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I. Introduction

Precipitation is one of the crucial factor in developing countries, owing to its vital importance of life supporting system on the Earth, particularly in the field of agriculture (Verdin et al. 2005; Wagesho 2016). Therefore, it is necessary to study temporal and spatial pattern as it is also the key factor of the drought and water resources monitoring and management, as well as climatic fluctuation(Bryan et al., 2009; De Luis et al., 2011;Yadav et al. 2014; Ahmad et al. 2015; Xu et al. 2015; Muchuru and Nhamo, 2019).

Africa is one of the mega continents that has both tropical and temperate zones in the Northern Hemisphere as well as the Southern Hemisphere in between the Equator. Hence, rainfall of Africa is highly variable that is affected not only due to climate change but also human activity (Bryan et al., 2009; Muchuru and Nhamo, 2019). Ethiopia is one the countries in the Horn of Africa where the rainfall quite erratic owing not only to regional and global climate factors, but also due to irregular topography (GulilatTefera Diro et al. 2011). Agricultural productivity is strongly linked to the seasonal and annual rainfall (Seleshi and Demaree 1995). Seasonal and internal variability of rainfall of the Ethiopia is controlled largely by atmospheric and oceanic interaction processes, such as, inter-tropical convergent zone (ITCZ), El Niño-Southern Oscillation(ENSO), Africa Easterly Jet (AEJ), Quasi Biennial Oscillation (QBO), Azores and Macarena's High pressure system, Somali Jet and low-level winds from Atlantic and Indian Oceans(Urgessa 2013; Seleshi and Zanke 2004; Minda et al. 2018; Hailesilassie and Tsidu 2015;Jury and Funk 2013;Girma, Tino, and Wayessa 2016; Ethiopian National Meteorological Agency 2007; Jury and Funk 2013; Korecha and Barnston 2007;Diro, Grimes, and Black 2011).However, owing to the irregular terrain the distribution of rainfall greatly differs in a smaller geographic area.

Various studies have been conducted to delineate the regional and global from local factors (Viste and Sorteberg 2013;Korecha and Barnston 2007; Shanko and Camberlin 1998; Hailesilassie and Tsidu 2015;Zeleke et al. 2013; Degefu et al. 2017; G. T. Diro et al. 2011).

The seasonality of rainfall also differ over different parts of Ethiopia (Seleshi and Zanke, 2004; Korecha and Barnston, 2007). Ethiopia receives rainfall during June-September (Kiremt), October-January (Bega) and February-May (Belg). Among these, Kiremt, the main rainy season of accounting 50% to 80% the annual rainfall, which is dominant in the northern and central parts of the country (Asfaw et al. 2018). Whereas, the southern and south-western parts of the country get considerable amount rainfall during Belg season, but Bega (October to January) is driest season in most parts of the country, however, occasionally north-eastern parts of Ethiopia get rain due to the

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development of Red Sea convergence zone, as well as the southward migration of the ITCZ gets rain over southern and south-eastern parts of the county (EPCC, 2015).

The trend analysis of precipitation has received a great deal of attention recently, because its accurate prediction determines the economic development and, adaption and mitigation plan of the country to combat climate extremes. A number of studies have been carried out to investigate precipitation trends across the country to know the spatial and temporal variability (Asfaw et al. 2018; Degefu and Bewket 2014; Dereje Ayalew 2012; Fekadu 2015; Girma et al. 2016; Haile et al. 2009; Mpeta 2002; Seleshi and Demaree 1995; Urgessa 2013; Wagesho 2016; Wodaje, Eshetu, and Argaw 2016; Ymeti 2007). In this study, Southern Regional State of Ethiopia has been selected in order to understand the high resolution spatial and temporal variability trends of rainfall as well as its trends and relationship among the sea-surface variability of Equatorial Pacific Ocean, by taking in account of particularly Nino 3.0, Nino 3.4 and Nino 4.0. The gridded high resolution data are obtained from the Climate Hazards Group InfraRed precipitation with Station (CHIRPS) to observe the links among seasonal rainfall anomalies and Tropical Pacific SSTs.

II. Material and Methods

a) Study Area

Southern Nations, Nationalities and People's Region (SNNPR; fig.1) is located in the south and south-western region of Ethiopia, covers an area of 110,931km^{2}with a population of 17.8 million (Sun et al. 2011). The topography of the region is part of Rift valley system comprising of with mountains, valleys, plains and lowlands. The altitude of the region ranges between 376 masl (meters above sea level) at Lake Rudolf to 4207 masl at Guge Mountain in GamoGofa zone. Based on the altitudinal variation the region is categorized under three agro-climate zones, Kolla (lowland), Woina Dega (mid altitude) and Dega (high altitude). The rainfall amount and distribution increases from south-east to north and north-west of the region. The mean annual rainfall fluctuates between 200mm/yr in the semi-aired lowland region and 2200mm/yr in higher altitudes (Hailesilassie and Tsidu 2015; Abiy et al. 2017).

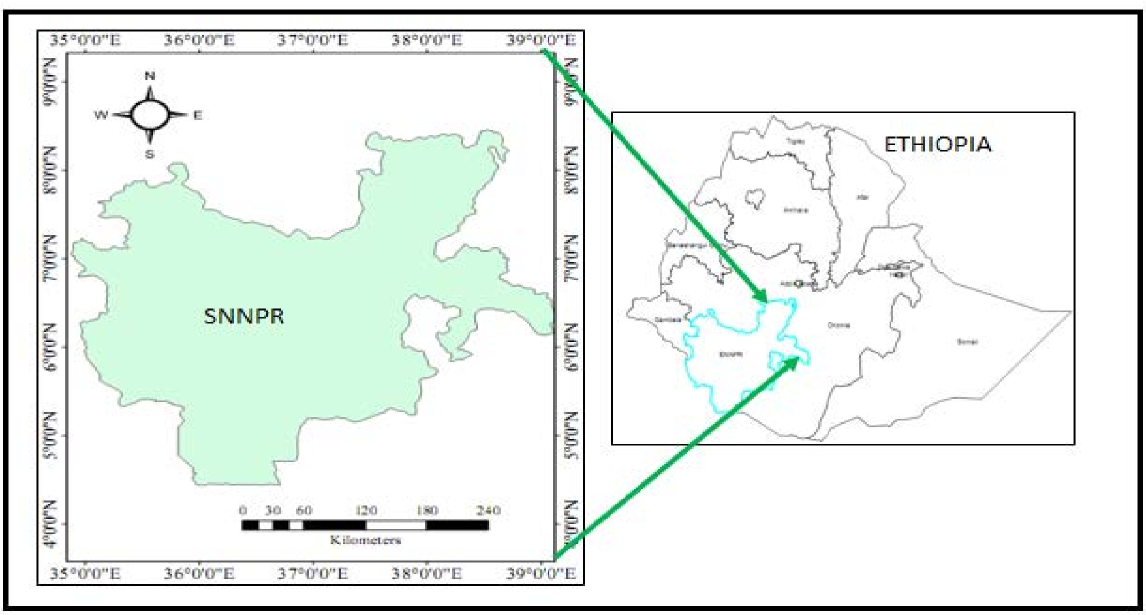


Figure 1: Map of Southern Nations, Nationalities and People's Regional State of Ethiopia

b) Data and Methodology

The high resolution, quasi-global (50^{0}S -50^{0}N at 0.05^{0}interval (grid)), precipitation data obtained from Climate Hazards Group Infra Red Precipitation with Station (CHIRPS) (http://chg.ucsb.edu/data/chirps/). It was originally developed to support the United State Agency for International Development Famine Early warning system Network (FEWS NET) as noted by(Hewett and Heard 1982; Janowiak et al. 2001;Chris Funk et al., 2015; Toté et al., 2015). The sea surface temperature of Equatorial Pacific Ocean at three different Nino regions and Southern Oscillation Index (SOI) data used to investigate precipitation pattern of the study area were obtained from (https://www.esrl.noaa.gov/psd/data/index.html). The data are computed for determining the coefficient variation, precipitation concentration index, standardized anomaly, non-parametric Mann Kendall and parametric linear regression methods and Theil-Sen's slope. Besides theses, standard descriptive statistics of the monthly, seasonal, annual and decadal scales of the rainfall data are presented in respective tables 1and 2.

The variability of rainfall is characterized by the coefficient of variation. As mentioned on Abyi et al. (2017), CV is used to categorize the degree of variation of rainfall in to the three known classes, less variable, moderate variable and highly variable. CV value less than 20% corresponds to low variability, CV value between 20% to 30% shows moderate variability and CV value greater than 30% depicts highly variable rainfall conditions (Tessema et al. 2017). Mathematically coefficient of variation (CV) is defined as, the ratio of standard deviation to mean value of the data.

$$CV = \frac{\delta}{\mu}\, x100 \qquad (1)$$

Where μ is the mean value of monthly rainfall and δ is standard deviation the data from its mean value.

