Spatio-Temporal Variability and Time Series Trends of Monthly and Seasonal Rainfall Over Northwestern Ethiopia

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Abstract: This study examined the variability and trends of observed monthly and seasonal rainfall during past years. This is a crucial work in countries and areas where rain-fed agriculture is predominant. Datasets for analysis were obtained from National Meteorological Agency of Ethiopia and Climate Hazard Group InfraRed Precipitation with Stations portal. Statistical tests and analysis were conducted employing advanced Python3. Monthly rainfall with temporal variability ranging from 9.77% to 141.93% was observed over 30 years. Highly variable (CV>30%) and less variable (CV<20%) rainfall was observed over 33 years. Rainfall during most months of the last 30 and 33 years showed a decreasing trend. Rainfall with temporal variability ranging from 12.7% to 75.92% and 8.111433% to 43.45% were observed over all three month seasons. Rainfall over three month seasons of the last 30 and 33 years showed a decreasing trend. Average total rainfall ranging from 107.203mm to 1016.82mm and 122.812mm to 1147.851mm, with variability from 9.163% to 55.6612% and 7.831% to 36.6821% were observed during the Belg, Kiremt and Bega seasons of the last 30 and 33 years, respectively. Decreasing in rainfall was tested over these three seasons of the last 30 and 33 years.

Key words: Spatio-Temporal Variability ᐧ Time Series Trend ᐧ Rainfall ᐧ Linear Regression Analysis

INTRODUCTION

Ethiopia receives rainfall at some stage in June-September (Kiremt), October-January (Bega) and February-May (Belg). Among these, Kiremt, the most important wet season, accounts for 50% to 80% of the annual rainfall, which is dominant in the northern and central parts of the c ountry [1]. The southern and south-western parts of the country get a significant quantity rainfall all through the Belg season, but Bega (October to January) is the driest season in most components of the country. However, on occasion north-eastern parts of Ethiopia get rain due to the development of the Red Sea convergence region as properly as the southward migration of the ITCZ gets rain over the southern and southeastern components of the

county [2]. The spatial and temporal distribution of rainfall in Ethiopia is generally managed by the annual north-south migration of the ITCZ over Ethiopia's complicated topography [3]. Agriculture is the major source of livelihood for a wide majority of Ethiopia's population. It employs 80% of the labor force and bills for 45% of the GDP and 85% of the export income [4] in any single year. Since an awful lot of the agriculture is rain-fed, the productiveness of agriculture and the nation's GDP varies in response to the amount and distribution of rainfall throughout the crop season [5].

It is estimated that a 10% reduce in seasonal rainfall commonly translates in to a 4.4% decrease in the country's food production [6]. Over the past 30 years, the country confronted seven extreme drought events in 1983–1985, 1988, 2000, 2002–2003, 2006, 2011 and 2015,

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with drought at some point of the duration 1983–1985 being one of the worst that the country has ever faced. El Niño-induced drought in 2015 affected 4.5 million humans in the drought-hit regions of Ethiopia [7]. The livelihoods and welfares of the humans are at once structured on and affected by the rainfall variability and extreme activities taken place. It undeniably affected human beings in distinctive geographical areas of the country. Although the exact have an impact on of climate change in Ethiopia has no longer been exhaustively investigated at large, previous studies indicated that the country has experienced rainfall variability-related issues like recurrent drought, desertification and occasional floods [8]. The variability and trend analysis of precipitation has obtained a top notch deal of interest lately due to the fact its accurate prediction determines the monetary development and, adaptation and mitigation plan of the country to fight local weather extremes. A range of studies have been carried out to check out precipitation developments throughout the country to be aware of the spatial and temporal variability [9-13]. The outcomes of this analysis can extensively contribute to management decision-making and policy planning approaches for one-of-a-kind economic improvement sectors of the country and the find out about vicinity with built-in climate. This study typically aimed to investigate the spatio-temporal variability and tendencies of rainfall that prevailed over the northwestern parts of Ethiopia in the case of the study area.

MATERIALS AND METHODS

Description of the Study Area: This rainfall evaluation was conducted at the Horro Guduru Wollega Zone of Oromia State. It was once located in the northwestern components of Ethiopia. It has about 12 administrative woredas. It lies between latitude 9°10' N and 9°50' N and longitude 36°00' E and 36°50' E direction. It has a total land coverage of 8, 097 km2 [14]. According to a record through [15], this zone has a complete population of 641, 575 of which 50.09% are male and 49.91% are female. According to the equal source, about 89% of the population lives in rural areas of the quarter riding their livelihoods based totally on rain-fed agriculture. The common annual temperature in the find out about vicinity is 22.1°C, with an average minimal of 13°C and an average maximum of 30°C [16]. The average altitude of the Horro Guduru Wollega Zone stages from 860 to 2657 meters above sea level [16].

