



**ANALYSIS AND PRIDITION OF METEOROLOGICAL DROUGHT  
USING STANDARDIZED PRECIPITATION INDEX:  
CASE STUDY OF EASTERN OROMIA**

**MSc. THESIS**

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**FEBRUARY, 2019**

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**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE  
STUDIES,**

**HAWASSA UNIVERSITY**

**HAWASSA, ETHIOPIA**

**IN PARTIAL FULFILLMENT OF THE**

**REQUIREMENTS FOR THE**

**DEGREE OF**

**MASTER OF SCIENCE IN HYDRAULIC ENGINEERING**

**FEBRUARY, 2019**

## **DECLARATION**

I Debebe Kebede, declare that the content of this thesis is entirely my own work with the exception of such quotations or references which have been attributed to their authors or sources. I also declare that all photographs are made or drawn by me except where I have acknowledged another as an author. This thesis has not been previously submitted to this or any other university for a degree.

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Debebe Kebede

## **ACKNOWLEDGEMENT**

I have no words, to express my deepest thank and gratitude to the Almighty God who gave me the courage and determination to materialize my wishes.

I would like to express my deep hearted appreciation to Hawasa University for giving this chance and ERA sponsored for funding tuition, and advisor fees. I would like to extend my sincere gratitude to my families and my Friends Daniel Gizachew and Mulubrehan Diro for the financial support during the research work.

My sincere thanks go to my advisors Dr. Mulugeta Dadi and Mr. Tashale Tadasse for provision of valuable guidance, comments and suggestions during my study.

I would like to thank from the bottom of my heart all my families and friends especially to Ato Fitsum Tilahun (MWU Lecturer and Researcher)and Mr. Lamiso Shura (HU lecturer) for giving moral and material support during my study.

Last but not least, I would like to pay due appreciation to my lovely wife Aster Begeshaw, special brother Samson Kebedeand my Co- advisor Mr. Tashale Tadasse.

## ABSTRACT

Ethiopia is one of the most drought affected country in Africa and suffered from acute drought many time in recent years. The objective of this study is to understand the rainfall variation and conduct an in-depth analysis and prediction of drought for to Eastern Oromia. Standardized precipitation index (SPI) was selected to characterize drought condition in the region.

Drought characteristics at a time scale of 2-month, 3-month, 6month and 12-month were computed separately for 22 selected rain gauge station. The most maximum drought characteristics at 2-month, 3-month, 6-month and 12-month time scales have been found in Hararegie over last 36 years (1979-2015). The spacial extent of drought and rainfall variation were determined from SPI and CV values computed separately for each rainfall have been interpolated between station in Arc view GIS environment. The rainfall variation shows that the rainfall over the study area is highly variable and increases from Arsi to East Harargie and in the recent last decade (2005-2015) the map of SIP-3 (Belg) shows that a spacial extent drought over study area was irregular and there were no period in recent decades (2005-2015) without drought at least mild drought and this shows that the area is vulnerable to drought. The maximum intensity of (5.33) was recorded at Fedis Station for SPI-3 (kiremt season) in a year 1996, maximum intensity of (4.04) was recorded at Kobo Station in a year 1985 for SPI-3 (Belg season), maximum intensity of (4.77 and 4.5) were recorded at Ticho Station for SPI-6 (both seasons) and SPI-12 (annual) respectively.

The drought prediction was made until 2043, using the Representative Concentration Path way (RCP) 8.5 Scenario.on the basis of the drought index measured by SPI. From the analysis of the drought index through the RCP 8.5 Scenario, extreme drought intensity will be more likely to occur. The long-term forecast (12-month period unit) showed that extreme drought would occur severely at station Diksis Sude, Hirna and Adelle from 2035 to 2040 and need more attention for this area.

**Key words:** Eastern Oromia, Meteorological Drought, RCP 8.5 Scenario, SPI

## TABLE OF CONTENTS

Contents	Page
ACKNOWLEDGEMENT .....	i
ABSTRACT.....	ii
TABLE OF CONTENTS.....	iii
LIST OF FIGURES .....	vi
LIST OF TABLES.....	vii
LIST OF TABLES IN APPENDIX.....	viii
LIST OF FIGURES IN APPENDIX .....	ix
LIST OF ABBREVIATION .....	x
1. INTRODUCTION .....	1
1.1 Back Ground.....	1
1.2 Statement of the Problem .....	2
1.3 Objectives of the Study .....	2
1.4 Scope of the Study.....	2
2. LITRATURE REVIEW .....	3
2.1 General .....	3
2.2 Types of drought.....	6
2.2.1 Meteorological Drought.....	6
2.2.2 Hydrological Drought .....	7
2.2.3 Agricultural Drought.....	7
2.2.4 Socio – Economic drought.....	7
2.3 Impacts of drought .....	8
2.4 Drought indicators .....	8
2.4.1 Percent of Normal (PN) .....	9
2.4.2 Standardized Precipitation Index(SPI).....	9
2.4.3 Palmer Drought Severity Index (PDSI) .....	11

2.4.4. Crop Moisture Index (CMI).....	14
2.4.5. Surface Water Supply Index (SWSI).....	14
2.4.6. Reclamation Drought Index (RDI) .....	16
2.4.7. Deciles .....	17
2.4.8. Dependable Rain (DR).....	17
2.4.9. National Rainfall Index (NRI) .....	17
2.5. Problems of current indices .....	19
2.5.1. Defining the period of water deficit.....	19
2.5.2. Time unit.....	19
2.5.3 Storing term of water resources .....	19
2.5.4 Considering the diminishing effect of water resources with time passage.....	19
2.5.5 Data used.....	20
<b>3 MATERIALS AND METHODS .....</b>	<b>21</b>
3.1 Description of the Study Area .....	21
3.1.1 Location and Topography .....	21
3.1.2 Climate Condition.....	22
3.1.3 Variability of Rain fall.....	22
3.2 Data Collection.....	23
3.3 Future Data of precipitation using RCP Scenarios.....	24
3.4 Data screening .....	26
3.5 Selection of drought index.....	27
3.6 Drought Characterization using SPI.....	28
3.6.1 Drought intensity .....	29
3.6.2 Drought Severity.....	29
3.6.3 Drought magnitude .....	29
3.6.4 Drought duration.....	29
3.6.5 Drought Frequency .....	29

3.7 SPI Calculation.....	29
4 RESULTS AND DISCUSSION .....	32
4.1 Rainfall Variability.....	32
4.2 Drought intensity.....	33
4.3 Drought Severity .....	36
4.4 Drought magnitude.....	38
4.5 Drought duration .....	40
4.6 Drought Frequency.....	45
4.7 Analyzing and predicting of the future Drought of SPI.....	49
4.8 Spatial extent .....	51
5 CONCLUSIONS AND RECOMMENDATIONS.....	54
5.1 Conclusions .....	54
5.2 Recommendations .....	56
REFERENCES .....	57
APPENDIX A.....	64
APPENDIX B.....	73
APPENDIX C.....	90

## LIST OF FIGURES

<b>Figures</b>	<b>Page</b>
Figure 3.1 Study area with metrological stations .....	21
Figure 3.2 Future precipitations by RCP 8.5 .....	25
Figure 3.3 Double mass curve plot made for stations after correction made .....	26
Figure 4.1 SPI of 3-months from July to Aug of Fedis station E.harargie .....	35
Figure 4.2SPI-3 (Kiremt) for Adele station (Arsi) .....	35
Figure 4.3SPI-3 (Kiremt) for Hirna station (W.Harargie) .....	35
Figure 4.4:Drought severity SPI-3(Kermit Season) .....	36
Figure 4.5: Drought severity SPI-3(Belg Season) .....	37
Figure 4.6: Drought severity SPI-6 (Belg &kiremt Season).....	37
Figure 4.7: Drought severity SPI-12 (annual) .....	38
Figure 4.8:Drought frequency SPI-3 (Kiremt Season) .....	46
Figure 4.9: Drought frequency SPI-3 (Belg Season).....	47
Figure 4.10:Drought Frequency SPI-12 (Annual) .....	48
Figure 4.11Predicted SPI –Values of Adele .....	50
Figure 4.12: Predicted SPI –Values of Hirna .....	50
Figure 4.13: Predicted SPI –Values of Diksis Sude .....	50
Figure 4.14: Severity maps based on SPI -3(Kiremt).....	53

## LIST OF TABLES

<b>Tables</b>	<b>Page</b>
Table 2.1 SPI Values Category.....	10
Table 2.2 Drought Classification by PDSI Value.....	12
Table 2.3 Reclamation Drought Index (RDI) classification.....	16
Table 2.4 Deciles classification.....	17
Table 2.5 Characteristic of drought indicators.....	18
Table 3.1 Selected stations for Study Area.....	24
Table 4.1 Coefficient of Variation (CV) of rain fall for different time scale.....	33
Table 4.2 SPI values of stations of different time scales.....	34
Table 4.3 Drought Parameter.....	39
Table 4.4 Summary of drought characteristics based on SPI-2.....	40
Table 4.5 Summary of drought characteristics based on SPI-3(Kiremt).....	41
Table 4.6 Summary of drought characteristics based on SPI-3 (Belg).....	42
Table 4.7 Summary of drought characteristics based on SPI-6 ( both season).....	43
Table 4.8 Summary of drought characteristics based on SPI-12 (annual).....	44

## LIST OF TABLES IN APPENDIX

<b>Tables</b>	<b>Page</b>
Table A 1. Statistical Parameters for stations for different time scales.....	65
Table A 2 SPI values .....	66
Table A 3 SPI values .....	67
Table A 4 SPI values .....	68
Table A 5 SPI values .....	69
Table A 6 SPI values .....	70
Table A 7 SPI values .....	71
Table A 8 SPI values .....	72
Table B 1. Drought parameters.....	74
Table C 1 Summary Drought Frequency and Intensity SPI-3 (kiremt).....	91
Table C 2 Summary Drought Frequency and Intensity SPI-3 (Belg).....	92
Table C 3 Summary Drought Frequency and Intensity SPI-12 (Annual).....	93

## LIST OF FIGURES IN APPENDIX

<b>Figures</b>	<b>Page</b>
Figure C 1. Severity maps based on SPI -3(Belg for 2005-2006) .....	94
Figure C 2 Severity maps based on SPI -3(Belgs for 2007-2008) .....	95
Figure C 3. Severity maps based on SPI -3(Belg for 2009-2010) .....	96
Figure C 4 Severity maps based on SPI -3(Belg for 2011-2012) .....	97
Figure C 5 Severity maps based on SPI -3(Belg for 2013-2014) .....	98

## LIST OF ABBREVIATION

%ED	Percent of Extreme Drought
%MD	Percent of Mild Drought
%MoD	Percent Moderate Drought
%SD	percent of Severe Drought
Au	August
AWC	Available water content
BoFED	Bureau of Finance and Economic Development
C	century
CMI	Crop moisture index
CSDI	Crop Specific drought index
CV	Coefficient of variation
D	December
DPPC	Disaster prevention and preparedness commission
DR	Dependable Rain
DR	Dependable rain
DrinC:	Drought Indices Calculator
ED	Extreme Drought
ET	Evapotranspiration
EV	Evaporation
F	February
GUI	Graphical User Interface
J	June
JY	July
m	month
Ma	March

Ma.s.l	meter above sea level
MD	Mild Drought
MoD	Moderate Drought
MoWR	Ministry of Water Resource
NMSA	National meteorology survey agency
NRI	National Rainfall Index
ONRS	Oromia National Regional State
P	precipitation
Pdf	probability density function
PDSI	Palmer drought Severity Index
PET	Potential Evapo Transpiration
PHDI	Palmer Hydrological Severity Drought Index
PN	Percent of Normal
RAI	Rain fall Anomaly Index
RCP	Representative Concentrations Paths
RD	Rain fall Deciles
RDI	Reconnaissance drought index
RO	Run off
S	September
s	season
s.d	standard deviation
SD	Sever Drought
SDI	Stream Flow Drought Index
SPATSIM	SPATial and Time Series Information model
SPI	standard precipitation index
SPI -3 (Belg)	Accumulation precipitation of 3 months (F, Ma and A)

SPI -6 (Both season)	Accumulation precipitation of 6 months (Ma to Au)
SPI-12 (Annual )	Accumulation precipitation of 12 months (J to D)
SPI-2 (JJY)	Accumulation precipitations of 2 months (J and JY)
SPI3- (Kiremt)	Accumulation precipitation of 3 months (Ju, Au and S)
SWSI	Surface Water Supply Index
T	Temperature
Y	year

## **1. INTRODUCTION**

### **1.1 Back Ground**

Drought is considered as a major natural hazard, affecting several sectors of the economy and the environment worldwide. It affects almost all the determinants of the hydrological cycle starting from precipitation and ending with stream flow in the surface water systems or the recharge and storage in the groundwater aquifers. Therefore, the determinant to be chosen depends upon which part of the hydrological cycle we are interested to focus our analysis (Tsakiris et al., 2013).

Conventionally, droughts are characterized by the determinant studied and are categorized as meteorological (precipitation, potential evapotranspiration), hydrological (stream flow or groundwater recharge), agricultural (soil moisture). Drought indices are essential tools for the characterization and the monitoring of drought, since they simplify the complex climatic functions and can quantify climatic anomalies as for their severity, duration and frequency. They are also very useful as they can communicate to the wider audience easily comprehensible information regarding the severity of drought episodes (Tsakiris et al., 2007c).

Drought indices can be used in the academic field (education, research, studies etc.), but also at strategic and operational levels (decision making, proactive management and drought mitigation etc.), having a wide range of potential users. Of course, no single index is universally suitable, so in most cases it is necessary to consider more than one index (Morid et al., 2006).

The U.S Weather Bureau define a drought as “lack of rainfall so great and long continued as to affect injuriously the plant and animals life of a place and deplete water supplies both for domestic purpose and for the operation of power plants, especially in those region where rainfall is normally sufficient for such purpose “The term “drought “has different connotation in various part of the world: in Bali, a period of six days without rain; in Egypt, any year the Nile river doesn’t flood is drought, regardless of rainfall; in Libya when annual rain fall is less than 180 mm, so, drought can be neither accurately define in term of mm of rainfall or by number of days without rains.

Ethiopia is one of the densely populated countries in Africa. It has often suffered from acute drought and famines. Drought was reported as early as 253 B.C. over the country. During the last four decades the occurrence of this natural disaster has been frequent. Drought damages national economy mainly depends on rain-fed agriculture. The extent of rain fall failure over the country varies from year to year and at the same time from one part to another (NMSA, quoted by Worku, 1996).

### **1.2 Statement of the Problem**

Most south eastern part of the region is a drought prone area. Despite the fact that, most of the people are engaged in rain fed agriculture crop production system and pastoralist activities. Therefore, the variability of rainfall in space and time highly affected the crop production and pastoralist activities, which ultimately cause drought, loss of million people, cattle and economical, environmental or social of the country.

### **1.3 Objectives of the Study**

The main objective of the study is to understand the rainfall variation and analyze drought by its characteristics using standardize precipitation index and to predict the occurrence drought at study area.

The Specific objective of the study area includes but not limited to the following:-

- ❖ To study relationship between rainfall variability and drought event over the study area.
- ❖ To determine spatial characteristics of drought (area cover) and Drought frequency of occurrence
- ❖ To determine drought characteristics such as drought intensity, severity and frequency.

### **1.4 Scope of the Study**

This research work is limited to analyze drought by their characteristics namely, drought intensity, duration, magnitude, frequency, Severity and spatial extent on 22 stations collected from NMSA in study area (Arsi, East Hararhie and West Harargie).

## **2. LITRATURE REVIEW**

### **2.1 General**

Drought occurrence has a long history in the region, but due to lack of data, it is difficult to trace back historical sequences of drought incidence in the region. Still, attempts have been done to reveal some drought events stroke the region. According to Senbeta (2009), major drought and rain delay events that hit some zones of the region (Arsi and East Shewa), were in 1983-84 (both Arfassa/Belgand Birra/Meherfailure), 1991-92 & 1997-98 (bad to failed Arfassa/Belgand Birra/Meher), 2002-03 (bad to failed Arfassa/Belgand Birra/Meher) and most recently in 2007/08 (complete Arfassa/Belgrain failure) west Arsi zone.

Similarly, a research conducted by Oxfam International cited that in 1972-1974, 1984-1985, 1999-2000, 2002-2003, 2007 drought attacked lowlands of the region, particularly resulted in the loss of thousands of livestock in Borena zone (Oxfam International, 2010).

Drought characterization can be valuable for the evaluation of the risk of future droughts, for the determination of the impacts of drought on various sectors (economy, environment, society etc.) and for the design of the preparedness plans for the management of the anticipated drought impacts (Rossi et al., 1992).

Drought indices are widely accepted as useful elements to characterize drought and its statistical properties. Some basic steps for drought characterization can be described as follows (Tsakiris et al., 2007a):

- i. Collect all the necessary monthly data of each reliable meteorological station of the selected area.
- ii. Transfer meteorological data at a basin or sub-basin level.
- iii. Calculate selected indices on an appropriate time scale (e.g. trimester, semester or annual scale).
- iv. Display the results graphically using colors for the various levels of drought intensity.
- v. Analyze the frequency of occurrence of 1-year drought using historical data. Other time steps could be also used.

The Centre for the Assessment of Natural Hazards and Proactive Planning of the National Technical University of Athens (NTUA) studied drought episodes on a regional level at the island of Crete. A series of annual drought maps were produced with the use of DrinC along with a spatial distribution model (Tsakiris et al., 2007d).

The Water Observatory of the Region of Sicily and the University of Palermo analyzed time series of climatic data (rainfall, temperature) using drought indices (SPI, RDI, NDVI) and vegetation data at the Oreto watershed in Sicily. Both satellite and conventional measurements were used in order to assess climatic effects on vegetation at the study area (Capodici et al., 2008).

The Meteorological Service of Cyprus has used DrinC in two studies for the assessment and the monitoring of drought in Cyprus, using an extensive network of meteorological stations and GIS techniques (Pashiardis and Michaelides 2008; Michaelides and Pashiardis, 2008).

The University of Thessaly used DrinC to assess meteorological drought for a period of 45 years, using three drought indices (Deciles, Palmer Z and RDI) (Kanellou et al., 2008).

The Water Directorate of the Malta Resources Authority used DrinC to analyse drought events in the country through RDI and SPI. Also, there was an attempt to assess the problems that could be caused by water shortage due to severe drought events (Borg, 2009).

The University of Isfahan and the Meteorological Organization of Iran used DrinC in a study for the operational drought monitoring in the region of Isfahan. Meteorological data from 10 stations were used for the calculation of RDI and SPI (MostafaviDarani et al., 2011).

The Lab. of Reclamation Works and Water Resources Management of the NTUA used DrinC along with Medbasin rainfall-runoff model (Tigkas and Tsakiris, 2004) in order to assess the drought and climatic change impact on stream flow in small watersheds. The case study was performed in 6 small watersheds in N. Peloponnese. RDI was calculated for several reference periods (3, 6, 9 and 12 months) and SDI was used to represent hydrological drought. Regression equations were derived between RDI and SDI, forecasting the level of hydrological drought for the entire year. Further, DrinC was used for the formulation of a wide range of scenarios representing possible climatic changes and drought events of varying severity in the area of N. Peloponnese. Nomograms were devised for estimating the annual stream flow

change caused by each climate change scenario (Tigkas et al., 2012).

The Hydro technical Engineering Department of the Polytechnics University of Timisoara performed a drought analysis for the western part of Romania, using SPI and RDI, computed with DrinC for several reference periods (Rares, 2013).

Several meteorological drought indices have been used in the past to assess drought severity. Most of the indices use monthly precipitation data (e.g. SPI) and in some cases additionally monthly potential evapotranspiration data (e.g. RDI). The objective of this paper is to present the new Reconnaissance Drought Index and its requirements and also to specify the requirements of a meteorological monitoring network aiming at providing data for the calculation of such indices. From the methodologies examined the one based on geostatistical tools such as the kriging method was tailored and successfully used for the purpose of drought monitoring. (Tsakiris G. et al., 2008).

The Standardized Precipitation Index (SPI) expresses the actual rainfall as standardized departure from rainfall probability distribution function. In this study severity and spatial pattern of meteorological drought was analyzed in the Puruliya District, West Bengal, India using multi-temporal SPI. Daily gridded data for the period 1971-2005 from 4 rainfall stations surrounding the study area were collected from IMD, Pune, and used in the analysis.

Using satellite data as input parameters for drought indices, spatiotemporal variation of seasonal agricultural drought patterns and severity are detected and mapped with the help of advanced techniques of GIS and remote sensing. The obtained result is in agreement with the ground based surveyed information. Hence, agricultural drought assessment using satellite data are paramount importance in order to assess the past and the current agricultural drought conditions , and generate baseline information that helps to monitor real time situation in the future for different adaptation options within relatively large geographical area and repetitive time scale coverage. (GizachewLegesse, 2010).

DrinC (Drought Indices Calculator) aims at providing a user-friendly tool for the calculation of several drought indices. Key objective in its design was the widest possible applicability for several types of drought (meteorological, hydrological, agricultural) and different locations. It was also taken into account that drought studies are particularly essential in arid and semi-arid

regions, where data availability is usually limited. Therefore, the main criteria for the selection of indices were:

a) To have relatively low data requirements, allowing the application of the software in many regions and

b) Their results to be clearly interpreted for direct and efficient operational use. Based on these criteria, two recently developed and two more widely known indices were included in DrinC: the Reconnaissance Drought Index (RDI), the Stream flow Drought Index (SDI), the Standardized Precipitation Index (SPI) and the Precipitation Deciles (PD). As can be easily understood, RDI, SPI and PD refer to the meteorological drought and use as main determinant the precipitation (and additionally the potential evapotranspiration for RDI only). Further, RDI can also be used for the agricultural drought analysis, as it can adequately describe the water balance, and it is particularly useful when reference periods related to development stages of the crop are selected (Tsakiris et al. 2010). On the other hand, SDI applies to hydrological drought and uses the stream flow as the key determinant. Apart from the originally proposed methods of calculation for each index, DrinC incorporates alternative methods that allow the comparison of the results among the indices. Further, this gives a key advantage to the user, since it provides the flexibility to select among various options for adjusting the outputs to his particular needs. Following, there is a short presentation and the key characteristics of the drought indices calculated by DrinC.

## **2.2 Types of drought**

As Wichita and Glantz stated in Afonso (2005), drought can be classified in to four types as Meteorological, Hydrological, Agricultural and Socio- economic drought. Descriptions of each type of drought given in subsequent section.

### **2.2.1 Meteorological Drought**

Meteorological drought is a measure of departure of precipitation from normal. It is characterized as a situation when the rain fall is substantially below its climatological expectations. In common language, large water shortage due to lack of precipitation is defined as meteorological drought. Meteorological definition of drought is highly variable around the world.(Ghosh, 1999)

### **2.2.2 Hydrological Drought**

Hydrological drought occurs when surface and subsurface water are below normal and concerned with the effect of dry spell on surface or subsurface hydrology rather than with meteorological explanation of events. Hydrological drought occur when river flows or stored water in reservoir, lake and aquifers fall below some critical levels. For example “period during which stream flows are inadequate to supply established user under a given water management system”. An objective approach to define drought may be followed, for example, an area is identified as drought (hydrological) affected if  $Q < 0.75 Q_0$  in which  $Q_0$  is the normal mean flow during the last several years. It is found that,  $Q < 0.75 Q_0$  in 25 % or more years under consideration than the area is considered as drought prone. If the coefficient of  $Q_0$  is less than 0.75 than the drought is sever. (Ghosh, 1999).

### **2.2.3 Agricultural Drought**

An agricultural drought refers to a situation when the amount of moisture in the soil no longer meets the needs of a particular crop. It occurs when yield drops much below the average crop production .This happens due to non-availability of desired level of natural soil moisture and the periods may not necessarily coincide with the periods of meteorological and hydrological drought.

In Ethiopia, shortages of food supplies due to poor crop yields are common during drought periods. Food shortages often lead to famine. Thus, famine may be regarded as an extreme case of agriculture drought. Nonetheless, famine may be also precipitated by factors such as conflicts or war, which have nothing to do prolonged soil moisture deficiencies.(facts about drought in Africa,2003)

### **2.2.4 Socio – Economic drought**

It refers to the situation that occurs when physical water shortage begins to affect people. It expresses features of the socio – economic effects of drought and can also incorporate features of meteorological, agricultural, and hydrological drought. They are usually associated with the supply and demand of some economic grounds (Donald, 1987). Since rainfall is the best indicators to study drought, and the most popular perception of a drought is a “Meteorological phenomenon”, in this research meteorological drought will be considered.

### **2.3 Impacts of drought**

Drought produces a complex web of impacts that spans many sectors of the economy and reaches well beyond the area experiencing physical drought. Impacts are commonly referred to as direct or indirect. Direct or primary impacts are usually biophysical. The few examples of direct impacts include reductions of crops, rangeland, and forest productivity; increased fire hazard; reduced water levels; increased livestock and wildlife mortality rates; and damages to wild life and fish habitat. The consequences of these impacts illustrate indirect impact. For example; a reduction in crop may result in reduced income of farmers and agribusiness, increased prices for food, unemployment, and reduced tax revenue.

### **2.4 Drought indicators**

Drought indicators are variables to describe the magnitude, duration, severity, and spatial extent of drought. Typical indicators are based on meteorological and hydrological variables, such as precipitation, stream flow, soil moisture, reservoir storage, and ground water levels. Indicators can be also synthesized into a single indicator on a quantitative scale, often called a drought index. Drought indices assimilate thousands of bits of data on rainfall, snow peak, stream flow and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, a more useful than raw data for decision making. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Such indices include percent a normal, Deciles, standardized precipitation index (SPI), Palmer Drought (PDS), crop moisture index (CMI) and surface water supply index (SWSI). None of the major indices is inherently superior to the rest in all circumstances; however, some indices may be better suited than others for certain uses. For example, the Palmer Drought severity index has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance, but PDSI is better when working with large areas of uniform topography. Areas with mountainous terrain and resulting complex regional micro climate find it useful to supplement Palmer with other indices. The U.S. national Drought mitigation center is using a newer index, the standardized precipitation index. Most water supply planners find it useful to consult one or more indices before making a decision.