Oliver (1980) pointed out that, periodic variation of precipitation at any location is fundamental aspect of climate change studies because of its importance to flood prediction and agricultural planning. Precipitation Concentration Index (PCI) was used by a number of authors to examine monthly and seasonal heterogeneity of rainfall (Al-shamarti 2016; Asfaw et al. 2018; Byakatonda et al. 2018; Dereje Ayalew 2012; Eshetu et al. 2018; Girma et al. 2016; De Luis et al. 2011; Mulugeta et al. 2017; Ngongondo et al. 2011; S.S. and K. 2018; Sangüesa et al. 2018; Valli, Sree, and Krishna 2013; Wagesho 2016; Wodaje et al. 2016). As depicted on S.S. and K. (2018), using the modified form of PCI, it is possible to estimate the monthly heterogeneity of rainfall and the long term rainfall variability a mount on seasonal and annual scale based on the mathematical equation shown below.

$$PCI_{\ annual} \ = \frac{\sum_{i=1}^{12} {P_i}^2}{(\sum_{i=1}^{12} P_i)^2}\, x\ 100 \qquad (2)$$

$$PCI_{\ seasonal} \ = \frac{\sum_{i=1}^{12} {P_i}^2}{(\sum_{i=1}^{12} P_i)^2}\, x\ 33 \qquad (3)$$

Where P_i is the monthly precipitation in month, i runs from January to December. Equation (2) shows annual PCI whereas equation (3), represents three seasonal PCI, in our context Bega (October to January), Belg (February to May) and Kiremt(June to September) as mentioned earlier.

As verified on Oliver (1980), the PCI values less than 10 indicate quite uniform distribution of precipitation, between 11 and 15 represent moderate distribution, whereas, from 16 to 20 indicate high precipitation index(i.e., quite erratic distribution of precipitation) and >20 denotes very high irregularities in the distribution of the rainfall.

The variability of precipitation can also be measured by standardized anomaly index (SAI). It is applied mainly to identify dry and wet seasons relative to the long-term mean(Patel et al. 2007; Wu et al., 2007;Eshetu et al. 2018). The SAI for the present study estimated as per the equation for the specified time period, Z.

$$Z = \frac{(X-\mu)}{\delta} \qquad (4)$$

Where Z is standardized rainfall anomaly; X is annual rainfall of particular year, μ is mean value of annual rainfall of long term and δ is standard deviation of annual rainfall. Based on these, the rainfall anomaly indices can be classified as follows (Patel et al. 2007; Wu et al., 2007; Eshetu et al. 2018; Table 1):

Table 1: Standardized rainfall anomaly index classifications

SAI Value	category
2+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near Normal
-1.0 to -.1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

In this study, we use non-parametric Mann-Kendall and Sen's slope estimator to investigate the trend of rainfall pattern during specified study period. Mann-Kendall trend analysis methodology have been widely used for climate change, geological, environmental and hydro meteorological studies(Ahmad et al. 2015; Degefu and Bewket 2014; Drapela and Drapelova 2011; Gocic and Trajkovic 2013; Karmeshu Supervisor Frederick Scatena 2015; Nourani et al., 2018; Partal and Kahya 2006; Seleshi and Zanke 2004; da Silva et al. 2015; Yadav et al. 2014). It is a non-parametric test, when the data set does not normally distributed and hence less sensitive to abrupt change/ breaks of rainfall due to in homogeneity over time (Karmeshu, 2015).

The Mann-Kendall test statistics is calculated using the formula

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} sgn(x_j - x_k\,) \qquad (5)$$

Where x_j and x_k are the annual values in years j and $k, j > k$, respectively, and

$$\mathrm{sgn}\ (x_{j} - x_k) = f(x) = \begin{cases} 1, & if\ x_j - x_k > 0 \\ 0, & if\ x_j - x_k = 0 \\ -1, & if\ x_j - x_k < 0 \end{cases} \quad (6)$$

If $n < 10$, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall (Drapela and Drapelova 2011). The two tailed test is used to level of significance. At certain probability level null hypothesis H_o is rejected in favour of alternative hypothesisH_1, if the absolute value of S equals or exceeds a specific value$S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has the probability less than $\alpha/2$ to label that the time series has no trend. Positive value of S indicates upward trend and the negative value of S indicates downward trends (Gocic and Trajkovic 2014; Meena et al. 2015; Ngongondo et al. 2011; Partal and Kahya 2006; Tabari and Talaee 2011).

For $n \geq 10$, the statistics S is approximately normally distributed with the mean and variance given as follows

$$E(S) = 0 \quad (7)$$

$$VAR(S) = \frac{1}{18}\left[n\,(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)(2t_p + 5\right] \quad (8)$$

Where q the number of is tied groups and t_p is the number of data values in the p^{th} group.

The vales of S and $VAR(S)$ are used compute the standard test statistics Z as given below

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad (9)$$

The existence of statistically significant trend is approved by using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. The statistics Z has a normal distribution. To test for either an upward or downward monotonic trend (a two tailed test) at α level of significance, H_0 is rejected if the $|Z| > Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution table.

According to Drapela and Drapelova (2011), if a linear trend is present in a time series, then the true slope can be estimated by using a simple nonparametric Sen's slope estimator. So linear model can be described as

$$f(t) = Qt + B \quad (10)$$

Where Q is the slope and B is the constant. The slope of all data pairs given as follow to estimate the Q,

$$Q_i = \frac{x_j - x_k}{j-k}, i = 1,2, \ldots N, j > k \quad (11)$$

Wherex_j and x_k are data values at time period j and k(j>k) respectively.

If there are n avlues x_j in the time serious, we get as many as $N = n(n-1)/2$ slope estimatesQ_i. The Sen's estimator slope is the median of these N values ofQ_i. The N values of Q are ranked from the smallest to the largest and the Sen's estimator is given by the following equation.

$$Q = \begin{cases} Q_{N+1/2} & \text{if N is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) & \text{if N is even} \end{cases} \quad (12)$$

The positive (negative) values of Q_i indicate an upward or increasing (decreasing or downward) trend in the series.

III. Results and Discussion

a) Annual and seasonal Rainfall variability and trend analysis

Based on the data used to this study, the mean annual rainfall of the region during entire study period from 1981 to 2017 was 1239.858mm, with the standard deviation and coefficient variations of 115.963mm and 9.00% respectively. The maximum annual rainfall 1481.883mm noted during 2006, which was associated with weak El-Nino year. Whereas, the minimum rainfall of 990.102mm that observed in 1984, the driest year in almost all over Ethiopia due to strong El-Nino effect. As the result shows the mean values obtained in this study are fairly consistent with other studies in the proximity of the study area (Abiy et al. 2017).

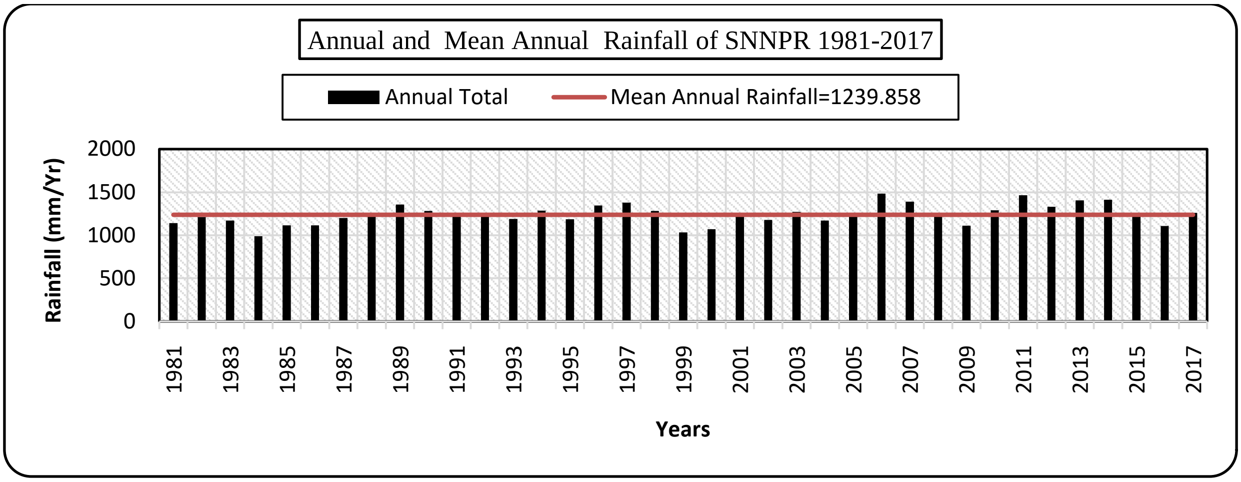


Figure 2: Annual and seasonal distribution of rainfall amount in SNNPR from 1981 to2017

On the monthly basis, maximum rainfall observed was 243.81mm during May 2011 which has been one the strongest La Nina years since 1951/52(Table 3) whereas, the minimum was 6.89mm recorded during the December 2005, which has been the driest month in the area of investigation. The highest coefficient variability of rainfall was observed during December (82%), followed by January (65%), February (64%), November (54%), July (20%), April and August (18%), with moderate variability observed during the remaining months. The detailed descriptive statistics of monthly rainfall over the period is presented in the Table 2.

