ANALYSIS OF SEASONAL PRECIPITATION VARIABILITY IN SOUTHERN TIGRAY REGION, NORTHERN ETHIOPIA, AFRICA

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ABSTRACT
Climate changes and variability in regional precipitation affect decreased agricultural production and potentially widespread food shortages. Africa has often shown rainfall variability and associated droughts leading to food shortages. Moreover, small scale spatial and temporal variability of the climate parameters in Northern Ethiopia, Tigray Region is highly complex and not well known yet or little is done recently. It is, therefore, essential to assess the temporal and spatial variability of rainfall and temperature so as to quantify its effects on socio-economic activities and specific challenges in the study areas. The study areas (Raya-Azebo and Raya-Alamata) are situated in the Raya Valley cluster, in the South zone of Tigray national regional state. In order to identify the monthly pattern of rainfall heterogeneity we used Precipitation Concentration Index. We found that, annual total rainfall shows high spatial and seasonal variability. In addition, belg season rainfall has an extreme inter-seasonal variability. Moreover, the study areas were characterized by episodic fluctuation of wet and dry years. This study emphasizes the helpfulness of PCI in distinguishing precipitation concentration and variability. It was observed that seasonal rainfall and PCI are changing and variable.

Keywords: Precipitation Concentration Index, Rainfall Variability, Ethiopia, Tigray

INTRODUCTION

The issue of climate change and variability has become more threatening not only to food security and sustainable progress of any nation, but also to the totality of human survival Gadgil et al. (1998). There is a significant worry over the worldwide problem of climate change and it is pronounced as the most common and irreversible environmental problem facing the planet Earth (IPCC, 2001a). The results of climate variability such as increasing temperature and changes in precipitation are irrefutably strong with impacts recently disturbing biophysical environment and human beings. Questionably one of the most extensive and potentially overwhelming effects of climate change in East Africa will be changes in the frequency, concentration, and likelihood of precipitation and temperature. Changes in precipitation disturb water availability and may lead to reduced agricultural production and potentially widespread food scarcities (Hulme et al. 2001, IPCC, 2001 and Michael, 2006).

Africa has often shown rainfall variability and associated droughts leading to food shortages (Wood, 2007; Pankhurst and Johnson, 1988). Similar to other African nations, Ethiopia is generally one of the most susceptible countries to climate change (Conway and Schipper, 2011). Ethiopia's economy is based mainly on agriculture and its share is 41% of the country's gross domestic product (GDP), employs 80% of the work force and sources for more than 80% of the foreign exchange earnings (You and Ringler, 2010). Agriculture in Ethiopia is primarily rainfed that comprises many small-scale farmers for survival (Deressa et al. 2009). This condition together with its geographical position, relief and little economic possessions, makes the country highly vulnerable to the severe effects of climate change (Gebreegziabher et al. 2011). Conferring to reports, climate variability has numerous effects on the country's economy and health of the population, such as flooding's, deficiencies of water, or hailstorms. Ethiopia is one of the least developed countries whose economy increases and decreases together with mean changes in precipitation and hence the country is best example about the effects of climate change and variability.

Among the regional states of Ethiopia, Tigray Regional State has been vulnerable to climate change (stable change over a long period of time usually 30 years or more). Climate change is expected to increase the frequency and magnitude of natural disasters and extreme weather events. Observations revealed that mean minimum and maximum temperatures of the region for the period 1954 to 2008 have increased by 0.72 and 0.36°C per decade, respectively indicating that the region is warming faster than the national average of 0.25°C (Gebrehiwot and van der Veen, 2013). Moreover, mean annual rainfall has shown a decreasing trend (Teka et al. 2012, Gebrehiwot and van der Veen, 2013). The onset and rainfall cessation date has changed towards decreasing the length of growing period (Hadgu et al. 2013).

The seasonal climate variability of Ethiopia, particularly rainfall, is influenced by weather systems of various scales; from meso-scales to the large scale, mainly El Nino-Southern Oscillation (ENSO) related phenomena (NMSA, 1996). It has been also noted that the rainfall is highly variable in amount, distribution and becomes unpredictable across regions and seasons (Tesfaye and Walker, 2004, Tilahun, 1999 and Mersha, 1999). This erratic rainfall and persistent droughts in Ethiopia distresses the lives of millions of people as the people's living rests on the availability of rainfall. In spite of these understandings, as a nation whose economy is highly reliant on rainfall and its pattern, depicting regional/local climate measures (temperature and rainfall trends) are the most important influences in elucidation several socio-economic complications. Therefore, depiction of temperature and rainfall state is essential, especially in Ethiopia whose economy exceedingly rest on smallholder agriculture production.

Northern Ethiopia is an area mostly affected by climate variability and thus series of droughts. More than a dozen localized and regional droughts had been recorded in this area with in the last three decades (Degefu, 1987, Camberline, 1997, DPPC, 1997 and Vste et al. 2013) and devastated agricultural productions millions of rural poor farmers and their environment. Yet, almost no study is imminent to see changes in rainfall characteristics and its associate relationships to agricultural productions in the study areas based on PCIs. However, (Bewket, 2009 and Abrha and Simhadri, 2015) has seen the relationship between rainfall variability and crop production using time series data and correlation analyses in the neighboring Amhara regional state. The latter the perception of local climate change and their adaptation options in Tigray regional state. The analysis was on aggregate level where annual rainfall and production records were taken for comparison based on historical data. The study also shows the role of climate-smart agricultural technologies in minimizing effects of climate change and variability. Moreover, small scale (local) spatial and temporal variability of the climate parameters over the country in general and Northern Ethiopia Tigray Region and Raya-Alamata and Raya-Azebo districts in particular is highly complex and not well known yet or little is done recently. It is, therefore, essential to assess the seasonal, temporal and spatial variability of rainfall in an area so as to quantify its effects on the socio-economic activities that could be translated into the best adaptation options according to the development potential and specific challenges in the study area.

Furthermore, in Ethiopia in general and in Northern Ethiopia, Tigray Region and Raya-Alamata and Raya-Azebo districts in particular, the risks of variability in climate patterns that smallholders face is believed to be due to the lack of regional/local climatic information, low adaptive capacity and limited adaptation options (Hadgu et al. 2013). Hence, understanding the historical and temporal dynamics of these shocks highlights the impacts on the food system and points the way to the timing of potential interventions. This information also helps determine the relative investment necessary to address one or more existing hazards in the study area at least. To that end, analyzing and charactering variability of rainfall and temperature through scientific investigations is crucial in order to help researchers, policymakers and developers to make sound decisions, at regional and/or local levels.

Therefore, the general objective of this study is analysis of the spatial and temporal variability of rainfall in Northern Ethiopia, Tigray Regional State i.e., Raya-Alamata and Raya-Azebo districts for the period 1980-2016. The study specific objectives are:

1. Analysis of seasonal precipitation distribution pattern in space and time;
2. Assessing inter-annual rainfall variability in Southern Tigray
3. Discussing the relationship between number of rainy-days and total amount of precipitation.
4.

MATERIALS AND METHODS OF THE STUDY

Description of the study areas

The Federal Democratic Republic of Ethiopia (FDRE) is a landlocked country located in the horn of Africa, bounded to the north by Eritrea, to the west by Sudan, to the south by Kenya and to the east by Somalia and Djibouti. It lies within the tropics between 3°24` and 14°53` N latitude; and 32°42` and 48°12` E longitude. The population was estimated at about 94 million in 2013, making it the second most populous country in Africa, after Nigeria (World Bank, 2015), with a growth rate of 2.6%. Rural population was more than 82% and the rest is urban (Central Statistics Agency, 2012). Ethiopia has nine administrative regions and two city administrative regions. Northern part of Ethiopia is covering Tigray Regional State. Tigray is one among the smallest regions of the country in terms of area surface 80,000 square miles (CSA, 2012). The Region is bounded by Eritrea in the North and North East, Sudan in the West, the Regional States of Amhara and Afar in South and Eastern part respectively (Solomon 2005). Tigray region is composed of 34 districts and 16 town administrations which are clustered in to 7 zonal administrations; such as Western Zone, North-western Zone, Central Zone, Eastern Zone, South-eastern Zone, *Mekelle* Zone and Southern Zone.

The study area is situated in the South zone of Tigray national regional state. The Raya-Alamata Woreda is geographically located between 1362240 and 1371780 north and 526941 and 582966 east longitude, in Southern Tigray. Raya-Azebo Woreda is located in the south eastern part of Tigray within1412230 to 1421000 north latitude and 561700 to 600025 east longitude. A semi-arid type of climate characterizes the study areas receiving highly variable rainfall. Though bi-modal, the annual rainfall also varies widely in space and in time. The study areas receive annual average rainfall between 450 and 700 mm. Eutric Vertisols, Lithic Leptosols (Cambic) and Lithic Leptosols (Orthic) are the soil types covering most of the land in the woreda's. In the study areas, farm land is ready for sowing seeds using old-style oxen draughts tool 'Mehresi'. The major cereal crops grown in the area are Sorghum (*Sorghum bicolor L*.), Maize (*Zea mays* L.) and Teff (*Eragrostis teff*) Southern Zone of Tigray Regional State (2016).

Ethiopia has four seasons which was classified mainly based on the precipitation and temperature patterns. These seasons include: **Kiremt** or Meher (Summer)-June, July and August are the summer season. Heavy rain falls in these three months. **Belg** (Autumn)-September, October and November are the spring season sometime known as the harvest season. **Bega** (Winter)-December, January and February are the dry season with frost in morning specially in January. **Tseday** (Spring)-March, April and May are the autumn season with occasional showers. May is the hottest month in Ethiopia.

Location of Meteorological Stations

The considered stations are Mechare, Waja, Alamata, Mehoni and Chercher. All stations are found within the study area. The daily climate data rainfall both observed and gridded data were collected from National Meteorological Agency of Ethiopia starting from 1980 to 2016. However, it is for very limited number of stations that the data on all required parameters is available. In addition, we have also faced problems with the quality of available data. The main problems are with missing data and outliers. Hence, we focused only on those stations that are representative of the target agroecology and have good continuous 30-year record with less than 10% missing data. A total of 5 station data was found to be suitable for use in this study. Of the 5 stations, the two stations Alamata and Chercher, although solar radiation data is either not available or available for few years, were selected as climate weather stations in the two districts. The daily precipitation data were collected from the above said station.