The major indices in use are elaborate in subsequent section.

#### **2.4.1 Percent of Normal (PN)**

One of the simplest measurements of rainfall for a location is the percent of normal. This index is especially effective when used for a single season or region. Percent of normal is also easily misunderstood and gives different indication of conditions, depending on the location and season. It calculated by dividing actual by normal precipitation and multiplied by 100%. Typically a 30 year mean is used to determine normal precipitation. Normal precipitation for a specific location is considered to be 100%.

One of the disadvantages of using the percent of normal precipitation is that the mean or average precipitation is often not the same as the median precipitation. Sometimes, the value exceeded by 50% of the precipitation occurrences in a long term climate record. The reason for this is that precipitation on monthly or seasonal scales does not have a normal distribution. Use of the percent of normal comparison implies normal distribution where the mean and median are considered being the same. Because of the variety in the precipitation records over time and location, there is no way to determine the frequency of the departures from the normal or compare different locations. This makes it difficult to link a value of a departure with a specific impact occurring as a result of the departure, inhibiting attempts to mitigate the risks of drought based on the departure from normal and from a plan of response (Smakhtinand Hughes, 2004)

#### **2.4.2 Standardized Precipitation Index(SPI)**

As McKee stated in Soto (2005), he desired to understand the different impacts that precipitation deficit has on ground water, reservoir storage, soil moisture, and stream flow that led to the development of the standardized precipitation index (SPI). The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impacts of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale, while ground water, stream flow, and reservoir storage reflect the long-term precipitation anomalies.

Therefore, the different time steps (1, 3, 6, 12, 24, and 48 months) for which the index is computed address the various types of drought: the shorter season for agriculture and

meteorological drought: the longer season for hydrological drought. The SPI calculation for any location is based on the long-term complete precipitation record (possibly, 25, or 50 or 100 years) for a desired period. As Edwards and McKee stated in Steinmann (2003), this long term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero.

The SPI is calculated by taking the difference of the precipitation from the mean for a particular time scale, and then dividing by the standard deviation. This is advantageous because the SPI is normalized so the wetted and drier climates can be represented in the same way. In addition, wet periods can be monitored using the SPI.

As McKee et.al (1993) explained in Hayes, McKee used the classification system shown in Table 2.1 to define drought intensities resulting from the SPI. A drought event occurs any time the SPI is continuously negative and reaches intensity where the SPI is -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The accumulated magnitude of drought can also be drought magnitude, and it is the positive sum of SPI for all the months within a drought event.

**Table 2.1** SPI Values Category

SPI Values	Drought category
2.0 or more	Extremely wet
1.5 to 1.99	Severely/very wet
1.0 to 1.49	Moderately wet
0 to 0.99	Mildly wet
0 to -0.99	Mild Drought
-1.0 to -1.49	Moderate dry (moderate drought)
-1.5 to -1.99	Severe dry (severe drought)
-2.0 and less	Extreme dry (extreme drought)

Guttman (2002) concluded the SPI is a better mediator show how drought in one region compares to drought in another region as stated in Sonmez (2005) Analysis of extreme drought events showed that the SPI provided a better spatial standardization than the PDSI

(Lloyd- Hughes and Saunders,2002). Another virtue of the SPI is that drought initiation and termination are implicit part of the index. Given advantage of the index standardization, the SPI has been largely used operationally to monitor climatic conditions across different locations.

As Guttman stated in Liloyd-Hughues (2002), besides its advantages, practical application of the SPI revealed some disadvantages. It is assumed that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization. Another limitation of the SPI emerges from the standardization process of the index itself. Drought measured by the SPI can occur with some frequency at all locations when considered over a long time period. A third is that misleadingly large positive or negative SPI values may result when the index is applied at short time step to regions of low seasonal precipitation.

### **2.4.3 Palmer Drought Severity Index (PDSI)**

Palmer developed an index to measure the departure of the moisture supply (palmer, 1965); Palmer based his to account more than just the precipitation deficit at the specific locations. The objective of the palmer drought severity index (PDSI) was to provide measurements of moisture conditions that were standardized so that compensations using the index could be made between locations and between months (palmer 1965).responds to weather conditions that have been abnormally dry abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking in to account stream flow, lake and reservoir levels, and other long term hydrologic impacts as karl and knight stated in Hayes (2003) the PDSI is calculated based on the precipitation and temperature data, as well as the local available water content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. Human impacts on the water balance. Such as irrigation are not considered. Table 2.2 shows the classification of drought using the PDSI value

**Table 2.2** Drought Classification by PDSI Value

PDSI Value	Classification
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

Palmer developed the PDSI to include the duration of a drought (or wet spell). His motivation was as follows: an abnormally wet month in the middle of long-term drought should not have major impacts on the index, or a series of month with near-normal precipitation following a serious drought does not mean that the drought is over. Therefore, Palmer developed criteria for determining when drought or a wet spell begins and ends, which adjust the PDSI accordingly. Palmer (1965) described this effort and gave examples, and it is also described in detail by Alley as stated in Hayes (2003). In near real time, Palmer's index referred to as the palmer Hydrological Droughtindex (PHDI) because it is based on moisture inflow (precipitation), outflow, and storage, and does not take into account the long term trend as karl and knight stated in Hayes (2003).

In 1989, a modified method to compute the PDSI was begun operationally by Heddinghaus and Sabol as stated in Hayes (2003), this modified PDSI differs from the PDSI during transition periods between dry and wet spells. Because of the similarities between dry and wet spells, Because of the similarities between those Palmer indices, the term Palmer index and Palmer drought index have been used to describe general characteristics of the indices.

The palmer index is popular and has been widely used for a variety of applications. It is most effective measuring impacts sensitive to soil moisture conditions, such as agriculture as Willeke et al. stated in Hayes (2003). It has also been useful as a drought monitoring tool and has been used to trigger actions associated with drought contingency plans as Willeke et al. and Alley stated in Hayes (2003) identified three positive characteristics of the Palmer index that contribute to the popularity.

- It provides decision makers with a measurement of abnormality of recent weather for a region.
- It provides an opportunity to place current condition in historical perspectives
- It provides special and temporal representations of historical drought.

There are considerable limitations when using the palmer index, and these are described in detail by Alley, Kari and Knight State in Hayesr (2003). Drawbacks of the palmer index include:

- The Palmer index is sensitive to the AWC of a soil type. Thus, applying the index for a Cleveland division may be too general.
- The two soil layers within the water balance computations are simplified and may not be accurately representative of a location.
- Snowfall, snow, cover, and frozen ground are not included in the index. All precipitation is treated as rain, so that the timing of PDSI or PHDI values may be inaccurate
- The natural lag between when precipitation falls and the resulting runoff is not considered. In addition, no runoff is allowed to take place in the model until the water capacity of the surface and subsurface soil layers is full. Leading to an underestimation of runoff. Potential Evapotranspiration is estimated using the Thorn Thwaite method. This technique has wide acceptance, but it is still only an approximation.

Several other researchers have presented additional limitation of the palmer index. Mckee et al. suggested in Hayes (2003). That the PDSI is designed for agriculture but does not accurately represent the hydrological impact resulting from longer droughts. One explanation for this is

provided by Smith et al. stated in Hayes (2003) who suggested that it does not do well in region where there are extremes in the variability of rainfall or runoff. Examples in Australia and South Africa were given.

#### **2.4.4. Crop Moisture Index (CMI)**

The crop moisture index (CMI) uses a meteorological approach to monitor week to week crop conditions. It was developed by palmer (1968) from procedure within the calculation of the PDSI as stated in Hayes (2003). Whereas the PDSI monitors long-term meteorological wet and dry spells, the CMI was designed to evaluate short-term moisture condition across a major crop producing region. It is based on the mean temperature and total precipitation for each week within a climate division, as well as the CMI Value from the previous week. The CMI responds rapidly to changing conditions, and it is weighted by location and time.

Because it is designed to monitor short-term moisture conditions affecting a developing crop, the CMI is not a good long-term drought monitoring tool. The CMI's rapid response to changing short-term conditions may provide misleading information about long-term conditions. For example, a beneficial rainfall during a drought may allow the CMI value to indicate adequate moisture conditions, while the long-term drought at that location persists. Another characteristic of the CMI that limits its use as a long term drought monitoring tool is that the CMI typically begins and ends each growing season near zero. This limitation prevents the CMI from being used to monitor moisture conditions outside the general growing season, especially in droughts that extends over several years. The CMI also may not be applicable during seed germination at the beginning of a specific crop's growing season. (Tilahun, 2004 quoted Eddy)

#### **2.4.5. Surface Water Supply Index (SWSI)**

The surface water supply index (SWSI) was developed by shafer and Dezman stated in Hayer (2003) to complement the palmer index for moisture conditions across the state of Colorado. The Palmer index is basically a soil moisture algorithm calibrated for relatively homogeneous regions, but it is not designed for large topographic variations across a region and does not account for snow accumulation and subsequent runoff. Shafer and Dezman designed the SWSI

to be an indicator of surface water conditions and described the index as “mountain water dependent “, in which mountain snowpack is a major component.

The objective of the SWSI was to incorporate both hydrological and climatologically features in to a single index value resembling the palmer index for each major river basin in the state of Colorado as Shafer and

Dezman stated in Hayes (2003). These values would be standardized to allow comparisons between basins. Four inputs are required within SWSI: snow pack, stream flow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI is computed with only snow peak, precipitation, and reservoir storage in the winter. During the summer months, stream flow replaces snow peak as a component within SWSI equation.

The procedure to determine the SWSI for a particular basin is as follows: monthly data are collected and summed for all the precipitation stations, reservoirs, and snow pack /stream flow measuring station over the basin.

Each summed component is normalized using a frequency analysis gathered from a long-term data set. The probability of non-exceedance, the probability that subsequent sums of that component will not be greater than the current sum is determined for each component based on the frequency analysis. This allows comparisons of the probabilities to be made between the components. Each component has a weight assigned to its typical contribution to the surface water within that basin, and these weighted components are summed to determine a SWSI value representing the entire basin. Like the Palmer index, the SWSI is centered on zero and has a range between -4.2 and +4.2.

Several characteristics of the SWSI limit its application, because the SWSI calculation is unique to each basins or region, it is difficult to compare SWSI values between basins or regions by Doesken et al. stated in Hayes (2003). Within a particular basins or regions, discontinuing any station means that new station needs to be added to the system and new frequency distribution need to be determined for that component. Additional changes in the water management will in a basin, such as flow diversions or new reservoirs, mean that the entire SWSI algorithm for that basin need to be redeveloped to account for changes in the weight of each component. Thus, it is difficult to maintain a homogeneous time series of the

index as Heddinghaus and Sabil stated in Hayes (2003). Extreme event also cause a problem if the events are beyond the historical time series, and the index will need to be reevaluated to include these events within the frequency distribution of a basin component.

#### 2.4.6. Reclamation Drought Index (RDI)

The Reclamation Drought index (RDI) was recently developed as a tool for defining severity and duration, and predicting the onset and end of periods of drought. Like the SWSI, the RDI is calculated at a river basin level, and it incorporates the supply component of precipitation, stream flow, and reservoir levels. The RDI differs from the SWSI in that it builds a temperature – based demand component and duration into the index. The RDI is adaptable to each particular region and its main strength is its ability to account for both climate and supply factors.

**Table 2.3** Reclamation Drought Index (RDI) classification

RDI Value	Condition
4.0 or more	Extremely wet
1.5 to 4.0	Moderately wet
1.0 to 1.5	Normal to mild wetness
0.to -1.5	Normal to mild drought
-1.5 to -4.0	Moderate drought
-4.0 or less	Extreme drought

Arranging monthly precipitation data in to deciles is another drought monitoring technique. It was developed by Gibbs and Maher stated in Hayes (2003) to avoid some of the weakness will in the “percent of normal “approach. The technique they developed divided the distribution of occurrences over a long-term precipitation record in tenths of the distribution. They called each of these categories a docile. The first deciles are the rainfall amount not Exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These decile is the largest precipitation amount within the long – term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrence over the period of record. The deciles are grouped in to five classifications.

#### 2.4.7. Deciles

The deciles method was selected as the meteorological measurements of drought with in the Australian Drought Watch System because it is relatively simple to calculate and requires less data and fewer assumption than the palmer Drought severity index Smith et. al stated in Hayes (2003). In this system, farmers and ranchers can only request government assistance if the drought is shown to be an event that occurs only once in 20-25 years (deciles 1 and 2 over a 100- year record) and has lasted longer than 12 months as White and O’Meagher stated in Hayes (2003). This uniformity in drought classifications, unlike a system based on the percent of normal precipitation, has assisted Australian authorities in determining appropriate drought responses. One disadvantage of the decile system is that along climatological record is needed to calculate the deciles accurately.

**Table 2.4** Deciles classification

Deciles 1-2: lowest 20%	Much below normal
Deciles 3-4: next lowest 20%	Below normal
Deciles 5-6: middle 20%	Near normal
Deciles 7-8: next highest 20%	Above normal
Deciles 9-10: highest 20%	Much above normal

#### 2.4.8. Dependable Rain (DR)

Another rainfall monitoring approach which has been applied to the African continent by Le Houerou (1993) stated in Hayes (2003) is the concept of dependable rain (DR).The researchers define dependable rains as the amount of rainfall that occurs in four of every five years (statistically, not consecutively). They recommended that plans for agricultural production. Be based on dependable rains. In Africa, the relationship of the DR to the mean is not straight forward and reflects the characteristics of annual precipitation across the continent.

#### 2.4.9. National Rainfall Index (NRI)

Used to compare precipitation patterns and abnormalities on a continental scale. The National Rainfall Index was developed by Gomme and Petrassi stated in Hayes (2003) to characterize recent precipitation patterns across Africa. It is calculated for each country by taking a national annual precipitation average weighted according to the long-term precipitation average of all

the individual stations. The NRI allow comparisons to be made between years and between countries.

The strength of the NRI also reveals its limitations. Gomme and Petrassi stated in Hayes (2003) demonstrate that the NRI is well correlated with national crop yields in Africa. This is helped by the fact that the NRI has a natural bias towards agriculture. Because it is weighted by annual rainfall, those stations in wetter areas of a country have a greater influence on the NRI than stations in naturally drier areas.

The characteristics of each index are summarized in Table 2.5

**Table 2.5** Characteristic of drought indicators

S.N	Name	Factors Used	TimeScale	Main concept
1	PDSI	P,T,ET,SM,RO	M	Based on moisture inflow, out flow and storage.
2	SNSI	PDSI,SN	M	Like the PDSI except considering SN
3	PN	P	M	Dividing actual P by the normal value
4	Deciles	P	M	Dividing the distribution of the occurrences over along term p record in to sections each representing ten percent.
5	SPI	P	3m,6m,12m, 24m,48m	Difference of P from the mean for a particular time and dividing it by the standard deviation.
6	CMI	P,T	W	Like the PDSI except considering available moisture in top 5 feet of soil profile.
7	SMDI	SM	Y	Summation of daily SM for a year.
8	CSDI	EV	S	Summation of the value of calculated EV Divided in to possible EV during the growth of specific crops.
9	NRI	P	Y,s	Patterns and abnormalities of P on a continental scale.
10	RAI	P	m ,y	P Compared to arbitrary value of +3 and -3, which is assigned to the mean of ten extreme +and – anomalies of P.
11	BMDI	P	M, y	Percent departure of P from the long-term mean

Note: P: Precipitation, ET: Evapotranspiration Ev: Evaporation, T: Temperature,

SM: Soil moisture, Ro: Runoff, Snow pack, W: week, m: month, si: season: year, c: century; 3m: 3month, etc

## **2.5. Problems of current indices**

### **2.5.1. Defining the period of water deficit**

Drought occurs with the deficiency of fresh water resources from the climatological mean. Important is that it is not only the deficiency at a specific time. But the consecutive occurrence of a deficiency. Therefore, when water deficit period began and how long it has lasted is very important. But most of current indices only assess the deficiency of water from the climatological mean on some predefined duration. Furthermore, no objective method defining the duration is known (Byun and Wilhite, 1996)

### **2.5.2. Time unit**

Most current drought indices use a monthly or longer time period as a unit, as shown in Table 2.5. No index uses a daily unit, but the day unit should be used because an affected drought region can return to normal condition with only a day's rainfall. Furthermore, it is important that the drought intensity be reevaluated frequently and presented at any time. This would allow the general public to prepare against the risks (Byun and Wilhite, 1996)

### **2.5.3 Storing term of water resources**

Drought damage can be categorized in to two kinds of causes. One is damage from a shortage of soil moisture; another is from shortage of reserved water. Soil dryness is influenced by a recent short term deficiency of precipitation. And water resources deficit in reservoirs or other sources are affected by longer- term precipitation totals. It is not easy to imagine other drought damages which are not associated with these two categories. So, categorizing these two separately is better method to assess drought. But it is very hard to find current drought indices which divide the two (Byun and Wilhite, 1996)

### **2.5.4 Considering the diminishing effect of water resources with time passage**

After rainfall Soil moisture diminishing day by day as a function of a runoff and evapotranspiration ratio. One day's diminishing of water is not small enough to simply be ignored. Therefore, because simple Summation of the precipitation can't provide good results, a time dependent reduction function is needed to estimate the current water deficiency.

However, almost all current drought indices use simple summation of precipitation (Byun and Wilhite, 1996)

#### **2.5.5 Data used**

Besides precipitation, current drought indices are calculated from the data of soil moisture, inflow and outflow by water ways, evaporation and evapotranspiration etc. But most of the parameters are not observed but have to be estimated from some meteorological data. During the estimation, unreasonable simplification is inevitable because these parameters are strongly dependent on the nature of the soil and topography, which vary widely. Also the important fact the origin of water included in these parameters is nothing but the rainfall itself, may be disregarded. After comparison of the PDSI (Palmer, 1965), with the RAI (Rooy, 1965) and BMDI (Bhalmeand Maher, 1967), said using only the precipitation data is better for the purpose of the meteorological use. As Alley stated in Byun Hi-and Wilhite (1996) also voiced the same opinion

### 3 MATERIALS AND METHODS

#### 3.1 Description of the Study Area

##### 3.1.1 Location and Topography

Oromia is the largest regional state in the Federal Democratic Republic of Ethiopia with respect to population size and area coverage. Total area coverage of the region roughly 357000km.sq.(BoFED, 2008).

It is located between 7°N and 10°N latitude and 39° and 43°E longitude. The elevation of the study area decreases from 4036m- 1000m. Above sea level.

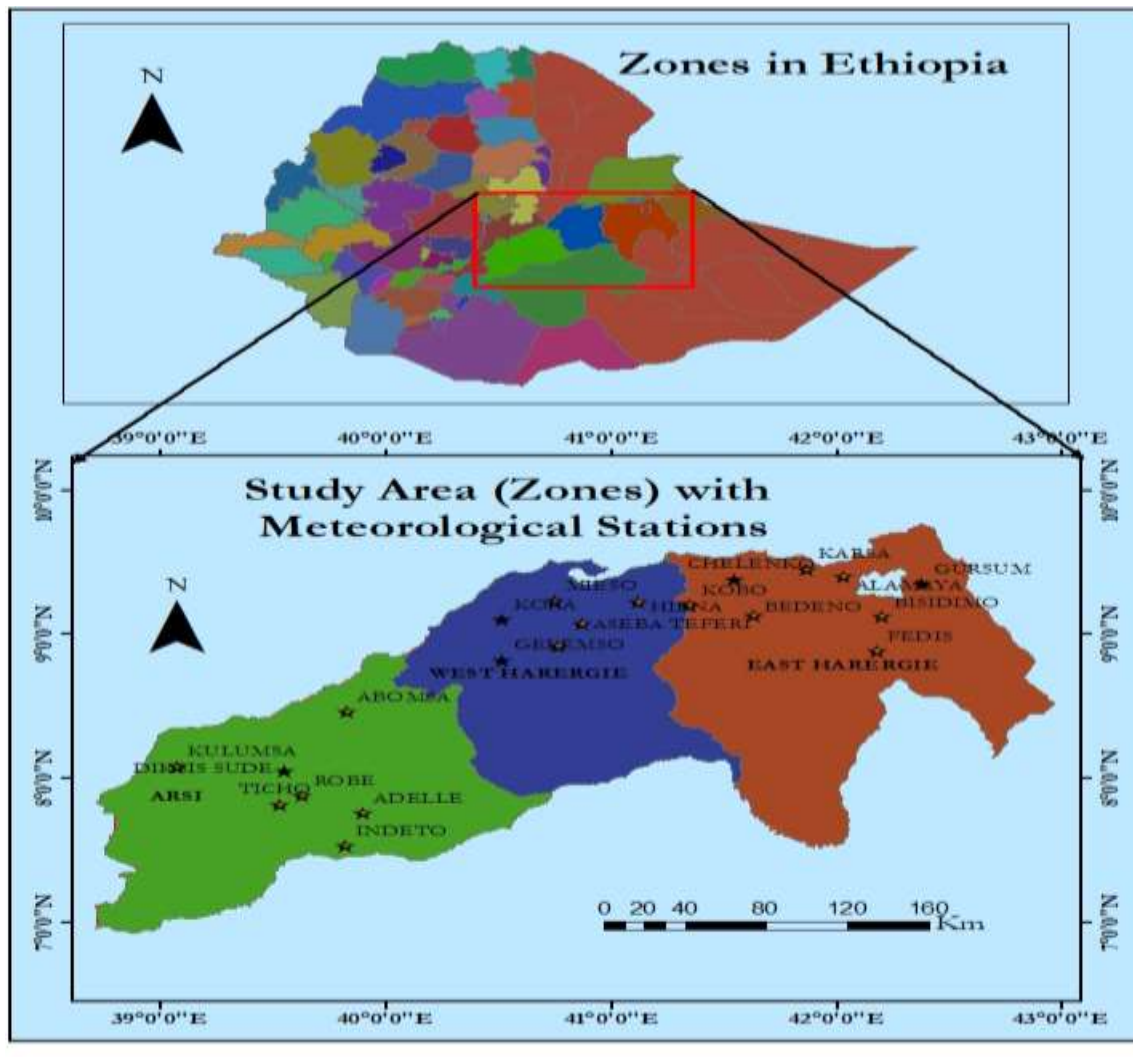


Figure 3.1 Study area with metrological stations

### 3.1.2 Climate Condition

The climate condition of the region, with various spatial distributions of hydro-meteorological parameters, reveals various climate characteristics. In general, the high lands of Eastern Oromia region receive relatively high annual average rainfall (>1500 mm), whereas the lowlands have comparably small annual average rainfall (<900 mm).

The western part of the eastern Oromia region receives highest annual precipitation, the high land of Arsi and Hararhge also receive high annual precipitation, while eastern and southern low land of Hararghe, Arsi and the low lands of Bale as well as the rift valley region receives least annual precipitation. It can be seen that rainfall varies greatly from year to year in all areas, especially in dry locations, the variability is higher. Most south eastern part is arid and semiarid together with low rainfall amount in each season makes them vulnerable to drought.

There are two seasonal rainfalls in Ethiopia, small rainfall season (February to May) and main rainy season (June to September) locally the former is known as Belg and the later as Kiremet. These are two seasonal rainfalls much more important and critical and the failure of this rain over the country varied from year to year and from region to region. The untimely, deficient and unevenly distribution rainfall had ushered unprecedented drought and famine condition which lead to the death of thousands of people and cattle besides heavy losses in Agricultural production.

The distribution of rainfall in time and space is very important in agricultural dependent economy. Rainfall is highly variable in tropics, Ethiopia is one of those countries depending on rain fed agriculture and frequently affected by drought.

### 3.1.3 Variability of Rain fall

The knowledge of the rain fall variation is useful for planning and management of water resource intervention. Rainfall variability is expressed by the coefficient variation (CV). CV is defined as the ratio of standard deviation to mean in percent, where mean and standard deviation are estimated from rainfall data.(NMSA,1996).

$$CV = \frac{s.d}{\bar{x}} * 10 \dots\dots\dots 3.1$$

$$\bar{x} = \sum_{i=1}^n \frac{x_i}{n} \dots\dots\dots 3.2$$

$$s.d = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} \dots\dots\dots 3.3$$

Where:  $x_i$  = rainfall (mm) of year 'i'

$n$  = number of rain fall (mm)

$\bar{x}$  = mean of rain fall

s.d = standard deviation (mm)

CV = coefficient of variation

According to Hare stated in NMSA (1996), area with  $CV > 30\%$  are said to be vulnerable to drought. CV is used to classify degree of variability as less, moderate and high variable as follows:

-  $CV < 20\%$  is less variable

-  $CV$  20 to 30% are moderate variables

-  $CV > 30\%$  highly variable

According to CV value, the central high land (with exception of few in southern and south west) and eastern highlands of the country are characterized by less than 30% CV value. This value increases to 70% or more to low lands of north, north east and south east. Generally the values of CV vary 10% to 70% in the country. The rain fall area of north, north eastern and southeastern region are symbolized by high CV value and are vulnerable to drought.

### **3.2 Data Collection**

Climatic data fairly available in the area, the data on the rain fall, temperature, wind speed and humidity; RCP (Representative Concentration Paths) data are obtained from national meteorological service Agency (NMSA) of Ethiopia. Station with more than 20 years monthly was considered in the study. Cumulative monthly rainfall for targeted time scale i.e. SPI-3 (Kiremt, main rainy season), SPI-6 (For both rainy seasons) and SPI-12 (Annual time scale) have been calculated for selected stations used for Drought analysis and prediction.