Table 2: Statistical Descriptions of SNNPR monthly rainfall during (1981-2017)

Months	Min	Max	Mean	SD	Percentage	CV	Skewness	Kurtosis	Kendall's tau	*L.Slope	R^2	p-value	Sen's slope
Jan	8.73	86.84	29.73	19.55	2.40	0.65	1.23	1.06	-0.02	-0.11	0.004	0.76	-0.02
Feb	7.97	128.15	38.65	24.91	3.12	0.64	1.43	2.58	-0.05	-0.35	0.024	0.55	-0.28
Mar	42.29	206.10	101.15	40.18	8.16	0.39	0.57	-0.35	-0.07	-0.58	0.025	0.55	-0.41
Apr	108.58	221.85	156.71	28.59	12.64	0.18	0.41	-0.57	0.16	0.50	0.035	0.13	0.76
May	108.49	243.81	162.18	34.81	13.08	0.21	0.72	-0.05	0.13	0.70	0.047	0.23	0.59
Jun	68.96	161.09	114.17	23.80	9.21	0.21	0.25	-0.90	0.19	0.56	0.065	0.07	0.64
Jul	87.43	202.88	134.95	27.87	10.88	0.20	0.50	-0.07	0.22	0.61	0.056	0.37	0.73
Aug	94.36	198.02	138.40	25.76	11.16	0.18	0.54	-0.45	0.14	0.41	0.031	0.23	0.43
Sep	96.52	190.56	132.82	28.05	10.71	0.21	0.49	-0.81	0.15	0.63	0.060	0.76	0.66
Oct	44.65	241.76	119.88	40.10	9.67	0.33	0.60	0.71	0.21	1.10	0.089	0.37	1.25
Nov	22.69	229.08	75.94	45.12	6.13	0.59	1.58	2.60	0.18	0.86	0.043	0.55	0.73
Dec	6.89	122.30	35.28	29.46	2.85	0.82	1.67	2.30	-0.11	-0.14	0.003	0.55	-0.21

According to Wolde-georgis (2014), there is clear and remarkable relationship exists between annual rainfall in Ethiopia and different regions and ENSO (El Niño Southern Oscillation) events, which is a coupled atmospheric and ocean interaction phenomenon that has global weather implications. Table 3 lists strength of the El Nino and La Nina year(s) since 1951/52 till recently.

Table 3: List of the strength of El Nino and La Nina years, since 1951/52 (https://ggweather.com/enso/oni.htm)

El Niño				La Niña		
Weak - 10	**Moderate - 7**	**Strong - 5**	**Very Strong - 3**	**Weak - 10**	**Moderate - 4**	**Strong - 7**
1952-53	1951-52	1957-58	1982-83	1954-55	1955-56	1973-74
1953-54	1963-64	1965-66	1997-98	1964-65	1970-71	1975-76
1958-59	1968-69	1972-73	2015-16	1971-72	1995-96	1988-89
1969-70	1986-87	1987-88		1974-75	2011-12	1998-99
1976-77	1994-95	1991-92		1983-84		1999-00
1977-78	2002-03			1984-85		2007-08
1979-80	2009-10			2000-01		2010-11
2004-05				2005-06		
2006-07				2008-09		
2014-15				2016-17		

The contributions of seasonal rainfall to the annual quantum, the Kiremt (JJAS) and Belg (FMAM) account the highest contributions with observed percentages 41.97% and 36.99% respectively. Whereas, the Bega (ONDGJ) accounts only 21.04% from annual amount. The average rainfall of Kiremt, Belg, and Bega rainfall observed to have been 520mm, 459 mm and 261 mm with standard deviation of 75, 72 mm and 78 mm, and coefficient variability 14%, 15% and 29% respectively. The details of seasonal variability of rainfall along with the descriptive statistics of the seasonal and annual rainfall are given in the Table 4.

Table 4: Statistical descriptions of seasonal and annual rainfall of SNNPR (1981-2017)

Seasons	Minimum	Maximum	Mean	Std. deviation	Percentage	CV	Skewness	Kurtosis	Kendall's tau	p-value	Sen's slope
ONDJ (Bega)	140.646	535.884	260.824	77.725	21.040	0.290	1.230	2.520	0.225	**0.002**	2.219
FMAM (Belg)	322.239	584.792	458.680	71.597	36.990	0.150	0.070	-0.900	0.033	0.661	0.163
JJAS (Kiremt)	406.833	678.699	520.354	74.918	41.970	0.140	0.510	-0.450	0.216	0.061	1.952
Annual	990.102	1481.883	1239.858	115.963	100.000	0.090	0.090	-0.360	0.270	**0.019**	4.116

NB: P values with bold show 95% significance level

In order to investigate the temporal distribution trend of rainfall, we employed a simple parametric linear regression and non-parametric Mann Kendal and Sen's slope estimator methods. Both method show similar results regarding the direction of trend while they have certain disagreements in depicting the magnitude of trend in the rainfall. As clearly presented in the Table 2, December, January, February and March show statistically insignificant decreasing trend, whereas the rest of all months show non-significant increasing trend during the record period (Fig. 2).

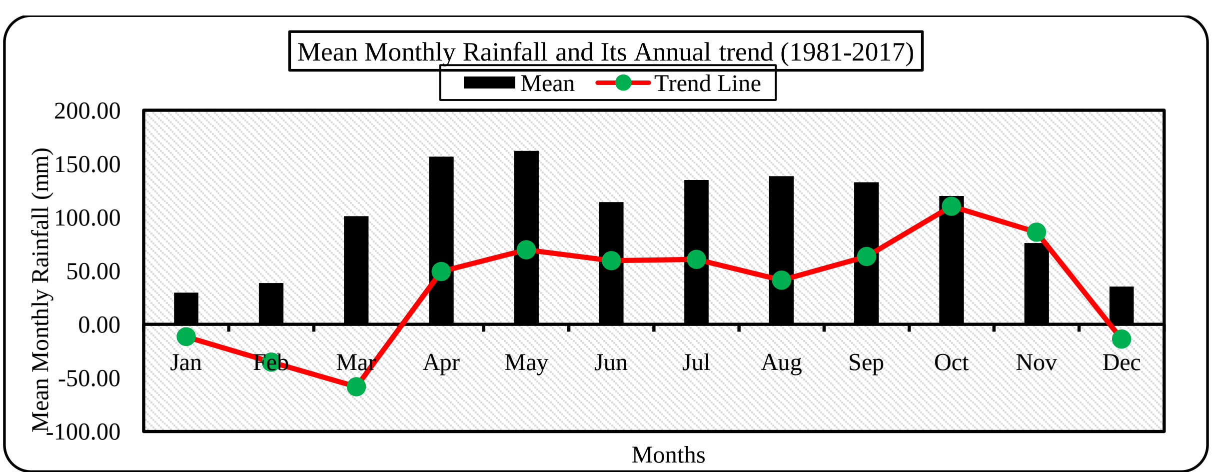


Figure 3: Monthly rainfall trend in SNNPR during (1981-2017)

As depicted in the Table 2, seasonal rainfall trend shows the statistically significant increasing trend on Bega and non-significant upward trends on Kiremt and Belg which are good seasons for agricultural activates. Also both parametric and non-parametric methods show significant increments in annual rainfall. Similar trend has also observed from western and south western regions, particularly at higher elevation of Ethiopia (McSweeney, 2012; Christensen, et al., 2007).

The annual and seasonal rainfall trends are presented in Fig. 4, where the slope of linear regression line indicates the rate of increments in rainfall during Kiremt (2.23mm/yr), Belg (0.26mm/yr), Bega (1.72mm/yr), and annual (4.2mm/yr) respectively. Similarly, statistically significant increasing trend have been observed in the area, particularly in the Omom-Gibe river basin of the region Degefu and Bewket (2014).