Data Kind and Sources: Rainfall records units from National Meteorological Agency (NMA) stations and suitable fine dataset from on line websites have been used. 4kmx4km resolution gridded day by day precipitation datasets had been received from the National Meteorological Agency (NMA) of Ethiopia. Totally 24 stations under the NMA, which includes stations located in the extent and close to the border of the find out about area, had been used as sources of the rainfall dataset (daily) for the statistical evaluation applied. The blended average of the rainfall dataset from 24 stations was once used to signify the full extent of the studied climatic envelope or area, whereas rainfall dataset from individual stations was used for the statistical spatial evaluation. Additionally, satellite-observed precipitation information from the Climate Hazard Group InfraRed Precipitation with station records (CHIRPS) Network Common Data formatted (netcdf) datasets for the place accessed by way of handy public link .

Data Analysis Techniques: All statistical analyses had been employed using Python3 built-in functionalities in the jupyter notebook platform imposing the functionality of Python3 codes, built-in and exterior and/or user-defined functions, modules, packages and libraries. The observed rainfall dataset was analyzed and interpreted on the temporal scale of monthly, seasonal, annual, decadal and 30 years length basis. Seasonal evaluation was once applied to three-month and four-month seasons separately. Three-month seasons involved winter weather or regionally Bega (December-January), spring (March-May), summer time (June-August) and autumn (September-November). Four-month seasons concerned Kiremt or Meher (main wet season) extending from June to September and Belg (short wet season extending from February to May and Bega (dry season) extending from October to January month. A variety of techniques have been developed for the analysis of rainfall, which generally fall in to variability and time series trend analysis categories. Total, average (mean), minimum, maximum, coefficient of variability (CV%), slope (m) and P are computed statistical values used for the interpretation of the spatio-temporal variability and fashion analysis results. These values are also computed for the time sequence observed rainfall dataset at every NMA station to describe and look into the spatial version on the groundwork of temporal time scales. CV was calculated to consider the variability of rainfall. A higher value of CV is an indicator of larger variability and vice versa, which is computed as:
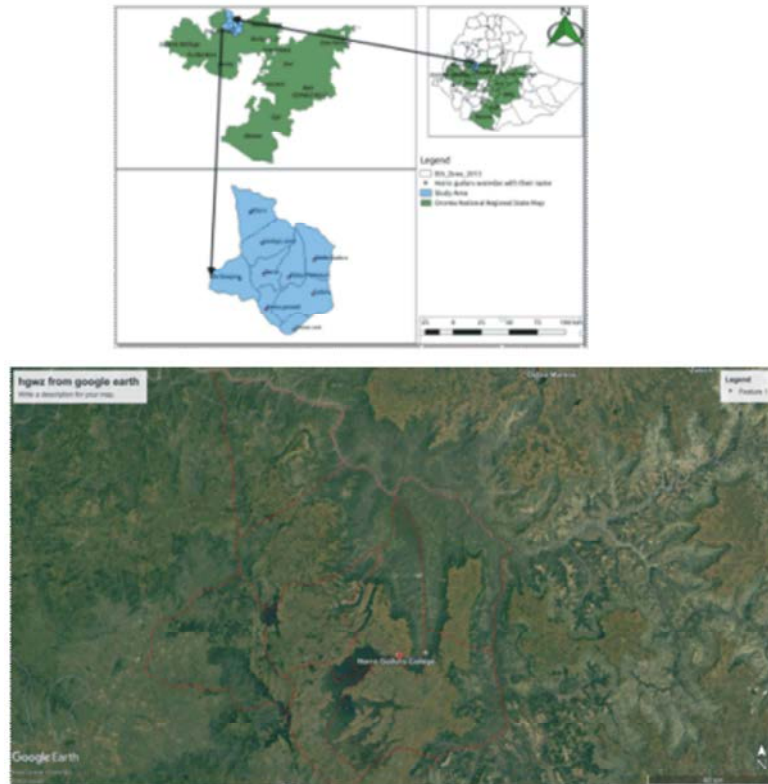
Fig. 1: Map of the study area

$CV = \sigma/\mu * 100;$

where CV is the coefficient of variation, ó is the standard deviation and ì is the average precipitation. According to Hare [17], CV is used to classify the variability of rainfall activities as less variable (CV < 20), moderately variable (20 < CV < 30) and highly variable (CV > 30). Trend detection and evaluation were performed by making use of the parametric check method. Linear regression evaluation was performed to detect the spatio-temporal trend of located rainfall that prevailed over the find out about area. A linear regression modeling was once developed the use of the functionality of the scikit-learn library of the Python3 programming language or software. Scikit-learn is a widely used Python3 library for machine learning, constructed on the package of Numpy and some different packages. It affords the ability for reprocessing data, lowering dimensionality, implementing regression, classification, clustering and more.