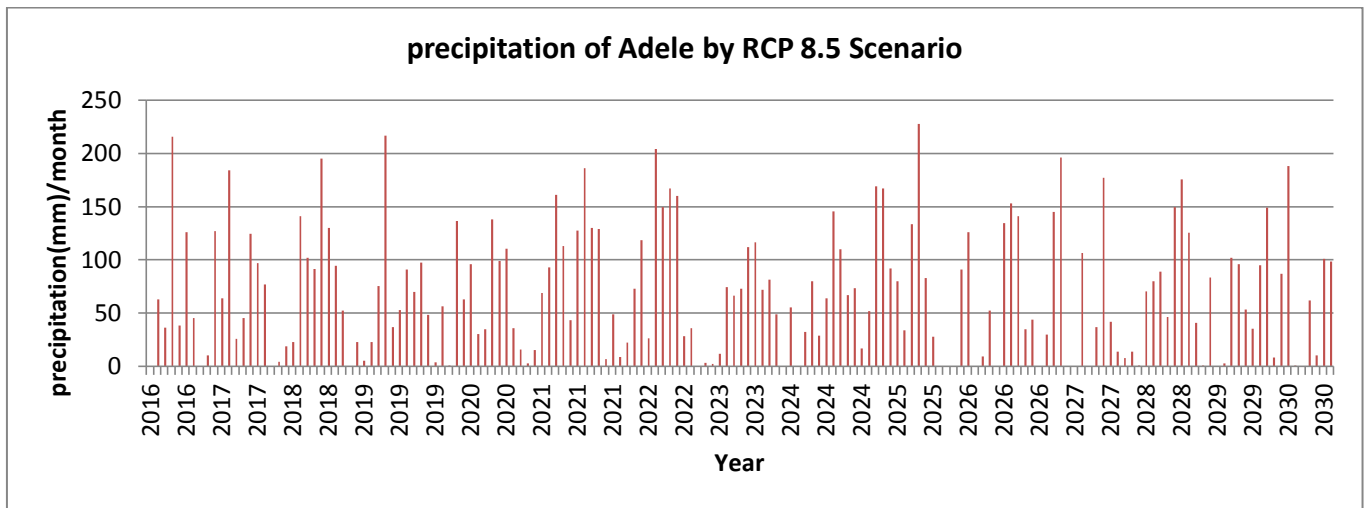
**Table 3.1** Selected stations for Study Area

No				Period data cons.		Total	Zone
	station name	lat(deg)	lon(deg)	beginning	End year		
1	GOBESSA	7.58	38.42	1979	2014	35	Arsi
2	DIKSIS SUDE	8.05	39.55	1988	2015	27	Arsi
3	KULUMSA	8.08	39.08	1978	2014	36	Arsi
4	TICHO	7.82	39.53	1988	2014	26	Arsi
5	ADELLE	7.76	39.9	1990	2015	25	Arsi
6	ABOMSA	8.46	39.83	1989	2014	25	Arsi
7	ROBE	7.88	39.63	1979	2015	36	Arsi
8	INDETO	7.53	39.82	1978	2014	36	Arsi
9	MIESO	9.23	40.75	1979	2015	36	W. Harargie
10	BEDESSA	8.92	40.77	1980	2014	34	W. Harargie
11	GELEMSO	8.82	40.52	1987	2014	27	W. Harargie
12	HIRNA	9.22	41.12	1978	2014	36	W. Harargie
13	ASEBA TEFERI	9.07	40.87	1978	2014	36	W. Harargie
14	KORA	9.1	40.52	1980	2015	26	W. Harargie
15	FEDIS	8.88	42.18	1978	2014	36	E. Harargie
16	GURSUM	9.35	42.38	1979	2014	35	E. Harargie
17	CHELENKO	9.38	41.55	1980	2014	34	E. Harargie
18	BEDENO	9.13	41.63	1980	2013	33	E. Harargie
19	ALAMAYA	9.4	42.033	1979	2015	36	E. Harargie
20	KARSA	9.45	41.87	1990	2015	25	E. Harargie
21	BISIDIMO	9.12	42.2	1989	2014	25	E. Harargie
22	KOBO	9.2	41.35	1978	2014	36	E. Harargie

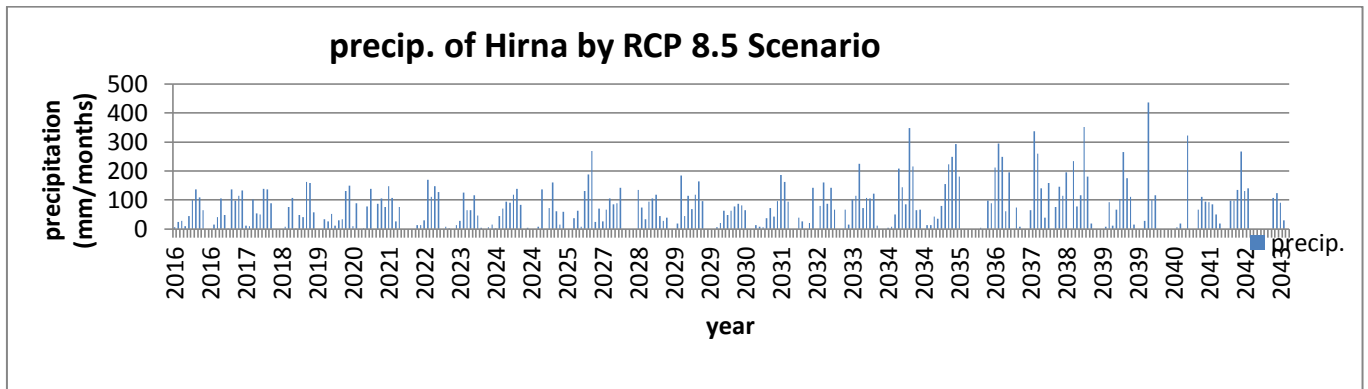
### 3.3 Future Data of precipitation using RCP Scenarios

To calculate the drought index, the RCP scenario's monthly precipitation data from 2016 to 2043 was provided by the NMSA and total of 13 precipitation observatories were selected to calculate analysis of drought induces by R-Studio.

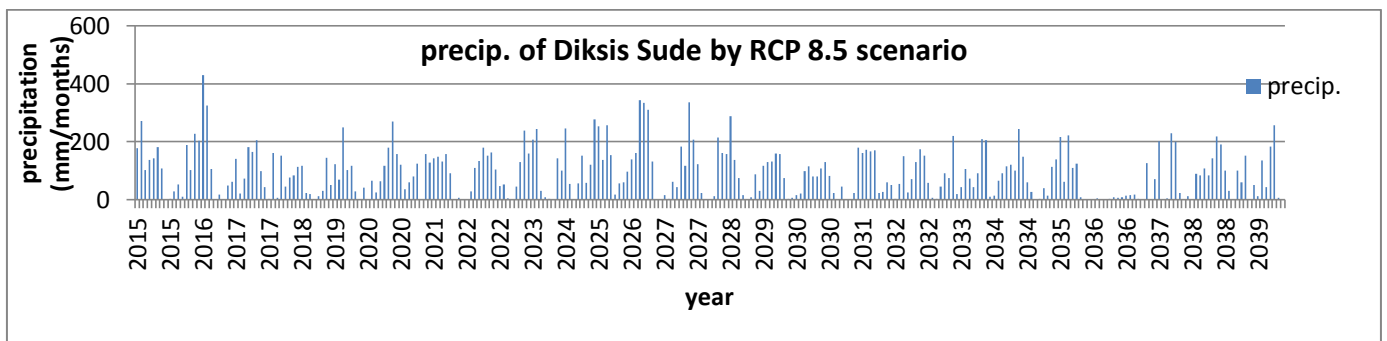
Figure 3.2 indicates the changes of monthly precipitation estimated by RCP Scenario at observations in Adele, Hirna and Diksis Sude.



(a)



(b)



(c)

**Figure 3.2** Future precipitations by RCP 8.5

### 3.4 Data screening

The basic procedure for screening of the rain fall was applied on annual values. This step was performed after finishing filling the missing data. Split record test on variance and mean are applied to detect the presence or absence of absolute consistence or homogeneity on an individual data series without comparison with other series and where there is sufficient stations double mass curve analysis was used to check the relative spatial consistency and homogeneity of the data (Dahmen , 1989)

$$S_i = \frac{\Delta Y_i}{\Delta X_i} \dots\dots\dots$$

Where,

- $S_i$  = is the slope of section i,
- $\Delta Y_i$  = is the change in the cumulative catchment for gage Y b/n the end points of the section i,
- $\Delta X_i$  = is the change in the cumulative catchment for the sum of the regional gages between the endpoints of section i.

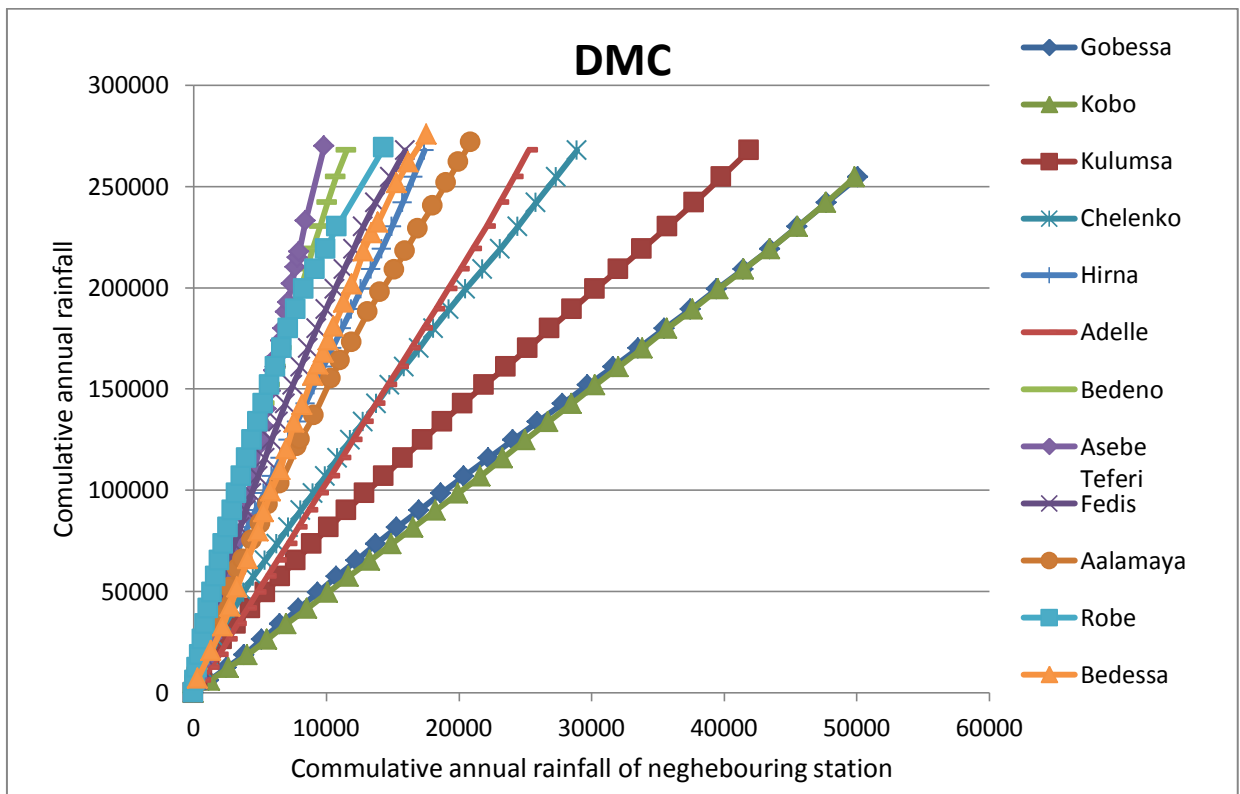


Figure 3.3 Double mass curve plot made for stations after correction made

### 3.5 Selection of drought index

The selection of method of analysis depends on the data and accuracy of the results required. Precipitation is the primary controlling factor of drought. Other climatic factors such as high wind, high temperature or low relative humidity can contribute to amplify its intensity. Usually quantitative indices are used to identify presence of drought and along the years several indices have been developed and adopted to measure drought or wet spell intensity. Among this indicators, percent a normal, Deciles, Standardized precipitation index(SPI),Palmer Drought severity index (PDSI), Crop moisture index (CMI), Surface water supply index (SWSI), Reconnaissance Drought Index (RDI) and Stream flow Drought Index (SDI) are those that are used most common.

It has been found that the indices based solely on precipitation data perform well when compared with complex indices such as traditional palmer drought severity index. It is known to be problematic as Allay and Oladipio stated in Lloyd-Hughes and Saunder (2002). The PDSI (palmer,1965) is the most used index in USA but has some limitations as Guttman and Mckee stated in Lloyd-Hughes and Saunder(2002). Komuscu,Seileret.,Min et.al., Anctil, Lana et al., Domokos , Wu et al., Lloyd-Hughes and Saunder stated in Rouault and Richard (2003).

Recent index, the SPI was used in Turkey, Argentina, Korea, Canada ,Spain, Hungary, China and Europe for analysis of drought. Moreover, most drought indices lack addressing multi-temporal nature of effect of rainfall deficiency and are computed for a certain interval (monthly or seasonal). However, standardized precipitation index (SPI) quantify the precipitation deficit for multiple time steps. This reflected the impact of precipitation deficit on the availability of the different water resource. Therefore, the different time step for which indices are computed address the various types of drought: the shorter season for agricultural and meteorological drought the longer season for hydrological drought. Hence, Standardize precipitation index (SPI) is selected for drought analysis in study area. Standardized precipitation index has the following advantages:

- ❖ It is simple , popular, recently used in different part of the world, based on only on rainfall and required only the computation of two parameter(Bhuiyan, 2004 quoted Komusu).

- ❖ It can be used effectively in both summer and winter by avoiding dependence on soil moisture condition.
- ❖ It is not affected adversely by topography
- ❖ It has a variable time scale, which allows it to describe drought conditions important for a range of meteorological, agricultural, and hydraulic applications. This temporal versatility is also helpful for the analysis of drought dynamics, especially the determination of onset and cessation, which have always been difficult to track with other indices.
- ❖ It has been in existence for only a decade, but it has been used with notable success in various applications, particularly in describing and monitoring drought conditions.
- ❖ It gives a better representation of abnormal wetness and dryness than the Palmer Drought Index.
- ❖ It is suitable for quantifying most types of drought events (Bussay et al., Szalai and Szinell stated in Liod-Hughes and Saunders, 2002)
- ❖ It is a more representative indicator of short-term precipitation, estimation of soil moisture and a better indicator of soil wetness than the Palmer Drought Severity Index (PDSI) (Guddings and Soto, 2005 quoted Sims).
- ❖ It ensures that the frequency of extreme events at any location and on any time scales are consistent.
- ❖ It is equally applied on wet and dry areas
- ❖ It can be applied universally to any location (American Meteorological Society, 2002)
- ❖ It has advantages over PDSI which is most widely used in the U.S., by statistical consistency, ability to reflect both short-term and long-term drought impact as Gultman, Keyantesh and Dracup, described in Spasove (2001).

### **3.6 Drought Characterization using SPI**

In this study, a total of 22 rainfall stations with 8 stations from East Harargie Zone, 8 stations from Arsi Zone, 6 stations from West Harargie Zone are selected to determine the drought characteristics using the Standardized Precipitation Index (SPI).

SPI is able to return five fundamental characteristics of drought in a simple and objective manner to analyze regional drought occurrence as Wilhite stated in Afonso (2005). Since the

objective of this study is to analyse and predict drought by its characteristics (parameters) like severity, duration, magnitude, drought frequency, intensity and spatial extent, these parameters were computed for each of 22 rain gauge stations.

### **3.6.1 Drought intensity**

SPI calculated by equation (3.4, 3.5, and 3.13) gives intensity as categorized in Table 2.1. Drought occurs when the SPI is negative 0 to -0.99 (mild drought). -1.0 to -1.49 (Moderate Drought), -1.5 to -1.99 (Sever Drought) and -2.0 and less (extreme drought).

### **3.6.2 Drought Severity**

Severity shows the degree of deficit. It can be expressed based on SPI value (Table 2.1). Severity is calculated by adding the positive values of every included month's intensity of Table 2.1.

### **3.6.3 Drought magnitude**

Magnitude is one basic drought parameter calculated by the ratio of severity to duration, maximum

### **3.6.4 Drought duration**

The duration of drought is the number of successive months during which SPI value is mild, moderate, severe or extreme.

### **3.6.5 Drought Frequency**

Drought frequency is the ratio between the number of events of certain intensity, and the total duration of the time series. Summary of drought frequency and intensity (moderate, sever and extreme) for all stations.

## **3.7 SPI Calculation**

The SPI is computed by fitting a probability density function to the frequency distribution of precipitation summed over the time scaled of interest. This is performed separately for each month (or whatever the temporal basis is of the raw precipitation time series) and for each location in space. Each probability density function is then transformed in to the standardized normal distribution. Thus, the SPI is said to be normalized in location and time scale. Once standardized, the strength of the anomaly is classified as shown table 2.1.

The process of SPI calculation can be resumed the following ways, as perfira stated in Afonso (2005).

1. Calculation of accumulated precipitation for targeted time scale
2. Adjustment accumulated precipitation to the distribution functions; the distribution may be Gamma, Pearson, lognormal, normal distribution, and so on, but fitting gamma distribution precipitation data is well as Thom, Edwards and Mckee, Lincoln, Nebraska, and Guttman as stated in Edward Dan (2000).
3. Select the distribution function that fit accumulated precipitation value
4. Transform the selected distribution function obtained in to SPI values, using the reduced normal distribute-on function, which corresponds to the reduced normal variable. SPI

value is more easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z: -On fitting the precipitation data to gamma distribution, SPI is

$$Z = SPI = - \left[ t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{for } 0 < H(x) \leq 0.5 \dots\dots\dots 3.4$$

$$Z = SPI = + \left[ t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{for } 0.5 < H(x) < 1 \dots\dots\dots 3.5$$

$$\text{Where: } t = \sqrt{\ln \left[ \frac{1}{(H(x))^2} \right]} \text{ for } 0 < H(x) \leq 0.5 \dots\dots\dots 3.6$$

$$\text{Transform } t = \sqrt{\ln \left[ \frac{1}{(1-H(x))^2} \right]} \text{ for } 0.5 < H(x) < 1 \dots\dots\dots 3.7$$

$C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.0100328, d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308$

$H(x)$  = cumulative probability

$$H(x) = q + (1-q) G(x)$$

$q$  – is the probability of zero precipitation gamma distribution is undefined

for  $X=0$  and  $q=p(x=0)>0$

$G(x)$  is cumulative probability

$$G(X) = \int_0^x q(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^\alpha e^{-\frac{x}{\beta}} dx \dots\dots\dots 3.8$$

Substitute t for  $\frac{x}{\beta}$

$$G(x) = \frac{1}{r(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt$$

\dots\dots\dots 3.9

g(x) is a probability density function (gamma distribution)

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \text{ For } x > 0 \dots\dots\dots 3.10$$

Where:  $\alpha > 0$

$\alpha$  is a shape parameter

$\beta > 0$

$\beta$  is a scale parameter

$x > 0$

x is precipitation amount

$$\Gamma(x) = \int_0^\infty y^{\alpha-1} e^{-y} dy \Gamma(x) \text{ is the gamma function}$$

Fitting the distribution to the data requires  $\alpha$  and  $\beta$  to be estimated using the approximation of Thom for maximum likelihood as stated in Edwards (2000) as follows

$$\alpha = \frac{1}{4A} \left( 1 + \sqrt{1 + \frac{4A}{3}} \right) \dots\dots\dots 3.11$$

Where for n observations

$$A = \ln(\bar{x}) - \sum \frac{\ln(x)}{n} \dots\dots\dots 3.12$$

$$\beta = \frac{\bar{x}}{2}$$

On fitting perception data to log normal distribution, SPI is

$$SPI = Z = \frac{\ln(x) - \mu y}{\delta y} \dots\dots\dots 3.13$$

Where:  $\mu y$  = mean

$\delta$  = Standard deviation

On fitting the precipitation data to the normal distribution SPI is

$$SPI = Z = \frac{(x - \mu)}{\delta} \dots\dots\dots 3.14$$

Where:  $\mu$  is mean

$\delta$  Is standard deviation

## 4 RESULTS AND DISCUSSION

### 4.1 Rainfall Variability

The monthly rainfall data for about 25 to 36 years' data for period of (1978 to 2015) were collected for 22 rain gauge stations. The statistical parameters (Appendix A, Table A2) were computed with objective of the extracting essential information from a set of data. The statistical parameters mean ( $\bar{x}$ ), standard deviation (s.d) and coefficient of variation (CV) were computed.

Variability of rainfall is expressed by CV. The CV varies from 12 to 122 over study area. The maximum CV (94%) of Kiremt rainfall was recorded at Alamaya, maximum CV(94%)belg rain fall was recorded at Hirna (West Harargie), maximum CV(122%) of 6 both rain fall was recorded at Alamaya, maximumCV (88%) of two months (July to June) recorded at Hirna,and maximum (77%) annual rainfall variation was recorded at Alamaya. CV computed separately for each of the 22 rain gauge stations (Table4.1) has been interpolated into aerial data in Arc View GIS to demarcate its spatial variability. Three categories given by NMSA (less, moderate and highly variable) don't clearly show all wide range of rainfall of variability. The Belg rainfall was highly variable compare to other time scales considered. Generally, rainfall variation increase from Arsi to East Hararegie.

**Table 4.1** Coefficient of Variation (CV) of rain fall for different time scale

Zone	Station	Annual J to D	3months(Kiremt JY to S)	Belg February to April	6month March to August	Early kiremt 2months (june-July)
East Harargie	FEDIS	39.49	45.95	51.72	42.31	55.56
	GURSUM	32.76	40.99	45.21	32.28	51.33
	CHELENKO	24.79	27.73	41.58	25.4	35.37
	BEDENO	41.39	43.85	42.19	41.89	58.02
	ALAMAYA	77.72	53.36	122.7	83.79	88.39
	KARSA	19.89	24.11	43.32	22.69	40.53
	BISIDIMO	24.89	29.27	36.45	27.08	41.87
	KOBO	48.37	47.87	57.43	50.78	51.86
West Harargie	MIESO	20.44	29.66	54.6	27.16	36.14
	BEDESSA	22.45	29.13	38.25	25.16	38.22
	GELEMSO	26.23	35.07	39.4	30.89	41.81
	HIRNA	75.62	94.07	62.96	74.61	88.39
	ASEBA TEFERI	22.97	32.6	53.72	27.13	44.83
	KORA	24.98	36.78	41.88	26.92	41.89
Arsi	GOBESSA	27.41	31.07	39.9	27.57	41.78
	DIKSIS SUDE	17.28	14.89	35.48	19.69	25.81
	KULUMSA	14.14	12.97	36.63	17.51	21.47
	TICHO	28.38	27.94	44.78	26.03	28.37
	ADELLE	17.03	29.55	23.8	18.28	37.72
	ABOMSA	25.89	29.87	39.71	28.8	36.55
	ROBE	20.25	25.96	33.8	19.01	27.03
	INDETO	19.3	24.94	32.09	25.52	39.69

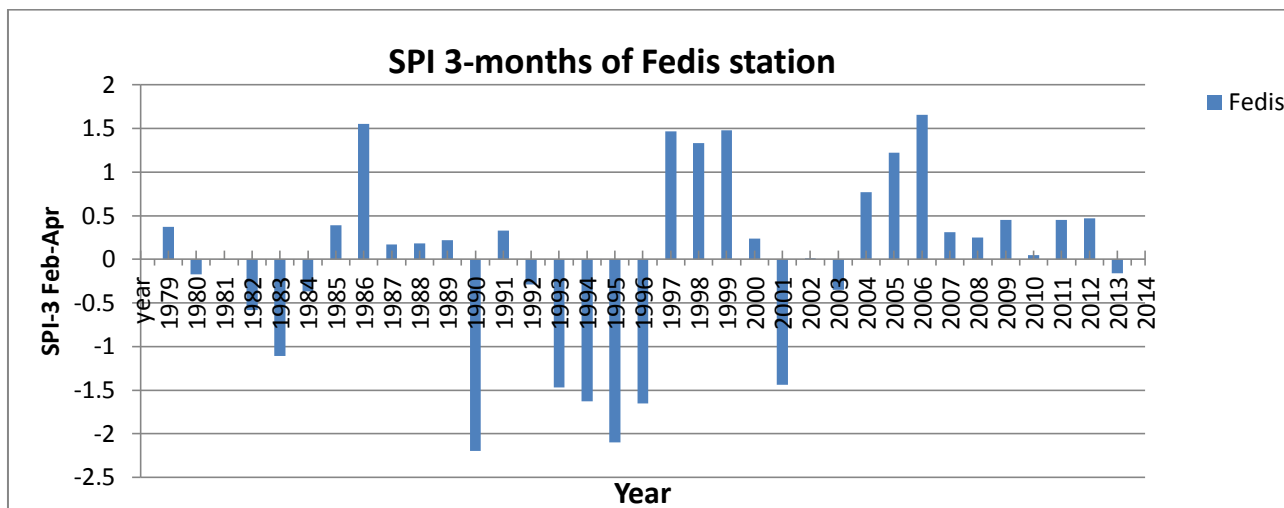
#### 4.2 Drought intensity

One station from each zone namely East Hararegie, West Hararegie, Arsi was selected to illustrate SPI-3 of Kiremt (JyAuS) in study area. (Figures 4.1 to 4.3), Table 4.2 illustrates drought intensity (SPI Value) calculated for different times scale for 3 stations and SPI value (intensity) for all other station (Appendix A, Tables) which also shows drought history.