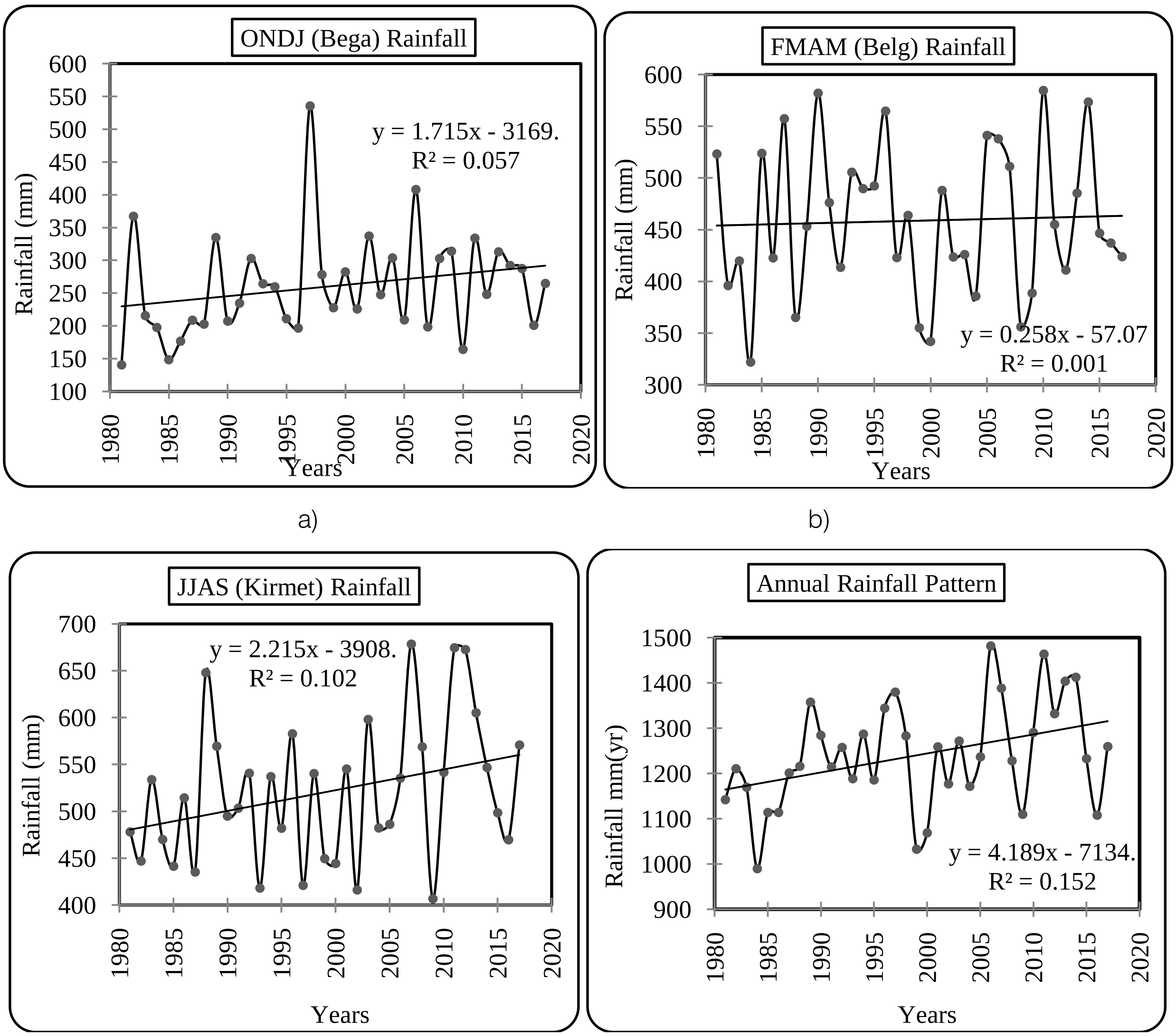
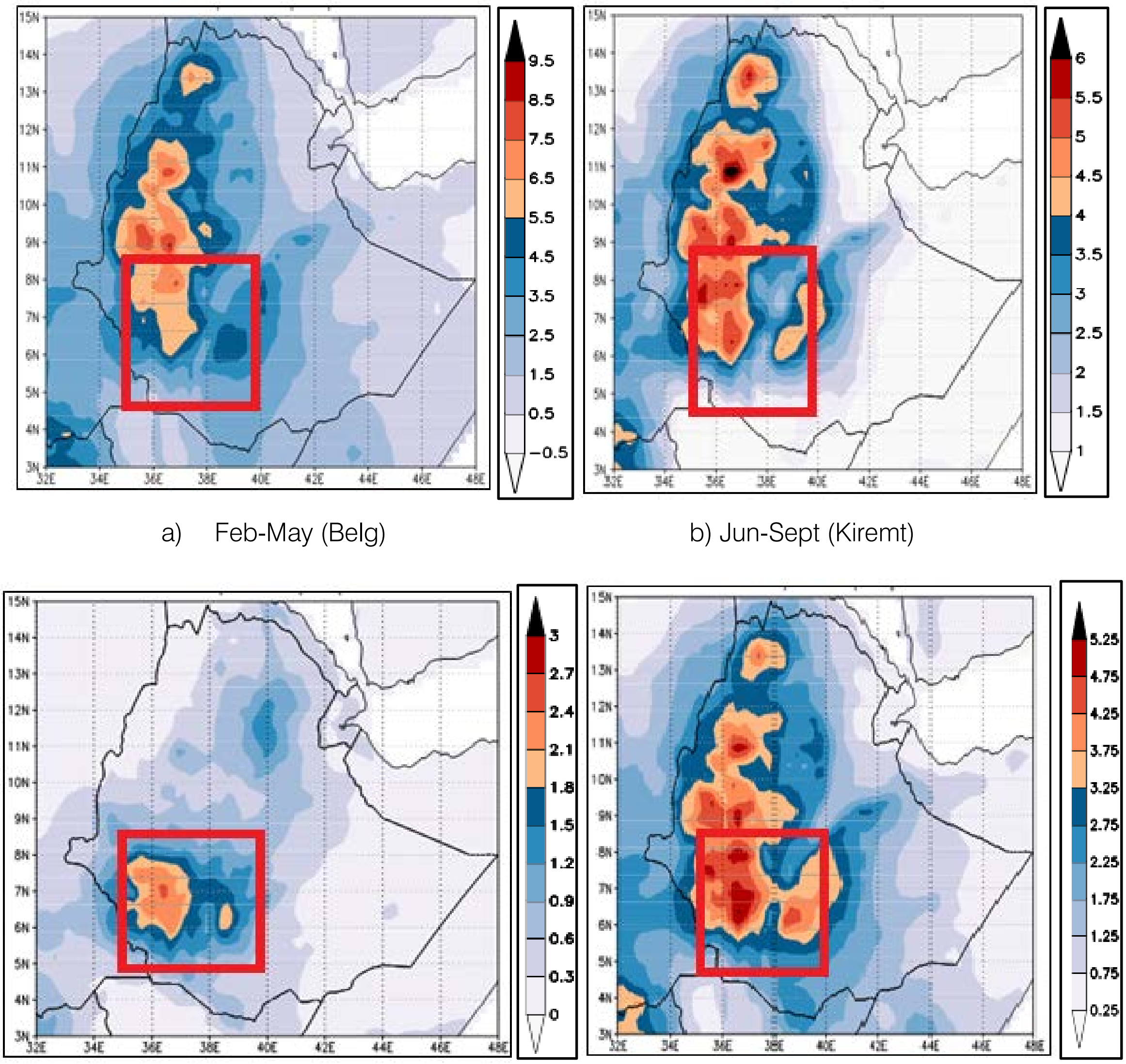


Figure 4: Seasonal and annual trends of rainfall of the study area

We used standardized anomaly index to point out the highest and lowest departure of rainfall from its long period mean. Southern, south central and south-western part of the country show considerable increasing trend as mentioned above.



a) Feb-May (Belg)

b) Jun-Sept (Kiremt)

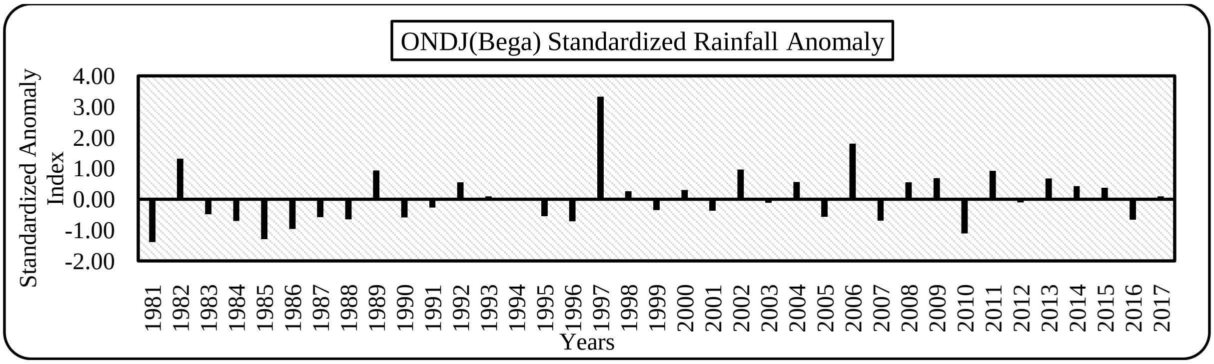
c) Oct -Jan (Bega)

d) Jan- Dec 1981- 2017 (annual averaged)

NB: The inset box encompasses the study area

Figure 5: Spatial distribution of annually and seasonally averaged rainfallanomaly over entire study period, with respect to 1981-2010 Climatology

The rainfall anomaly patterns show quite a complex relation with the historical record of El Nino and La Nina years (Table 3). Departure of rainfall from its mean value is characterized by rainfall anomaly index has been inferred to identify the anomalous dry and wet periods in the past, in order to prepare to combat drought situation (Nathaniel B. 1999). In this study deficiency of rainfall noticed during, 1984, 1999, 2000, 2009 and 2016, but excess during 1989, 1997/98, 2006/07, 2011/12 and 2013/14 as compared to the long term mean. As it can be seen from the Fig. 6 that the annual rainfall data indicates that most of drought years are associated with El Nino years, whereas, most of excess rainfall years are related to La Nina years. However, seasonal response to the ENSO climate forcing has been quite different. For example, seasonal rainfall pattern in 1997, which was a strong El Nino year, the driest season (Bega) showed extremely wet condition (SAI = 3.33), whereas, moderately deficit to nearly normal conditions during Kiremt (SAI= -1.22) and Belg (SAI= -0.46) respectively.



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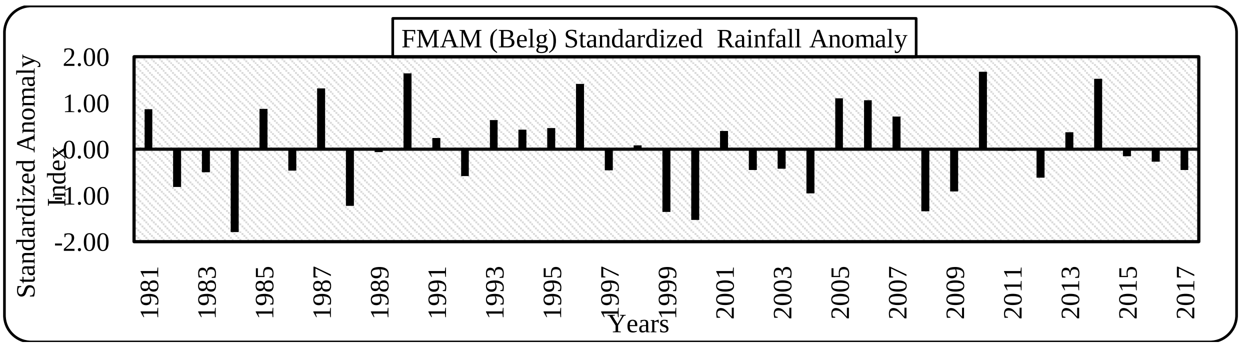