Table 1 geographical locations and rainfall characteristics of stations in study area

Station	Easting	Northing	Elevation	Mean rainfall mm	Mean Temperature ^{0}C
Alamata	577170	1370399	1579m	748.92	22.29
Chercher	583226	1386609	1781m	673.92	23.52

Source: NMA, 2017

Consequently, every historical data sets were patched for any missing values. The metrological data of these stations is not complete due to the occurrence of missing data. For example, the Alamata station has six unrecorded years of temperature. The missing records were supplemented and filled using the best approximate AgMERRA data set available from the Agricultural Model Intercomparing and Improvement Project (AgMIP) to complete the series (Flato et al. 2013).

Detecting outliers

As (Gonzalez-Rouco et al. 2011) urges, primary emphasis was given to identify outliers in the climate data. Outliers are values greater than a threshold value of a specific time series data that can affect detection of inhomogeneity. For non-normally distributed data like rainfall, the Turkey fence is recommended for trimming the outlier (Ngongondo et al. 2011). The Turkey fence applied in this study was set only for upper limit on the presumption that any rainfall value below zero is considered an outlier. Values outside the Turkey fence were considered as outliers and such outliers were set to a limit value corresponding to **+- 1.5 *IQR**.

Hence, the fence is represented as: [Q_3+1.5*IQR] as upper limit. ………………..…. (1)

Where: Q3 is upper quartile point, 1.5 standard deviations from the mean and IQR is interquartile range.

Precipitation Variability and Concentration Indexes

Precipitation variability and extremes can, therefore be quantified by the frequency analysis of rainfall series and precipitation heterogeneity indexes (Kumbuyo et al. 2014). Some straight forward indicators have been employed to evaluate precipitation concentration used to provide information on its variability (De Luis et al. 2011 and Apaydin et al. 2006). These indices include Precipitation Concentration Index (PCI) (De Luis et al. 2011 and Oliver, 1980) Simple Daily Intensity Index, Precipitation Concentration Degree (PCD) and Precipitation Concentration Period (PCP), modified Fourier Index (Hernando and Romana, 2015), Seasonality Index (Kumbuyo et al. 2014) etc. A higher precipitation concentration represented by greater percentages of the yearly total precipitation in a few rainy days has the potential to cause flood and drought phenomena.

It is actually imperative to examine precipitation difference and concentration. As a result, the main aim of this paper is to evaluate the concentration and variability of rainfall in time using PCI and to explore possible relationship between PCI and annual rainfall total; and between PCI and seasons. Therefore, in this study we used PCI and based on recommendations by numerous studies that it provides information on long-term total variability in the amount of rainfall received (De Luis et al. 2011, Apaydin et al. 2006, Michiels et al. 1992 and De Luis et al. 2010b). Moreover, the monthly mean rainfall in millimeters (mm) was investigated at the woreda level for both woredas and standard values, mean, standard deviation (SD), and coefficient of variation (CV) were computed.

In order to identify the monthly pattern of rainfall heterogeneity in our study areas, we applied (Oliver, 1980) Precipitation Concentration Index (PCI), analyzed at annual scale (January-December).

$$\mathbf{PCI = 100 * \left[\frac{\sum r_{mi-12}^{2}}{(\sum r_{mi-12})^{2}}\right]} \ldots\ldots\ldots\ldots \textbf{(2)}$$

Where r_m is the amount of rainfall in the m_i-12th, month which runs from 1-12th month.

In order to recognize the monthly pattern of rainfall heterogeneity in our study areas, we applied (Oliver, 1980) Precipitation Concentration Index (PCI), examined at seasonal scale (January-February-March, April-May-June, July-August-September, October-November-December).

Seasonal Precipitation Concentration Index were described as:

$$\mathbf{PCI = 25 * \left[\frac{\sum r_{mi-3}^{2}}{(\sum r_{mi-3})^{2}}\right]} \ldots\ldots\ldots\ldots \textbf{(3)}$$

Where r_m is the amount of rainfall in the m_i-3rd month which runs from 1-3rd month. The seasonal PCI was calculated using eq. 3

Moreover, the standard precipitation concentration index (**SPCI**) are calculated to understand the features of annual precipitation concentration variations (Hernando and Romana, 2015).

Standard Precipitation Concentration Index were described as:

$$\boldsymbol{SPCIzi = (PCIzi - AVERAGE\ PCIz)/AVERAGE\ PCIz} \ldots\ldots \textbf{(4)}$$

Where is the PCI of i-th year at station Z; and is the average PCI at station Z.

The PCI is a powerful indicator of temporal distribution of precipitation; as the value increases, the precipitation is more concentrated. PCI values of less than 10 indicate uniform monthly distribution of rainfall (low precipitation concentration); values between 11 and 15 indicate moderate precipitation concentration; PCI between 16 and 20 indicate irregular distribution; and values above 21 indicate very high precipitation concentration, i.e., strong irregularity (Oliver, 1980).

Furthermore, as indicated in (Agnew et al. 1999) the standardized rainfall anomalies were calculated and graphically presented to evaluate inter annual fluctuations of rainfall in the study area over the period of observation.

Standardized Rainfall Anomalies were described as:

$$\boldsymbol{SRA = (Pt - Pm)/SD} \ldots\ldots\ldots\ldots \textbf{(5)}$$

Where:

- SRA is standardized rainfall anomaly;
- Pt is an annual rainfall in year t;
- Pm is long-term mean annual rainfall over a period of observation; and
- SD is the standard deviation of annual rainfall over the period of observation.

The drought severity classes are 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).
Tools, software's and tests used in the study includes: Ms-Excel Pivot table analysis, SPSS, Pearson correlation coefficients.

RESULTS AND DISCUSSIONS

ANNUAL AND SEASONAL VARIABILITY OF RAINFALL

Based on the daily rainfall collected the data is presented as monthly, seasonal and annual basis for the period 1980 to 2016. An analysis of PCI shows an increasing trend towards deficit and scanty rainfall in both districts (Annex-D, E, G and H). The excess and deficit years for annual rainfall and for two seasons during the period 1980-2009 are identified using mean and standard deviation (S.D). In the study, the summer period shows a positive trend, while the annual and the seasonal scale analysis show a predominantly negative trend (Annex-D, E, G and H). The Precipitation Concentration Index values for the two districts of Northern Ethiopia were calculated based on the eq. 2 and eq. 3 given by (Oliver, 1980). The results are presented in Table-2 and it indicates highly irregular distribution of rainfall is occurring in both districts.

Annual patterns of rainfall

The annual total rainfall of Alamata district varies temporally and spatially, ranged from 187mm to 1079mm both recorded in Alamata station (Table-3 and Annex-B). The long-term mean annual precipitation of Alamata station was 749.44mm with a standard deviation of 177.84mm and 23.72% coefficient variation (Table-3). In addition, the annual rainfall at Chercher district ranges from 406mm to 1079mm. The long-term annual mean rainfall of Chercher station was 685.49mm with 142.73mm standard deviation and 20.82% of coefficient variation. The variation of long-term annual mean rainfall has been lowered in Chercher relative with Alamata station (Table-2 and Annex-B). The findings of (Abrha and Simhadri 2015, Dereje et al. 2012, and Bewket et al. 2007), reveal that the Tigray National Regional State receives much of the rainfall in June, July, August and September. Moreover, the contribution of kiremt rainfall to an annual total in Chercher is high. Precipitation Concentration Index (PCI) value of Chercher Station shows that 23%, which is characterized by high to very high monthly rainfall concentration (Table-2).
The findings also in agreement with [50], study on the variability in space and time of the PCI trends in the Mediterranean fringe of Iberian Peninsula, shows that higher PCI values were obtained in the south and south-eastern parts, which indicated more trends towards irregularity in rainfall (De Luis et al. 2010). Ayalew et al. (2012) computed the annual and seasonal patterns of the rainfall in Amhara region and examined for all 10 stations based on inter-seasonal spread of the rainfall using PCI which showed a decline in the period of September to December. The computation of yearly, seasonal, wet and dry periods in Spain has revealed rise in rainfall concentration in the wet season on the yearly scale. However, the seasonal changes are localized (De Luis et al. 2011). Hence, it can be concluded that the PCI is complex and effect the local precipitating conditions and is also related to the global atmospheric features in the region. Consequently, the trends and the variability in rainfall both annual and seasonal was analyzed for annual and seasonal data.

Kiremt season rainfall

Alamata and Chercher stations heavily experienced high rainfall during June, July, August and September. According to (Seleshi and Zanke, 2004), the kiremt season starts in July, lasts for about three-four months as a result of convergence in low-pressure systems and the Inter Tropical Convergence Zone (ITCZ). Similarly, we found that kiremt season contributes 59.60% and 78.81% of the mean annual rainfall at Alamata and Chercher stations respectively (Table-2). The mean annual rainfall of kiremt season is 451.32mm and 546.06mm in

Alamata and Chercher stations respectively (Table-3 and Annex-B). The finding was consistent with that of (Bewket et al. 2007 and Ayalew et al. 2012) in their study in the Amhara regional state of Ethiopia, *kiremt* and *belg* rainfall had contributed 55 to 85% and 8 to 24%, respectively to the annual rainfall totals.

Table 2 annual and seasonal PCI in percent 1980-2016

Station Name	Kiremt	Belg	Bega	PCI %
Alamata	59.60	24.93	15.47	21.17
Chercher	78.81	12.45	8.75	23

Sources: Analysis of Climatic Data, 2017

Belg season rainfall

From the present study it was possible to note that, Belg (March, April and May) rainfall has not a significant contribution to the annual total rainfall in Chercher (12.45%) as compared to Alamata (24.93%) (Table-2) during the period considered.