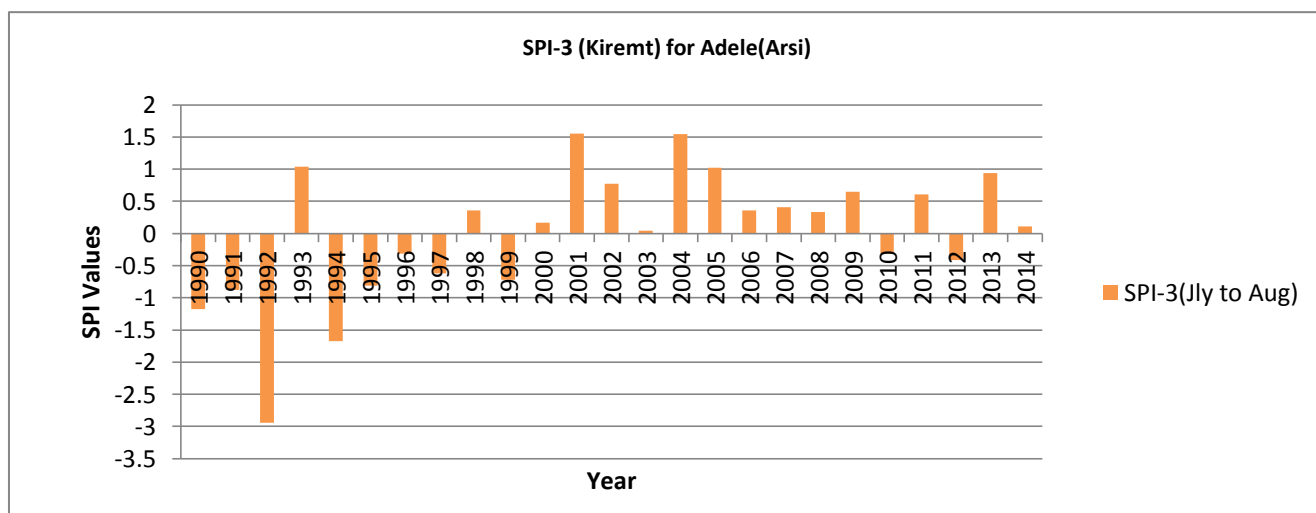
Maximum intensity of (7.03) was recorded at Bedeno and Ticho stations for SPI-2 (JJy) in year 1985 and 1995 respectively, maximum intensity of (5.33) was recorded at Fedis Station for SPI-3 (kiremt season) in a year 1996, maximum intensity of (4.04) was recorded at Kobo Station in a year 1985 for SPI-3 (Belg season), maximum intensity of (4.77 and 4.5) were recorded at Ticho Station for SPI-6 (both seasons) and SPI-12 (annual) respectively.

**Table 4.2** SPI values of stations of different time scales

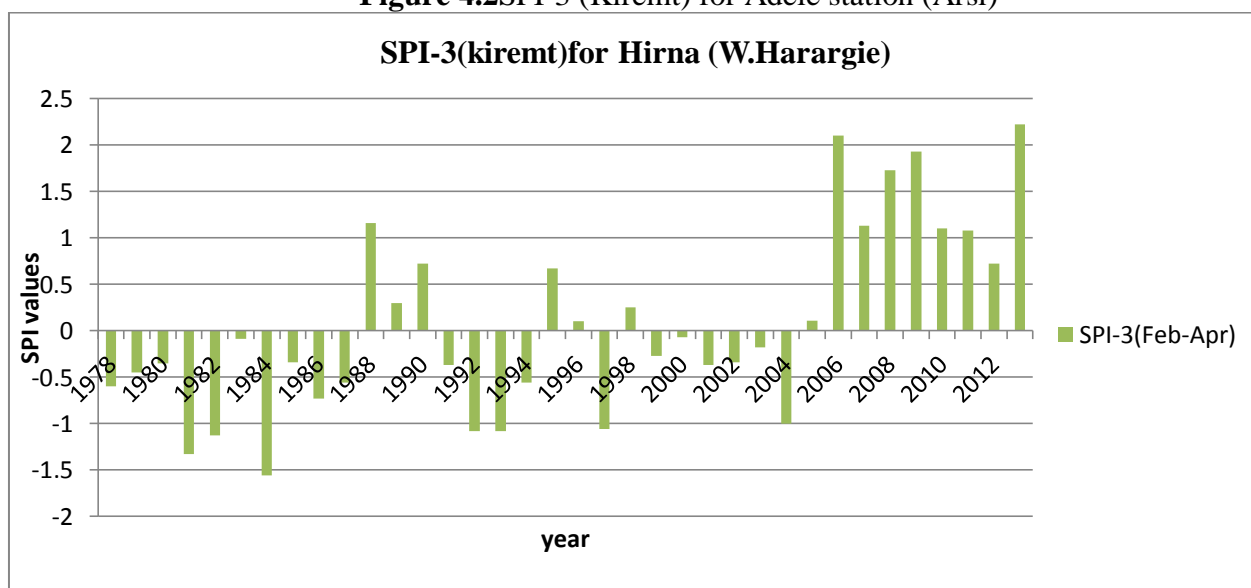
Station		Fedis					Kobo					Asebe Teferi				
s.No	year	SPI-2 Ju to jly	SPI-3(Jly-Au)	SPI-3(F-Ap)	SPI6(Ma-Au)	SPI-12(J-D)	SPI-2(Ju-jly)	SPI-3(Jly - Au)	SPI-3(Feb-Apr)	SPI-6 Mar-Aug	SPI-12 J-D	SPI-2 Ju to jly	SPI-3 Jly to Aug	SPI-3 Feb-Apr	SPI-6 Mar-Aug	SPI-12 J-D
1	1979	-1.07	-0.70	0.37	0.19	0.33	1.03	0.42	0.05	0.40	0.33	1.15	0.10	-0.95	-0.29	-0.43
2	1980	0.16	0.88	-0.17	0.38	0.71	-0.65	0.66	0.13	0.24	0.33	0.13	1.35	0.33	0.75	0.99
3	1981	-0.25	-0.50	-0.01	0.11	0.09	0.34	-0.04	0.12	0.18	-0.05	-0.38	-0.99	-0.57	-0.53	-1.15
4	1982	-0.38	-0.07	-0.58	-0.36	-0.36	-4.26	-2.53	-1.81	-2.73	-2.79	0.78	-0.45	-0.28	0.37	-0.28
5	1983	-0.05	-1.01	-1.11	-0.54	-0.31	-2.57	-2.32	-1.46	-2.20	-2.62	1.43	0.95	-2.02	-0.35	-0.57
6	1984	-0.98	-0.36	-0.17	-0.43	-0.44	-1.11	-0.31	-0.39	-0.62	-0.84	0.64	-0.43	0.76	0.43	0.09
7	1985	2.62	0.15	0.39	1.00	0.70	0.44	0.06	-4.04	-1.36	-1.26	2.13	1.17	-1.08	0.54	-0.12
8	1986	1.12	0.69	1.55	1.44	1.45	2.96	1.77	1.84	2.16	2.41	-0.61	-0.48	-0.17	-0.93	-0.41
9	1987	1.49	-0.26	0.17	0.69	0.73	3.29	1.37	1.60	2.22	1.82	1.04	0.25	-0.68	-0.17	0.07
10	1988	0.48	2.46	0.18	1.07	1.20	-7.03	-1.67	-0.72	-2.01	-1.73	1.79	1.41	-0.84	0.26	0.94
11	1989	0.36	-0.77	0.22	0.29	0.68	0.87	0.54	0.47	0.38	0.51	-0.07	-1.05	0.03	-0.46	0.01
12	1990	-3.69	-4.02	-2.20	-2.36	-2.62	-2.61	-0.54	-0.51	-0.88	-0.92	0.12	-0.60	-0.03	-0.76	-0.68
13	1991	-3.03	-1.68	0.33	-0.51	-0.51	-2.15	1.05	1.17	0.90	1.00	-0.91	0.51	1.37	1.17	0.88
14	1992	-1.11	-2.29	-0.29	-0.54	-0.83	-0.82	0.12	0.67	0.29	0.50	-1.04	-1.31	1.36	0.71	0.93
15	1993	-1.42	-3.00	-1.47	-1.25	-1.53	0.94	1.02	0.71	0.84	0.76	-2.25	-0.43	0.40	-0.18	0.07
16	1994	0.07	-0.52	-1.63	-0.56	-0.52	0.12	0.25	0.44	0.31	0.13	-0.23	-0.66	-0.18	-0.75	-1.12
17	1995	-4.66	-4.97	-2.10	-2.67	-2.89	-0.01	-0.03	0.76	0.44	0.39	0.84	0.58	2.49	2.34	1.77
18	1996	-2.53	-5.33	-1.65	-1.98	-2.29	0.04	0.27	0.74	0.35	0.38	-0.70	-0.21	0.50	-0.07	-0.50
19	1997	-2.28	0.38	1.47	1.10	1.04	-0.95	-0.05	0.54	0.05	0.13	-1.38	-0.90	2.14	1.42	0.34
20	1998	0.01	0.63	1.33	1.00	1.10	1.48	0.64	-0.47	0.00	0.17	0.26	1.08	-2.01	-1.28	-0.46
21	1999	-0.37	-0.02	1.48	0.99	1.10	0.23	0.19	1.32	0.81	0.85	-0.48	-0.02	1.15	0.64	0.60
22	2000	-1.63	-0.93	0.24	0.04	-0.16	-1.49	-0.75	-0.47	-0.97	-0.48	-0.07	0.66	1.02	0.91	0.98
23	2001	-3.37	-2.79	-1.44	-2.13	-0.53	-1.78	-1.05	-0.76	-1.19	-1.20	0.57	0.30	0.60	0.58	0.40
24	2002	-0.36	-0.70	0.01	0.04	-0.06	0.53	0.16	0.11	0.18	0.13	0.60	0.37	0.72	0.70	0.50
25	2003	-0.83	-0.38	-0.35	-0.17	-0.08	-1.01	0.06	0.23	0.07	0.15	0.41	0.79	-0.07	0.09	0.32
26	2004	0.54	-0.32	0.77	0.60	0.44	2.68	1.08	-0.40	0.35	0.32	2.86	1.57	-0.18	1.18	0.94
27	2005	0.38	-0.01	1.22	0.97	0.63	1.12	0.34	0.38	0.26	0.13	-1.67	-2.28	-0.81	-2.29	-2.76
28	2006	0.37	-0.95	1.66	1.31	1.07	1.54	0.04	0.28	0.54	0.34	-1.74	-1.57	-0.50	-1.62	-2.32
29	2007	-0.28	-0.66	0.31	0.24	0.11	1.19	0.15	0.78	0.71	0.64	1.33	-0.17	0.72	-0.37	0.65
30	2008	-0.37	-1.05	0.25	-0.07	0.50	2.18	-0.17	0.00	0.15	0.17	0.46	-0.34	-1.76	-1.60	-1.19
31	2009	-0.28	-0.67	0.45	0.32	0.22	1.37	0.34	0.05	0.21	0.23	1.26	1.36	0.54	1.23	1.61
32	2010	-2.02	0.15	0.05	0.29	0.24	-0.55	-0.01	0.02	-0.26	-0.18	0.89	0.32	0.00	-0.02	0.79
33	2011	-0.84	-1.94	0.45	0.36	-0.04	0.18	0.29	0.16	0.29	0.09	-1.65	-1.73	-0.17	-2.18	-1.61
34	2012	0.11	-0.15	0.47	0.58	0.39	2.31	0.79	-0.16	0.39	0.57	-0.09	-1.53	0.38	0.07	-0.52
35	2013	-0.05	-0.83	-0.16	-0.12	0.00	0.00	0.16	-0.42	-0.17	-0.21	1.80	1.40	-0.50	0.76	0.47
36	2014	0.16	-0.60	0.00	0.12	-0.09	0.52	0.01	0.20	0.04	0.01	-0.01	1.03	-0.04	-0.24	0.55



**Figure 4.1** SPI of 3-months from July to Aug of Fedis station E.harargie



**Figure 4.2** SPI-3 (Kiremt) for Adele station (Arsi)



**Figure 4.3** SPI-3 (Kiremt) for Hirna station (W.Harargie)

### 4.3 Drought Severity

Severity shows the degree of deficit. It can be expressed based on SPI value (Table 2.1). Severity is calculated by adding the positive values of every included month's intensity of Table 2.1. Maximum severity (22.57) recorded at Fedis station (East Hararegie) for SPI-3 Kiremt season (JyAuS) from 1989 to 1996, maximum severity (35.13 to 38.26) recorded at Hirna (West Haraegie) stations for SPI-2 from 1989 to 2006 , maximum severity (9.91) recorded at the same station for SPI-3 Belg (FmaA) from 1983 to 1990, maximum severity (9.87) recorded at Fedis station for SPI-6 and maximum severity (11.18) recorded at Fedis Station for SPI-12. Figures 4.4 to 4.7 show drought severity for SPI-3 (Kiremt), SPI-3(Belg), -6(Kiremt and Belg) and SPI-12 for each station.

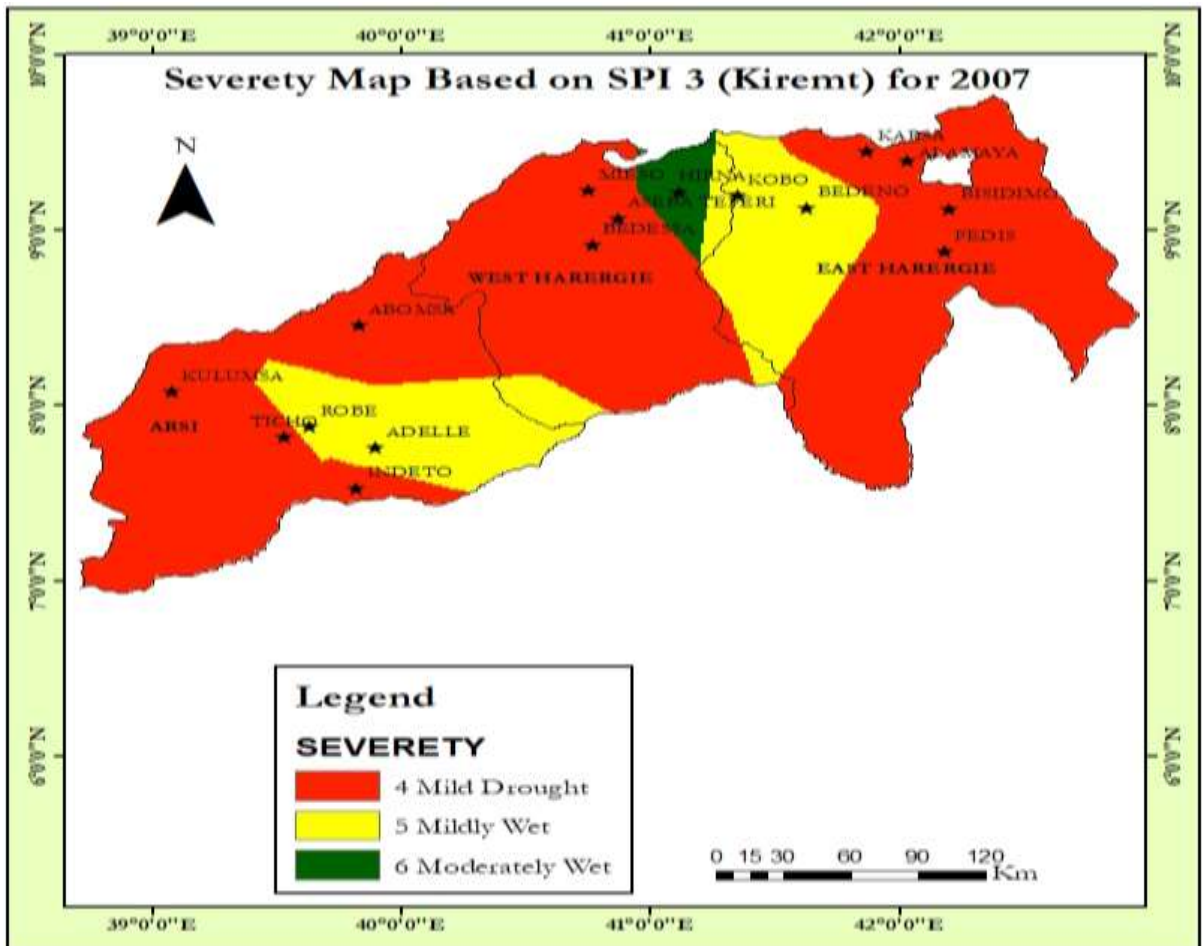


Figure 4.4: Drought severity SPI-3 (Kermit Season)

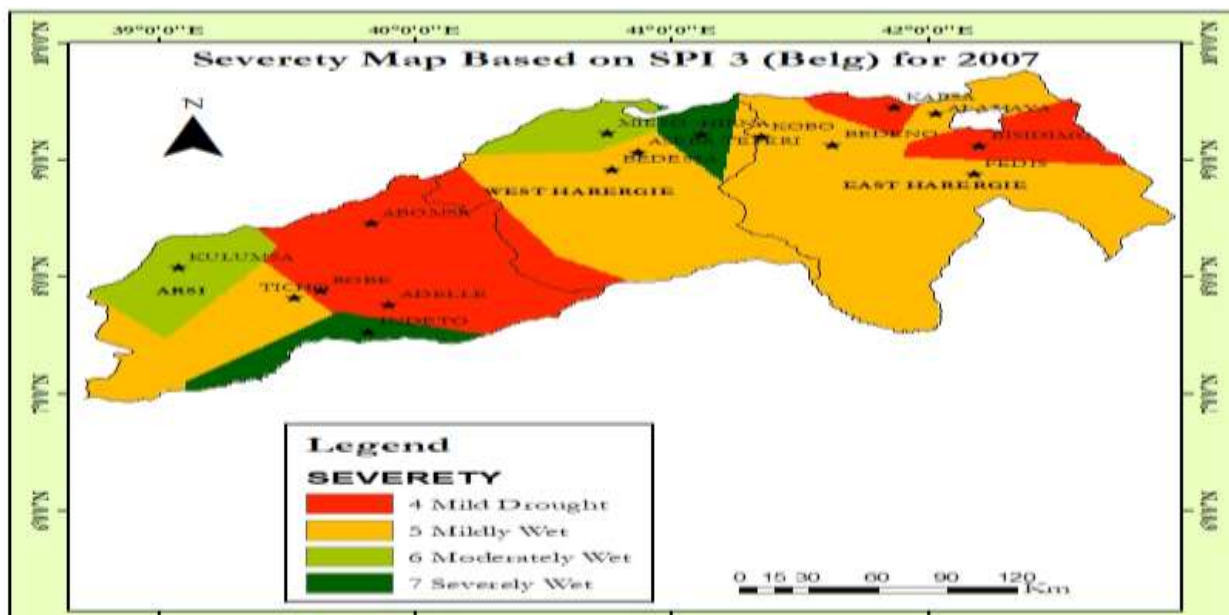


Figure 4.5: Drought severity SPI-3(Belg Season)

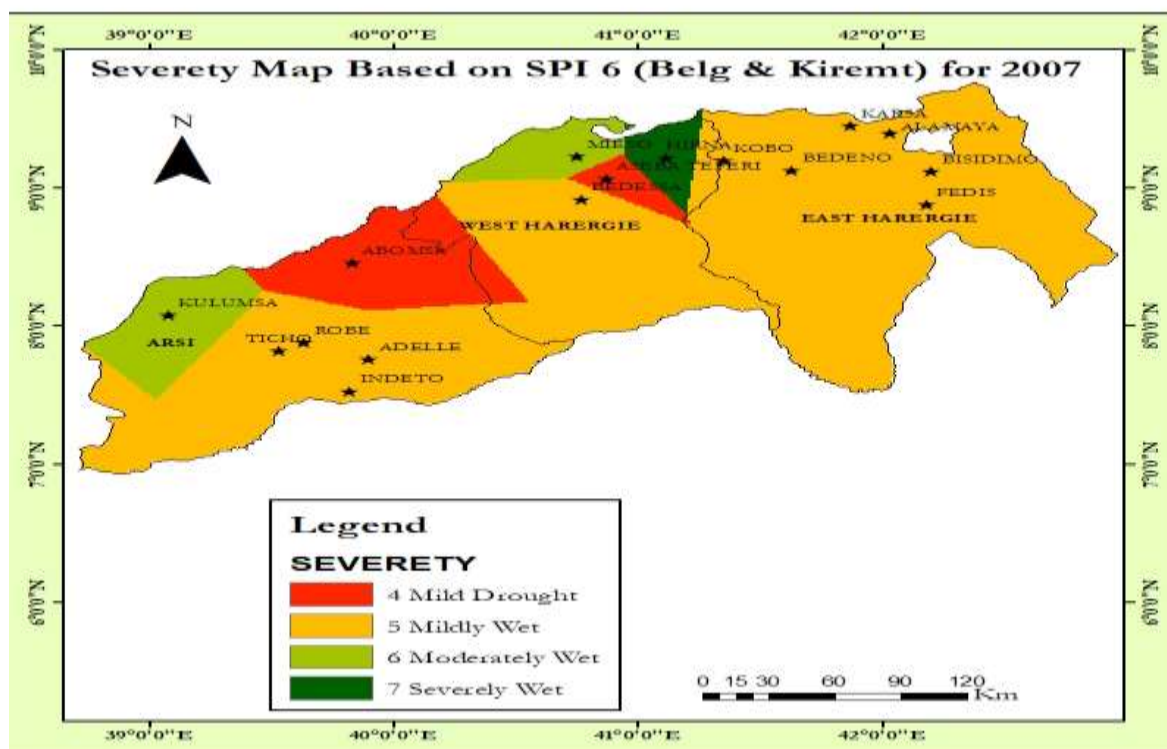
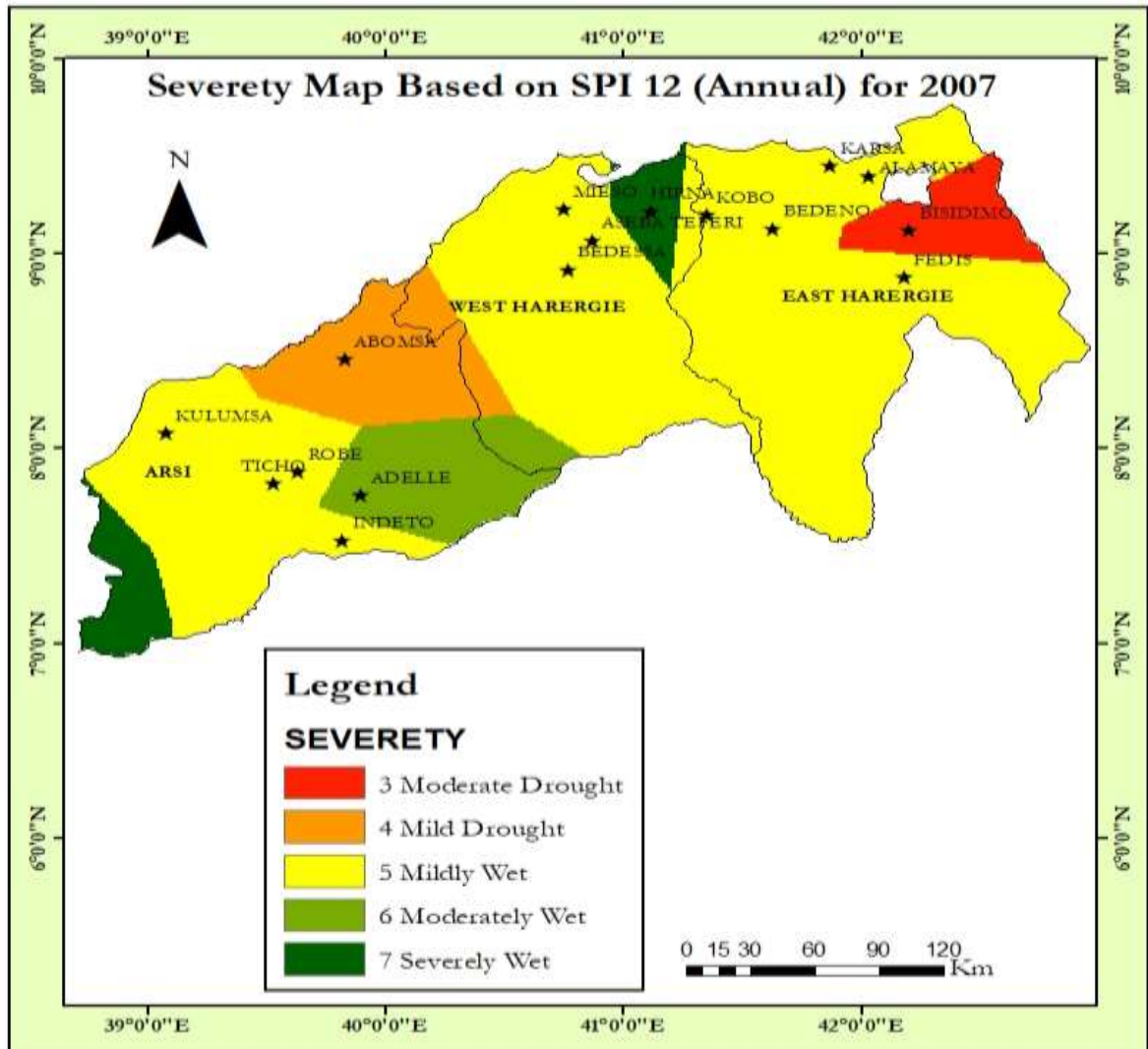


Figure 4.6: Drought severity SPI-6 (Belg & kiremt Season)



**Figure 4.7:** Drought severity SPI-12 (annual)

#### 4.4 Drought magnitude

Magnitude is one basic drought parameter calculated by the ratio of severity to duration, maximum SPI-3 (kiremt) drought magnitude (1.60) recorded at Ticho station (Arsi Zone) during 1995, maximum SPI-2(JJY) drought magnitude (3.5) recorded at Bedeno station (E. Harargie) during 1988, maximum SPI-3 (Belg) drought magnitude (1.35) recorded at Kobo (E.Harargie), maximum SPI-6 (both season) drought magnitude (0.8) recorded at Ticho during 1995 and maximum SPI-12(annual) drought magnitude (0.21) recorded at Ticho (Arsi) during 1994-1995. Table 4.3 illustrates drought magnitude and other parameter (start and end, duration, severity ,no of drought year and frequency )for Fedis station E.Harargie Zone.(AppendxB, tables) show drought parameters for other stations.