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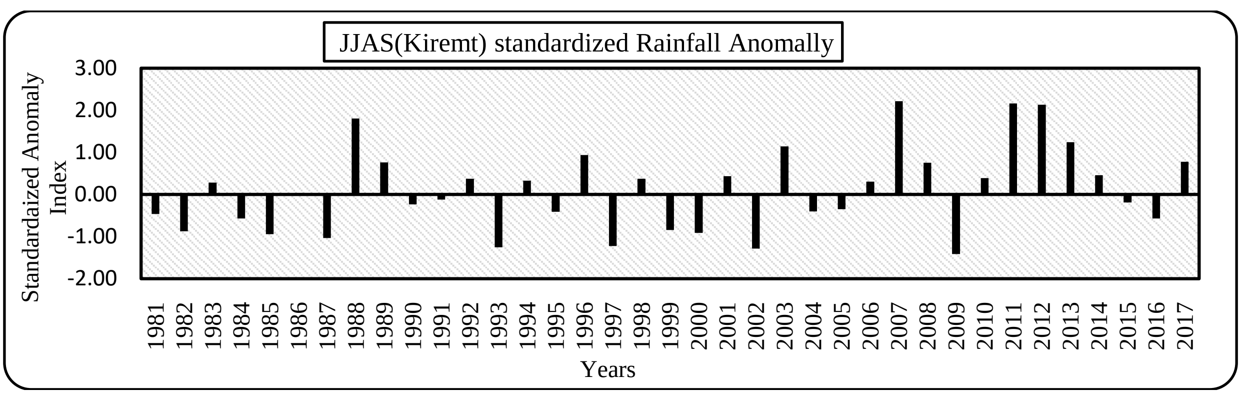

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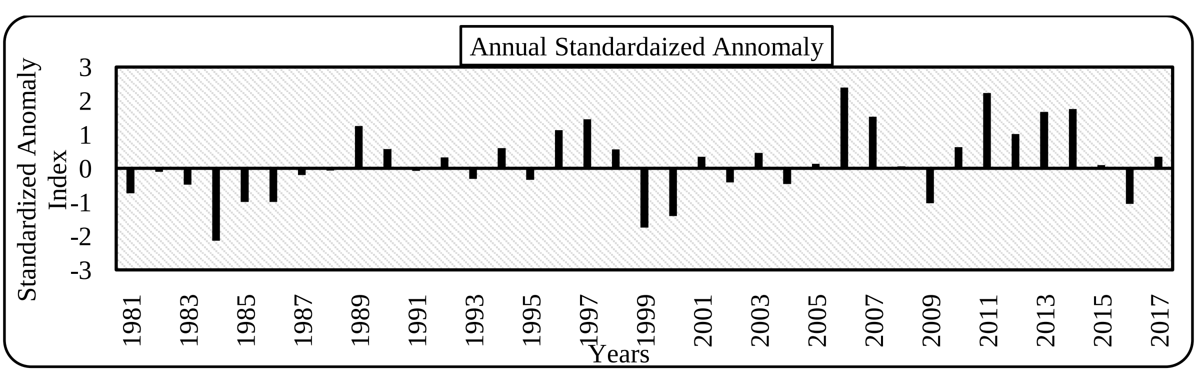


d)

Figure 6: Standardized rainfall anomaly Index seasonal (a, b and c) and annual (d) during (1981 to 20170)

The computed standardized precipitation concentration index (Fig. 7) shows an increasing trend for Bega and Kiremt, but decreasing trend for Belg, nevertheless, although statistically insignificant, the annual precipitation shows an increasing trend during the study period. Precipitation concentration index presented in the Table 5 below revealed that, Bega, (ONFJ), Kiremt (JJAS) and annual have uniform precipitation (low concentration), but Belg (FMAM) season showed relatively moderate precipitation.

Table 5: Precipitation concentration and annual and seasonal rainfall linear trends

Seasons	Mean PCI	R^2	slope(mm/yr)
ONDJ	10.47	0.06	1.72
JJAS	8.52	0.11	2.23
FMAM	12.22	0.25	0.01
Annual	10.63	0.15	4.12

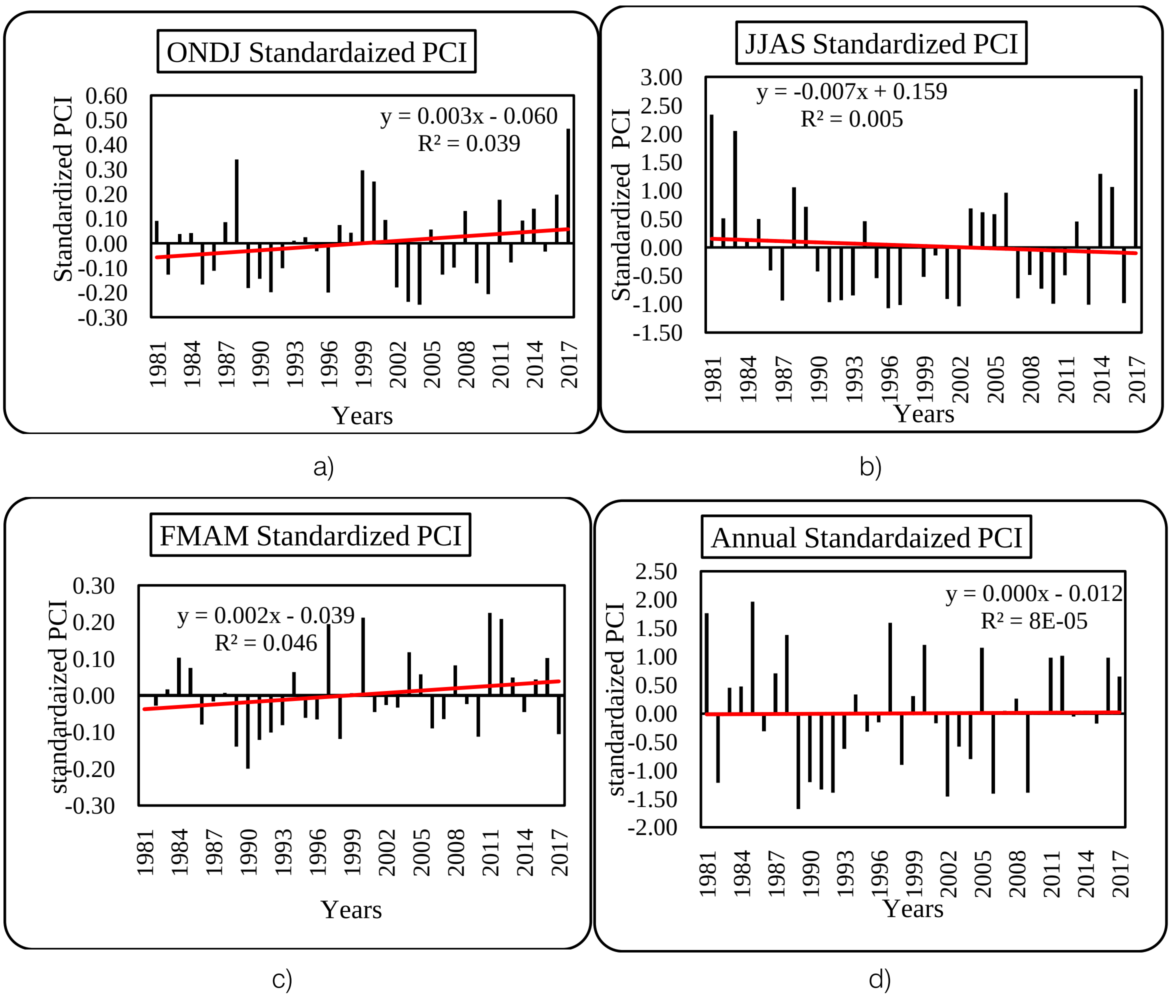


Figure 7: Trends of seasonal (a, b and c) and annual (d) standardized precipitation concentration Index

b) Decadal rainfall variability and trends

We also investigated the decadal rainfall pattern of the study region by using both parametric and non-parametric statistical methods. The result revealed that, decadal oscillation of rainfall trend become evident in the region. Statistically non-significant increasing trend was observed in the first decade (1981-1990), even though historically the worst deficit of rainfall was recorded during this time. The second and third decades verified non-significant decreasing and increasing trends respectively. The last seven years show remarkable decreasing trends when compared within decades. This indicates the decreasing trend may persist in this decade too, although the aggregate rainfall showing an increasing trend throughout the period.

Table 6: Summary statistics for decadal rainfall pattern in the study area (1981-2017)

Decade	Minimum	Maximum	Mean	Std. deviation	Kendall's tau	p-value	Sen's slope
1981-1990	990.10	1357.99	1180.10	100.82	0.42	0.11	16.35
1991-2000	1032.64	1380.05	1224.26	111.02	-0.11	0.72	-7.29
2001-2010	1110.01	1481.88	1261.72	108.25	0.02	1.00	2.68
2011-2017*	1108.34	1463.97	1316.28	124.12	-0.52	0.13	-36.00

**represents only the past seven year trends*

The figure below show the decadal rainfall trend in the study area.