Table 3 annual and seasonal mean of rainfall, S.D and coefficient of variation (%)

Station	**Annual**			**Kiremt**			**Belg**			**Bega**		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Alamata	749.44	177.84	23.72	451.32	181.72	40.26	179.37	106.6	59.43	118.74	100.66	84.77
Chercher	685.49	142.73	20.82	546.06	166.66	30.52	84.58	55.65	65.64	54.66	49.93	91.35

Sources: Analysis of Climatic Data 1980-2016, 2017

Bega season rainfall

The remaining months, these are, October, November, December, January and February have taken as Bega season. The amount of Belg rainfall was 118.74mm and 54.66mm with the coefficient of variation 84.77% and 91.35% in Alamata and Chercher stations respectively (Table-3). During the long-term period as observed the maximum precipitation in Alamata and Chercher stations are 422.60mm and 282.80mm respectively (Annex-B). Generally, Northern Ethiopia (Alamata and Chercher) annual total rainfall shows high spatial and seasonal variability. The coefficient variation indicates that Belg and Bega season rainfall of Alamata and Chercher was highly variable than Kiremt rainfall in which the coefficient variation is low during study periods (Table-3).

Our finding was in agreement with (Taye et al. 2013) in their study analyzed 5 stations and reported that belg and the Bega rainfalls are found much more variation (>30%) than the kiremt rainfall in which the coefficient of variation is lower than 30%. In addition, (Dereje et al. 2012) in their study 10 stations were analyzed and they noted that belg and Bega rainfalls are found much more variation (>30%) than kiremt rainfall in which the coefficient of variation is lower than 30%. Further, (Abrha and Simhadri, 2015) belg season rainfall has an extreme inter-seasonal variability in the highland areas with CV values above 47%. Furthermore, regarding belg rainfall, the findings agree with (Hadgu et al. 2015, 2013 and Abrha and Simhadri, 2015) who found a declining trend at Alamata station. This significantly drying trend for belg rainfall means a lot for local farmers who used to rely on belg rains for food production. When it gets dry, production that could cover food demand for about two months is lost. For an already food insecure community, having lost crop production in belg season will further threaten the food security in the study area.

Inter annual rainfall variability at Alamata and Chercher stations

The result of standardized rainfall anomalies indicated in (Fig. 5 and Fig. 6; Annex-B) shows that the inter annual variability of rainfall and shows lack of annual total rainfall trends for the period from 1980 to 2016 at Alamata and Chercher station. Precipitation in the study area displays substantial decadal inconsistency, this means a year with a positive irregularity tracked by another year with a positive difference vice versa with negative incongruities. Regarding with the annual rainfall anomaly, more than 40% of the study area showed below average rainfall record while more than 50% showed above average rainfall amount throughout the observation periods.

In Chercher station, annual rainfall shows negative anomaly for the 1980-1990 decade, except for 1980-1981, 1986 and 1988 when a slight positive anomaly has occurred. Whereas positive anomalies occurred in the 1991-2001 decade, except in 1991-1992. In addition, from 2002-2016-time periods the annual rainfall shows negative anomaly except 2010-2011 and 2016 (Annex-B). During the wettest year`s annual rainfall at Chercher station has been 2.8 times the standard deviations above the long-term (1980-2016) average. On the other hand, annual rainfall was found to be 2 times the standard deviation below the long-term average during the dry years (Fig. 5 and Annex-B).

Substantial positive rainfall anomalies occurred in Alamata station for the 1980-1990 decade, except for the 1982, 1987 and 1990 years when a slight negative anomaly has occurred. Whereas, positive anomalies occurred in the 1991-2001 decade, except the year 1991 and 1994 when a slight negative anomaly has occurred. Moreover, from 2002-2016-time periods the annual rainfall shows negative anomaly except 2006, 2010 and 2016 when a slight positive anomaly has occurred (Fig. and Annex-B).

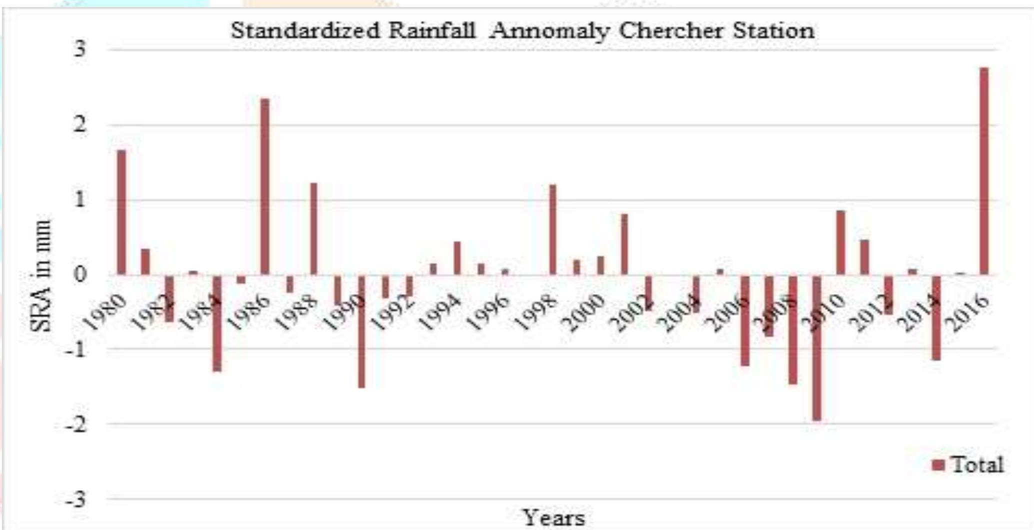

Figure 5 standardized anomalies of annual rainfall in Chercher station (1980-2016)

During 1980s and 1990s the wettest years, the annual rainfall was 0.8 and 1.2 times the standard deviations above the 1980-2016 mean annual rainfall respectively. The negative anomalies occurred in Alamata station during the 1980s and 1990s driest year rainfall have been 3.2 and 0.5 times the standard deviations above the 1980-2016 mean annual rainfall respectively. Moreover, the negative anomalies occurred in Alamata station during the 2002, 2010,2012 and 2014 driest year rainfall have been 0.5, 1.3, 2.5 and 1.3 times the standard deviations above the 1980-2016 mean annual rainfall respectively (Fig. 6 and Annex-B).

To sum up, the trend analysis of total annual rainfall of the study area reveals that, the area characterized by episodic fluctuation of the wet and dry years. Therefore, overall rainfall trend in the study area can be distinguished that increased during the observation period (1980-2016) at Alamata. However, the condition at Chercher was not the same. Even if, the contribution of belg and Bega rainfall to annual mean was insignificant it shows spatial and temporal variation during the observation period. Alamata station received the highest mean belg and Bega rainfall than Chercher station. In general rainfall, in the study area has monomodal characteristics, has high to moderate spatial and temporal variation. Besides it shows moderate inter-annual variation. The variation is too much for bega and belg rainfall than kiremt rainfall.

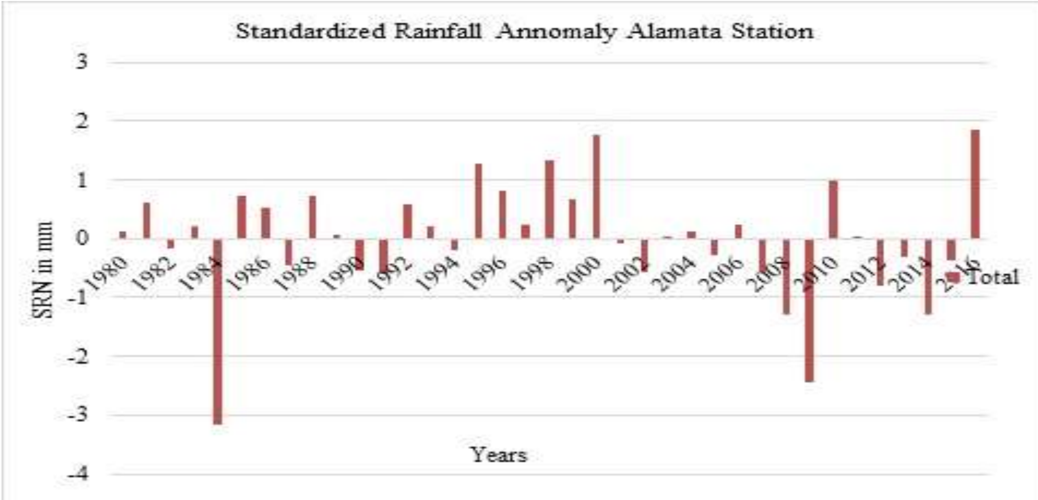

Figure 6 standardized anomalies of annual rainfall in Alamata station (1980-2016)

The outcome of the study is in line with the findings of Abrha and Simhadri (2015) who found that monthly rainfall results show variation in the spatiotemporal distribution and gradual concentration of rainfall in a few months to increase the prevalence of lengthy dry-spells. In addition, it also agrees with [14] who found a declining trend at Alamata station. In addition, the finding also agrees with studies of (DPPC, 1997b, DPPC, 1998, DPPC, 2004, DRMFSS, 2011, FAO, 2009 and 2012) who reported that almost every year, southern Tigray has experienced localized droughts due to abnormally low, untimely and variable rainfall causing crop failure to jeopardies rural livelihoods and food security in the region.

ANALYSIS OF PRECIPITATION CONCENTRATION INDEX

Both stations have dry years more than wet years of study period as the result the drought that effect on the study area because the number of dry years of all station is larger than wet years. In order to understand the variances of PCI value during the study period in both stations it has paramount importance to group the months and years in the study periods in terms of annual and three seasons (Kiremt, Belg and Bega).

Annual PCI

The annual analysis of Precipitation Concentration Index shows the range of PCI<10 has never been recorded in both stations (Table-4). In addition, most years of the study period varies between PCI 16-20 and PCI >21 for all stations which indicates that the concentration of precipitation is not low for the study area. Therefore, the precipitation of the study areas was highly irregular at Chercher than at Alamata stations i.e., PCI >16 at Alamata was 83.78% and PCI<16 at Chercher has never recorded during the study period (see Annex-D, E, G and H). Thus, precipitation was highly varied in Chercher station than in Alamata station.

According to results, the months of the years are classified into seasons based on their importance for farming activities (preparation, growing and cultivation). Hence, June, July, August, and September months are classified as ‘Kiremt’ summer season. March, April and May months are grouped under ‘Belg’ season. And the rest months are grouped as ‘Bega’ season. Therefore, it has vital to discuss PCI with respect to seasons.