**Table 4.3 Drought Parameter**

Drought parameter							No. drought years					Drought Frequency				
SPI	Station	Start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JIY)	Fedis	1979	1979	2	1.07	0.54	11.00	3.00	1.00	7.00	22.00	30.56	8.33	2.78	19.44	61.11
		1981	1983	6	0.68	0.11										
		1990	1993	8	9.25	1.16										
		1995	1997	6	9.67	1.61										
		1999	2003	10	6.56	0.66										
		2007	2011	10	3.73	0.37										
		2013	2013	2	0.05	0.03										
SPI3(JL-Augs)	Fedis	1979	1979	3	0.70	0.23	18.00	2.00	2.00	6.00	28.00	50.00	5.56	5.56	16.67	77.78
		1981	1983	9												
		1987	1987	3												
		1989	1996	24												
		1999	2009	33												
		2011	2014	12												
SPI-3(F-A)	Fedis	1980	1983	12	1.88	0.16	6.00	3.00	2.00	2.00	13.00	16.67	8.33	5.56	5.56	36.11
		1990	1990	3												
		1992	1996	15												
		2001	2001	3												
		2003	2003	3												
		2013	2013	3												
SPI-6(Mr-Augs)	Fedis	1982	1983	12	0.89	0.07	8.00	1.00	1.00	3.00	13.00	22.22	2.78	2.78	8.33	36.11
		1990	1996	42												
		2001	2001	6												
		2003	2003	6												
		2008	2008	6												
		2013	2013	6												
SPI-12(J-D)	Fedis	1982	1983	24	0.69	0.03	11.00	0.00	1.00	3.00	15.00	30.56	0.00	2.78	8.33	41.67
		1990	1996	84												
		2000	2003	48												
		2011	2011	12												
		2014	2014	12												

MD- Mild drought

Mod - Moderate drought

SD -Severe drought

ED -Extreme drought

% percent

All drought (MD+MoD+S)

#### 4.5 Drought duration

The duration of drought is the number of successive months during which SPI value is mild, moderate, severe or extreme. Maximum SPI-3 (Kiremt) drought (33months) was recorded at Fedis during 1999 to 2009, maximum SPI-2 (early Kiremt) drought duration (36 months) was recorded at Hirna during 1988 to 2009, maximum SPI-3 (Belg) drought duration (30 months) was recorded at Hirna and Alemaya during 1979 to 1988, maximum SPI-6 (Kiremt and Belg) drought duration (54 months) was recorded at Hirna and Alemaya during 1979 to 1987 and 1979 to 2002 respectively, maximum SPI-12 (annual) drought duration (204 months) was recorded also at Hirna during 1990 to 2009. Table 4.4 to 4.8 show Summary of drought characteristics based on SPI-3 (Kiremt), SPI-3 (Belg), SPI-6 and SPI-12.

**Table 4.4** Summary of drought characteristics based on SPI-2

ZONE	Station	Duretion (months)		Severity		Magnitude		intensity	
		max.	min.	max.	min.	max.	min.	max.	min.
EAST HARARHIE	FEDIS	10	2	9.67	0.05	1.61	0.03	4.86	0.05
	GURSUM	14	2	4.48	0.07	0.81	0.04	2.1	0.04
	CHELENKO	2	0	3.11	0.17	1.56	0.09	3.11	0.17
	BEDENO	2	0	7.03	0.01	3.52	0.01	7.03	0.01
	ALAMAYA	18	2	11.55	0.29	1.56	0.18	3.12	0.06
	KARSA	4	2	2.55	0.07	1.28	0.04	2.55	0.07
	BISIDIMO	12	2	5.46	0.11	0.46	0.06	1.94	0.02
	KOBO	6	2	7.94	0.01	3.52	0.01	7.03	0.01
WEST HARARGIE	MIESO	6	2	3.12	0.09	1.35	0.05	2.7	0.08
	BEDESSA	7	0	3.63	0.27	1.82	0.14	3.63	0.27
	GELEMSO	6	2	2.27	0.06	0.14	0.03	1.64	0.06
	HIRNA	36	18	38.28	23.06	1.28	1.06	3.77	0.14
	ASEBA TEFERI	8	2	4.43	0.01	0.85	0.01	2.25	0.07
	KORA	6	2	5.97	0.1	1.39	0.05	2.99	0.1
ARSI	GOBESSA	4	2	1.25	0.03	0.41	0.02	0.98	0.06
	DIKSI SUDE	2	0	0.32	0.02	0.16	0.01	0.32	0.02
	KULUMSA	2	0	0.83	0.01	0.42	0.01	0.83	0.01
	TICHO	2	0	7.03	0	3.52	0	7.03	0
	ADELLE	4	2	6.4	0.29	0.89	0.16	2.18	0.08
	ABOMSA				0.35				
	ROBE	4	2	2.01	0.35	1.01	0.18	2.01	0.35
	INDETO	12	2	4.34	0.05	0.54	0.11	1.36	0.05

**Table 4.5** Summary of drought characteristics based on SPI-3(Kiremt)

ZONE	Station	Duretion (months)		Severity		Magnitude		Intensity	
		max.	min.	max.	min.	max.	min.	max.	min.
EAST HARARHIE	FEDIS	33	3	22.57	0.26	0.94	0.09	5.33	0.01
	GURSUM	12	3	4.49	0.6	0.58	0.2	1.47	0.24
	CHELENKO	15	3	4.68	0.06	0.52	0.02	2.24	0.05
	BEDENO	12	3	3.48	0.07	1.16	0.02	3.48	0.01
	ALAMAYA	12	3	0.44	0.25	0.77	0.06	1.89	0.04
	KARSA	18	3	6.67	0.12	0.37	0.04	3.33	0.05
	BISIDIMO	24	3	4.49	2.04	0.34	0.19	2.26	0.03
	KOBO	12	3	5.19	0.01	0.56	0	2.53	0.01
WEST HARARGIE	MIESO	12	3	8.47	0.19	0.71	0.06	2.79	0.14
	BEDESSA	6	3	1.71	0.07	0.29	0.02	1.31	0.07
	GELEMSO	18	3	5.03	0.08	0.32	0.03	1.57	0.03
	HIRNA	30	24	6.25	3.93	0.21	0.16	3.77	0.06
	ASEBA TEFERI	12	3	4.36	0.02	0.56	0.01	2.28	0.02
	KORA	12	3	4.61	0.07	0.51	0.02	3.52	0.04
ARSI	GOBESSA	18	3	4.47	0.38	0.57	0.13	1.98	0.08
	DIKSIS SUDE	6	3	3.8	0.33	0.65	0.11	1.94	0.24
	KULUMSA	12	3	4.41	0.08	0.53	0.03	2.16	0.18
	TICHO	9	3	3.69	0.61	0.65	0.07	4.79	0.05
	ADELLE	12	3	4	0.31	0.33	0.1	2.94	0.31
	ABOMSA		3						
	ROBE	15	3	4.43	0.25	0.74	0.08	2.83	0.02
	INDETO	12	3	5.23	0.32	0.58	0.1	1.8	0.01

**Table 4.6** Summary of drought characteristics based on SPI-3 (Belg)

ZONE	Station	Duretion (months)		Severity		Magnitude		Intensity	
		max.	min.	max.	min.	max.	min.	max.	min.
EAST HARARHIE	FEDIS	15	3	7.22	0.18	0.76	0.06	2.28	0.01
	GURSUM	18	3	6.23	0.36	0.44	0.12	1.88	0.08
	CHELENKO	12	3	2.69	0.22	0.9	0.07	2.69	0.03
	BEDENO	15	3	3.71	0.22	0.62	0.08	3.38	0.01
	ALAMAYA	30	3	4.13	0.85	0.28	0.14	1.29	0.01
	KARSA	24	3	5.45	0.5	0.38	0.17	1.76	0.03
	BISIDIMO	15	3	4.52	0.62	0.43	0.21	2.28	0.2
	KOBO	9	3	7.71	0.02	1.35	0.01	4.04	0.02
WEST HARARGIE	MIESO	21	3	4.43	0.54	1.48	0.12	3.89	0.09
	BEDESSA	18	3	1.53	0.19	0.26	0.06	0.78	0.07
	GELEMSO	12	3	3.88	0.36	0.65	0.12	3.49	0.36
	HIRNA	30	3	7.84	1.06	0.35	0.12	1.56	0.07
	ASEBA TEFERI	18	3	4.03	0.17	0.67	0.06	2.02	0.04
	KORA	12	3	3.39	0.35	0.45	0.12	1.46	0.31
	GOBESSA	18	3	4.15	0.08	0.52	0.03	1.89	0.08
ARSI	DIKSIS SUDE	9	3	2.83	0.04	0.56	0.01	2.08	0.03
	KULUMSA	9	3	2.06	0.16	0.61	0.05	2.06	0.2
	TICHO	12	3	4.77	0.08	0.8	0.01	3.63	0.06
	ADELLE	9	3	2.57	0.37	0.86	0.06	2.57	0.03
	ABOMSA	21	3	6.87	0.05	0.33	0.02	1.65	0.05
	ROBE	12	3	4.03	0.07	0.45	0.02	2.13	0.07
	INDETO	15	3	3.13	0.14	0.65	0.05	1.94	0.14

**Table 4.7** Summary of drought characteristics based on SPI-6 ( both season)

ZONE	Station	Duretion (months)		Severity		Magnitude		Intensity	
		max.	min.	max.	min.	max.	min.	max.	min.
EAST HARARHIE	FEDIS	42	6	9.87	0.07	0.36	0.01	2.67	0.12
	GURSUM	30	6	6.27	0.08	0.24	0.01	1.79	0.12
	CHELENKO	30	6	5.18	0.86	0.2	0.07	2.4	0.03
	BEDENO	30	6	3.72	0.17	0.44	0.03	3.44	0.02
	ALAMAYA	54	6	4.95	0.65	0.27	0.05	1.59	0.06
	KARSA	12	6	1.96	0.64	0.33	0.05	1.96	0.14
	BISIDIMO	42	6	5.39	0.01	0.13	0	2	0.01
WEST HARARGIE	KOBO	24	6	6.99	0.21	0.29	0.02	2.73	0.04
	MIESO	24	6	3.47	0.44	0.66	0.08	2.08	0.13
	BEDESSA	12	6	0.56	0.06	0.09	0.01	0.56	0.01
	GELEMSO	30	6	4.54	0.53	0.15	0.09	2.16	0.06
	HIRNA	104	54	8.7	6.83	0.13	0.08	1.17	0.17
	ASEBA TEFERI	24	6	5.89	0.07	0.25	0.01	2.29	0.02
ARSI	KORA	24	6	5.03	0.21	0.21	0.04	3.1	0.01
	GOBESSA	36	6	4.3	0.21	0.39	0.04	2.31	0.01
	DIKSIS SUDE	18	6	3.09	0.34	0.35	0.09	2.13	0.2
	KULUMSA	60	6	3.17	0.18	0.37	0	1.6	0.06
	TICHO	6	6	4.77	0.08	0.8	0.01	4.77	0.08
	ADELLE	18	6	4.96	0.19	0.28	0.03	2.73	0.06
	ABOMSA	48	12	8.69	0.9	0.18	0.03	2.48	0.15
	ROBE	24	6	5.14	0.09	0.29	0.02	2.33	0.17
INDETO	18	6	1.82	0.11	0.3	0.02	2.4	0.01	

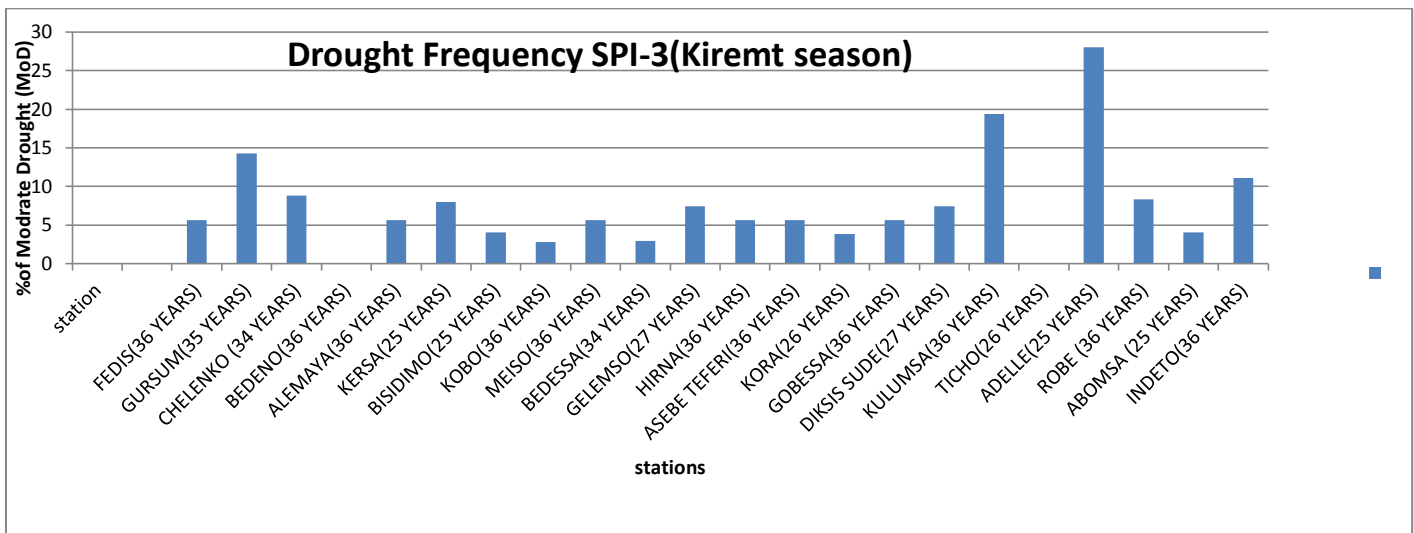
**Table 4.8** Summary of drought characteristics based on SPI-12 (annual)

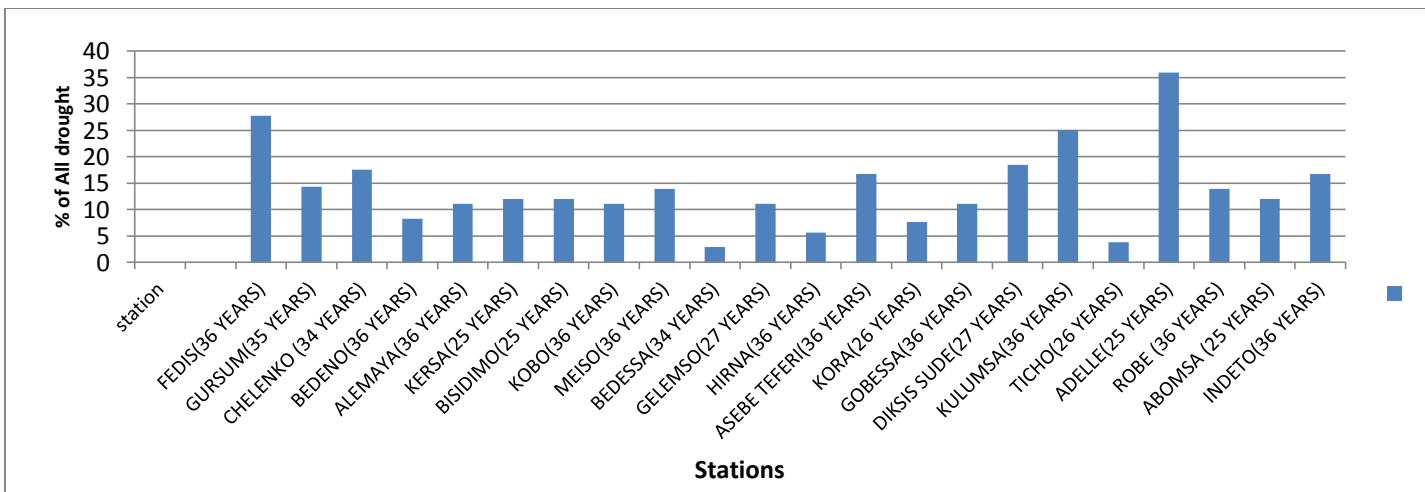
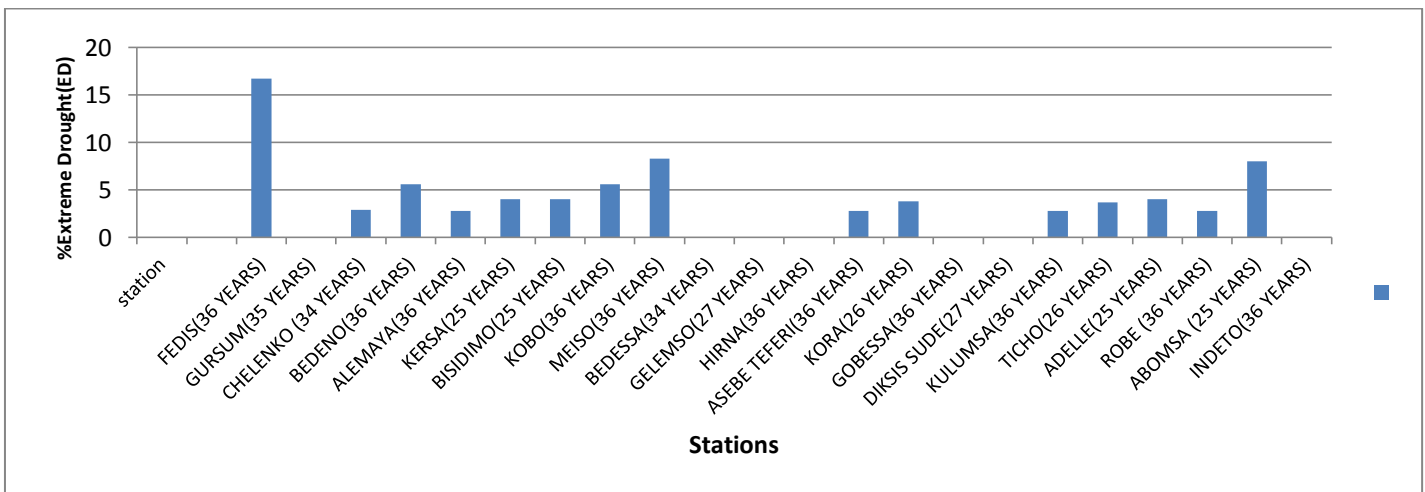
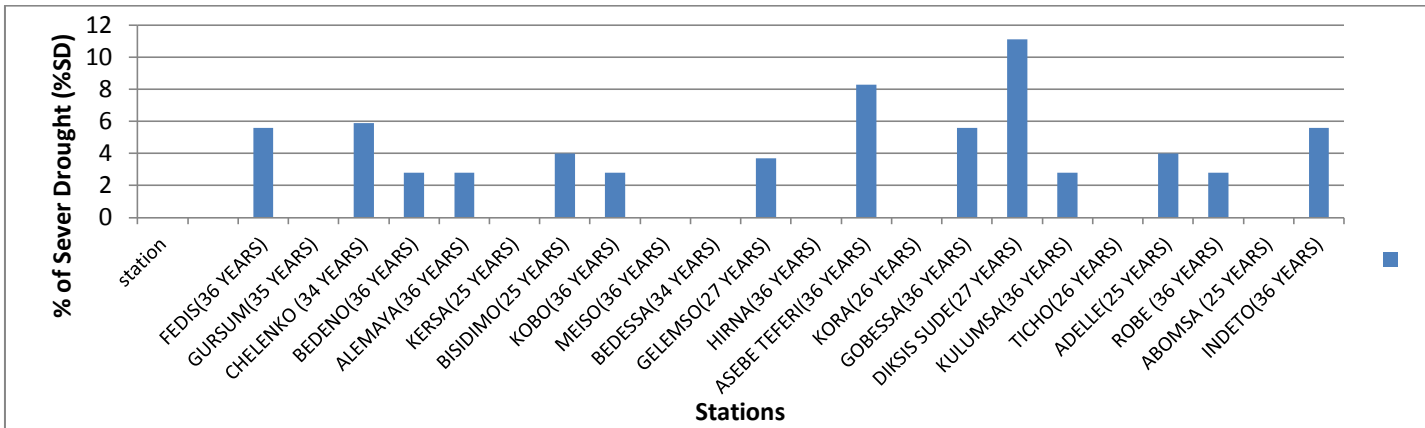
ZONE	Station	Duretion (months)		Severity		Magnitude		Intensity	
		max.	min.	max.	min.	max.	min.	max.	min.
EAST HARARHIE	FEDIS	84	12	11.18	0.04	0.13	0	2.89	0.06
	GURSUM	108	12	7.97	0.49	0.07	0.02	1.74	0.01
	CHELENKO	60	12	4.18	0.44	0.07	0.01	1.79	0.04
	BEDENO	72	12	3.86	0.01	0.16	0	3.54	0.01
	ALAMAYA	84	12	3.67	0.18	0.13	0.02	1.61	0.04
	KARSA	36	12	3.21	0.28	0.16	0.02	1.94	0.28
	BISIDIMO	60	12	3.96	0.17	0.07	0.01	1.51	0.06
KOBO	60	12	7.57	0.16	0.14	0.01	2.79	0.05	
WEST HARARGIE	MIESO	36	12	4.72	0.08	0.19	0.01	2.71	0.01
	BEDESSA	24	12	0.72	0.13	0.03	0.01	0.42	0.11
	GELEMSO	36	12	3.03	0.33	0.13	0.03	1.69	0.14
	HIRNA	204	108	8.7	6.63	0.06	0.03	1.05	0.16
	ASEBA TEFERI	36	12	4.08	0.5	0.17	0.02	2.76	0.12
	KORA	48	12	5.34	0.04	0.11	0	3.4	0.04
ARSI	GOBESSA	48	12	3.03	0.14	0.2	0.01	2.45	0.06
	DIKSIS SUDE	48	12	4.84	0.27	0.12	0.02	2.77	0.06
	KULUMSA	86	12	3.64	0.15	0.15	0.01	2.05	0.1
	TICHO	36	12	5.01	0.21	0.21	0.02	4.51	0.14
	ADELLE	36	12	3.83	0.16	0.16	0.03	2.88	0.01
	ABOMSA	96	12	8.93	0.13	0.09	0.01	2.59	0.13
	ROBE	48	12	4.03	0.07	0.11	0.01	1.77	0.05
INDETO	36	12	3.91	0.06	0.16	0.01	2.62	0.06	

#### 4.6 Drought Frequency

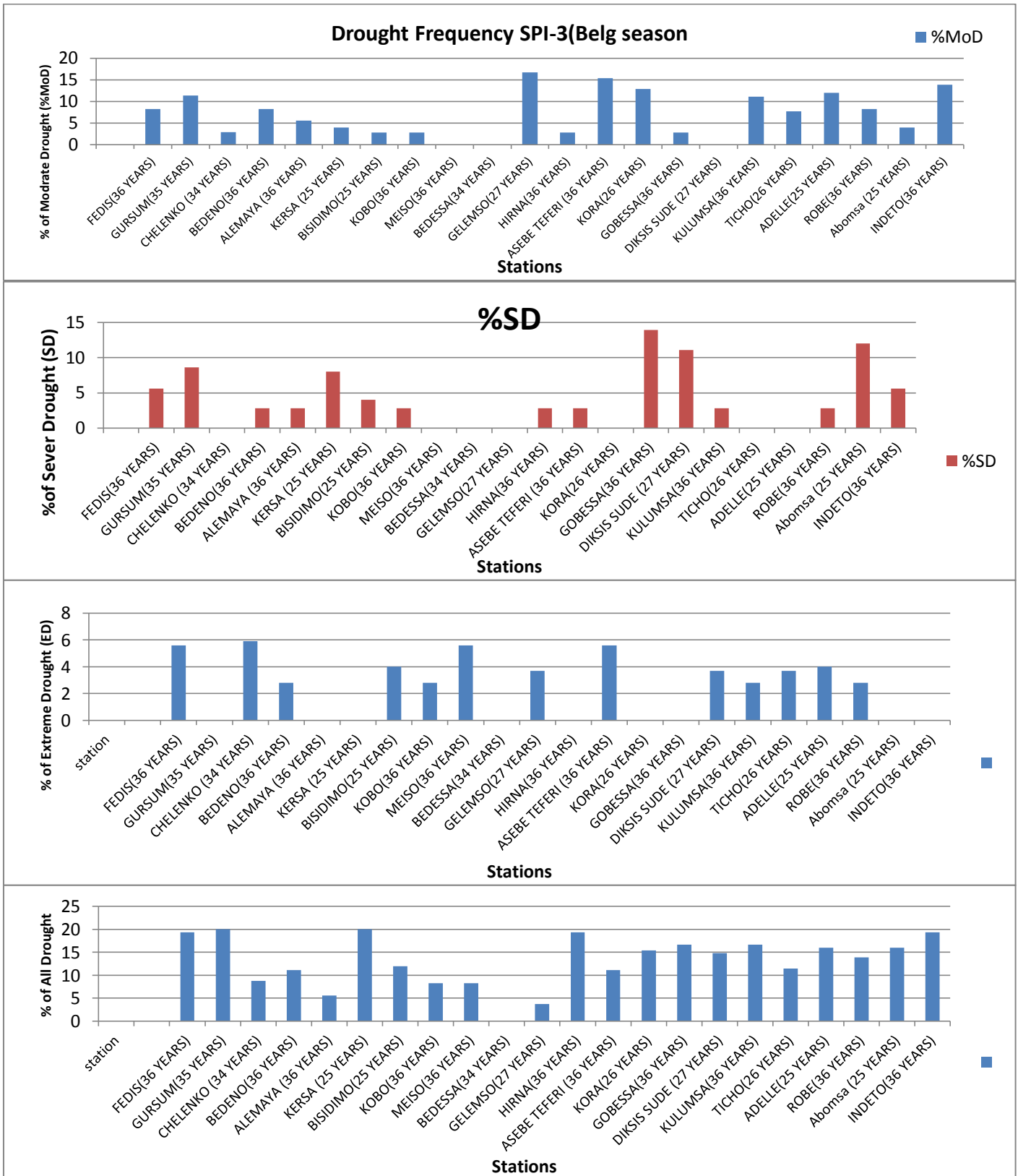
Drought frequency is the ratio between the number of events of certain intensity, and the total duration of the time series. Summary of drought frequency and intensity (moderate, sever and extreme) for all stations are show in Appendix C, Table C1 to Table C3

The frequency of different type of drought intensity namely severe, moderate, and extreme were irregular over the study area. In general, the mild drought is more frequent than moderate, severe and extreme drought. Maximum (78%) of all droughts (Mild, moderate, severe and extreme) frequency for SPI-3 (Kiremt) was recorded at Fedis station in East Hararegie. Seventy-eight (78%) percent of all drought frequency means the station was affected at least by one of drought intensity 78% of time series from mild to extreme (i.e. 22% of time series (36 years) from 1979 to 2014 there was no any type of drought). Maximum (69%) all drought frequency for SPI-3 (Belg) was recorded at Hirna and Alamaya and maximum (69, 67, and 63) all drought frequency for SPI-12 (Annual) were recorded at Alamaya (East Hararegie) and Gursum (East Hararegie). Figures. 4.8 to 4.10 show drought frequency for 3 time scales SPI-3 (Kiremt), SPI-3 (Belg) and SPI-12 (Annual) for moderate, severe and extreme drought and all drought (moderate, sever and extreme).





