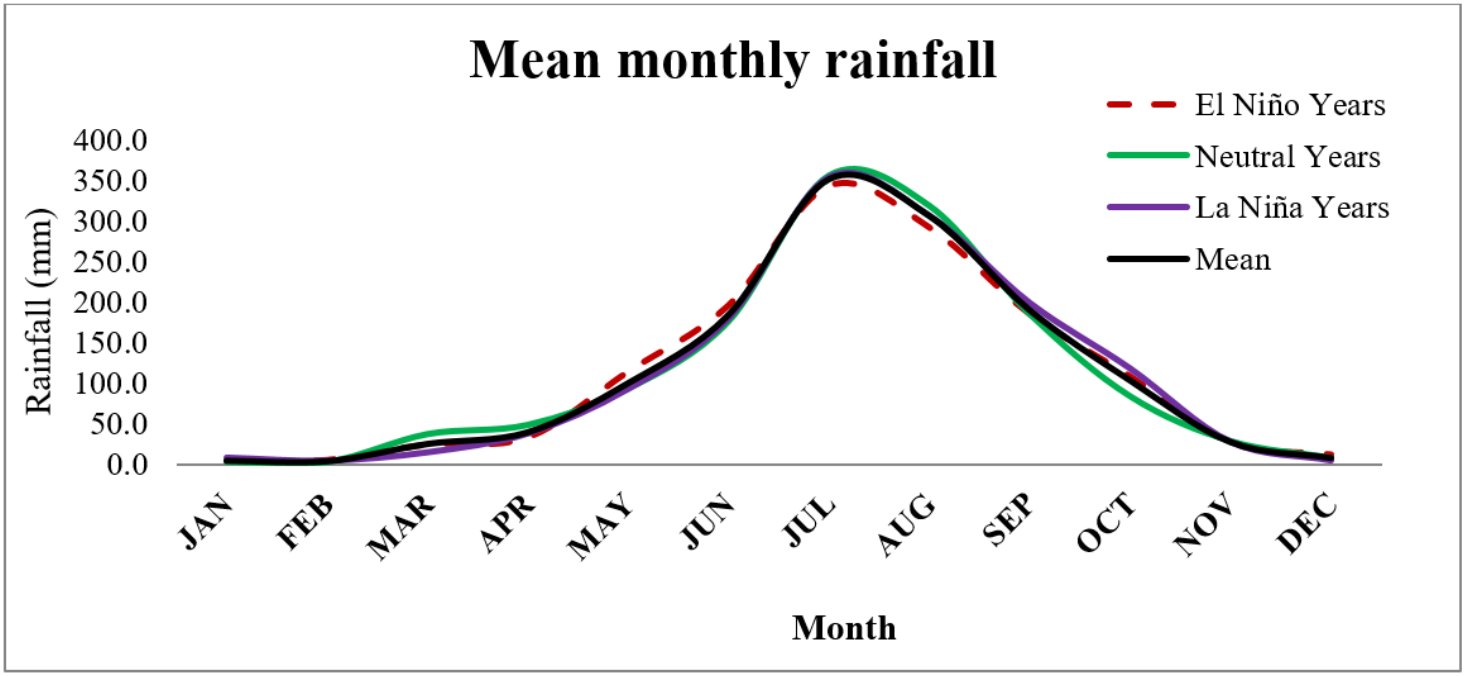


Figure 11

Mean monthly rainfall of North Gondar in mm (1986-2015).