RESULTS AND DISCUSSION

Descriptions, Variability and Time Series Trends of Monthly Rainfall: There was a non-significant difference (P=0.55) among months (inter-month variations) in the observed average rainfall prevailed over the range of study period from 1987 to 2016 (30 years) and 1987 to 2019 (P = 0.474), as presented in Appendix 1. Monthly rainfall analysis results showed that relatively the highest average total rainfall was observed during the month of July (298.01556mm), followed by August (287.72361mm), June (225.39722mm) and September (205.6835mm) months over the study period ranging from 1987 to 2016, respectively (Appendix 1). The lowest average total rainfall was observed during January month (4.366667mm). The amount of observed rainfall during the February and December months of the period from 1987 to 2016 was very low when compared to other months of the same period (Appendix 1). During the last 30 years, the highest maximum total rainfall was recorded during the month of July (372.16667mm), whereas January, February and December were the three months with no rainfall or least minimum rainfall records per month (0mm) (Appendix 1). Statistical examination applied to the 1987 to 2019 observed monthly rainfall dataset showed that relatively the highest average total rainfall was observed during the month of August (365.9864mm) followed by July month (310.0924mm), as indicated in Appendix 1.

Table 1: Observed monthly total rainfall (4km by 4km resolution rainfall) at 24 meteorological stations during the period from 1987 to 2016

Month	Min.	Max.	Mean	Stdev.	CV(%)	Sign.
January	32 (sebader)	408 (Kokeffe)	131.0	96.53	73.7	0.96
February	44 (BSh)	464 (Goben)	170.38	104.455	61.31	0.885
March	325.0 Ayehu	1959 (Kachise)	972.92	455.4	46.81	0.969
April	982 kuy	2108 (Goben)	1433.7	317.122	22.12	0.48
May	2892.0 (kuy)	6170 (kokeffe)	4414.8	981.02	22.22	0.78
June	4637. (BSh)	8412.0 (Fincha)	6761.92	1029.7	15.23	0.283344
July	5409 (Gedo)	11760 (kokeffe)	8933.12	1585.1	17.744	0.046257
August	5539 (Gedo)	11235 (Kachise)	8631.71	1460.545	16.921	0.02
September	3642 (Gedo)	9327 (kokeffe)	6170.504	1331.42301	21.6	0.059
October	1234 (Gedo)	3564 (Haro)	2289.42	539.645	23.6	0.612
November	326 (Homi)	1023 (Haro)	550.1	140.221	25.5	0.966423
December	137 (AM)	421 (Haro)	245.6	82.7	33.7	0.811

BSh = Birr Sheleko; AM = Agallo Mitti

The rainfall observed during the December and February months of the year from 1987 to 2016 (30 years) was highly variable (CV > 30%) with a coefficient of variation value of 141.93% and 126.44616%, respectively (Appendix 1). The 1987-2016 August, July and June month rainfall was found to be less variable (relatively uniform pattern) with CV values of 9.77%, 10.058% and 15.326%, respectively (Appendix 1). It was investigated that most months of the year 1987 to 2019 were with high intra-month variability (CV > 30%) in a similar mode when compared to the months of the period from 1987 to 2016, except for June, July, August and September, with less variable (CV < 20%) rainfall observed over this period (Appendix 1). The monthly rainfall trend analysis results revealed that the trend of May and November rainfall over the period 1987 to 2016 is increasing. It was also investigated that the trend of July and November rainfall increased, whereas decreased over the remaining all months of the period from 1987 to 2019.

Descriptions, Variability and Time Series Trends of Observed Seasonal Rainfall: The numerical variation of observed rainfall over seasons was subjected to a significance test using F-test with P-value, which indicated statistically non-significant results (P>0.05), except for a numerical difference among seasons of both 30 years period (Appendix 1). Seasonal (winter, spring, summer, autumn) rainfall analysis (temporal) indicates that the highest average total rainfall observed during the summer season of the 30 years period (811.14 mm/season), whereas 18.232 mm/season is the lowest rainfall recorded during the winter season (Appendix 1). The winter season rainfall (30 years period) was highly variable (CV=75.92%),

followed by rainfall observed during the spring season of the 30 years period with CV% value of 38.01 (Appendix 1). The summer season rainfall over similar periods was found to be less variable (CV < 20%) with a CV% value of 12.7% (Appendix 1). The analysis results of observed rainfall over the 33 years period (CHIRPS dataset) indicated non-significantly different rainfall prevalence (Appendix 1). Relatively the highest amount of average total rainfall was observed during the summer season (918.2mm/season), whereas a low amount of average rainfall (total) was observed during the winter season of the 33 years period (Appendix 1). Statistically less variable (CV < 20%) total rainfall was observed over the summer and autumn seasons of this period. However, the observed rainfall (total) over the winter and spring seasons of the same period (33 years) were found to be highly variable (CV > 30%), with values 43.45% and 35.41%, respectively.