Kiremt season PCI

Kiremt season is the main season in Ethiopia where most of the rainfall obtained. As indicated in Table-4 Kiremt PCI<10 at Chercher station (45.95%) is higher than that of at Alamata station (13.51%). The implication is that nearly the same amount of rainfall occurs in each month of the Kiremt season and hence perfect uniform precipitation distribution in Chercher than Alamata during the Kiremt season. In addition, during Kiremt season PCI<16 was the highest at Alamata (81.08%) than Chercher (43.24%) and both stations have 5.41% years with

PCI >16. Therefore, precipitation in Kiremt season is more or less moderately uniform in both stations since PCI <16 94.59% and 89.19% at Alamata and Chercher respectively (see Annex-D, E, G and H).

Table 4 annual and seasonal PCI 1980-2016

Station	**Annual**	**% of years PCI**	**Kiremit**	**% of years PCI**	**Belg**	**% of years PCI**	**Bega**	**% of years PCI**
Alamata								
PCI=<10	0	00.00	5	13.51	16	43.24	2	5.41
PCI=11-15	6	16.22	30	81.08	14	37.84	14	37.84
PCI=16-20	12	32.43	2	5.41	3	8.11	8	21.62
PCI=>21	19	51.35	0	00.00	3	8.11	13	35.14
Chercher								
PCI=<10	0	00.00	17	45.95	22	59.46	4	10.81
PCI=11-15	0	00.00	16	43.24	10	27.03	23	62.16
PCI=16-20	8	21.62	2	5.41	3	8.11	5	13.51
PCI=>21	29	78.37	0	00.00	2	5.41	5	13.51

Source: Analysis of Observation rainfall data 1980-2016, 2018.

Belg season PCI

Belg season is the second rain bearing season in Ethiopia. However, as shown in Table-4 both stations have fluctuation between 16<PCI>16 because the amount of precipitation is fluctuated. Chercher station takes a maximum frequency of PCI<16 with 86.49% of all years during study period (1980-2016). In addition, Alamata stations have a frequency of PCI<16 with 81.08% of all years during the study period. Therefore, based on the PCI analysis the precipitation during Belg season was moderately uniform with PCI less than 16 in both stations in the study areas (see Annex-D, E, G and H).

Bega season PCI

Bega season in Ethiopia is almost dry sometimes called the driest season, however there may be some rains during some of the months in Bega season particularly towards the end of April and May. Station with PCI<16 72.97% and 43.25% of years have recorded at Chercher and at Alamata station respectively. On the other hand, PCI>16 was found the highest for Alamata station (56.76%) of years than Chercher station (27.02%) of years. As shown in the, (Fig. 7 and Annex-G and H), SPCI graph it is clearly observed that precipitation was highly variable at Alamata station than at Chercher.

To characterize further the behavior of PCI at Alamata and Chercher stations, a correlation analysis was performed to evaluate its relationship with annual precipitation and annual PCI using SPSS 20. The values of the Pearson's correlation coefficient were calculated for annual precipitation and annual PCI (see Annex-F, G and H), which show that the correlation is significant at the respective significance $p=<0.05$ in both stations. The result shows a negative and statically significant correlation ($r=-0.379$) was observed between annual precipitation and annual PCI values at 0.05 confidence level of significance (Annex-F) (i.e. the rainfall concentration on a small number of rainy days is apparently greater in areas with low annual means).

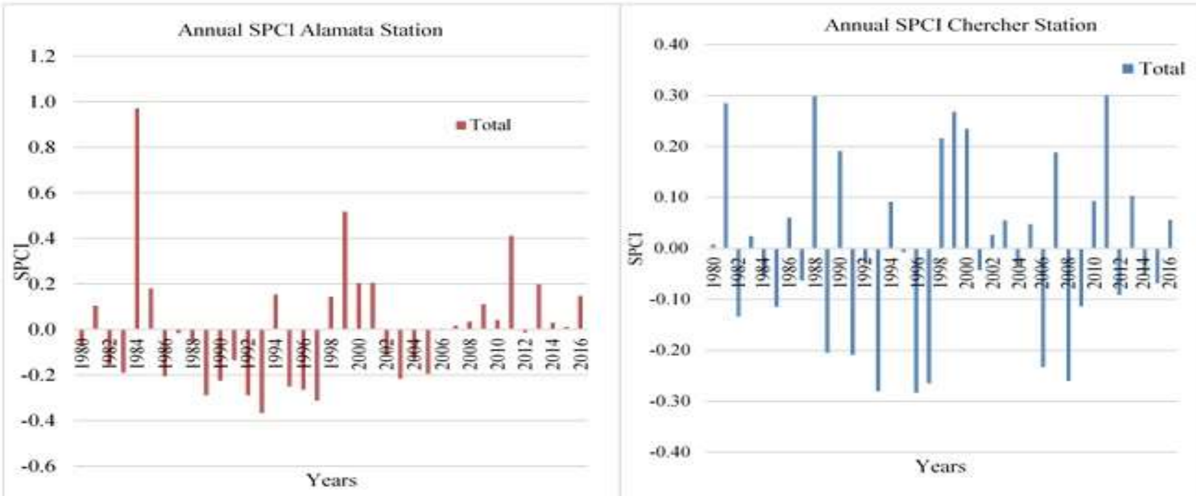

Figure 7 annual standardized precipitation concentration index

This implies that PCI is expected to increase with decrease in annual rainfall total for Alamata station. Similarly, a correlation analysis was also performed for Chercher station.

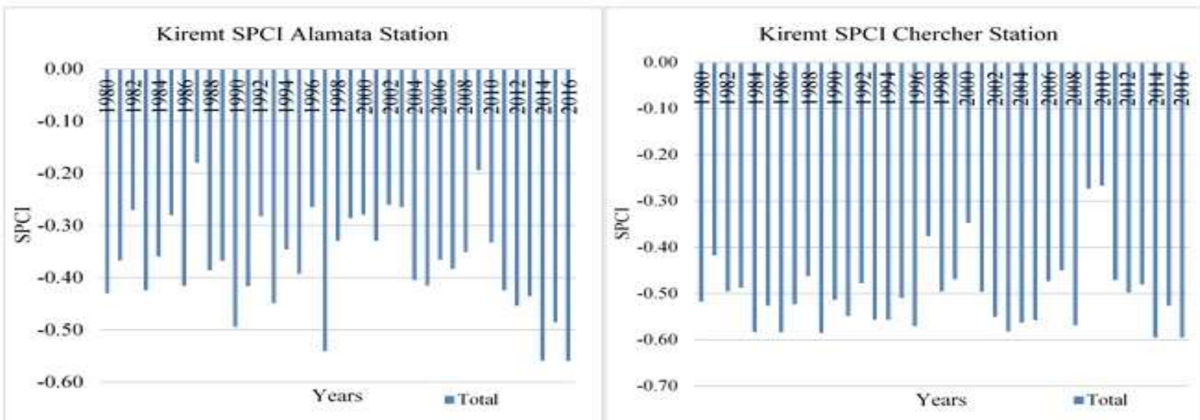

Figure 8 kiremt season standardized precipitation concentration index

A negative and statistically significant relationships was observed between annual precipitation and annual PCI at 5% level of significance ($r=-0.362$ and $p=0.028$). The negative relationship shows as the amount of precipitation increases in the year of observation the annual PCI decreases. Furthermore, standard precipitation concentration index (SPCI) was analyzed in order to understand the stations variances of PCI values based on annual, Kiremt, Belg and Bega seasons during the study period. The standard precipitation concentration index SPCI was found to understand the variation of PCI of all station according to the classification of SPCI variation. Fig. 7, 8, 9 and 10 show the fluctuations of SPCI of each station and season according to SPCI values. The SPCI of Kiremt season at both station have negative anomaly but no positive anomaly was recorded during the years of observation 1980-2016.

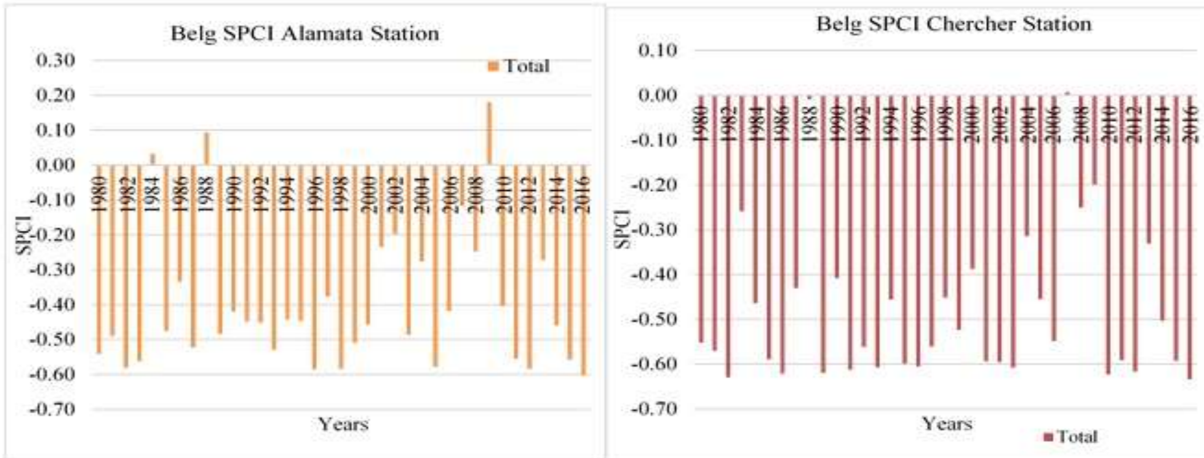

Figure 9 belg season standardized precipitation concentration index

In addition, during Belg season both station shows negative anomalies during the years of observation 1980-2016, except 1984, 1988 and 2009 years at Alamata station and 1988 and 2007 years at Chercher station when little positive anomalies were recorded at the time of observation (see Annex-F). Moreover, the SPCI is fluctuating between positive and negative anomaly in both stations. However, the fluctuation is more at Alamata station than at Chercher station (Fig. 9 and 10).