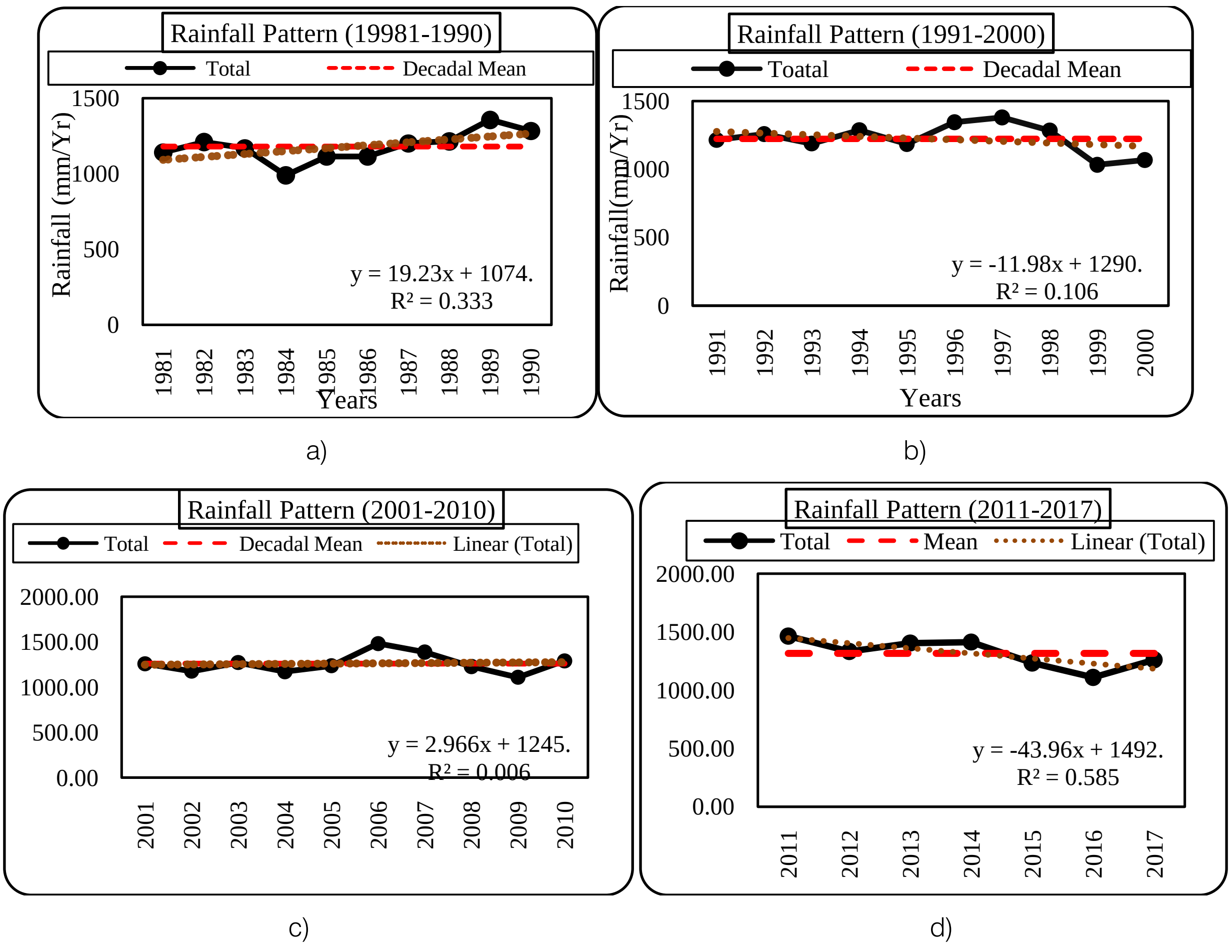
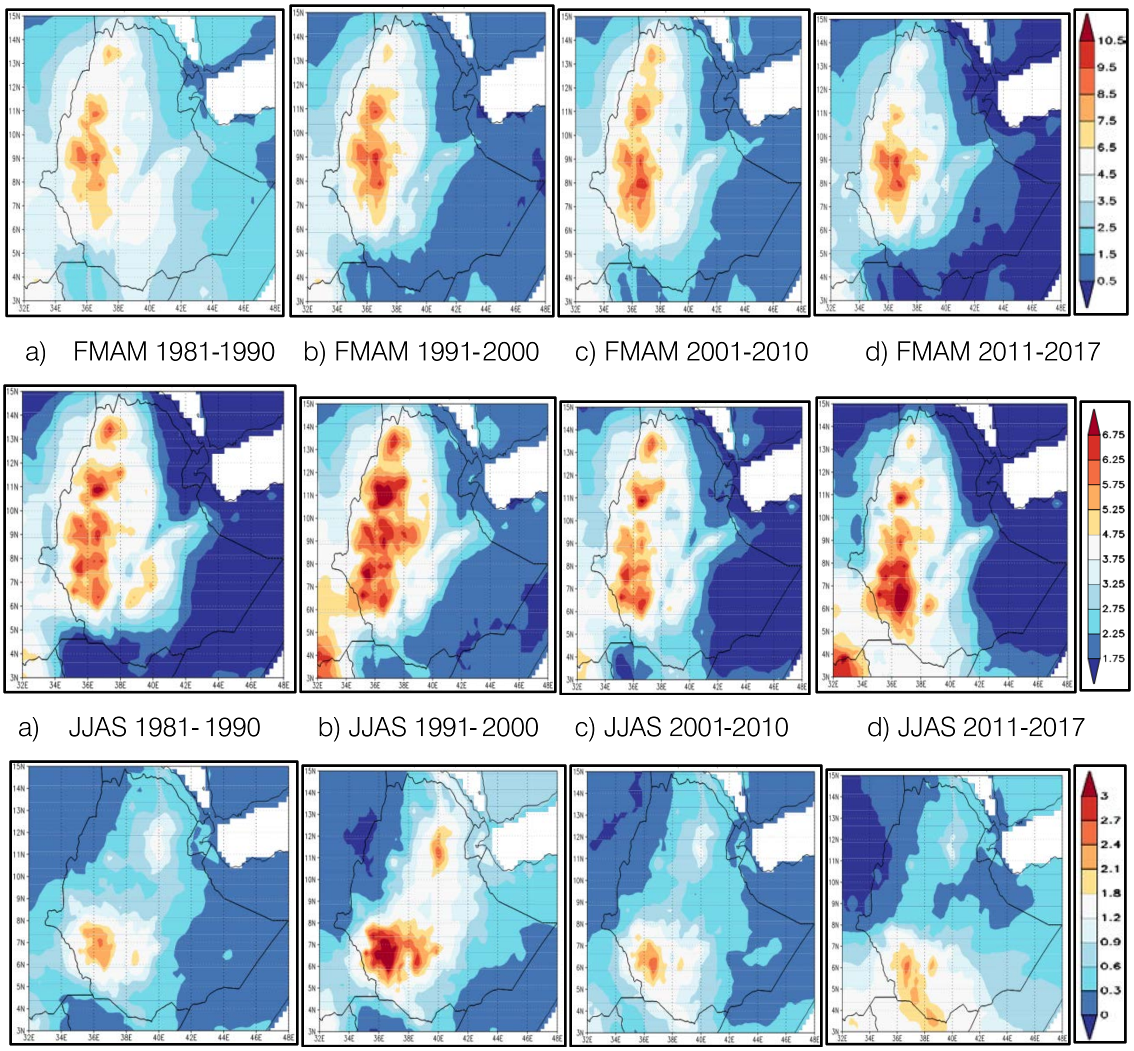


Figure 8: Decadal rainfall trend, a) (1981-1990), b) (1991-2000), c) (2001-2010) and d) (2011-2017)

The seasonality in the spatial distribution pattern of rainfall (Fig. 9) shows that the western and south western region of the area of investigation have high positive anomaly than the rest of the country. Particularly in the southern region, the rainfall decreases from the western part of the region to eastern and south eastern parts of the region. The Figure 9, also shows that a strong positive anomaly observed during the Kiremt than the rest of seasons. However, some studies reveal contrasting results (Degefu and Bewket, 2014) that the southern part, particularly Omo-Ghibe river basin showing an increasing trend, however, statistically significant decreasing trend observed in southern part of the region (Seleshi and Zanke (2004). Nevertheless, the observed and projected rainfall trends derived from the high resolution data and ensemble models show that an increasing trend of rainfall in the study region, including the East Africa (Christensen, et al. 2007).

These discrepancies may be due to difference in the delineation of climatological zones. Climatologically, the southern region means not exactly southern regional state of Ethiopia, as pointed in our study (4.43°- 8.58° N and 34.88° - 39.14° East) which encompasses the state, and the finding attributes mainly to the selected region.



a) FMAM 1981-1990 b) FMAM 1991-2000 c) FMAM 2001-2010 d) FMAM 2011-2017

a) JJAS 1981-1990 b) JJAS 1991-2000 c) JJAS 2001-2010 d) JJAS 2011-2017

a) ONDJ 1981-1990 b) ONDJ 1991-2000 c) ONDJ 2001-2010 d) ONDJ 2011-2017

Figure 9: Seasonal variability of rainfall changes over decades from 1981-2010. Months FMAM, JJAS and ONDJ represent Belg (moderate rainy season), Kiremt (main rainy season) and Bega (dry season) respectively

c) *Large scale Teleconnection features associated to seasonal precipitation*

Large-scale atmospheric driving force from the warming of sea surface temperature (SST) is one of the main factors for the modulation of seasonal rainfall pattern of the study area. Physical processes associated with the extreme SST anomaly in tropical Eastern Pacific causing climate variability over thousands of miles away (Wolde-Georgis, 2014). In this study, we find out the association among the SST anomalies in the Eastern Equatorial Pacific Ocean (Nino 3; 5° S - 5° N, 150° W - 90° W), Nino 3.4 (5° S - 5° N, 170° W - 120° W) and Nino 4 (5° S - 5° N, 160° E-150° W; Fig 10), and Southern Oscillation Index (SOI) with rainfall pattern in the study area. We used one month lag correlation of Nino SST and zero lag correlation of SOI to the seasonally averaged rainfall anomaly of the study area. .