A decreasing trend of rainfall was observed over the winter (DJF), spring (MAM), summer (JJA) and autumn (SON) seasons of the 30 years period ranging from 1987 to 2016 (Figure 4). Similarly, time series trend analysis results showed a decreasing trend of rainfall observed over the winter (DJF), spring (MAM), summer (JJA) and autumn (SON) seasons of the 33 years period ranging from 1987 to 2019. The time series trend analysis applied with the linear regression model produced a negative coefficient of regression association between all three month seasons and the rainfall variable. The analysis results indicated that the observed seasonal rainfall decreased with an increase in one unit season per year (one year duration) during both the 30 and 33 year periods of time (Figure 4).
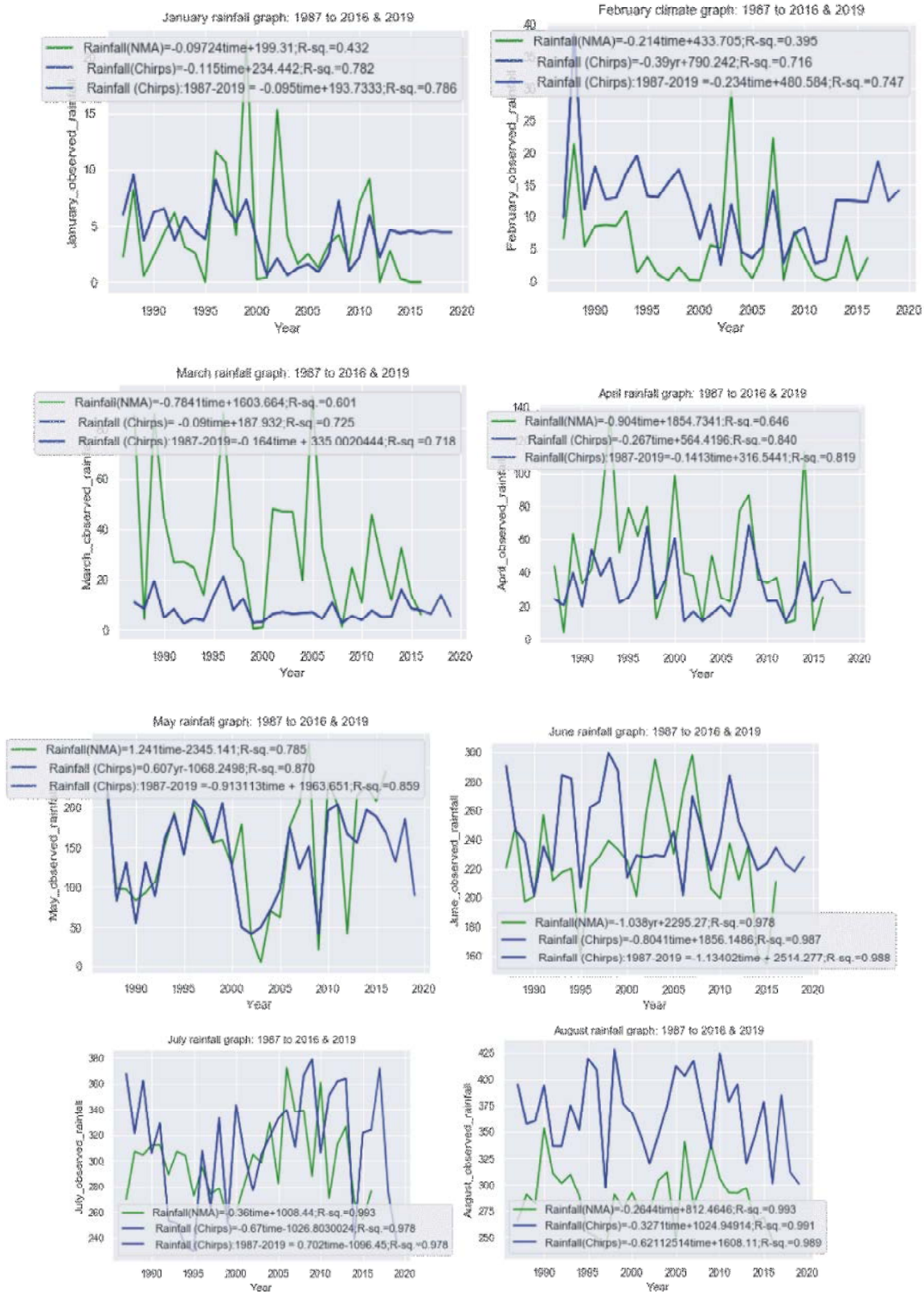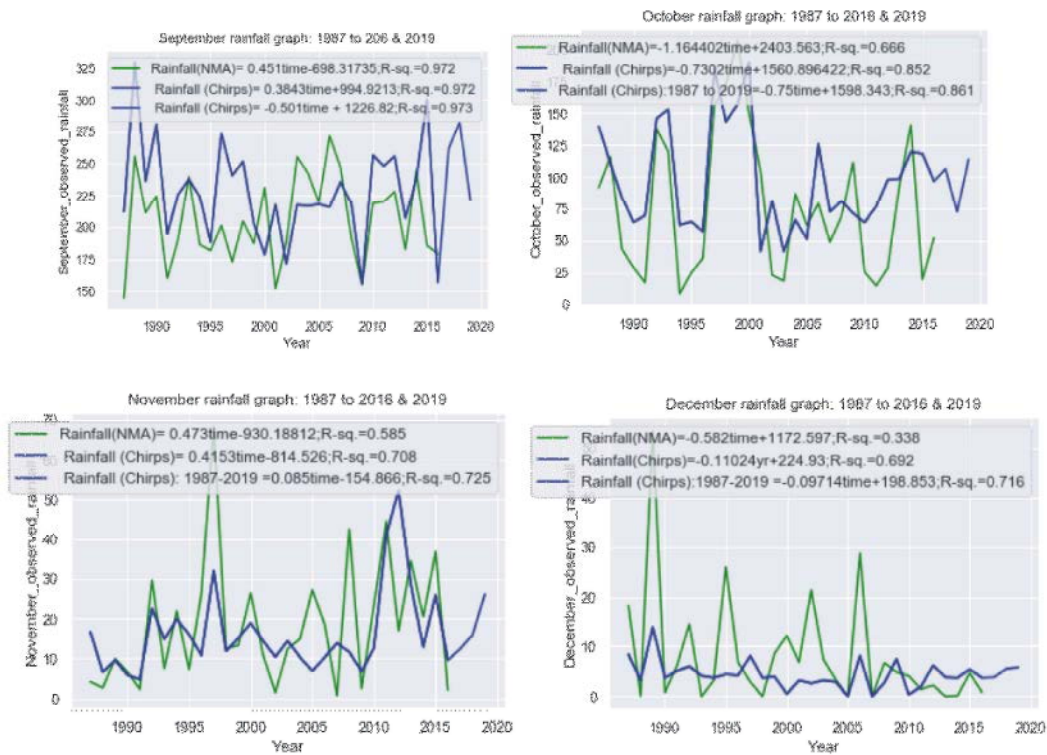
Fig. 2: Continued