**Figure 4.8:** Drought frequency SPI-3 (Kiremt Season)



**Figure 4.9:** Drought frequency SPI-3 (Belg Season)

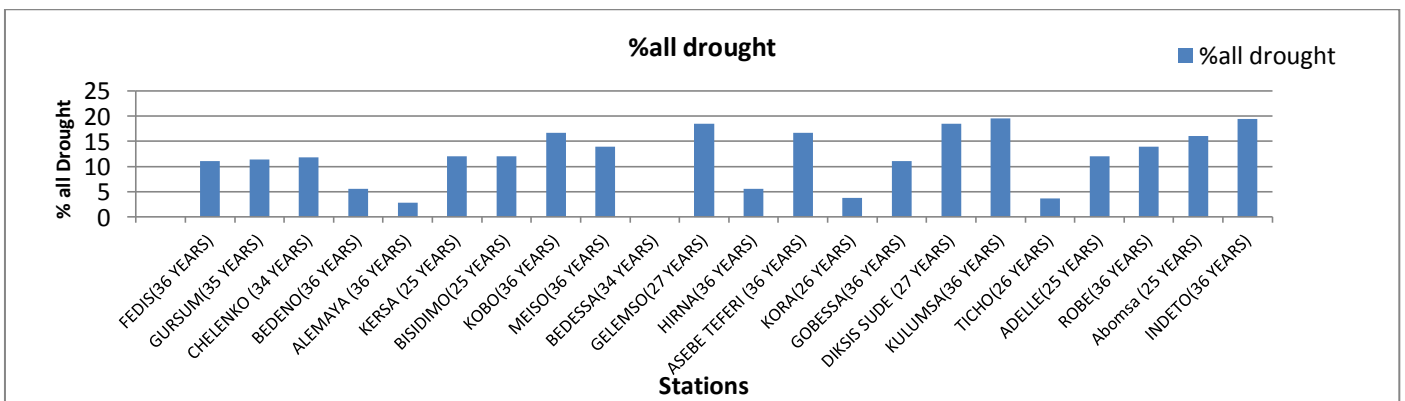
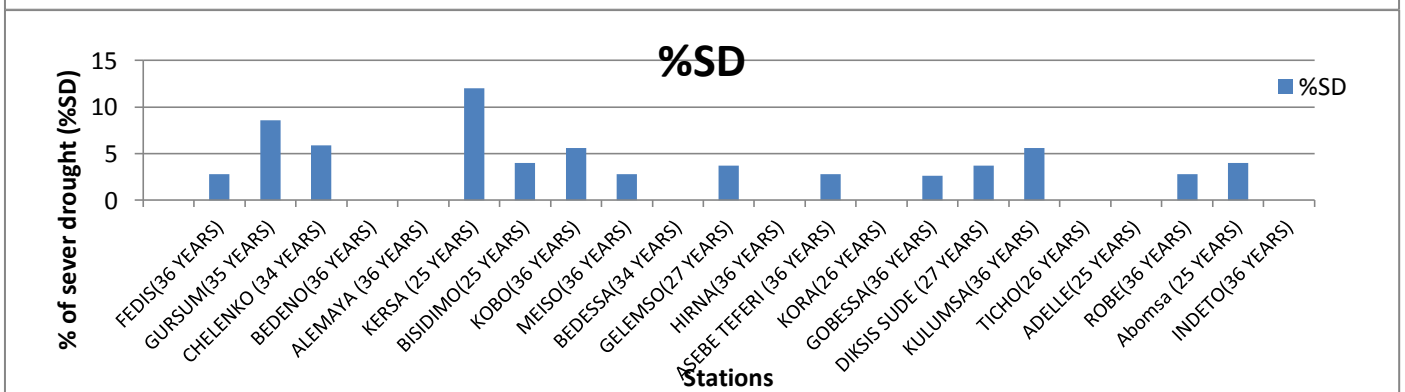
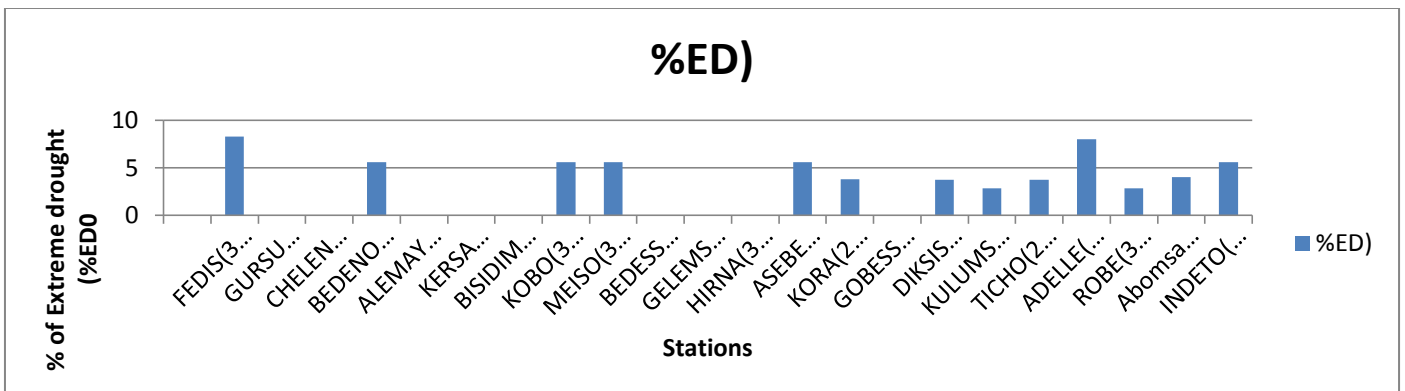
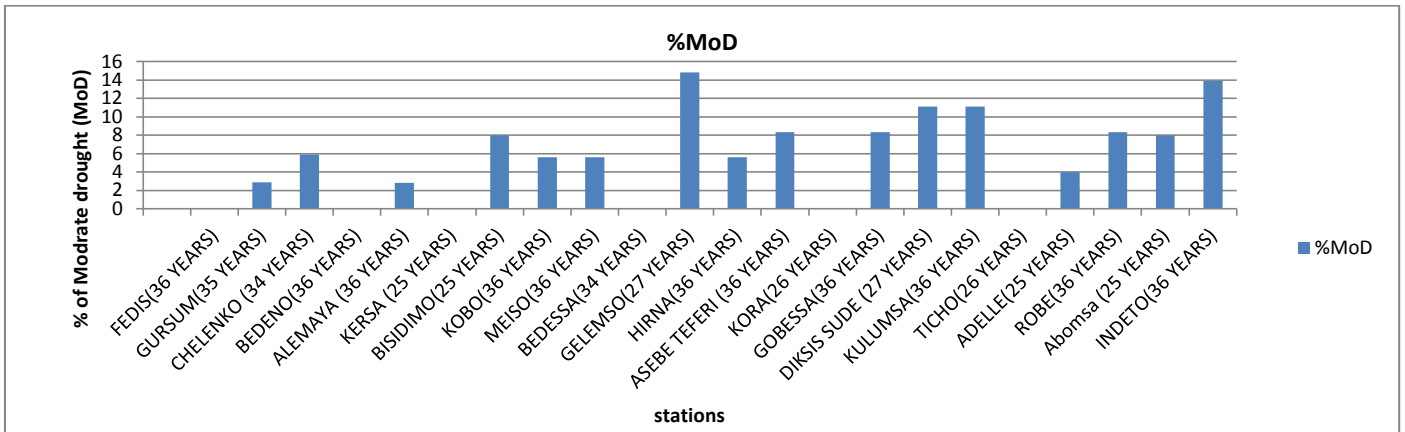


Figure 4.10: Drought Frequency SPI-12 (Annual)

#### **4.7 Analyzing and predicting of the future Drought of SPI**

The study conducted future drought analysis based on Representative concentration path (RCP)8.5Scenario by using SPI for periods of three, six and twelve months. In order to analysis and calculate R-Studio was used with place values of the 13 observatories consisting of precipitation.

Figure 4.below shows the number of droughts predicted by the SPI on a basis of three-, six-, twelve-month periods. In Adele, Hirna and Diksis Sude the SPI predicted that extreme drought would occur at the years 2022 to 2023, 2025 to 2026 and 2027 for station Adele, and at the year 2017,2021,2023 to 2024, 2035,2040 and 2042 at station Hirna and at the year 2018,2030, 2035 to 2037 at station of Diksis Sude causing severe drought damage to the regions. The long-term forecast (12-month period unit) showed that extreme drought would occur severely at station Diksis Sude from 2035 to 2037and need more attention for this area

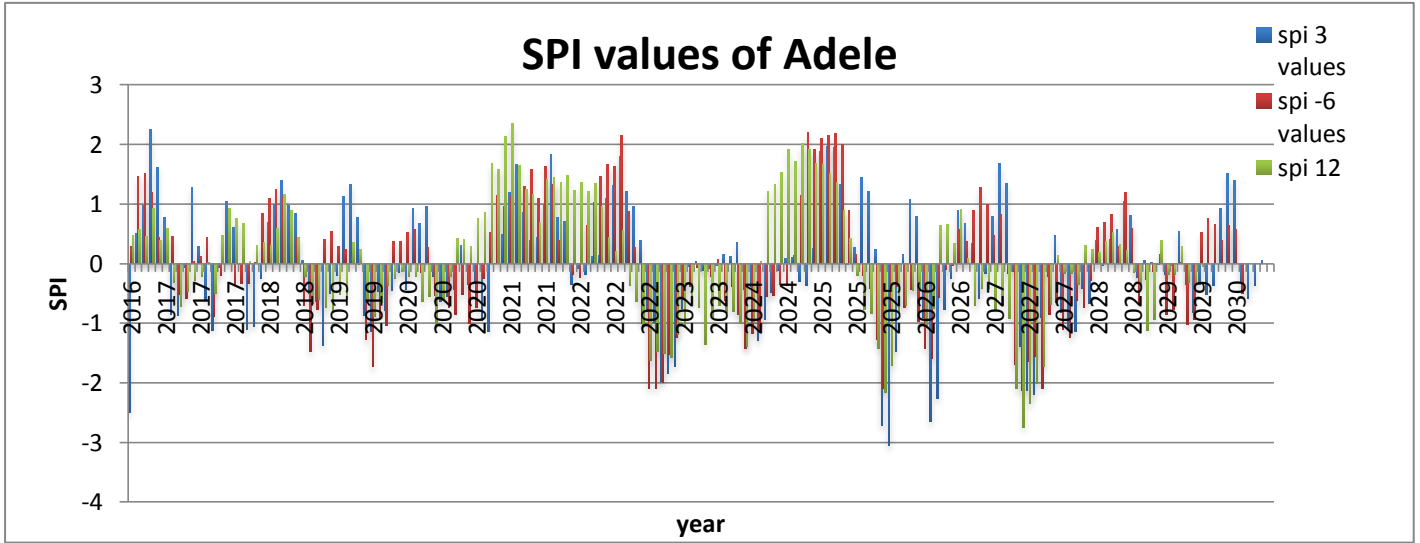


Figure 4.11 Predicted SPI –Values of Adele

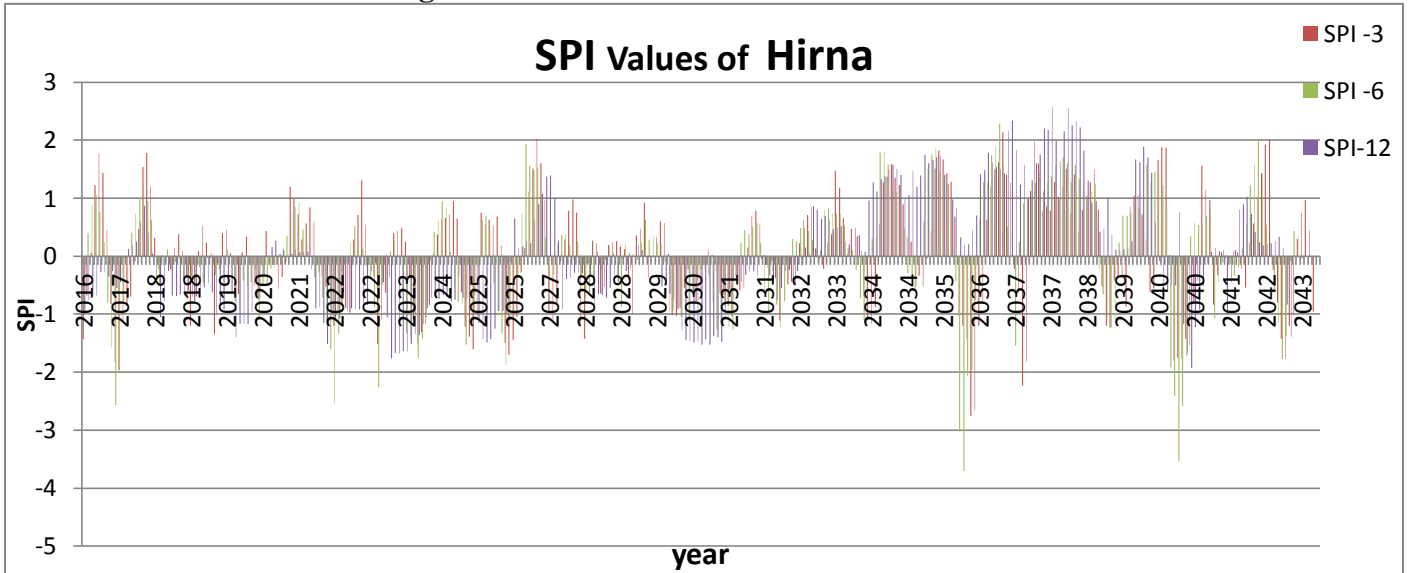


Figure 4.12: Predicted SPI –Values of Hirna

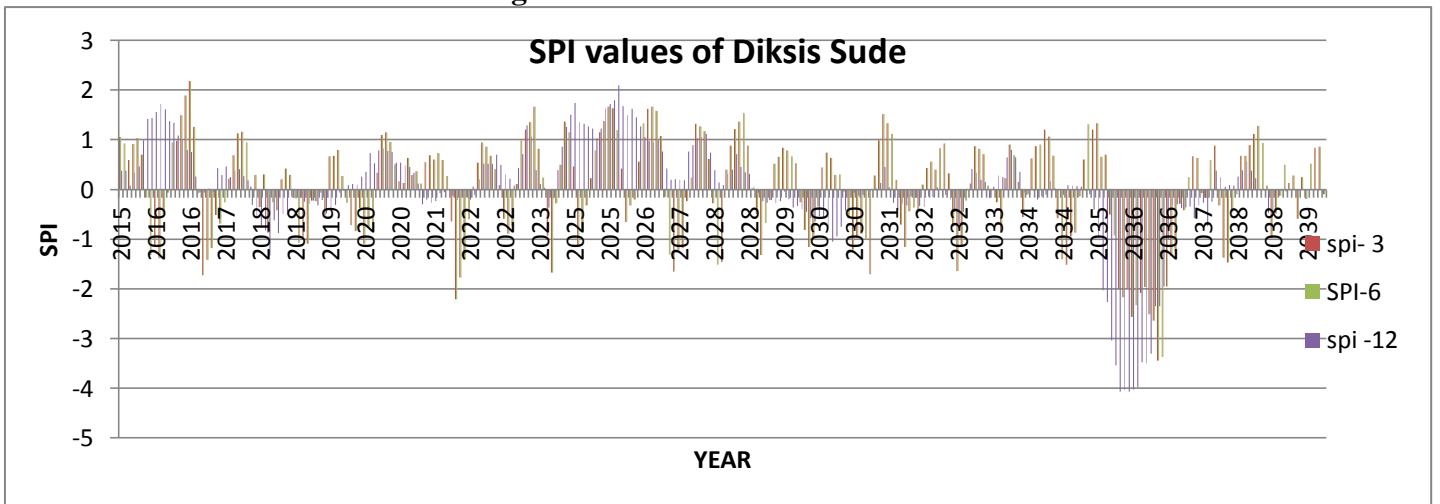
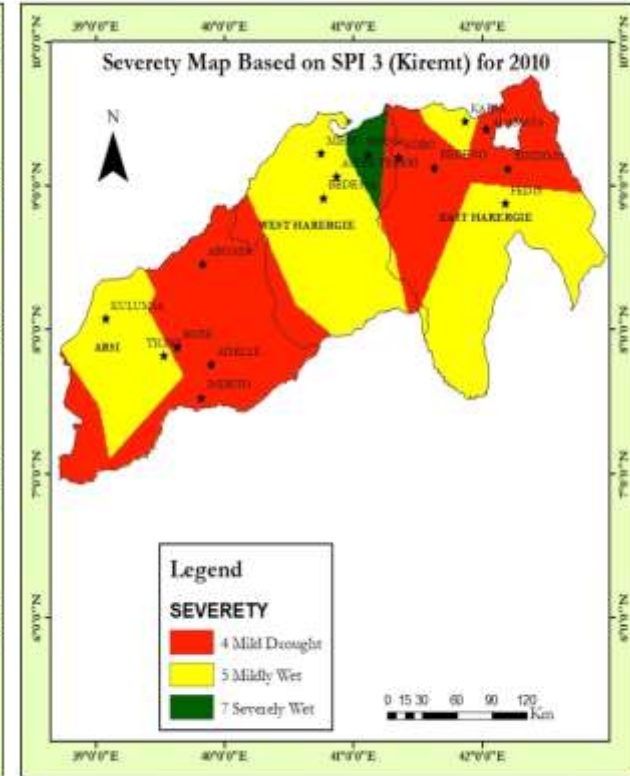
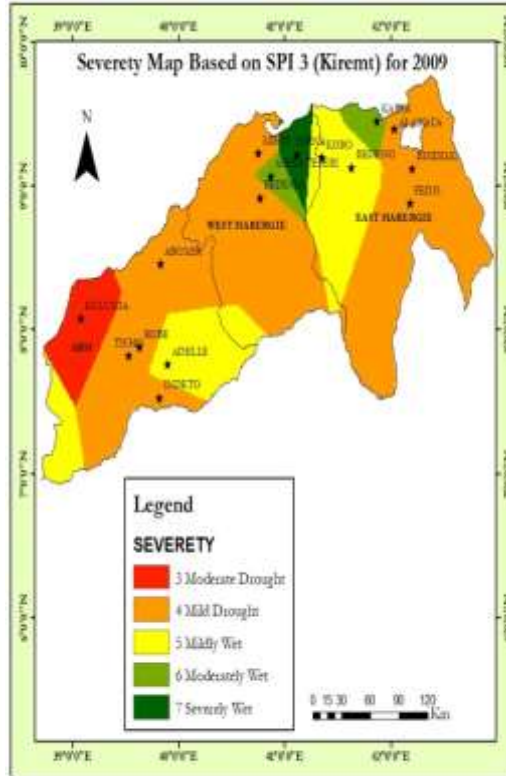
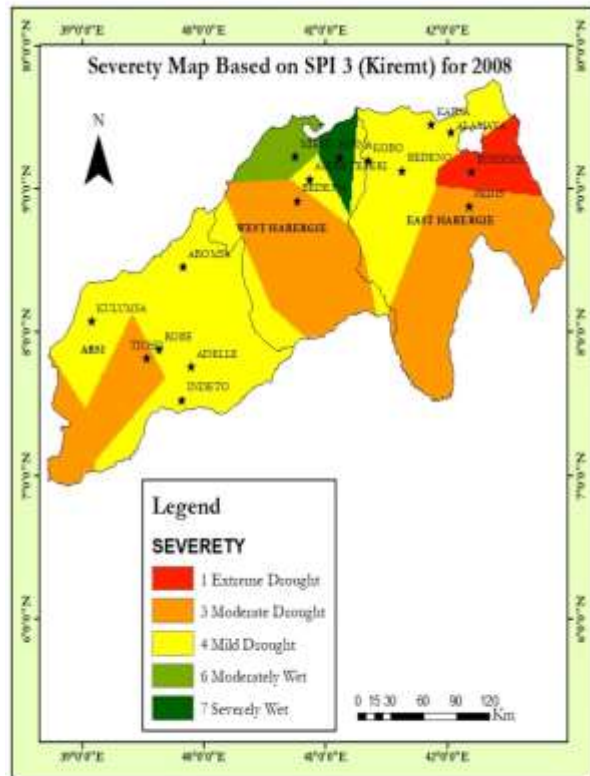


Figure 4.13: Predicted SPI –Values of Diksis Sude

#### **4.8 Spatial extent**

Major strength of SPI is to calculated on a site basis, but drought is a regional phenomenon, SPI values computed separately for each of the 22 rain gauge station have been linearly interpolated between station in Arc view GIS to demarcate its spatial extent. The result was essential to know the coverage of a specific type of drought.

A successive SPI drought map of recent decades (2005 to 2014) as shown Figure 4.35 for SPI-3 Kiremt and Appendix C Figures C1 to C10 for SPI-3 Belg show a spatial extent of the drought over study area was irregular. There was no time in recent decades (2005-2014) without drought, at least mild drought. Most of the all area covered with drought of different intensity in 2014, 2013, 2008 and 2007 for SPI-3 Kiremt and 2008, and 2012 for SPI-3 Belg with different types of intensity from mild to extreme drought.



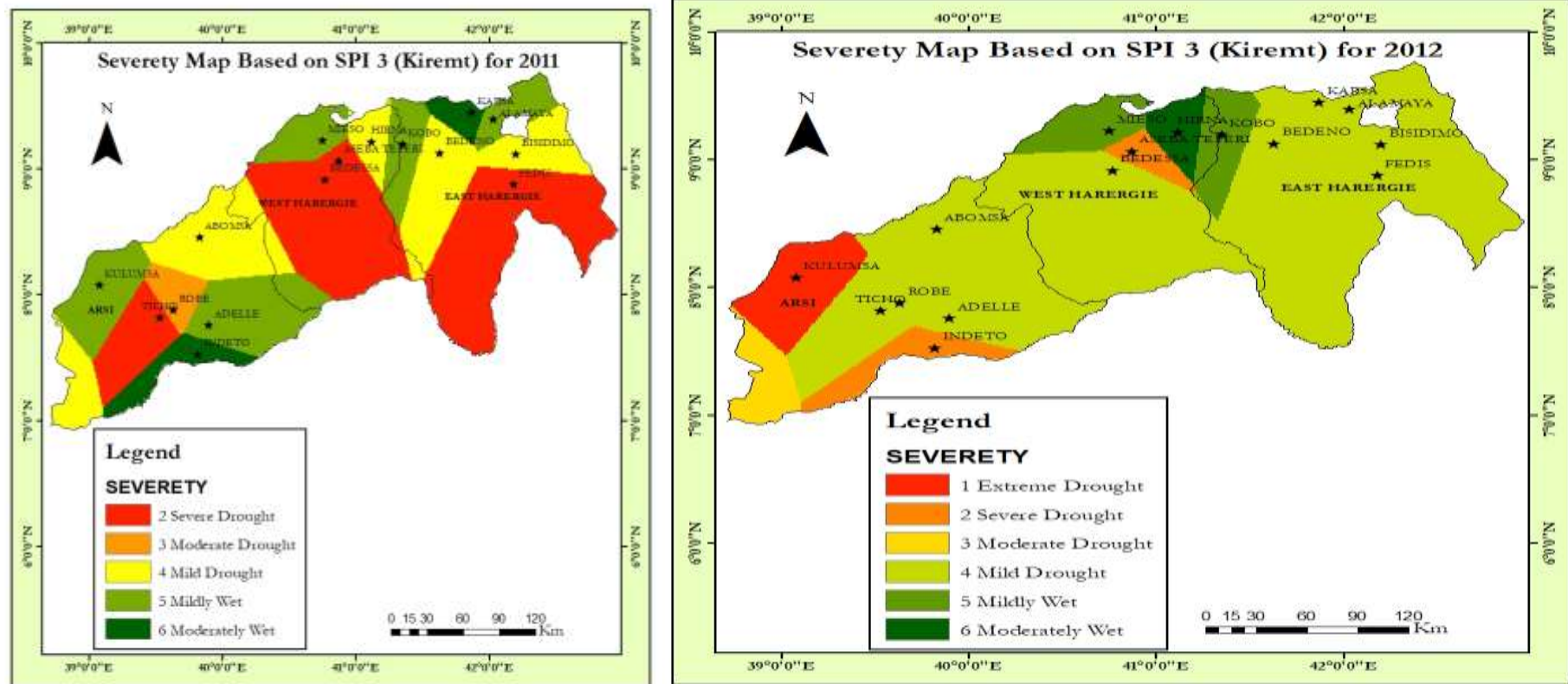


Figure 4.14: Severity maps based on SPI -3(Kiremt)

## 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

The main objective of the study was to understand rainfall variation in the study area and analyse and Predict drought by its characteristics namely, duration, intensity, severity, magnitude and frequency and special extent.