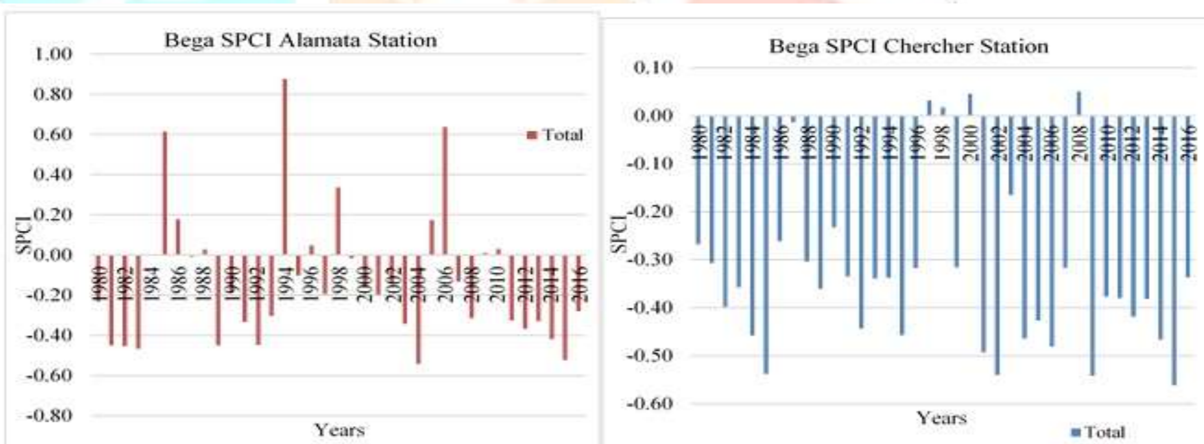

Figure 10 bega season standardized precipitation concentration index

Number of Rain-Days and Total Rainfall

The rain days study can provide the information regarding frequency and intensity of rain events during different weather conditions. For example, drought season may be marked by both fewer rain days and less rain per day as compared to periods of normal and above-normal rainfall. Therefore, statistical features of the daily rainfall distribution at different stations over lengthy time period enough to determine climate parameters are fascinating and vital facets of climatology analysis specially concentration and distributions of precipitation. In view of this, an attempt has been made to study the annual rainfall with reference to number of rainy days for the period of 1980 to 2016 over Alamata and Chercher Stations in Southern Tigray, Ethiopia.

Thoughtful climatic features of wet and dry days are indispensable for effective agricultural processes. On the day of climate change the study of rain and dry-days have greater importance, therefore in recent decades world-wide attempts have been made to appreciate the problem on regional/local scales. This sub section devoted to study the number of rain-days and dry-days across the stations in order to examine the main characteristics of rain-days and dry-days, which are crucial for agricultural activities in the study areas.

In the foregoing discussion it was analyzed that the distribution of precipitation was highly concentrated in few days of the month. Hence, it is obvious that the variations in the rainfall amounts on the rainfall days could, therefore, be expected to exert a major control on the total amount of precipitation.

As displayed in Fig. 11the number of rainy-days fluctuates beween 41 and 108 with their corrosponding total amount of precipitation 680mm and 651mm in Chercher stations respectively. From this, it can be conlcuded that in most cases as the number of rainy-days increases total amount of precipitation increases, however, this doesnot mean always true as in the case of Chercher station during 2003. In addition, the highest number of rainy-days was recorder during 1987, however, in this year the recorded amount of rainfall was not the highest, since some rainy-days may have very little amount of rainfall, for example the threshold values. Moreover, during the year 2002-2004 the number of rainy-days are minimum as compared the number of rainy-days during 2006-2008 in the latter case the total amount of rainfall is minimum incomparison to the earlier.

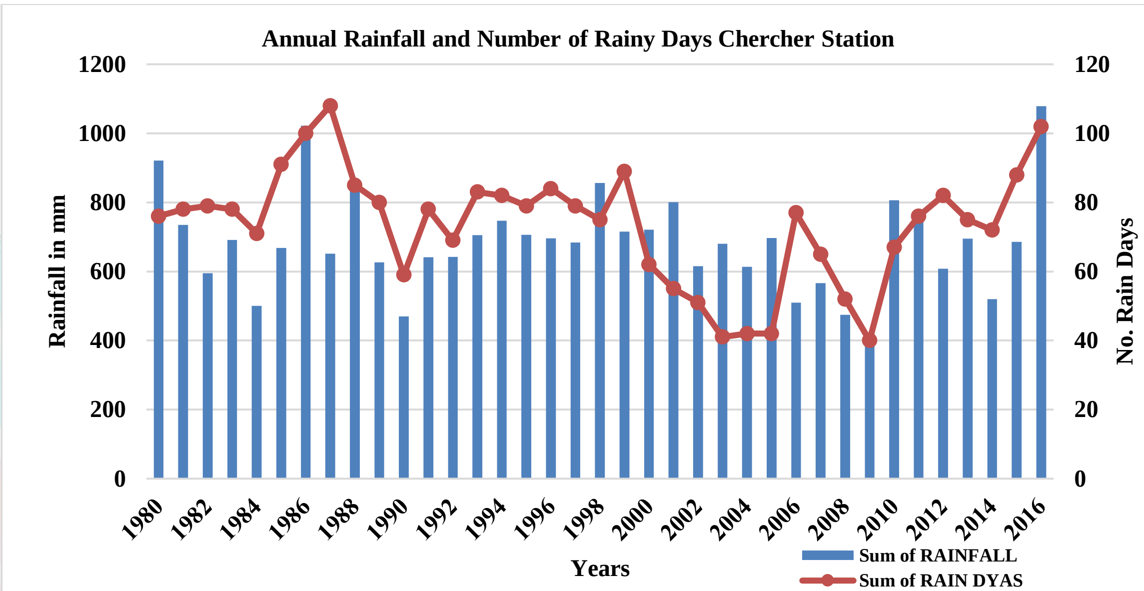

Figure 11 Annual Rainfall and Number of Raindays in Chercher Station

Similarly, as shown in Fig. 12, in Alamata station the number of rainy-days varies between 17 and 100 rainy-days with their corresponding total amount of rainfall 187mm and 1071mm respectively. During the year 1984 and 2009 one of the lowest number of rainy-days which corrosponds to the lowest amount of total rainfall during the study period in Alamata stations. In addition, during the year between 1995-2000 the number of rain-days 66, 78 and 81 conforming to 868mm, 1063mm and 984mm rainfall. This implies that as the number of days increased the total amount of precipitation did not increased in parallel. The main justification is may be because the variability of daily precipitation concentration which might have significant cumulative effect in the monthly and annual rainfall distribution.

Generally, the number of rain-days and the total amount of precipitation is inconsistent, i.e., as the number of rain-days increased it does not always increase the total amount of precipitation. It may be due to the daily intensity and duration of rainfall distribution that means within a few rainy days there may be very high amount of precipitation and vice versa. Therefore, in future studies it has paramount importance to analyze the daily intensity and variability of precipitation so as to have more clear understanding on the effect of daily rainfall particularly on agricultural activities.

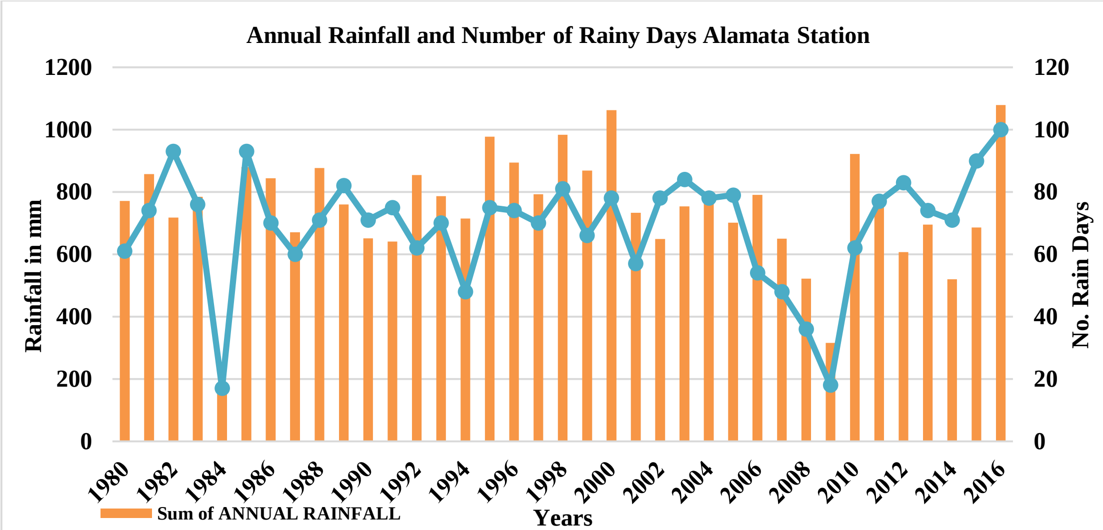

Figure 12 Annual Rainfall and Number of Rain days in Alamata Station

Generally, contrasting results of trend in annual and seasonal rainfall in some parts of the country as explained by (Easterling et al. 2000 and Sileshi and Zanke, 2004) might have been steamed from the use of different periods, some studies have been based on areal averages (Seleshi and Demar'ee, 1995 and Osman and Sauerborn, 2002) while others have been based on too few stations to be fully representative of the spatial variability in the study regions (Meze-Hausken, 2004 and Sileshi and Zanke, 2004). Rainfall is not well approximated by normal distributions (IPCC, 2001). On the other hand, (Meze-Hausken, 2004, Seleshi and Camberlin, 2006 and Cheung et al. 2008) did not find any significant trend over the northern and northeastern part of the country. Previous studies on rainfall analysis concentrated on the central highlands of the country (Seleshi and Demar'ee, 1995, Osman and Sauerborn, 2002 and Cheung et al. 2008).