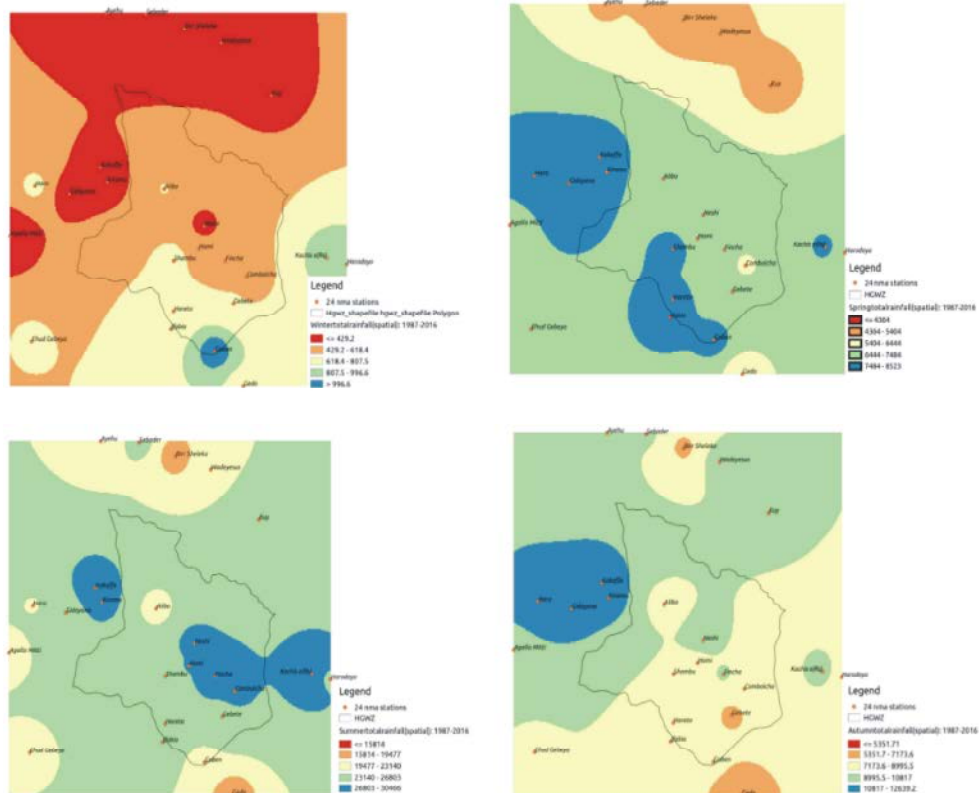Fig. 2: Time series trends of observed monthly total rainfall

Fig. 3: GIS-based plots of winter, spring, summer and autumn observed 30-years total rainfall spatial coverage features

Table 2: Winter, spring, summer and autumn season's rainfall (4km by 4km resolution rainfall) observed at 24 meteorological stations over the period from 1987 to 2016