Effective drought management depends on drought indicator. Drought indicators are variables to detect and characterize drought conditions. These indicators are based on meteorological and hydrological variable, such as precipitation, stream flows, soil moisture, reservoir storage, and ground water levels. For this study, the drought indicator namely standardized precipitation index (SPI) was used. SPI is a powerful tool, requiring only rainfall data for its calculation, and delivering 5 major dimensions of drought: duration, intensity, severity, magnitude, and frequency.

In this study, 22 stations were used for drought analysis, drought characteristics for each of the station was calculated for time scale of SPI-2, SPI-3 (Kiremt and Belg), SPI-6 and SPI-12. Sustainable development and reduction in drought vulnerability can be achieved through effective management of drought and effective quantification of drought characteristics and spatial extent. These help to identify risks associated with the drought and degree of vulnerability at multiple time steps to reflect influence of rainfall deficiency on different water resources. All drought types originate from lack of precipitation and 80-90% of the rainfall over most part of the Ethiopia occurred during Kiremt and Belg seasons. Therefore, more emphasis given to SPI-3 (Kiremt) and SPI-3 (Belg) in this study, remaining SPI's were calculated to obtain preliminary information for further study about drought situation in the area. From the analysis of drought in all stations considered in the study the following conclusions were drawn. considered in the study the following conclusions were drawn.

1. Belg rainfall was highly variable than Kiremt rainfall and variability rainfall increase from Arsi to East Hararegie CV Belg increase minimum from 24 to maximum 122 and CV kiremt increase minimum from 12 maximum 94.
2. Maximum drought severity occurred in 1983 to 1996 for all the 5 time scales considered.

3. Maximum drought magnitudes occurred in 1988 to 1995 for the 5 time scales considered.
4. Maximum drought durations occurred from 1986 to 2003 for all the 5 time scales considered for all stations.
5. The most severe and the most extreme intensities occurred in Hararegie at Bedeno, Fedis, and Kobo stations
6. Frequency of moderate drought in Kiremt season increased in the direction from East Hararegie to Arsi but the maximum moderate drought occurred at Adelle(Arsi)
7. Frequency of severe drought in Kiremt season were Irregular in study area maximum at Diksis Sude (Arsi)
8. Frequency of extreme drought in Kiremt season increased from Arsi to East Hararegie
9. Frequency of all Kiremt season drought (moderate,severe, extreme) largest happened all Arsi and maximum at Adelle (Arsi)
10. Map of SPI-3 Kiremt shows that in 2014, 2013, 2003 and 2007 in almost all parts of study area affected by mild drought but in 2007 most parts of East and West Hararegie and Partial parts Arsi affected by moderate and severe drought
11. Almost all parts of East and West Hararegie affected by at least mild drought every year

It can be observed from the SPI map the study area affected by different type intensity during SPI-3 Kiremt and Belg each year, and most drought characteristics were increase from Arsi to East Hararegie, which also shows that Hararegie was more vulnerable to drought than study areas.

According to NMSA, in 1985 almost all part of Ethiopia and 1997 most Hararegie, and Rift Valley were affected by drought. The SPI calculated for stations in study areas also reveals the same reality.

This study drew the following conclusion from the analysis of Meteorological Drought based on RCP 8.5 scenario conducted at nationwide observatories by applying the SPI. According to the drought indices estimated at the observatories of Eastern Oromia from 2016 to 2043, the SPI predicted the trend graph of drought index would be maintained over time.

## 5.2 Recommendations

It is obvious that drought phenomena will create more vulnerable environment for the agricultural sector and water resources. The study area is characterized by high rainfall variation and drought proneness. Agricultural system of the area mainly depend on rainfed agriculture and are frequently affected by drought. Drought and its consequences also impact on societies which lead to drought vulnerability unless governmental and public attentions were given (Shaaban, 2003). The following practices should be undertaken to reduce drought impacts and develop drought resilient society.

Just as critically important is the development of delivery systems that provide decision makers at all levels and for all primary sectors with data and information that will assist them in making timely decisions. These decision support tools provide end users with information they need to reduce the most serious consequences of drought and reduce the need for government and donor intervention in the form of drought assistance and relief.

The Standard Precipitation Index is one of the tools used to analyze the areal extent and frequency of drought in a certain region. In this study data obtained from limited stations that have a relatively long year record of rain fall have been used for the computation of the Standard Precipitation Index (SPI). A better result would have been obtained if there is more number of stations with longer years of record.

The future research steps will be to investigate the interconnectivity of meteorological drought with hydrological and water resources drought, to evaluate the forecasting potential of droughts using Representative concentration path (e.g. RCP 8.5 scenarios). Drought management policies should be implemented in drought prone areas especially low land of study area (Hararegije).

1. Drought awareness and preparedness should be done (To develop culture of prevention and used of early warning system).
2. Water resources management should be implemented (store water during rain seasons) and effective utilization during dry seasons. Finally, it is recommended to consider more than one index, examine the sensitivity and accuracy of indices and apply on larger area for further study.

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## **APPENDIX A**

**Table A**

**Table A 1. Statistical Parameters for stations for different time scales**

Zone	station	No. of Year	Mean				standard deviation				Best fitting dist.
			Annual	kiremt	Belg	6 moths	Annual	kiremt	Belg	6 moths	
EAST HARARHIE	FEDIS	36	681.77	263.6	262.57	490.24	265.45	119.36	133.9	201.51	pearson III
	GURSUM	36	618.5	363.94	286.26	587.83	264.3	147.01	127.56	197.6	pearson III
	CHELENKO	36	1144.86	616.95	337.32	846.52	279.59	168.54	138.19	208.55	Gamma
	BEDENO	36	1151.57	475.21	419.69	844.27	476.9	210.71	175.51	355.91	Gamma
	ALAMAYA	36	582.4	401.2	368.46	722.68	752.81	211.08	445.73	597.09	Gamma
	KARSA	25	993.55	480.37	321.81	425.91	193.67	113.49	136.61	167.39	Gamma
	BISIDIMO	25	708.83	280.47	268.8	520.41	172.89	80.43	96	138.08	Gamma
	KOBO	36	954.29	405.03	358.67	710.01	455.16	191.17	200.27	355.51	Gamma
WEST HARARGIE	MIESO	36	783.77	352.73	260.47	585.16	157.93	103.16	140.23	156.72	Gamma
	BEDESSA	36	1119.25	481.99	359.48	771.36	247.84	138.4	135.69	191.44	Gamma
	GELEMSO	27	1003.22	389.49	324.18	713.67	264.89	133.84	127.39	220.93	Gamma
	HIRNA	36	416.89	205.52	118.72	304.88	310.84	190.62	73.7	224.3	Gamma
	ASEBA TEFERI	36	871.51	388.9	271.58	607.87	197.36	125.02	143.64	162.6	Gamma
	KORA	26	785.23	333.17	276.82	568.33	196.16	122.55	115.94	152.97	Gamma
ARSI	GOBESSA	36	1229	481.99	400.81	805.81	332.23	138.4	153.73	218.81	Gamma
	DIKSIS SUDE	27	850.55	430.13	217.27	618.62	144.23	62.84	75.64	119.53	Gamma
	KULUMSA	36	813.66	349.14	250.72	592.49	113.66	46.64	90.55	102.31	Gamma
	TICHO	27	1163.7	439.54	339.73	742.94	329.35	122.81	152.13	193.35	Gamma
	ADELLE	25	786.8	340.19	254.44	568.24	131.3	98.49	59.33	101.75	Gamma
	ABOMSA	25	1245.95	643.15	302.05	893.45	194.59	188.41	117.61	252.34	Gamma
	ROBE	36	974.79	459.65	274.26	692.88	316.29	117.65	91.41	129.88	Gamma
	INDETO	36	857.7	342.98	288.64	604.08	163.21	84.34	91.33	151.98	Gamma

**Table A 2 SPI values**

No	Year	Indato					Kersa					Bisidimo				
		SPI-2 Ju to jly	SPI-3(Jly to Aug)	SPI-3(Feb-Apr)	SPI-6(Mar-Aug)	SPI-12(J-D)	SPI-2(Ju-jly)	SPI-3(Jly - Aug)	SPI-3(Feb-Apr)	SPI-6 Mar-Aug	SPI-12 J-D	SPI-2 Ju to jly	SPI-3 Jly to Aug	SPI-3 Feb-Apr	SPI-6 Mar-Aug	SPI-12 J-D
1	1990	-1.44	-1.18	-2.57	-2.73	-2.2	0.81	-0.67	-1.15	-1.16	1.59	0.43	0.01	-0.72	-0.01	-0.63
2	1991	-1.61	-0.88	1.28	-0.5	0.41	-1.43	0.43	1.68	1.22	0.98	-1.41	1.51	1.48	0.76	1.19
3	1992	-2.18	-2.94	-0.28	-1.73	-1.05	1.45	0.75	1.32	2.05	2.21	-0.08	0.93	1.02	0.83	2.21
4	1993	-0.05	1.04	-0.03	0.39	0.71	-1.22	-0.05	1.14	-0.35	1.14	1.13	2.62	0.9	2.22	-0.47
5	1994	-0.79	-1.67	-1.48	-1.34	-2.88	-0.37	-1.33	-0.5	-1.29	-1.87	-0.06	0.58	-1.66	-0.72	-1.09
6	1995	0.88	-0.81	1.39	-0.06	-0.95	0.41	-0.35	1.33	0.76	0.09	-1.05	-0.97	-0.22	0.72	-0.36
7	1996	-1.77	-0.31	0.26	0.47	0.18	0.25	-1.04	0.31	0.01	-0.3	-0.58	-1.07	0.36	0.07	1.2
8	1997	1.53	-0.62	1.82	0.08	-0.09	-2.55	-3.33	1.41	-0.25	-0.97	-1.94	0.35	1.94	0.97	-0.21
9	1998	-0.29	0.36	0.26	0.98	0.84	0.75	-0.58	-1.62	-1.58	-1.94	0.26	1	-0.84	-0.52	0.96
10	1999	0.16	-0.72	1.48	0.01	0.13	1.13	0.97	-0.03	0.89	0.35	0.01	-0.26	1.72	1.06	-0.63
11	2000	0.87	0.17	-1.1	-0.99	0.05	-0.29	1.21	0.56	0.44	1.74	-1.29	-0.33	-0.62	-0.76	-0.77
12	2001	0.49	1.55	0.63	1.22	0.66	0.27	0.37	0.77	0.43	0.43	-1.97	-1.96	0.34	0.75	0.1
13	2002	-0.28	0.77	-0.33	0.79	1.19	0.1	-0.19	-0.77	-0.97	-0.54	-0.02	0.74	-0.5	0.09	0.21
14	2003	1.19	0.04	-0.04	-0.4	0.67	0.1	-0.19	-0.16	-0.48	-0.38	-0.36	0.23	0.06	0.03	0.06
15	2004	0.44	1.54	0.09	1.16	0.86	2.73	1.32	-0.8	0.44	0.12	0.9	0.52	0.35	0.47	-0.17
16	2005	0.07	1.02	1.47	0.9	1.19	0.45	-0.12	0.43	0.5	-0.28	-0.11	0.25	0.69	0.39	1.45
17	2006	1.17	0.36	0.12	0.58	-0.01	0.92	0.25	1.52	1.76	0.86	1.68	0.36	0.97	2.07	-0.25
18	2007	0.68	0.41	-0.4	0.62	1.21	1.85	-0.17	-0.28	0.24	0.6	0.72	-0.16	-0.2	0.13	-1.29
19	2008	1.39	0.33	-0.2	0.33	0.64	0.24	0.13	-1.76	-1.96	-0.75	-1.13	-2.26	-2.28	-2.9	0.16
20	2009	-1.12	0.65	0.29	1.36	0.49	1.65	1.5	-1.14	0.57	1	-0.4	-0.06	-0.38	-0.4	-0.99
21	2010	0.34	-0.31	-1.1	-1.23	-0.69	-0.48	0.66	-0.57	-0.84	-0.35	-0.87	-0.31	0.51	-0.62	-1.51
22	2011	-0.3	0.61	-0.55	0.5	-0.11	1.65	1.27	-0.24	1.08	0.38	-1.51	-0.83	-0.43	-0.63	-0.83
23	2012	0.74	-0.41	-0.54	-0.89	-0.83	-0.07	-0.2	-1.25	-0.92	-0.3	-0.95	-0.37	-0.45	-0.26	-0.57
24	2013	0.26	0.94	0.42	0.67	0.55	1.09	0.17	-0.17	-0.14	-0.31	-0.51	-0.47	0.28	-0.27	0.06
25	2014	-0.83	0.11	-0.86	-0.19	-0.3	0.22	-0.54	-0.05	-0.44	-0.34	0.61	-0.03	-1.3	-0.31	0.32

**Table A 3 SPI values**

Station s.No	year	Robe					Indeto				
		SPI-3 Jly to Aug	SPI-3 Feb-Apr	SPI-6 Mar-Aug	SPI-12 J-D	SPI-2 Ju to jly	SPI-3 Jly to Aug	SPI-3 Feb-Apr	SPI-6 Mar-Aug	SPI-12 J-D	
1	1979	0.6	-0.97	0.74	-0.02	-0.13	0.46	-0.44	0.78	0.43	0.52
2	1980	0.56	1.36	-0.63	0.2	0.23	0.95	1.85	1.11	1.31	1.8
3	1981	0.7	-1.03	-0.07	-0.12	-0.7	-0.65	-0.22	0.53	0.38	-0.19
4	1982	1.55	-0.25	-0.39	0.01	0.2	0.08	-0.74	0.43	0.33	0.3
5	1983	0.86	0.75	-1.16	0.16	-0.37	0.3	0.37	-0.8	-0.25	-1.15
6	1984	0.7	-0.02	1.52	1.13	0.05	0.6	1.22	0.91	1.21	0.57
7	1985	0.56	1.47	-1.12	0.61	-0.12	1	0.33	-1.5	-0.72	-1.04
8	1986	0.5	-0.3	0.8	0.17	3.45	0.04	0.02	0.46	0.23	0.05
9	1987	2.17	1.14	0.6	0.76	-0.38	-0.59	0.09	-1.62	-1.82	0.36
10	1988	1.24	-1.02	2.13	-0.19	-0.5	0.92	1.55	-0.44	0.45	1.04
11	1989	1.1	-0.28	-0.31	-0.71	-1.11	0.99	-1.8	0.72	0.33	0.3
12	1990	0.7	1.64	-1.35	-0.8	1.84	-1.06	-1.34	-1.94	-2.4	-2.62
13	1991	1.18	-0.91	2.04	2.28	0.77	-1.02	-0.67	0.39	-0.47	-1.29
14	1992	0.87	0.23	1.62	0.64	0.35	-0.32	-1.42	-0.14	-0.72	0.07
15	1993	0.26	-0.67	0.25	0.33	-1.63	-1.36	0.45	0.19	0.08	0.79
16	1994	1.06	-0.03	-0.97	-1.75	-1.27	-0.49	-1.04	-1.44	-1.34	-2.08
17	1995	1.12	-1.28	-0.73	-1.29	0.04	-0.99	-0.39	0.2	-0.48	-1.25
18	1996	-2.01	-2.83	1.25	0.55	-1.21	0.66	-1.47	1.16	0.6	0.35
19	1997	0.9	0.05	1.54	-1.23	-0.05	-1.07	-0.37	1.07	-0.21	-0.14
20	1998	1.44	-0.31	-0.13	-0.17	-0.05	1.81	1.65	-1.23	0.27	0.64
21	1999	0.45	-0.05	0.33	-0.29	0.02	0.78	0.5	1.01	0.45	0.78
22	2000	1.66	2.2	1.22	2.73	1.37	-2.29	-0.36	0.46	-0.11	0.04
23	2001	1.12	1.66	-1.12	0.63	0.52	0.26	0.8	0.06	0.12	-0.31
24	2002	0.06	0.43	-0.59	-0.47	1.73	0.09	0.11	-0.22	-0.01	0.51
25	2003	2.17	0.74	-0.55	0.35	0.13	-1.03	-0.94	-0.22	-0.88	-0.06
26	2004	0.76	0.1	0.92	0.66	0.37	1.75	1.13	-1.34	-0.07	0.33
27	2005	1.85	0.05	0.36	0.81	-0.15	0.63	0.33	0.23	0.26	0.02
28	2006	0.56	-0.02	0.6	0.24	0.14	3.03	-2.22	2.77	3.64	2.91
29	2007	1.04	0.21	-0.43	0.3	0.53	-0.05	-0.11	1.66	0.97	0.61
30	2008	1.55	-0.09	-0.74	-0.49	-0.3	0.71	-0.43	-0.52	-0.11	0.15
31	2009	-0.35	-0.57	0.29	-0.59	-0.72	0.75	-0.6	-1.38	-0.98	-0.84
32	2010	1.9	-0.43	1.15	1.02	0.11	0.07	-0.01	-0.36	-0.12	0.16
33	2011	-0.45	-1.48	-1.22	-2.33	-1.16	1.66	1.35	-0.28	0.9	0.57
34	2012	-0.42	-0.8	-0.55	-1.43	-1.77	-0.85	-1.73	-0.59	-1.29	-1.28
35	2013	0.65	0.12	-1.07	-1.16	-0.84	0.88	0.33	0.08	0.43	-0.09
36	2014	0.21	-0.03	0.17	0.63	1.06	-0.22	-0.32	0.18	-0.46	-0.25

**Table A 4 SPI values**

Station s.No	year	Adele					Kersa					Bisidimo				
		SPI-2 Ju to jly	SPI- 3(Jly to Aug)	SPI- 3(Feb- Apr)	SPI- 6(Mar- Aug)	SPI- 12(J-D)	SPI- 2(Ju- jly)	SPI- 3(Jly - Aug)	SPI- 3(Feb- Apr)	SPI-6 Mar- Aug	SPI-12 J- D	SPI-2 Ju to jly	SPI-3 Jly to Aug	SPI-3 Feb- Apr	SPI-6 Mar- Aug	SPI-12 J- D
1	1990	-1.44	-1.18	-2.57	-2.73	-2.2	0.81	-0.67	-1.15	-1.16	1.59	0.43	0.01	-0.72	-0.01	-0.63
2	1991	-1.61	-0.88	1.28	-0.5	0.41	-1.43	0.43	1.68	1.22	0.98	-1.41	1.51	1.48	0.76	1.19
3	1992	-2.18	-2.94	-0.28	-1.73	-1.05	1.45	0.75	1.32	2.05	2.21	-0.08	0.93	1.02	0.83	2.21
4	1993	-0.05	1.04	-0.03	0.39	0.71	-1.22	-0.05	1.14	-0.35	1.14	1.13	2.62	0.9	2.22	-0.47
5	1994	-0.79	-1.67	-1.48	-1.34	-2.88	-0.37	-1.33	-0.5	-1.29	-1.87	-0.06	0.58	-1.66	-0.72	-1.09
6	1995	0.88	-0.81	1.39	-0.06	-0.95	0.41	-0.35	1.33	0.76	0.09	-1.05	-0.97	-0.22	0.72	-0.36
7	1996	-1.77	-0.31	0.26	0.47	0.18	0.25	-1.04	0.31	0.01	-0.3	-0.58	-1.07	0.36	0.07	1.2
8	1997	1.53	-0.62	1.82	0.08	-0.09	-2.55	-3.33	1.41	-0.25	-0.97	-1.94	0.35	1.94	0.97	-0.21
9	1998	-0.29	0.36	0.26	0.98	0.84	0.75	-0.58	-1.62	-1.58	-1.94	0.26	1	-0.84	-0.52	0.96
10	1999	0.16	-0.72	1.48	0.01	0.13	1.13	0.97	-0.03	0.89	0.35	0.01	-0.26	1.72	1.06	-0.63
11	2000	0.87	0.17	-1.1	-0.99	0.05	-0.29	1.21	0.56	0.44	1.74	-1.29	-0.33	-0.62	-0.76	-0.77
12	2001	0.49	1.55	0.63	1.22	0.66	0.27	0.37	0.77	0.43	0.43	-1.97	-1.96	0.34	0.75	0.1
13	2002	-0.28	0.77	-0.33	0.79	1.19	0.1	-0.19	-0.77	-0.97	-0.54	-0.02	0.74	-0.5	0.09	0.21
14	2003	1.19	0.04	-0.04	-0.4	0.67	0.1	-0.19	-0.16	-0.48	-0.38	-0.36	0.23	0.06	0.03	0.06
15	2004	0.44	1.54	0.09	1.16	0.86	2.73	1.32	-0.8	0.44	0.12	0.9	0.52	0.35	0.47	-0.17
16	2005	0.07	1.02	1.47	0.9	1.19	0.45	-0.12	0.43	0.5	-0.28	-0.11	0.25	0.69	0.39	1.45
17	2006	1.17	0.36	0.12	0.58	-0.01	0.92	0.25	1.52	1.76	0.86	1.68	0.36	0.97	2.07	-0.25
18	2007	0.68	0.41	-0.4	0.62	1.21	1.85	-0.17	-0.28	0.24	0.6	0.72	-0.16	-0.2	0.13	-1.29
19	2008	1.39	0.33	-0.2	0.33	0.64	0.24	0.13	-1.76	-1.96	-0.75	-1.13	-2.26	-2.28	-2.9	0.16
20	2009	-1.12	0.65	0.29	1.36	0.49	1.65	1.5	-1.14	0.57	1	-0.4	-0.06	-0.38	-0.4	-0.99
21	2010	0.34	-0.31	-1.1	-1.23	-0.69	-0.48	0.66	-0.57	-0.84	-0.35	-0.87	-0.31	0.51	-0.62	-1.51
22	2011	-0.3	0.61	-0.55	0.5	-0.11	1.65	1.27	-0.24	1.08	0.38	-1.51	-0.83	-0.43	-0.63	-0.83
23	2012	0.74	-0.41	-0.54	-0.89	-0.83	-0.07	-0.2	-1.25	-0.92	-0.3	-0.95	-0.37	-0.45	-0.26	-0.57
24	2013	0.26	0.94	0.42	0.67	0.55	1.09	0.17	-0.17	-0.14	-0.31	-0.51	-0.47	0.28	-0.27	0.06
25	2014	-0.83	0.11	-0.86	-0.19	-0.3	0.22	-0.54	-0.05	-0.44	-0.34	0.61	-0.03	-1.3	-0.31	0.32

Table A 5 SPI values

Station	year	Mieso					Hirna				
		SPI-2(Ju- jly)	SPI-3(Jly - Aug)	SPI-3(Feb-Apr)	SPI-6 Mar-Aug	SPI-12 J-D	SPI-2 Ju to jly	SPI-3(Jly to Aug)	SPI-3(Feb-Apr)	SPI-6(Mar-Aug)	SPI-12(J-D)
1	1979	1.20	-0.14	0.52	0.46	0.73	-3.30	-0.62	-0.60	-0.91	-0.87
2	1980	0.49	1.64	0.28	1.11	1.49	-1.67	-0.06	-0.45	-0.39	-0.26
3	1981	-0.26	0.28	0.41	0.41	0.03	-2.60	-0.63	-0.55	-0.61	-0.56
4	1982	0.41	0.54	0.62	0.60	0.43	-2.95	-1.29	-1.13	-1.17	-1.05
5	1983	0.39	0.40	0.22	0.16	0.00	-2.85	-0.83	-1.13	-0.94	-0.98
6	1984	1.54	0.53	0.22	0.19	0.14	-2.68	-1.02	-0.09	-0.63	-0.79
7	1985	1.37	0.86	-0.58	0.06	-0.39	-1.95	-0.53	-1.56	-0.75	-0.71
8	1986	0.49	0.28	0.13	0.40	0.20	-2.73	-0.88	-0.84	-0.83	-0.91
9	1987	0.09	0.64	-0.09	-0.23	0.76	-2.48	-0.41	-0.73	-0.61	-0.49
10	1988	-0.36	0.49	-1.06	-1.06	-0.32	0.35	0.40	-0.56	0.26	0.16
11	1989	-0.27	0.95	-0.29	-0.26	1.06	-0.41	0.35	1.16	0.77	0.77
12	1990	-0.08	-0.41	0.32	-0.13	0.44	-1.89	-0.40	0.30	-0.15	-0.24
13	1991	0.02	0.95	1.09	1.51	1.02	-3.77	-0.76	0.72	-0.27	-0.45
14	1992	0.42	0.24	0.20	0.18	-0.31	-1.59	-0.28	-0.37	-0.39	-0.39
15	1993	0.97	0.10	0.71	1.05	0.64	-2.77	-0.87	-1.08	-0.96	-0.84
16	1994	0.11	-2.23	-0.42	-1.37	-2.71	-2.12	-0.89	-1.05	-0.86	-1.01
17	1995	0.21	-1.08	0.45	-0.24	-0.91	-3.09	-0.52	-0.56	-0.88	-0.78
18	1996	0.21	-0.57	0.56	0.06	-0.83	-2.23	-0.79	-0.67	-0.72	0.57
19	1997	-2.70	-2.15	0.70	0.28	-0.43	-3.19	-0.58	0.10	-0.45	-0.51
20	1998	0.32	-0.45	3.69	-2.09	-2.28	-1.02	0.04	-1.06	-0.44	-0.20
21	1999	-0.67	-2.79	2.08	1.82	0.81	-1.69	-0.39	0.25	-0.17	-0.16
22	2000	-0.53	0.32	-2.70	-1.47	-1.22	-2.51	-0.66	-0.27	-0.66	-0.52
23	2001	0.27	-0.32	0.88	0.49	0.41	-1.84	-0.39	-0.07	-0.31	-0.32
24	2002	-1.63	0.60	0.32	0.00	0.33	-2.04	-0.46	-0.37	-0.48	-0.46
25	2003	-1.65	0.44	-0.42	-0.23	-0.01	-1.97	-0.47	-0.34	-0.46	-0.45
26	2004	2.03	-0.60	-0.14	-0.92	-1.00	-1.92	-0.70	-0.18	-0.38	-0.60
27	2005	0.12	-0.99	-0.18	-1.48	-0.60	-2.16	-0.41	-1.00	-0.63	-0.78
28	2006	1.65	0.68	0.74	1.18	0.51	-2.04	-0.46	0.11	-0.29	-0.42
29	2007	-0.26	-0.75	1.25	1.21	0.62	1.59	1.11	2.10	1.76	1.95
30	2008	-0.33	1.22	1.31	2.32	2.16	0.99	1.74	1.13	1.44	1.59
31	2009	0.42	-0.65	0.29	-0.29	1.69	2.40	1.71	1.73	2.08	1.75
32	2010	0.34	0.31	-0.54	-1.47	-0.54	0.28	1.85	1.93	1.74	1.78
33	2011	1.07	0.35	-0.35	-0.43	-0.28	0.24	2.04	1.10	1.80	1.63
34	2012	-1.08	0.42	-0.78	-0.88	0.05	1.16	1.38	1.08	1.56	1.51
35	2013	0.76	1.88	0.00	1.01	0.74	1.70	2.19	0.72	1.77	1.85
36	2014	-0.09	-1.41	-0.50	-1.82	-1.99	1.26	1.67	2.22	1.75	1.87