Therefore, Ethiopia as a country; information about climate variability is so crucial; hence different studies have been done so far in different disciplines. In addition, current climate variability as it impacts, for example on agricultural systems and farmers, is an immediate problem to be addressed, but longer-term effects of climate change are not well studied in Ethiopia in general and the study area in particular.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Generally, the annual precipitation of Alamata and Chercher stations fluctuate between dry and wet years throughout study period. During Kiremt season PCI<16 was the highest at Alamata (81.08%) than Chercher (43.24%) and both stations have 5.41% years with PCI >16. On the other hand, Chercher station in Belg season takes the maximum frequency of PCI<16 with 86.49% of all years during study period (1980-2016).

On annual scales, PCI was found to range from the lowest and highest value of 13.42 and 41.71 in 1993 and 1984, for the 37 years period under study, at Alamata station respectively. Whereas, at Chercher station the lowest and highest annual PCI value were recorded as 16.48 and 29.85 during 1996 and 1988, for the 37 years period under study (1980-2016). This implies that rainfall pattern in the study area is not uniformly distributed but had fluctuated between moderate irregularity and irregular distribution range. At both stations the PCI was negatively correlated with both variables but, while it is statistically significant at P=0.05 with annual precipitation.

A good knowledge of critical values of the series of various climatic elements such as rainfall and some of their derived indexes is of great importance in detecting variability which has implications for water resource planning and management, drought monitoring and disaster preparedness planning and management etc. This study emphasizes the usefulness of PCI in detecting precipitation concentration and variability. It was observed based on the plot for rainfall and PCI that this climatic variable and the associated index are changing.

Recommendations

Climate change and variability at local scale is central to effective adaptation and mitigation responses which will depend on policies and measures across multiple scales: national, regional, zonal and local. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation which in turn depend on the robustness of climate change and variability analysis. A PCI analytical approaches for evaluating climate change and variability is vital for informed and effective decision-making processes to limit climate change and its effects.

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Annex A

Annual, Seasonal Mean and Coefficients of Variation Rainfall at Alamata and Chercher Stations

Variables	Mean	SD	CV
Alamata Station			
Annual	749.44	177.84	23.73
Kiremt	451.32	181.72	40.26
Belg	179.37	106.60	59.43
Bega	118.74	100.66	84.77
Chercher Station			
Annual	685.49	142.73	20.82
Kiremt	546.06	166.66	30.52

Belg	84.78	55.65	65.64
Bega	54.66	49.93	91.35

Annex B

Annual and Seasonal Precipitation and their contribution to Annual Rainfall Alamata Station

Annual and Seasonal Precipitation and their contribution to Annual Rainfall Alamata Station								Standardized Annual Rainfall Anomaly Alamata Station				
Years	ANNUAL	Seasons			Contribution to Annual							
		KIREMT	BELG	BEGA	KIREMT	BELG	BEGA	MEAN	Pt-MPt	SD	Pt-MPt/SD	SRAN
1980	771.1	542.3	115	113.8	70.33	14.91	14.76	749.44	21.66	177.84	0.12	0.12
1981	857.2	619	200.1	38.1	72.21	23.34	4.44	749.44	107.76	177.84	0.61	0.61
1982	718.1	401.2	195.7	121.2	55.87	27.25	16.88	749.44	-31.34	177.84	-0.18	-0.18
1983	784.8	466	260.8	58	59.38	33.23	7.39	749.44	35.36	177.84	0.20	0.20
1984	187.1	49	124.4	13.7	26.19	66.49	7.32	749.44	-562.34	177.84	-3.16	-3.16
1985	880.4	227.1	230.7	422.6	25.80	26.20	48.00	749.44	130.96	177.84	0.74	0.74
1986	843.8	427.8	250.3	165.7	50.70	29.66	19.64	749.44	94.36	177.84	0.53	0.53
1987	670.7	202.4	418.9	49.4	30.18	62.46	7.37	749.44	-78.74	177.84	-0.44	-0.44
1988	877.4	555	129.6	192.8	63.26	14.77	21.97	749.44	127.96	177.84	0.72	0.72
1989	759.6	343.4	280.6	135.6	45.21	36.94	17.85	749.44	10.16	177.84	0.06	0.06
1990	651.7	423.6	122.6	105.5	65.00	18.81	16.19	749.44	-97.74	177.84	-0.55	-0.55
1991	641.3	410.5	150.5	80.3	64.01	23.47	12.52	749.44	-108.14	177.84	-0.61	-0.61
1992	854.1	396.2	129	328.9	46.39	15.10	38.51	749.44	104.66	177.84	0.59	0.59
1993	786.3	262.8	345.2	178.3	33.42	43.90	22.68	749.44	36.86	177.84	0.21	0.21
1994	715.1	511.3	182.7	21.1	71.50	25.55	2.95	749.44	-34.34	177.84	-0.19	-0.19
1995	977.1	392.5	407	177.6	40.17	41.65	18.18	749.44	227.66	177.84	1.28	1.28
1996	894.7	387.8	307.8	199.1	43.34	34.40	22.25	749.44	145.26	177.84	0.82	0.82
1997	792.4	235.4	180.3	376.7	29.71	22.75	47.54	749.44	42.96	177.84	0.24	0.24
1998	984.1	683.9	80.2	220	69.49	8.15	22.36	749.44	234.66	177.84	1.32	1.32
1999	868.7	720.5	36.8	111.4	82.94	4.24	12.82	749.44	119.26	177.84	0.67	0.67
2000	1063.1	764.7	127.5	170.9	71.93	11.99	16.08	749.44	313.66	177.84	1.76	1.76
2001	733.4	510.7	200.2	22.5	69.63	27.30	3.07	749.44	-16.04	177.84	-0.09	-0.09
2002	649.4	335.7	138.3	175.4	51.69	21.30	27.01	749.44	-100.04	177.84	-0.56	-0.56
2003	754.3	381.5	160.6	212.2	50.58	21.29	28.13	749.44	4.86	177.84	0.03	0.03
2004	769.9	450.1	221.2	98.6	58.46	28.73	12.81	749.44	20.46	177.84	0.12	0.12
2005	701.5	365.1	307.7	28.7	52.05	43.86	4.09	749.44	-47.94	177.84	-0.27	-0.27
2006	791.2	369.2	396.1	25.9	46.66	50.06	3.27	749.44	41.76	177.84	0.23	0.23
2007	650.6	440.3	127	83.3	67.68	19.52	12.80	749.44	-98.84	177.84	-0.56	-0.56
2008	522.2	357.7	27.7	136.8	68.50	5.30	26.20	749.44	-227.24	177.84	-1.28	-1.28
2009	316.2	161.2	89.4	65.6	50.98	28.27	20.75	749.44	-433.24	177.84	-2.44	-2.44
2010	922.4	599.1	256	67.3	64.95	27.75	7.30	749.44	172.96	177.84	0.97	0.97
2011	751.2	677	50.2	24	90.12	6.68	3.19	749.44	1.76	177.84	0.01	0.01
2012	607.5	457.2	105.4	44.9	75.26	17.35	7.39	749.44	-141.94	177.84	-0.80	-0.80
2013	695.4	571.2	92.9	31.3	82.14	13.36	4.50	749.44	-54.04	177.84	-0.30	-0.30
2014	520.2	455.9	30.2	34.1	87.64	5.81	6.56	749.44	-229.24	177.84	-1.29	-1.29
2015	686	541.3	112.5	32.2	78.91	16.40	4.69	749.44	-63.44	177.84	-0.36	-0.36
2016	1079.1	1003.4	45.7	30	92.98	4.24	2.78	749.44	329.66	177.84	1.85	1.85

Annex B

Annual and Seasonal Precipitation and their contribution to Annual Rainfall Chercher Station

Annual and Seasonal Precipitation and their contribution to Annual Rainfall Chercher Station								Standardized Annual Rainfall Anomaly Alamata Station				
Years	ANNUAL	Seasons			Contribution to Annual							
		KIREMT	BELG	BEGA	KIREMT	BELG	BEGA	MEAN	Pt-MPt	SD	Pt-MPt/SD	SRAN
1980	921.3	755.7	116.6	49	82.03	12.66	5.32	685.49	235.81	142.73	1.65	1.65
1981	734.8	650.8	56.7	27.3	88.57	7.72	3.72	685.49	49.31	142.73	0.35	0.35
1982	595	433.3	112.2	49.5	72.82	18.86	8.32	685.49	-90.49	142.73	-0.63	-0.63
1983	691.7	538.5	118.2	35	77.85	17.09	5.06	685.49	6.21	142.73	0.04	0.04
1984	500.1	430.7	35.1	34.3	86.12	7.02	6.86	685.49	-185.39	142.73	-1.30	-1.30
1985	667.9	508.6	124.3	35	76.15	18.61	5.24	685.49	-17.59	142.73	-0.12	-0.12
1986	1022.2	938.1	50.3	33.8	91.77	4.92	3.31	685.49	336.71	142.73	2.36	2.36
1987	651.3	501.8	125.7	23.8	77.05	19.30	3.65	685.49	-34.19	142.73	-0.24	-0.24
1988	858.3	765.6	36.8	55.9	89.20	4.29	6.51	685.49	172.81	142.73	1.21	1.21
1989	626.5	487.8	88.7	50	77.86	14.16	7.98	685.49	-58.99	142.73	-0.41	-0.41
1990	469.9	422.1	31.6	16.2	89.83	6.72	3.45	685.49	-215.59	142.73	-1.51	-1.51
1991	641.6	472.6	97.1	71.9	73.66	15.13	11.21	685.49	-43.89	142.73	-0.31	-0.31
1992	642	493.7	79.3	69	76.90	12.35	10.75	685.49	-43.49	142.73	-0.30	-0.30
1993	705.3	476.9	182.3	46.1	67.62	25.85	6.54	685.49	19.81	142.73	0.14	0.14
1994	747.4	673.1	49.8	24.5	90.06	6.66	3.28	685.49	61.91	142.73	0.43	0.43
1995	706.1	568	107	31.1	80.44	15.15	4.40	685.49	20.61	142.73	0.14	0.14
1996	696.2	483.9	160.9	51.4	69.51	23.11	7.38	685.49	10.71	142.73	0.08	0.08
1997	683.9	190.9	210.2	282.8	27.91	30.74	41.35	685.49	-1.59	142.73	-0.01	-0.01
1998	856.6	763	61.7	31.9	89.07	7.20	3.72	685.49	171.11	142.73	1.20	1.20
1999	715.1	634.1	18.5	62.5	88.67	2.59	8.74	685.49	29.61	142.73	0.21	0.21
2000	721	557	68.2	95.8	77.25	9.46	13.29	685.49	35.51	142.73	0.25	0.25
2001	800.4	624.8	94.2	81.4	78.06	11.77	10.17	685.49	114.91	142.73	0.81	0.81
2002	615.1	531.9	56	27.2	86.47	9.10	4.42	685.49	-70.39	142.73	-0.49	-0.49
2003	680.4	621.5	29.9	29	91.34	4.39	4.26	685.49	-5.09	142.73	-0.04	-0.04
2004	613.9	521.7	36.1	56.1	84.98	5.88	9.14	685.49	-71.59	142.73	-0.50	-0.50
2005	696.5	613.4	59.9	23.2	88.07	8.60	3.33	685.49	11.01	142.73	0.08	0.08
2006	509.9	327.1	117.4	65.4	64.15	23.02	12.83	685.49	-175.59	142.73	-1.23	-1.23
2007	566	471.1	52.5	42.4	83.23	9.28	7.49	685.49	-119.49	142.73	-0.84	-0.84
2008	474.6	286.9	39.5	148.2	60.45	8.32	31.23	685.49	-210.89	142.73	-1.48	-1.48
2009	406.6	231.5	12.8	162.3	56.94	3.15	39.92	685.49	-278.89	142.73	-1.95	-1.95
2010	806.1	522	270.3	13.8	64.76	33.53	1.71	685.49	120.61	142.73	0.85	0.85
2011	751.2	677	50.2	24	90.12	6.68	3.19	685.49	65.71	142.73	0.46	0.46
2012	607.5	457.2	105.4	44.9	75.26	17.35	7.39	685.49	-77.99	142.73	-0.55	-0.55
2013	695.4	571.2	92.9	31.3	82.14	13.36	4.50	685.49	9.91	142.73	0.07	0.07
2014	520.2	455.9	30.2	34.1	87.64	5.81	6.56	685.49	-165.29	142.73	-1.16	-1.16
2015	686	541.3	112.5	32.2	78.91	16.40	4.69	685.49	0.51	142.73	0.00	0.00
2016	1079.1	1003.4	45.7	30	92.98	4.24	2.78	685.49	393.61	142.73	2.76	2.76