Season	Min.	Max.	Mean	Stdev	CV%	Sign.
Winter	240.0 AM	1186.0 Goben	546.96	253.517	46.3503	0.906732
Spring	4364.0 BSh	8524.0 Gidayana	6821.375	1237.50341	18.1416	0.6732
Summer	15808.0 Gedo	30471.0 Kokeffe	24326.8	3792.66465	15.5905	0.040214
Autumn	5350.0 Gedo	12641.0 Kokeffe	9010.004	1804.8	20.0311	0.127

AM = Agallo Mitti station; Birr Sheleko

Table 3: Observed rainfall (4kmx4km resolution rainfall) during the *Belg, Kiremt* and *Bega* seasons at 24 meteorological stations over the period 1987 to 2016

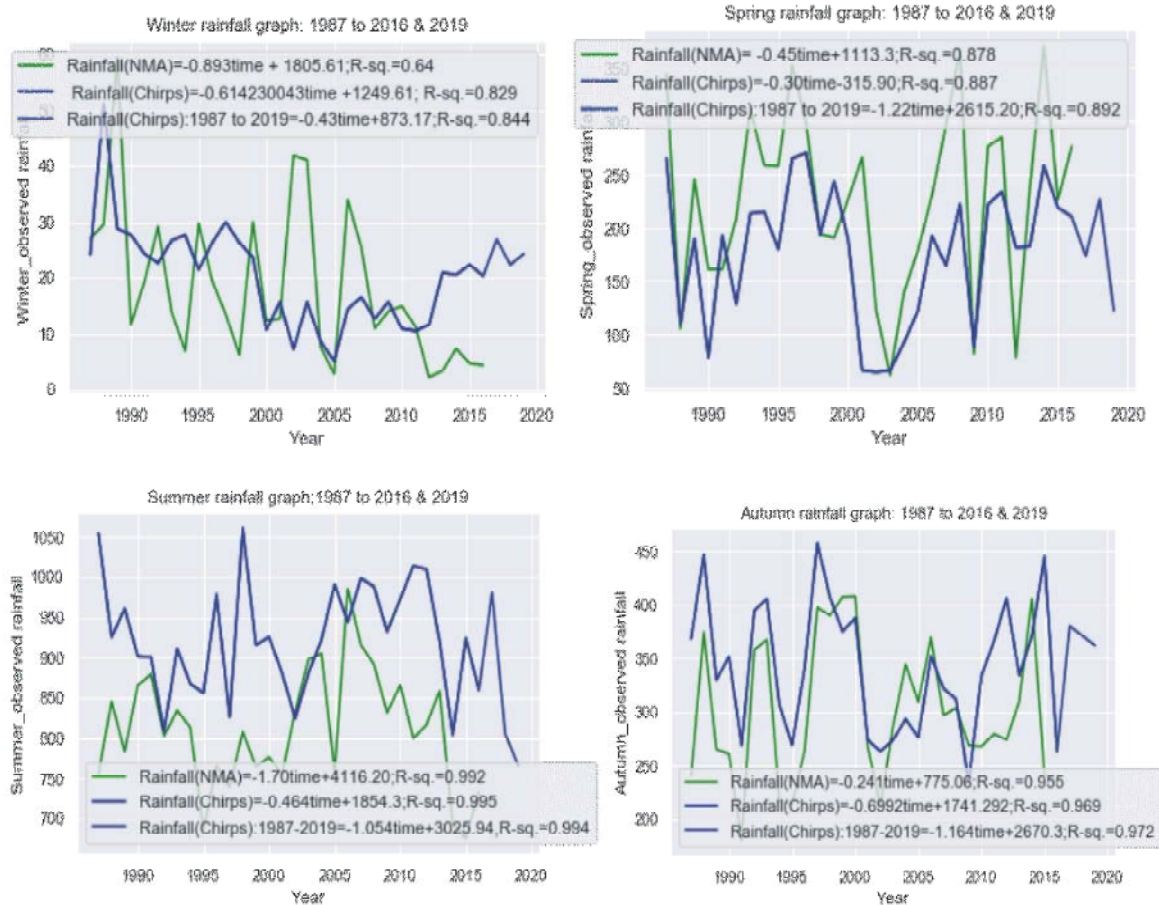| Season	Min.	Max.	Mean	Stdev.	CV%	Sign.
Belg (Short rainy season)	4408 BSh	8635 GA	6991	1278.02	18.3	0.692
Kiremt (Long rainy season)	19450 Gedo	39798 Kokeffe	30497.3	4745.9	15.6	0.03
Bega (Dry season)	2123 Gedo	5147 Haro	3216.1	597.733	18.6	0.672