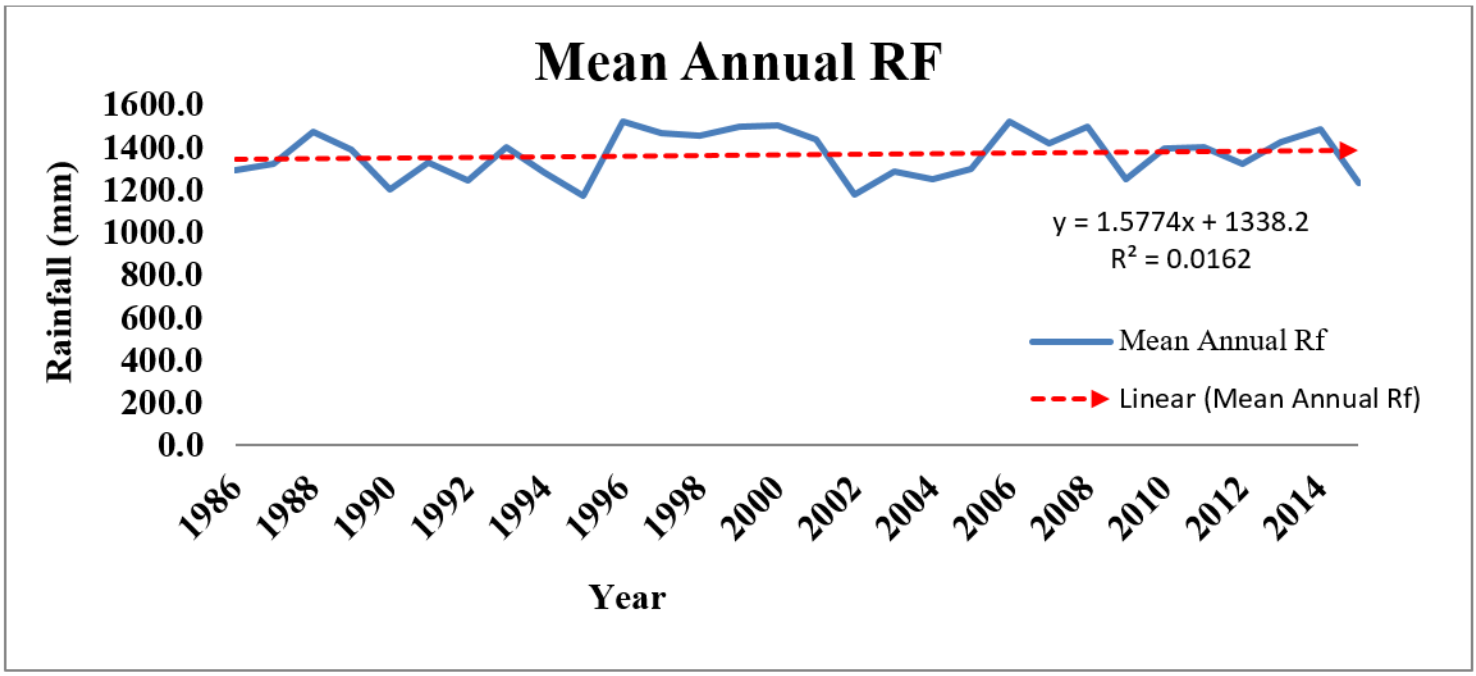


Figure 12

Annual average Rainfall of Western Amhara in mm (1986-2015).

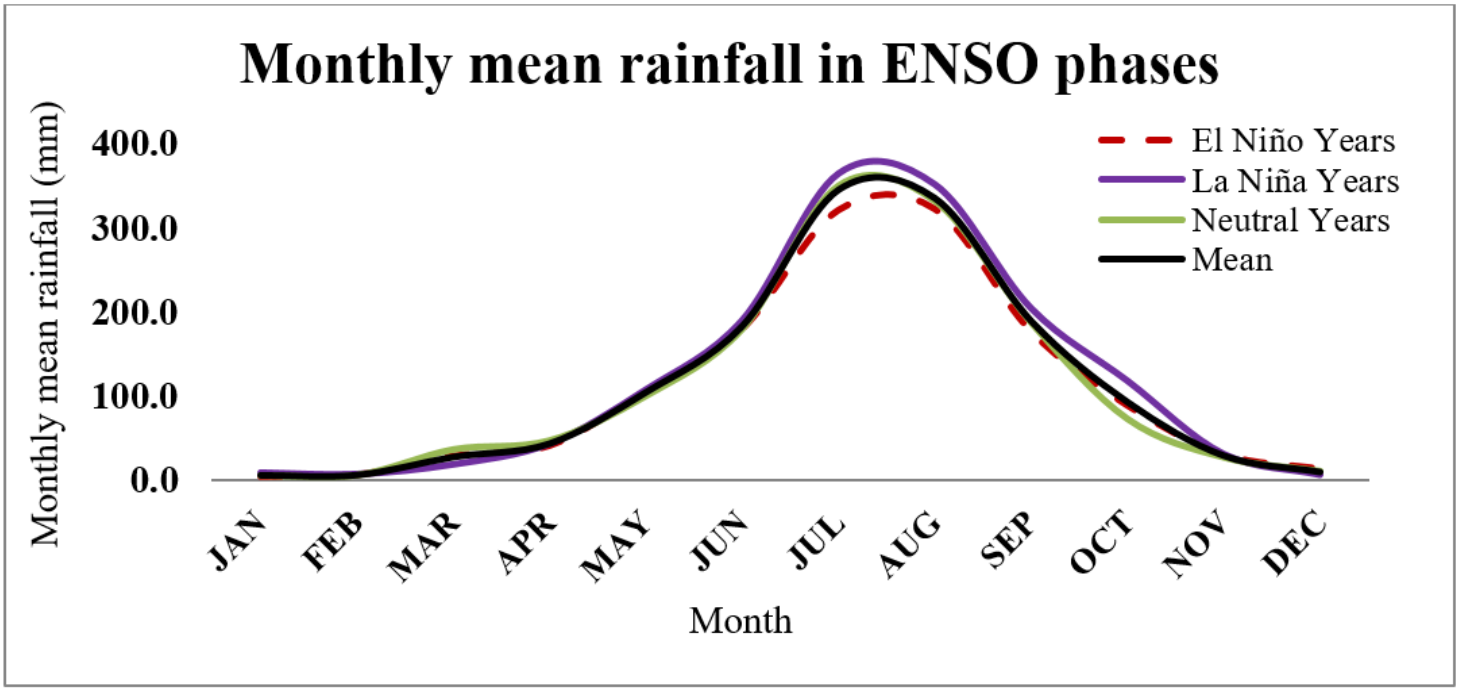


Figure 13

Mean monthly rainfall of Western Amhara in mm forEl Niño, Neutral and La Niña years (1986-2015).