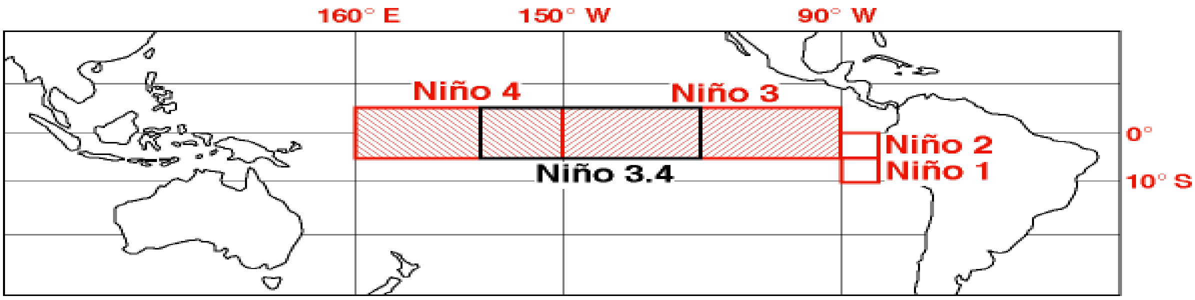
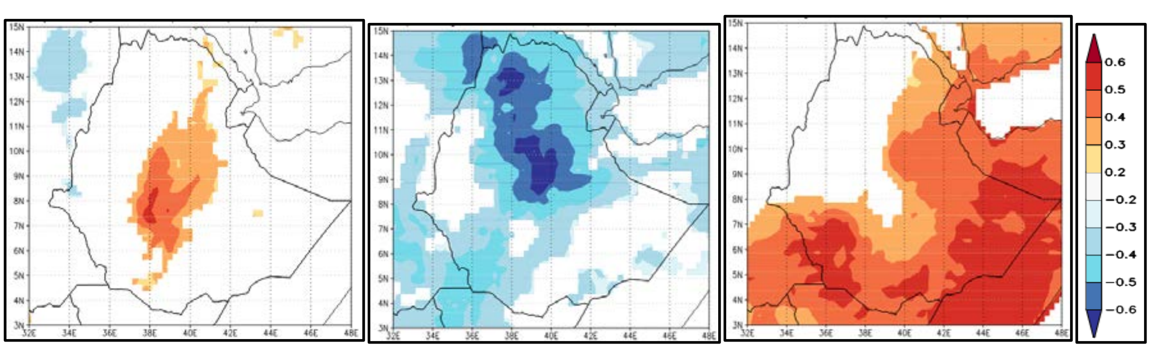


Figure 10: Locations of the Niño sea surface temperature demarcated regions (http://www.aoml.noaa.gov/hrd/Landsea/lanina/figures.html)

The results indicate that, rainfall during JJAS (long rainy season) has been negatively correlated with the sea surface anomalies of all three Niño regions, while the maximum negative correlation noticed with the Nino 3.4 region. The rainfall during FMAM (short rainy season) season was observed to have positive (one month lag) correlation with all Nino three regions, but higher statistically significant correlation $(r = 0.35)$ observed with only Nino 4 region at $(\alpha = 0.05)$level. The driest season (ONDJ) show statically significant positive one month lag correlation with three Nino regions, but maximum correlation $(r = 0.62)$ was observed with the Nino 3 region. Similar findings were noticed by many researchers (Degefu et al.2017;Korecha and Barnston, 2007), especially correlation of JJAS (Kiremt) and FMAM (Belg) with SST anomaly of the Nino 3.4 region. These two seasons are important for agricultural activities across the country. However, the correlation between SST anomaly and rainfall is stronger for the northern and north western highland parts of the country than the south and south eastern parts of the country (Degefu et al., 2017). Similarly, statistically significant negative correlations (≥ -0.34) observed between JJAS rainfall and Nino 3.4 SST in northern, southern highlands and south-western Ethiopia (r=-0.37; Korecha and Barnston (2007)). This is further supported by scatter plot of the JJAS standardized rainfall anomaly with Nino 3 SST anomaly (r = -0.36; Fig 15). However, insignificant correlation noticed for JJAS standardized rainfall anomaly data with Nino 4 SST anomaly (r= -0.26 at $\alpha = 0.05$ level).

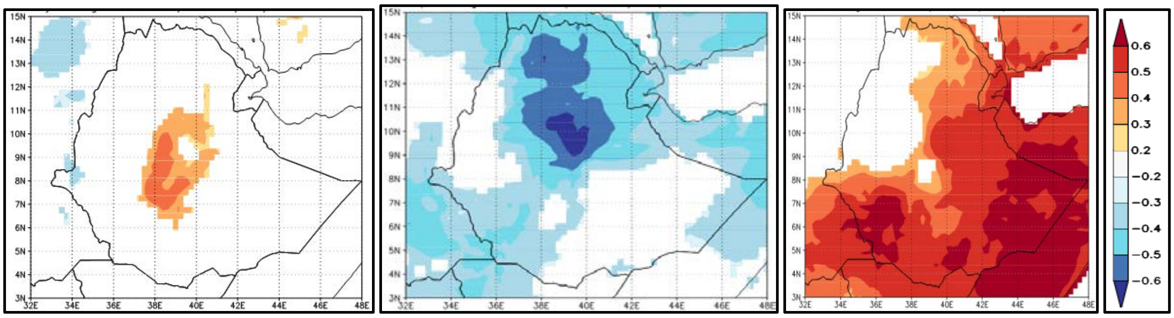
The SST anomaly of the tropical Eastern and Central Pacific Ocean found to be negatively correlated to Kiremet rainfall (JJAS) and positively correlated to Bega season (FMAM; Babu, 2009). During the El Nino years (warm SST), the atmospheric circulation particularly in the tropics is disturbed as a result of rain producing component during Kiremt (JJAS) either weakened or dislocated, however, during Bega (FMAM) enhanced. Intensive analysis done on predictability of Kiremt (JJAS) rainfall across the country (Korecha and Barnston, 2007) indicates that, a moderately strong teleconnectivity observed between the boreal summer ENSO state and concurrent JJAS Ethiopian seasonal rainfall, whereas during La Nina (El Nina) were amiably associated with enhanced (suppressed) JJAS rainfall across the country.

1. *Relationships between spatial correlation and Nino SSTs*



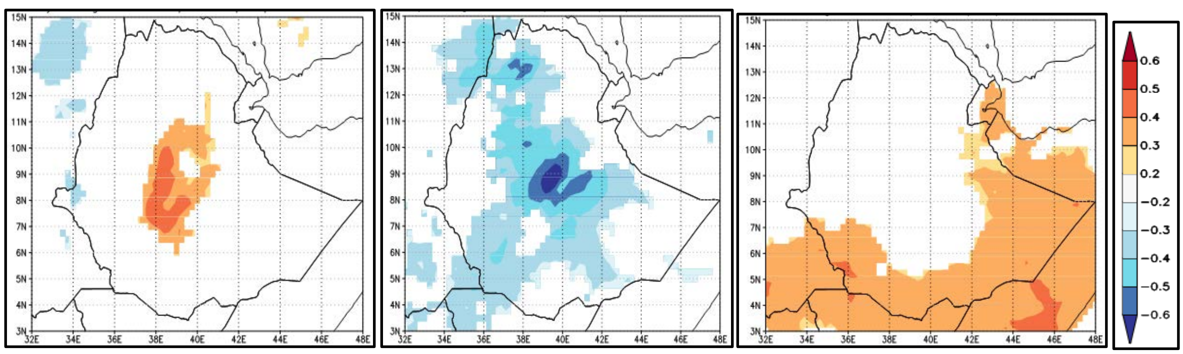
a) b) c)

Figure 11: Relationships among the spatial correlations of rainfall anomaly with one month lag of a) Feb-May (Belg), Jun-Sept (Kiremt) and c) Oct-Jan (Bega) with Nino 3.4 SSTs during 1981-2017.



a) b) c)

Figure 12: Relationships among the spatial correlations of rainfall anomaly with one month lag of a) Feb-May (Belg), Jun-Sept (Kiremt) and c) Oct-Jan (Bega) with Nino 3.0 SSTs during 1981-2017.

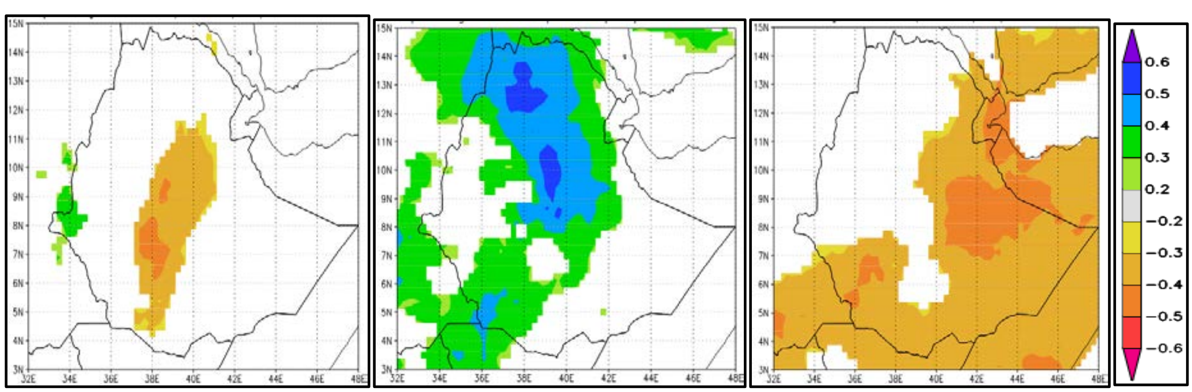


a) b) c)

Figure 13: Relationships among the spatial correlations of rainfall anomaly with one month lag of a) Feb-May (Belg), Jun-Sept (Kiremt) and c) Oct-Jan (Bega) with Nino 4.0 SSTs during 1981-2017

Similarly, the relationship between the Southern Oscillation Index (SOI) and seasonally averaged rainfall anomaly indicates that, statistically non-significant, weak negative correlation noticed between the standardized rainfall anomalies of Bega (ONDJ) and Belg (FMAM), and moderately positive correlation found between standardized Kirmt (JJAS) rainfall anomaly and SOI at 95% statistical confidence level. Likewise, the Kiremt/Belg seasonal mean of Southern Oscillation Index (SOI) is positively/ negatively correlated with Kiremt/ Belg rainfall.