BSh = Birr Sheleko; GA = Gidayana

Fig. 4: Graphical representations of time series trends of winter, spring, summer and autumn season observed rainfall prevailed over the 30- and 33 year periods of time. R-sq.= R-squared value
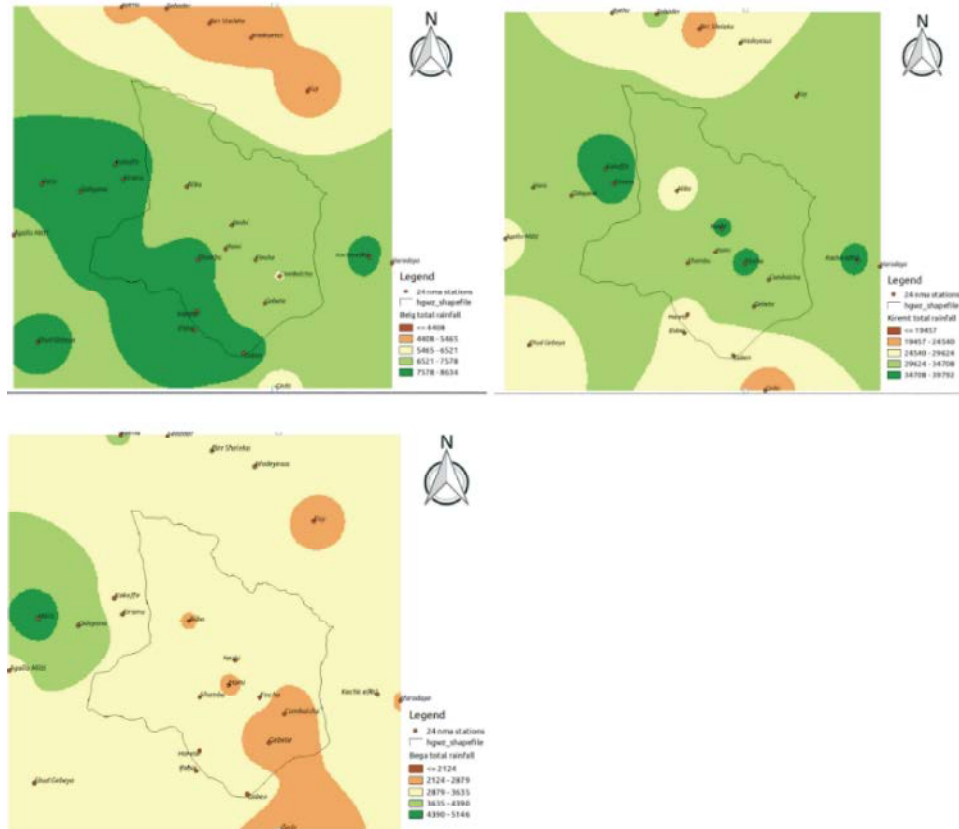
Fig. 5: GIS-based spatial plots of the *Belg, Kiremt* and *Bega* seasons observed rainfall over the period of 30-years
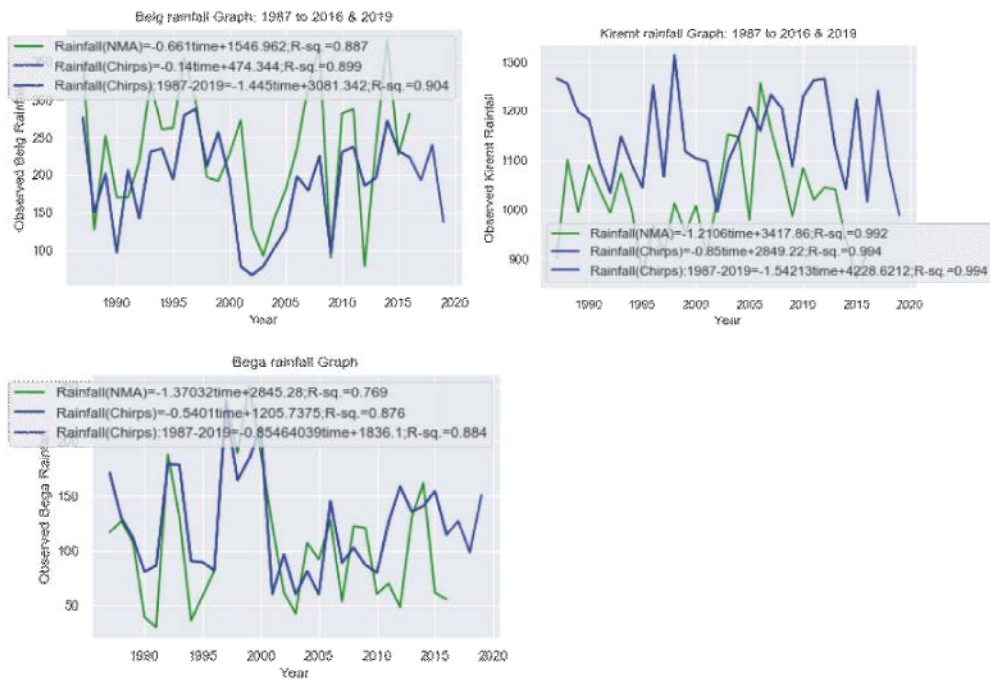

Fig. 6: Graphical representations of time series trends of *Belg, Kiremt* and *Bega* seasons observed rainfall prevailed over the period of 30 and 33 years. R-sq.= R-squared value