Annex D

Annual and Seasonal PCI at Alamata Station					
Years	Annual PPT	PCI ANNUAl	PCI KIREMT	PCI BElG	PCI BEGA
1980	771.10	19.65	12.07	9.73	16.28
1981	857.20	23.39	13.40	10.82	11.65
1982	718.10	17.90	15.44	8.88	11.57

1983	784.80	17.14	12.18	9.27	11.26
1984	187.10	41.71	13.57	21.85	21.15
1985	880.40	25.00	15.24	11.10	34.18
1986	843.80	16.82	12.37	14.11	24.95
1987	670.70	20.81	17.37	10.12	21.01
1988	877.40	20.16	13.00	23.15	21.77
1989	759.60	15.08	13.39	10.93	11.66
1990	651.70	16.41	10.71	12.28	17.17
1991	641.30	18.30	12.35	11.68	14.11
1992	854.10	15.04	15.19	11.61	11.69
1993	786.30	13.42	11.67	9.97	14.78
1994	715.10	24.43	13.85	11.79	39.73
1995	977.10	15.86	12.86	11.70	19.01
1996	894.70	15.58	15.57	8.78	22.19
1997	792.40	14.58	9.73	13.21	17.07
1998	984.10	24.22	14.20	8.82	28.32
1999	868.70	32.13	15.12	10.39	20.84
2000	1063.10	25.47	15.25	11.49	17.77
2001	733.40	25.52	14.19	16.20	16.97
2002	649.40	18.83	15.66	16.99	18.19
2003	754.30	16.58	15.57	10.88	13.93
2004	769.90	18.39	12.62	15.33	9.70
2005	701.50	17.04	12.38	8.93	24.87
2006	791.20	21.24	13.43	12.34	34.65
2007	650.60	21.53	13.06	18.67	18.35
2008	522.20	21.94	13.75	15.93	14.51
2009	316.20	23.51	17.06	25.00	21.37
2010	922.40	22.06	14.12	12.62	21.82
2011	751.20	29.91	12.18	9.41	14.25
2012	607.50	20.89	11.56	8.82	13.38
2013	695.40	25.37	11.95	15.39	14.22
2014	520.20	21.80	9.33	11.42	12.27
2015	686.00	21.42	10.89	9.37	10.08
2016	1079.10	24.28	9.32	8.43	15.25
MEAN	749.44	21.17	13.29	12.63	18.43

Annex E

Annual and Seasonal PCI at Chercher Station					
Years	Annual PPt	ANNUAL PCI	KIREMT PCI	BELG PCI	BEGA PCI
1980	921.30	23.18	11.09	10.31	16.83
1981	734.80	29.56	13.40	9.88	15.94
1982	595.00	19.93	11.61	8.53	13.84
1983	691.70	23.56	11.80	17.04	14.78
1984	500.10	21.76	9.60	12.32	12.47
1985	667.90	20.35	10.90	9.44	10.63
1986	1022.20	24.38	9.59	8.72	16.99
1987	651.30	21.56	10.96	13.12	22.67

1988	858.30	29.85	12.36	22.80	16.01
1989	626.50	18.29	9.54	8.76	14.70
1990	469.90	27.39	11.18	13.61	17.64
1991	641.60	18.20	10.38	8.92	15.29
1992	642.00	22.30	12.01	10.08	12.81
1993	705.30	16.56	10.19	9.04	15.21
1994	747.40	25.10	10.20	12.50	15.24
1995	706.10	22.84	11.29	9.22	12.50
1996	696.20	16.48	9.88	9.09	15.70
1997	683.90	16.92	14.35	10.11	23.74
1998	856.60	27.97	11.60	12.62	23.41
1999	715.10	29.16	12.22	10.98	15.73
2000	721.00	28.41	15.00	14.09	24.05
2001	800.40	22.01	11.59	9.35	11.66
2002	615.10	23.60	10.35	9.30	10.59
2003	680.40	24.26	9.62	9.02	19.21
2004	613.90	22.26	10.05	15.76	12.32
2005	696.50	24.10	10.17	12.55	13.20
2006	509.90	17.65	12.12	10.38	11.95
2007	566.00	27.33	12.65	23.17	15.72
2008	474.60	17.01	9.92	17.23	24.16
2009	406.60	20.37	16.71	18.41	10.55
2010	806.10	25.14	16.85	8.68	14.34
2011	751.20	29.91	12.18	9.41	14.25
2012	607.50	20.89	11.56	8.82	13.38
2013	695.40	25.37	11.95	15.39	14.22
2014	520.20	21.80	9.33	11.42	12.27
2015	686.00	21.42	10.89	9.37	10.08
2016	1079.10	24.28	9.32	8.43	15.25
MEAN	685.49	23.01	11.47	11.83	15.39

Annex F

Correlations between Annual PCI and Annual Rainfall at Alamata and Chercher Stations

Correlations Alamata and Chercher Stations		Alamata Station		**Chercher Station**	
		ANNUAL_PCI	ANNUAL_RAINFALL	ANNUAL_PCI	ANNUAL_RAINFALL
ANNUAL_PCI	r	1	-.379*	1	.362*
	Sig. (2-tailed)		.021		.028
	N	37	37	37	37
ANNUAL_RAINFALL	r	-.379*	1	.362*	1
	Sig. (2-tailed)	.021		.028	
	N	37	37	37	37

*. Correlation is significant at the 0.05 level (2-tailed).

Annex G

Standardized Annual Seasonal Precipitation Concentration Indexes at Alamata Station

Years	ANNUAl PCI	ANNUAL SPCI			KIREMT SPCI			BELG SPCI			BEGA SPCI		
		Annual_Mean PCI	PCIi-PCIMean	SPCI ANNUAL	PCI KIREMT	PCIi-PCIMean	SPCI KIREMT	PCI BELG	PCIi-PCIMean	SPCI BELG	PCI BEGA	PCIi-PCIMean	SPCI BEGA
1980	19.65	21.17	-1.52	-0.07	12.07	-9.10	-0.42981	9.73	-11.44	-0.54	16.28	-4.89	-0.23
1981	23.39	21.17	2.22	0.11	13.40	-7.77	-0.36715	10.82	-10.35	-0.49	11.65	-9.52	-0.45
1982	17.90	21.17	-3.27	-0.15	15.44	-5.73	-0.27053	8.88	-12.29	-0.58	11.57	-9.60	-0.45
1983	17.14	21.17	-4.03	-0.19	12.18	-8.99	-0.4245	9.27	-11.90	-0.56	11.26	-9.91	-0.47
1984	41.71	21.17	20.54	0.97	13.57	-7.60	-0.35916	21.85	0.68	0.03	21.15	-0.02	0.00
1985	25.00	21.17	3.83	0.18	15.24	-5.93	-0.28022	11.10	-10.07	-0.48	34.18	13.01	0.61
1986	16.82	21.17	-4.35	-0.21	12.37	-8.80	-0.4158	14.11	-7.06	-0.33	24.95	3.78	0.18
1987	20.81	21.17	-0.36	-0.02	17.37	-3.80	-0.17964	10.12	-11.05	-0.52	21.01	-0.16	-0.01
1988	20.16	21.17	-1.01	-0.05	13.00	-8.17	-0.38612	23.15	1.98	0.09	21.77	0.60	0.03
1989	15.08	21.17	-6.09	-0.29	13.39	-7.78	-0.36767	10.93	-10.24	-0.48	11.66	-9.51	-0.45
1990	16.41	21.17	-4.76	-0.22	10.71	-10.46	-0.49406	12.28	-8.89	-0.42	17.17	-4.00	-0.19
1991	18.30	21.17	-2.87	-0.14	12.35	-8.82	-0.41676	11.68	-9.49	-0.45	14.11	-7.06	-0.33
1992	15.04	21.17	-6.13	-0.29	15.19	-5.98	-0.28235	11.61	-9.56	-0.45	11.69	-9.48	-0.45