2. *Spatial correlation between seasonally averaged precipitation and corresponding SOI anomalies*



a) b) c)

Figure 14 : Relationships among average precipitation anomalies of a) Feb-May (Belg), b) Jun-Sept (kiremt) c) Oct-Jan (Bega) with the corresponding SOI data

The scatter plot of correlations among seasonally averaged standardized rainfall anomalies one month lag with the standardized Nino 3.0, Nino 3.4 and Nino 4.0 SST anomalies showing inverse relationships, with the exception for the mean seasonal SOI.

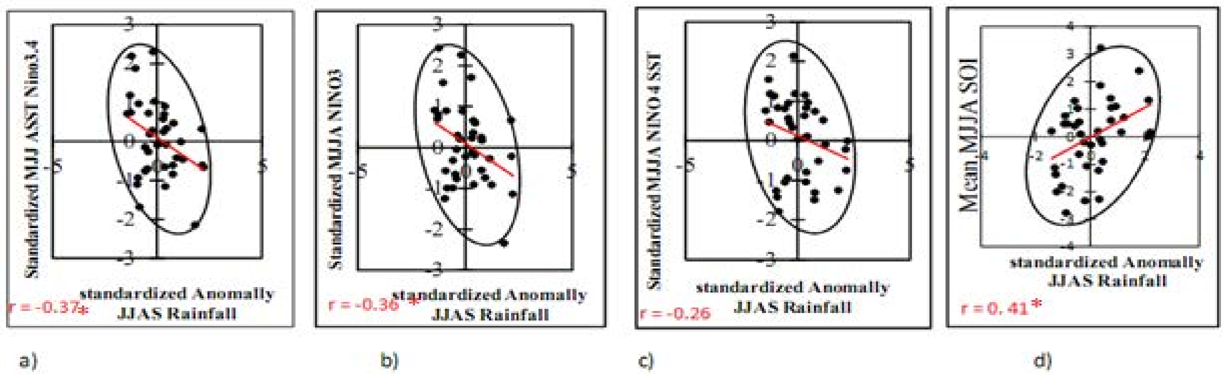


Figure 15: Correlations among standardized rainfall during JJAS with standardized MJJA Nino 3.4, Nino 3, Nino 4 SST anomaly and JJAS SOI.

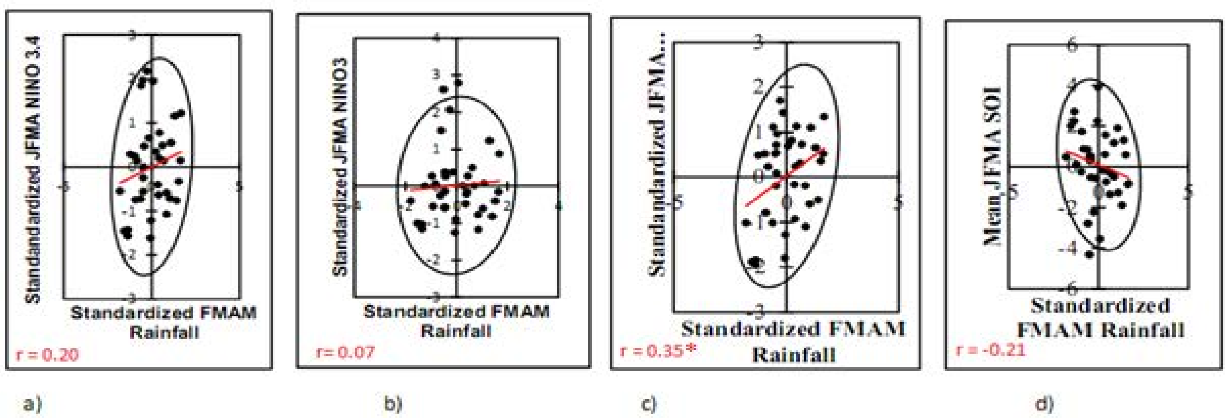


Figure 16: Figure 17: Correlation among standardized rainfall anomaly during FMAM with standardized JFMA Nino 3.4, Nino 3, Nino 4 SST anomaly and FMAM SOI.

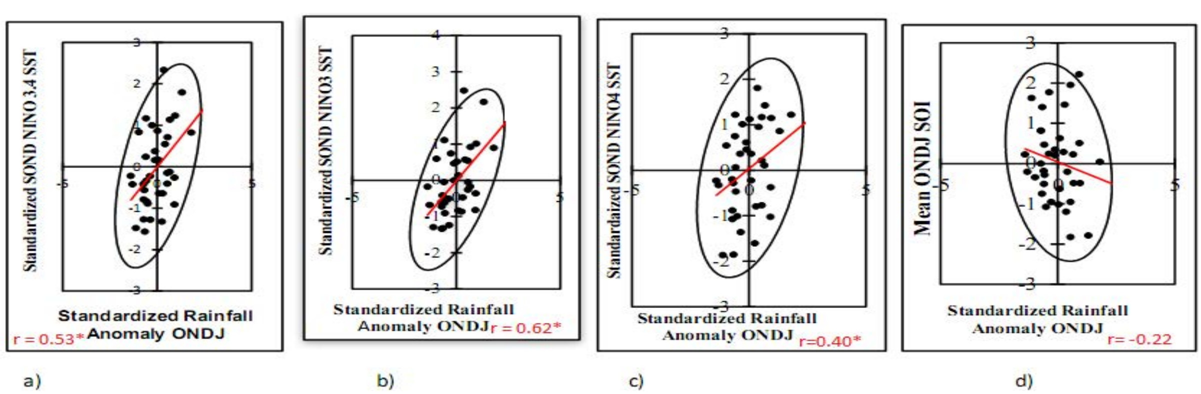


Figure 17: Correlation among ONDJ standardized rainfall anomaly with standardized SOND Nino 3.4, Nino 3, Nino 4 SST anomaly and ONDJ SOI (*correlation is significant at $\alpha = 0.05$ level)

IV. Conclusion

In this study, we use high resolution CHRISP rainfall data of the southern regional state of Ethiopia, Oceanic Nino indices and ENSO data to explore teleconnectivity of climate signals and distant Oceanic dynamics. Parametric and non-parametric statistical tests have been conducted to understand the monthly, seasonal, annual and decadal trends in rainfall patterns and controlling mechanisms. Statistically non-significant decreasing trends observed during December, January, February and March, while non-significant increasing trends were observed in the other months. The long rainy season- Kiremt (JJAS) and short rainy season Bega (FMAM) show non–significant increasing trend, but the driest season Bega (ONDJ) shows statistically significant increasing trend at $\alpha = 0.05$ level. Annual rainfall shows increasing trend of 4.12 mm/yr which is statistically significant 95% confidence level. On decadal basis, both non-significant increasing and decreasing trends were observed, the first (1981-1990) and the third (2001-2010) decades show increasing trend, whereas the second (1991-2000) and the recent (2011-2017) show decreasing trend. Annual and seasonal precipitation concentration indices computed show that low in annual (10.63), JJAS (8.52), ONDJ (10.47) and moderate index in FMAM (12.22), which represent low and moderate precipitation distribution respectively. Cross checking year of excess and deficit rainfall implicates La Nina and El Nino years respectively. El Niño tends to supress the Kiremt (JJAS) rainfall, but enhance Belg (FMAM) rainfall, however, the La Nina conditions tend to enhance Kiremt rainfall, but suppress Belg and Bega rainy seasons.

Changes in atmospheric circulation patterns in response to the tropical ocean's SST seem to be prominent controlling factors for excess/deficit quantum of the rainfall. Warming/cooling of Eastern and Central Pacific Ocean depress/enhance Kiremt (JJAS) rainfall in the study region. The Belg and Bega seasons show a different response for SST anomaly than Kiremt. Kiremt (JJAS) which showed statistically significant correlation after one month lag with Nino 3 ($r = -0.37$) and Nino 3.4 ($r = -0.36$) standardized SST anomalies at$\alpha = 0.05$ level, while relatively weak non-significant correlation was observed with Nino 4.0 ($r = -0.26$) standardized SST anomaly, but significant positive correlation was observed with mean seasonal Southern Oscillation Index (SOI) ($r = 0.41$). The analysis Belg (FMAM) season showed statistically significant positive correlation with Nino 4.0 SST anomaly ($r = 0.35$) at $\alpha = 0.05$ level. Compared to Kiremt and Belg seasons, but the driest season Bega (ONDJ) showed relatively strong significant positive correlations with all three Nino regions. The atmospheric circulation characterized by SOI shows insignificant weak association with Belg ($r = -0.21$) and Bega ($r = -0.22$) seasons respectively. The results of the previous studies conducted in the region by and large consistent with our study. Nevertheless, our study focus on the region covering regional state boundary. Therefore, this study suggests for a better preparedness for the optimum utility of the water resource for societal and sustainable development.

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