DISCUSSION

The temporal variability and trends of determined rainfall over 33 years can be linked to the exchange in the amount and distribution patterns of rainfall over a changing series of time series. In this study, it is distinctly anticipated that with the moving of each time scale i.e months, seasons, years and decades, there were modifications in the climatic tactics and systems that would possibly have been brought about by using natural and anthropogenic factors. This inturn would possibly have led to a alternate in the features of the located rainfall. In line with this, in the paper of Fitsum *et al.* [18], it is mentioned that temporal rainfall variation over specific parts of Ethiopia is the end result of the macro-scale pressure structures and moisture flows, which are associated to the changes in air stress systems over one-of-a-kind time scales. The rainfall variations over the study area during considered time scales may be due to the modifications in these stress structures over time. The spatial variability of rainfall over one-of-a-kind time scales might be due to altitudinal and region differences, which can force spatial version of rainfall over a duration of time. As concluded in preceding studies, owing to the irregular terrain (landscape), the distribution of rainfall radically differs even in a smaller geographic vicinity like the study area. In line with this, Sridhar Gummadi *et al*. [19] mentioned that rainfall over Ethiopia (including the find out about area) exhibits excessive spatial variability caused by means of giant editions in topography or altitude, giving upward jab to a multitude of agro-ecological zones (AEZs). According to paper with the aid of Fitsum *et al*. [18], it is cited that the spatial editions in rainfall are influenced by using adjustments in the intensity, position and path of motion of the rain-producing air pressure systems over the country. Also, in this paper, it is truly referred to that the spatial distribution of rainfall in Ethiopia is drastically influenced by using complex topography.

CONCLUSION

The highest total rainfall was found in the course of the month of July, observed by way of August, June and September months over the ultimate 30 years study period, ranging from 1987 to 2016. Average total rainfall in the course of summer season and winter used to be observed to be the highest and lowest observation per season. The minimum and maximum mean rainfall used to be determined at some point of the winter and summer time seasons. The highest and much less variable common total rainfall used to be discovered at some stage in the Kiremt season of the period, ranging from the 12 months 1987 to 2016 and 1987 to 2019.

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Appendix 1: Basic statistics of observed monthly, seasonal, annual, decadal and 30-years rainfall for the period 1987 to 2016 and 1987 to 2019

Month	1987 to 2016 Rainfall (30 years)					1987 to 2019 Rainfall (33 years)				
	Mean	Std	Min	Max	CV	Mean	Std	Min	Max	CV
Monthly										
January	4.366667	5.027456	0	21.375	57.873763	4.262121	2.339439	0.6	9.5	54.88907
February	5.679167	7.181088	0	29.625	126.44616	11.80758	6.821475	2.5	38.4	57.772
March	32.430556	26.314356	0.375	92.958333	81.141	7.75	4.646302	2.3	21.1	59.952
April	47.788889	33.31015	3.958333	135.08333	69.703	30.84394	15.72025	10.6	68.5	50.967
May	147.15972	73.138891	5.083333	280.08333	49.7003	138.8864	55.95936	41.1	230.6	40.291
June	225.39722	34.544532	153.875	298.1667	15.326	242.1197	27.43316	201.2	299.5	11.3304
July	298.01556	29.974992	253.8417	372.16667	10.058	310.0924	45.54445	229.6	378.9	14.687
August	287.72361	28.116448	238.2083	353.375	9.77	365.9864	38.13766	296.8	428.2	10.421
Sept.	205.6835	33.917611	144.1667	271.54167	16.49	229.379	38.86308	155.8	329.7	16.943
Oct.	76.31389	54.920645	8.375	206.91667	71.97	97.7788	39.80163	41.8	190.1	40.706
Nov.	18.33611	15.731988	0.791667	68.375	85.80	16.42879	10.31394	4.8	52.3	62.78
Dec.	8.186111	11.618511	0	53.541667	141.93	4.342424	2.77275	0	13.9	63.85
P-value	0.55					0.474				
3-monthly										
Winter(DJF)	18.232	13.84114	2.21	59.5	75.92	20.41212	8.87	5.1	51.1	43.45
Spring(MAM)	227.38	86.42	63.38	371.21	38.01	177.5	62.844	65.0	270.8	35.41
Summer(JJA)	811.14	72.8	676.01	984.92	12.70	918.2	74.5	766.0	1060.6	8.111433
Autumn(SON)	300.334	66.6	179.3333	407.71	22.2	343.6	59.15	233.9	457.8	17.215
P-value	0.451403					0.44				
4-monthly										
Belg(FMAM)	233.06	84.51	78.46	378.08333	36.3	189.452	62.8	67.5	286.1	33.15
Kiremt(JJAS)	1016.82	93.2	861.3	1256.46	9.163	1147.851	89.9	987.5	1312.3	7.831
Bega(ONDJ)	107.203	59.7	30.13	250.17	55.6612	122.812	45.05	59.8	232	36.6821
P-value	0.918495					0.963				