1993	13.42	21.17	-7.75	-0.37	11.67	-9.50	-0.44852	9.97	-11.20	-0.53	14.78	-6.39	-0.30
1994	24.43	21.17	3.26	0.15	13.85	-7.32	-0.34557	11.79	-9.38	-0.44	39.73	18.56	0.88
1995	15.86	21.17	-5.31	-0.25	12.86	-8.31	-0.39253	11.70	-9.47	-0.45	19.01	-2.16	-0.10
1996	15.58	21.17	-5.59	-0.26	15.57	-5.60	-0.26476	8.78	-12.39	-0.59	22.19	1.02	0.05
1997	14.58	21.17	-6.59	-0.31	9.73	-11.44	-0.54024	13.21	-7.96	-0.38	17.07	-4.10	-0.19
1998	24.22	21.17	3.05	0.14	14.20	-6.97	-0.32935	8.82	-12.35	-0.58	28.32	7.15	0.34
1999	32.13	21.17	10.96	0.52	15.12	-6.05	-0.2858	10.39	-10.78	-0.51	20.84	-0.33	-0.02
2000	25.47	21.17	4.30	0.20	15.25	-5.92	-0.27941	11.49	-9.68	-0.46	17.77	-3.40	-0.16
2001	25.52	21.17	4.35	0.21	14.19	-6.98	-0.32986	16.20	-4.97	-0.23	16.97	-4.20	-0.20
2002	18.83	21.17	-2.34	-0.11	15.66	-5.51	-0.26036	16.99	-4.18	-0.20	18.19	-2.98	-0.14
2003	16.58	21.17	-4.59	-0.22	15.57	-5.60	-0.26475	10.88	-10.29	-0.49	13.93	-7.24	-0.34
2004	18.39	21.17	-2.78	-0.13	12.62	-8.55	-0.404	15.33	-5.84	-0.28	9.70	-11.47	-0.54
2005	17.04	21.17	-4.13	-0.19	12.38	-8.79	-0.41518	8.93	-12.24	-0.58	24.87	3.70	0.17
2006	21.24	21.17	0.07	0.00	13.43	-7.74	-0.36579	12.34	-8.83	-0.42	34.65	13.48	0.64
2007	21.53	21.17	0.36	0.02	13.06	-8.11	-0.38305	18.67	-2.50	-0.12	18.35	-2.82	-0.13
2008	21.94	21.17	0.77	0.04	13.75	-7.42	-0.3507	15.93	-5.24	-0.25	14.51	-6.66	-0.31
2009	23.51	21.17	2.34	0.11	17.06	-4.11	-0.19429	25.00	3.83	0.18	21.37	0.20	0.01
2010	22.06	21.17	0.89	0.04	14.12	-7.05	-0.33287	12.62	-8.55	-0.40	21.82	0.65	0.03
2011	29.91	21.17	8.74	0.41	12.18	-8.99	-0.42465	9.41	-11.76	-0.56	14.25	-6.92	-0.33
2012	20.89	21.17	-0.28	-0.01	11.56	-9.61	-0.45412	8.82	-12.35	-0.58	13.38	-7.79	-0.37
2013	25.37	21.17	4.20	0.20	11.95	-9.22	-0.43568	15.39	-5.78	-0.27	14.22	-6.95	-0.33
2014	21.80	21.17	0.63	0.03	9.33	-11.84	-0.55925	11.42	-9.75	-0.46	12.27	-8.90	-0.42
2015	21.42	21.17	0.25	0.01	10.89	-10.28	-0.48565	9.37	-11.80	-0.56	10.08	-11.09	-0.52
2016	24.28	21.17	3.11	0.15	9.32	-11.85	-0.55983	8.43	-12.74	-0.60	15.25	-5.92	-0.28
MEAN	**21.17**	**21.17**			**13.29**			**12.63**			**18.43**		

Annex H

Standardized Annual Seasonal Precipitation Concentration Indexes at Chercher Station

Years	ANNUAl PCI	ANNUAL SPCI			KIREMT SPCI			BELG SPCI			BEGA SPCI		
		Annual_Mean PCI	PCIi-PCIMean	SPCI ANNUAL	PCI KIREMT	PCIi-PCIMean	SPCI KIREMT	PCI BELG	PCIi-PCIMean	SPCI BELG	PCI BEGA	PCIi-PCIMean	SPCI BEGA
1980	23.18	23.00	0.18	0.01	11.09054	-11.91	-0.52	10.31	-12.69	-0.55	16.83	-6.17	-0.27
1981	29.56	23.00	6.56	0.29	13.39748	-9.60	-0.42	9.88	-13.12	-0.57	15.94	-7.06	-0.31
1982	19.93	23.00	-3.07	-0.13	11.60655	-11.39	-0.50	8.53	-14.47	-0.63	13.84	-9.16	-0.40
1983	23.56	23.00	0.56	0.02	11.80161	-11.20	-0.49	17.04	-5.96	-0.26	14.78	-8.22	-0.36
1984	21.76	23.00	-1.24	-0.05	9.59796	-13.40	-0.58	12.32	-10.68	-0.46	12.47	-10.53	-0.46
1985	20.35	23.00	-2.65	-0.12	10.89736	-12.10	-0.53	9.44	-13.56	-0.59	10.63	-12.37	-0.54
1986	24.38	23.00	1.38	0.06	9.587349	-13.41	-0.58	8.72	-14.28	-0.62	16.99	-6.01	-0.26
1987	21.56	23.00	-1.44	-0.06	10.95718	-12.04	-0.52	13.12	-9.88	-0.43	22.67	-0.33	-0.01
1988	29.85	23.00	6.85	0.30	12.3552	-10.64	-0.46	22.80	-0.20	-0.01	16.01	-6.99	-0.30
1989	18.29	23.00	-4.71	-0.20	9.537399	-13.46	-0.59	8.76	-14.24	-0.62	14.70	-8.30	-0.36
1990	27.39	23.00	4.39	0.19	11.18166	-11.82	-0.51	13.61	-9.39	-0.41	17.64	-5.36	-0.23
1991	18.20	23.00	-4.80	-0.21	10.38404	-12.62	-0.55	8.92	-14.08	-0.61	15.29	-7.71	-0.34
1992	22.30	23.00	-0.70	-0.03	12.00937	-10.99	-0.48	10.08	-12.92	-0.56	12.81	-10.19	-0.44
1993	16.56	23.00	-6.44	-0.28	10.19041	-12.81	-0.56	9.04	-13.96	-0.61	15.21	-7.79	-0.34
1994	25.10	23.00	2.10	0.09	10.19881	-12.80	-0.56	12.50	-10.50	-0.46	15.24	-7.76	-0.34
1995	22.84	23.00	-0.16	-0.01	11.28683	-11.71	-0.51	9.22	-13.78	-0.60	12.50	-10.50	-0.46
1996	16.48	23.00	-6.52	-0.28	9.883118	-13.12	-0.57	9.09	-13.91	-0.60	15.70	-7.30	-0.32
1997	16.92	23.00	-6.08	-0.26	14.34941	-8.65	-0.38	10.11	-12.89	-0.56	23.74	0.74	0.03
1998	27.97	23.00	4.97	0.22	11.59634	-11.40	-0.50	12.62	-10.38	-0.45	23.41	0.41	0.02
1999	29.16	23.00	6.16	0.27	12.21688	-10.78	-0.47	10.98	-12.02	-0.52	15.73	-7.27	-0.32
2000	28.41	23.00	5.41	0.24	15.00179	-8.00	-0.35	14.09	-8.91	-0.39	24.05	1.05	0.05
2001	22.01	23.00	-0.99	-0.04	11.58865	-11.41	-0.50	9.35	-13.65	-0.59	11.66	-11.34	-0.49
2002	23.60	23.00	0.60	0.03	10.35219	-12.65	-0.55	9.30	-13.70	-0.60	10.59	-12.41	-0.54

2003	24.26	23.00	1.26	0.05	9.622819	-13.38	-0.58	9.02	-13.98	-0.61	19.21	-3.79	-0.16
2004	22.26	23.00	-0.74	-0.03	10.04747	-12.95	-0.56	15.76	-7.24	-0.31	12.32	-10.68	-0.46
2005	24.10	23.00	1.10	0.05	10.17164	-12.83	-0.56	12.55	-10.45	-0.45	13.20	-9.80	-0.43
2006	17.65	23.00	-5.35	-0.23	12.11937	-10.88	-0.47	10.38	-12.62	-0.55	11.95	-11.05	-0.48
2007	27.33	23.00	4.33	0.19	12.65107	-10.35	-0.45	23.17	0.17	0.01	15.72	-7.28	-0.32
2008	17.01	23.00	-5.99	-0.26	9.916875	-13.08	-0.57	17.23	-5.77	-0.25	24.16	1.16	0.05
2009	20.37	23.00	-2.63	-0.11	16.71003	-6.29	-0.27	18.41	-4.59	-0.20	10.55	-12.45	-0.54
2010	25.14	23.00	2.14	0.09	16.85422	-6.15	-0.27	8.68	-14.32	-0.62	14.34	-8.66	-0.38
2011	29.91	23.00	6.91	0.30	12.1802	-10.82	-0.47	9.41	-13.59	-0.59	14.25	-8.75	-0.38
2012	20.89	23.00	-2.11	-0.09	11.55634	-11.44	-0.50	8.82	-14.18	-0.62	13.38	-9.62	-0.42
2013	25.37	23.00	2.37	0.10	11.94667	-11.05	-0.48	15.39	-7.61	-0.33	14.22	-8.78	-0.38
2014	21.80	23.00	-1.20	-0.05	9.330736	-13.67	-0.59	11.42	-11.58	-0.50	12.27	-10.73	-0.47
2015	21.42	23.00	-1.58	-0.07	10.88869	-12.11	-0.53	9.37	-13.63	-0.59	10.08	-12.92	-0.56
2016	24.28	23.00	1.28	0.06	9.31843	-13.68	-0.59	8.43	-14.57	-0.63	15.25	-7.75	-0.34
MEAN	**23.01**	**23.00**			**11.47**			**11.83**			**15.39**		