**Table A 6SPI values**

Station s.No	Alamaya						Ticho				
	year	SPI-2(Ju- jly)	SPI-3(Jly - Aug)	SPI-3(Feb-Apr)	SPI-6 Mar-Aug	SPI-12 J-D	SPI-2 Ju to jly	SPI-3(Jly to Aug)	SPI-3(Feb-Apr)	SPI-6(Mar-Aug)	SPI-12(J-D)
1	1979	-0.06	-0.25	-0.57	-0.39	-0.38	-1.07	-0.70	0.37	0.19	0.33
2	1980	-0.23	0.31	-0.28	-0.06	-0.1	0.16	0.88	-0.17	0.38	0.71
3	1981	0.13	-0.4	-0.34	-0.38	-0.38	-0.25	-0.50	-0.01	0.11	0.09
4	1982	0.02	-0.29	0.44	-0.16	-0.19	-0.38	-0.07	-0.58	-0.36	-0.36
5	1983	0.41	-0.53	-1.29	-0.99	-0.81	-0.05	-1.01	-1.11	-0.54	-0.31
6	1984	0.2	-0.09	-0.05	-0.05	-0.26	0.98	0.36	0.17	0.43	0.44
7	1985	0.6	0.24	-0.3	-0.09	-0.25	2.62	0.15	0.39	1.00	0.70
8	1986	0.04	2.81	-0.05	1.18	1.49	1.12	0.69	1.55	1.44	1.45
9	1987	-1	0.28	-0.35	-0.45	0.16	1.49	-0.26	0.17	0.69	0.73
10	1988	1.1	0.01	-0.46	-0.2	-0.18	0.48	2.46	0.18	1.07	1.20
11	1989	-0.35	1.39	-0.81	1.1	1.48	0.36	-0.77	0.22	0.29	0.68
12	1990	4.52	1.63	1.7	2.14	2.04	-3.69	-4.02	-2.20	-2.36	-2.62
13	1991	1.77	2.32	3.38	2.85	2.89	-3.03	-1.68	0.33	-0.51	-0.51
14	1992	4.64	0.59	3.43	3.25	2.96	-1.11	-2.29	-0.29	-0.54	-0.83
15	1993	0.48	0.16	-0.27	0.06	-0.25	-1.42	-3.00	-1.47	-1.25	-1.53
16	1994	-2.51	-0.89	-0.45	-1.17	-1.25	0.07	-0.52	-1.63	-0.56	-0.52
17	1995	-0.15	-0.19	-0.63	-0.77	-0.77	-4.66	-4.97	-2.10	-2.67	-2.89
18	1996	-1.2	-0.9	-0.97	-0.84	-0.97	-2.53	-5.33	-1.65	-1.98	-2.29
19	1997	-3	-1.45	0.48	-0.2	-0.43	-2.28	0.38	1.47	1.10	1.04
20	1998	-0.64	0.97	-0.85	-0.25	-0.09	0.01	0.63	1.33	1.00	1.10
21	1999	-0.99	0.17	0.09	-0.14	-0.05	-0.37	-0.02	1.48	0.99	1.10
22	2000	-0.69	-0.55	-0.52	-0.61	-0.79	-1.63	-0.93	0.24	0.04	-0.16
23	2001	-2.12	0.12	-0.17	-0.35	-0.23	-3.37	-2.79	-1.44	-2.13	-0.53
24	2002	-0.25	-0.53	-0.64	-0.63	-0.61	-0.36	-0.70	0.01	0.04	-0.06
25	2003	0.5	0.28	0.38	0.34	0.35	-0.83	-0.38	-0.35	-0.17	-0.08
26	2004	-3.12	-2.3	-0.84	-1.59	-1.61	0.54	-0.32	0.77	0.60	0.44
27	2005	0.33	0.9	-0.01	0.29	0.06	0.38	-0.01	1.22	0.97	0.63
28	2006	1.18	0.28	0.37	0.47	0.36	0.37	-0.95	1.66	1.31	1.07
29	2007	0.87	-0.46	0.18	0.08	0.17	-0.28	-0.66	0.31	0.24	0.11
30	2008	0.6	0.24	-0.87	-0.57	-0.36	-0.37	-1.05	0.25	-0.07	0.50
31	2009	-1.13	-0.29	-0.5	-0.53	-0.28	-0.28	-0.67	0.45	0.32	0.22
32	2010	-1.96	-0.04	-0.55	-0.44	-0.53	-2.02	0.15	0.05	0.29	0.24
33	2011	-0.34	0.21	-0.33	-0.06	-0.36	-0.84	-1.94	0.45	0.36	-0.04
34	2012	-0.71	-0.94	-0.25	-0.52	-0.7	0.11	-0.15	0.47	0.58	0.39
35	2013	-2.19	-1.08	-0.22	0.73	-0.74	-0.05	-0.83	-0.16	-0.12	0.00
36	2014	-0.81	-0.24	0.2	-0.11	-0.1	0.16	-0.60	0.00	0.12	-0.09

Table A 7 SPI values

Station s.No	year	Abomsa					Kulumsa				
		SPI-2(Ju- jly)	SPI-3(Jly - Aug)	SPI-3(Feb-Apr)	SPI-6 Mar-Aug	SPI-12 J-D	SPI-2(Ju- jly)	SPI-3(Jly - Aug)	SPI-3(Feb-Apr)	SPI-6 Mar-Aug	SPI-12 J-D
1	1979						0.84	0.05	-0.71	-0.33	0.14
2	1980						-0.26	-1.2	0.89	-0.28	0.03
3	1981	1.77	-0.60	-1.64	-0.99	-1.21	0.8	-1.48	0.25	-0.04	-0.61
4	1982	1.40	0.15	-1.52	-0.90	-1.03	-0.02	-1.73	0.08	-1.26	-1.13
5	1983	0.64	-0.86	-0.07	-0.85	-0.41	1.3	1.67	-0.89	-0.48	-0.56
6	1984	1.25	-0.48	-0.73	-0.83	-0.66	1.04	0.91	0.27	0.68	0.26
7	1985	-0.49	-2.52	-1.65	-2.48	-2.59	1.49	-0.23	-1.04	-0.27	-1.33
8	1986	-0.18	-2.09	-1.01	-1.94	-1.90	0.45	-0.18	0.59	0.68	0.49
9	1987	1.46	-0.37	-0.25	-0.36	-0.32	1.15	0.46	0.41	0.78	1.92
10	1988	-1.80	-1.46	1.17	-0.34	-0.80	0.59	1.36	-1.84	-1.11	-0.38
11	1989	1.82	0.80	-0.46	0.03	0.14	0.28	0.44	1.37	1.1	1.09
12	1990	1.64	-0.81	-0.56	-0.66	-0.61	0.9	-1.41	-0.92	-1.11	-2.05
13	1991	1.51	-0.10	0.60	-0.24	0.20	0.23	0.17	0.09	-0.66	-1.21
14	1992	1.95	-0.01	0.22	0.03	-0.13	0.57	0.74	-0.16	-0.06	1.23
15	1993	1.14	0.03	0.15	-0.15	0.77	0.65	1.6	1.84	2.21	1.34
16	1994	1.82	0.15	-0.05	-0.23	0.39	0.03	-0.08	-0.97	-1.11	-1.77
17	1995	3.61	1.29	0.09	1.14	1.05	0.41	-0.09	-0.99	-1.5	-1.88
18	1996	2.03	-0.17	0.07	0.02	-0.65	0.82	-1.08	0.52	-0.02	1.06
19	1997	1.79	0.10	1.28	0.63	0.36	-0.47	-1.41	1.63	0.75	-0.1
20	1998	1.87	-0.34	-0.57	-0.38	-0.53	0.74	0.97	-0.48	-0.5	0.55
21	1999	2.43	1.11	-0.04	0.98	0.88	1.12	0.97	0.35	1.07	0.93
22	2000	3.23	0.93	-0.90	0.42	0.87	1.44	1.33	0.49	0.83	1.42
23	2001	3.12	1.13	0.26	1.03	1.39	0.79	0.46	0.52	0.46	-0.12
24	2002	3.12	1.13	0.26	1.03	1.39	0.22	0.87	-2.06	-1.48	0
25	2003	3.02	1.49	1.19	1.89	1.35	-0.01	1.03	0.75	0.41	1.08
26	2004	0.97	0.36	1.89	1.02	0.70	1.34	0.26	-1.25	-0.41	-0.87
27	2005	3.49	1.23	-0.29	1.02	0.59	0.52	-0.24	1.24	1.15	0.49
28	2006						1.3	-0.7	1.28	1.38	0.56
29	2007						1.14	-0.99	1.22	1.28	0.85
30	2008						0	0.8	-0.4	-0.35	0.47
31	2009						0.81	-1.09	-1.02	-1	-0.5
32	2010						1.93	0.15	-0.2	0.43	0.04
33	2011						1.09	0.13	1.39	1.91	0.98
34	2012						-0.83	-2.16	-0.86	-1.47	-1.3
35	2013						1	-1.04	0.03	-0.09	-0.45
36	2014						0.65	0.28	-1.01	-1.6	-0.67

Table A 8 SPI values

Station	year	Badesa					Bedano					Gobessa				
		SPI-2 Ju to jly	SPI-3(Jly to Aug)	SPI-3(Feb-Apr)	SPI-6(Mar-Aug)	SPI-12(J-D)	SPI-2 Ju to jly	SPI-3 Jly to Aug	SPI-3 Feb-Apr	SPI-6 Mar-Aug	SPI-12 J-D	SPI-2 Ju to jly	SPI-3 Jly to Aug	SPI-3 Feb-Apr	SPI-6 Mar-Aug	SPI-12 J-D
1	1979	0.78	-0.70	0.37	0.19	0.33	0.96	-0.12	0.32	0.27	0.21	0.67	-0.43	0.88	0.49	0.65
2	1980	-1.55	0.88	-0.17	0.38	0.71	0.72	0.52	-0.83	-0.22	-0.08	0.67	0.59	0.56	0.52	0.69
3	1981	0.36	-0.50	-0.01	0.11	0.09	1.30	0.40	0.32	0.42	0.25	0.64	0.47	0.50	0.71	0.33
4	1982	1.37	-0.07	-0.58	-0.36	-0.36	-4.26	-3.48	-3.36	-3.44	-3.54	0.59	-0.58	-0.10	-0.44	-0.22
5	1983	3.03	-1.01	-1.11	-0.54	-0.31	0.63	0.08	-0.33	-0.23	-0.32	1.11	1.79	-1.89	-0.16	-0.49
6	1984	1.03	0.36	0.17	0.43	0.44	2.05	0.37	1.11	0.72	0.53	0.94	0.06	0.43	0.26	0.27
7	1985	2.21	0.15	0.39	1.00	0.70	0.36	-0.07	-0.22	0.15	-0.28	1.76	0.03	-0.61	-0.10	-0.82
8	1986	1.41	0.69	1.55	1.44	1.45	2.96	1.74	2.21	1.96	2.19	0.57	-0.34	-0.46	-0.69	0.88
9	1987	0.60	-0.26	0.17	0.69	0.73	3.28	1.41	1.85	2.03	1.62	0.43	0.67	-0.27	-0.36	0.10
10	1988	1.28	2.46	0.18	1.07	1.20	-7.03	-2.43	-1.70	-2.64	-2.35	1.18	-0.74	-1.62	-1.45	-0.92
11	1989	1.83	-0.77	0.22	0.29	0.68	0.87	0.36	0.13	0.02	0.11	-0.33	-1.07	0.07	-0.55	-0.37
12	1990	-3.69	-4.02	-2.20	-2.36	-2.62	0.33	0.10	-0.25	0.17	0.26	1.40	-0.27	-1.58	-1.15	-1.41
13	1991	-3.03	-1.68	0.33	-0.51	-0.51	-2.15	0.87	1.19	0.58	0.73	-0.03	0.16	0.58	0.23	-0.33
14	1992	-1.11	-2.29	-0.29	-0.54	-0.83	1.28	0.59	0.10	0.42	1.30	1.06	0.05	-0.08	-0.21	0.39
15	1993	-1.42	-3.00	-1.47	-1.25	-1.53	3.48	0.74	0.72	1.20	0.94	0.63	-0.43	0.51	0.03	0.09
16	1994	0.07	-0.52	-1.63	-0.56	-0.52	-0.01	-0.43	0.57	0.30	0.01	0.40	-0.36	-1.56	-1.64	-1.82
17	1995	-4.66	-4.97	-2.10	-2.67	-2.89	0.04	-0.07	0.54	0.02	0.01	0.76	-0.08	0.81	0.58	-0.06
18	1996	-2.53	-5.33	-1.65	-1.98	-2.29	2.15	0.30	0.65	0.71	0.63	1.14	-0.89	0.24	0.00	-0.24
19	1997	-2.28	0.38	1.47	1.10	1.04	-0.81	-0.11	0.40	-0.06	-0.09	-0.98	-1.98	0.56	-0.65	-1.03
20	1998	0.01	0.63	1.33	1.00	1.10	1.48	0.38	-1.42	-0.44	0.29	-0.27	-0.74	-1.12	-1.23	-1.01
21	1999	-0.37	-0.02	1.48	0.99	1.10	4.44	2.14	1.02	1.68	1.89	0.12	0.10	0.21	-0.29	0.20
22	2000	-1.63	-0.93	0.24	0.04	-0.16	0.74	1.52	1.02	0.78	0.73	-0.31	-0.38	0.19	0.25	-0.09
23	2001	-3.37	-2.79	-1.44	-2.13	-0.53	-1.78	-1.67	0.32	-0.53	-0.58	1.10	0.19	0.32	0.52	0.08
24	2002	-0.36	-0.70	0.01	0.04	-0.06	0.53	-0.20	-0.41	-0.20	-0.30	0.88	0.29	-0.46	0.02	0.16
25	2003	-0.83	-0.38	-0.35	-0.17	-0.08	-1.01	0.32	-0.23	-0.32	-0.27	-0.82	0.53	0.91	0.75	2.10
26	2004	0.54	-0.32	0.77	0.60	0.44	2.37	0.91	-1.21	-0.11	-0.17	4.02	3.11	0.67	2.54	1.57
27	2005	0.38	-0.01	1.22	0.97	0.63	1.12	0.02	-0.01	-0.11	-0.30	-0.60	0.14	3.12	2.31	1.69
28	2006	0.37	-0.95	1.66	1.31	1.07	1.54	-0.34	-0.16	0.19	-0.07	3.10	1.19	1.52	2.08	1.30
29	2007	-0.28	-0.66	0.31	0.24	0.11	1.19	0.21	0.60	0.38	0.29	1.87	-0.61	0.71	0.54	1.59
30	2008	-0.37	-1.05	0.25	-0.07	0.50	0.53	-0.39	-0.44	-0.59	-0.18	-0.58	2.03	1.09	1.11	2.01
31	2009	-0.28	-0.67	0.45	0.32	0.22	1.84	0.52	0.22	0.41	0.28	1.56	0.88	-0.77	-0.39	0.01
32	2010	-2.02	0.15	0.05	0.29	0.24	0.44	-0.18	-0.52	-0.55	-0.30	0.31	-0.14	-0.62	-0.64	-0.14
33	2011	-0.84	-1.94	0.45	0.36	-0.04	-0.28	-0.55	-0.62	-0.44	-0.78	1.50	-0.49	-0.25	-0.01	0.04
34	2012	0.11	-0.15	0.47	0.58	0.39	1.13	-0.01	-0.42	-0.29	-0.01	0.50	-1.21	-0.30	-0.73	-0.53
35	2013	-0.05	-0.83	-0.16	-0.12	0.00	0.76	-0.19	-0.78	-0.35	-0.58	2.14	1.39	-0.46	0.65	0.23
36	2014	0.16	-0.60	0.00	0.12	-0.09	-1.07	-0.81	-0.16	-0.73	-0.54	-0.25	-1.70	-1.76	-2.31	-2.45

## **APPENDIX B**

**Table B 1. Drought parameters**

Drought parameter							No. drought years					Drought Frequency				
SPI	Station	start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JY)	Adele	1990	1995	12	6.4	0.53	6.00	2.00	2.00	1.00	11.0	24.00	8.00	9.00	4.00	44.00
		1997	1997	2	1.77	0.89										
		1999	1999	2	0.29	0.15										
		2003	2003	2	0.28	0.14										
		2010	2010	2	1.12	0.56										
		2012	2012	2	0.3	0.15										
SPI3(JL-Augs)	Adele	1990	1992	9	4.00	0.44	10.00	7.00	1.00	1.00	10.0	40.00	28.00	4.00	4.00	40.00
		1994	1997	12	3.41	0.28										
		1999	1999	3	0.72	0.24										
		2010	2010	3	0.31	0.1										
		2012	2012	3	0.41	0.14										
SPI-3(F-A)	Adele	1990	1990	3	2.57	0.86	9.00	3.00	0.00	1.00	13.0	36.00	12.00	0.00	4.00	52.00
		1992	1994	9	1.79	0.2										
		2000	2000	3	1.1	0.37										
		2002	2003	6	0.37	0.06										
		2007	2008	6	0.6	0.1										
		2010	2012	9	2.19	0.24										
		2012	2014	3	0.86	0.29										
SPI-6(Mr-Augs)	Adele	1990	1992	12	4.96	0.28	6.00	2.00	1.00	1.00	10.00	24.00	8.00	4.00	4.00	40.00
		1994	1995	6	1.4	0.12										
		2000	2000	6	0.99	0.17										
		2003	2003	6	0.4	0.07										
		2010	2010	6	1.23	0.21										
		2012	2012	6	0.89	0.15										
		2014	2014	6	0.19	0.03										
SPI-12(J-D)	Adele	1990	1992	36	3.66	0.10	6.00	1.00	0.00	2.00	11.00	32.00	4.00	0.00	8.00	44.00
		1994	1995	24	3.83	0.16										
		1997	1997	12	0.09	0.01										
		2006	2006	12	0.01	0										
		2010	2012	36	1.65	0.05										
		2014	2014	12	0.3	0.03										
SPI	Station	start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought

SPI 2(J-JIY)	Endeto	1981	1981	2	0.68	0.34	8.00	5.00	0.00	0.00	13.00	22.22	12.89	0.00	0.00	36.11
		1987	1987	12	0.59	0.3										
		1990	1995	2	4.34	0.36										
		1997	1997	2	1.07	0.54										
		2000	2000	2	0.29	0.15										
		2003	2003	2	0.03	0.52										
		2007	2007	2	0.05	0.03										
		2012	2012	2	0.85	0.43										
		2014	2014	2	0.22	0.11										
SPI3(JL-Augs)	Endeto	1979	1979	3	0.44	0.15	13.00	4.00	2.00	0.00	19.00	36.11	11.11	5.56	0.00	52.78
		1981	1982	6	0.96	0.16										
		1989	1992	12	5.23	0.44										
		1994	1997	12	3.17	0.26										
		1998	1998	3	0.36	0.12										
		2003	2003	3	0.94	0.31										
		2007	2010	12	1.16	0.1										
		2010	2012	3	1.73	0.58										
		2012	2014	3	0.32	0.11										
SPI-3(F-A)	Endeto	1983	1983	3	0.80	0.27	10.00	5.00	2.00	0.00	17.00	27.78	13.69	6.56	0.00	47.22
		1985	1985	3	1.50	0.50										
		1987	1988	6	1.06	0.18										
		1990	1990	3	1.94	0.65										
		1992	1992	3	0.14	0.05										
		1994	1995	6	1.64	0.27										
		1998	1998	3	1.23	0.41										
		2002	2004	9	1.78	0.2										
		2008	2012	15	3.13	0.21										
SPI-6(Mr-Augs)	Endeto	1983	1983	6	0.25	0.04	14.00	2.00	1.00	1.00	18.00	38.39	5.56	2.78	2.78	50.00
		1985	1985	6	0.72	0.30										
		1987	1987	6	1.82	0.25										
		1990	1992	18	1.49	0.1										
		1994	1995	12	1.82	0.02										
		1997	1997	6	0.21	0.02										
		2000	2000	18	0.11	0.02										
		2002	2004	18	0.96	0.05										
		2006	2010	6	1.21	0.07										
		2012	2012	6	1.29	0.22										
		2014	2014	6	0.46	0.08										

SPI-12(J-D)	Endeto	1981	1981	12	0.19	0.02	8.00	5.00	0.00	2.00	15.00	22.22	13.69	0.00	5.56	41.67
		1983	1983	12	1.15	0.1										
		1985	1985	12	1.04	0.09										
		1990	1991	24	3.91	0.16										
		1994	1995	24	3.33	0.14										
		1997	1997	12	0.14	0.01										
		2001	2001	12	0.31	0.03										
		2003	2003	12	0.06	0.01										
		2009	2010	34	1	0.04										
		2012	2014	36	1.62	0.05										

Drought parameter							No. drought years					Drought Frequency				
SPI	Station	start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JIY)	karsa	1991	1991	2	1.43	0.72	4.00	2.00	0.00	1.00	7.00	16.00	8.00	0.00	4.00	28.00
		1993	1994	4	1.59	0.4										
		1997	1997	2	2.55	1.28										
		2010	2010	2	0.48	0.24										
		2012	2012	2	0.07	0.04										
SPI3(JL-Augs)	karsa	1990	1990	3	0.87	0.29	10.00	2.00	0.00	1.00	13.00	40.00	8.00	0.00	4.00	52.00
		1993	1998	18	6.67	0.37										
		2002	2003	6	0.38	0.05										
		2005	2005	3	0.12	0.04										
		2007	2007	3	0.17	0.06										
		2012	2012	3	0.2	0.07										
		2014	2014	3	0.54	0.18										
SPI-3(F-A)	karsa	1990	1990	3	1.15	0.38	10.00	3.00	2.00	0.00	15.00	40.00	12.00	8.00	0.00	60.00

		1994	1994	3	0.5	0.13										
		1998	1999	6	1.65	0.28										
		2002	2004	9	1.73	0.19										
		2007	2014	24	5.45	0.23										
SPI-6(Mr-Augs)	karsa	1990	1990	6	1.16	0.19	9.00	1.00	2.00	0.00	12.00	36.00	4.00	8.00	0.00	48.00
		1993	1994	12	0.64	0.05										
		1997	1998	12	1.83	0.15										
		2002	2003	12	1.45	0.12										
		2008	2008	6	1.96	0.33										
		2010	2010	6	0.84	0.14										
		2012	2014	18	1.5	0.08										
SPI-12(J-D)	karsa	1990	1990	12	1.58	0.13	10.00	0.00	3.00	0.00	13.00	40.00	0.00	12.00	0.00	52.00
		1994	1994	12	1.87	0.16										
		1996	1998	36	3.21	0.09										
		2002	2003	24	0.92	0.04										
		2005	2005	12	0.28	0.02										
		2008	2008	12	0.75	0.06										
		2010	2010	12	0.35	0.03										
		2012	2014	36	0.95	0.03										
Drought parameter							No. drought years					Drought Frequency				
SPI		start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JIY)	Gursum	1979	1982	8	4.49	0.56	16.00	5.00	0.00	1.00	22.00	45.71	14.29	0.00	2.86	62.86
		1984	1987	8	2.39	0.3										

		1991	1992	4	3.25	0.81										
		1996	1997	4	1.64	0.41										
		1999	1999	2	0.07	0.04										
		2001	2001	2	0.5	0.25										
		2003	2003	2	1.26	0.63										
		2007	2013	14	3.12	0.22										
SPI3(JL-Augs)	Gursum	1979	1982	12	4.49	0.37	11.00	5.00	0.00	0.00	16.00	31.45	14.29	0.00	0.00	45.71
		1985	1985	3	1.43	0.48										
		1987	1987	3	0.60	0.20										
		1996	1997	6	2.64	0.44										
		1999	1999	3	1.74	0.58										
		2000	2003	3	0.74	0.25										
		2006	2008	9	1.59	0.18										
		2011	2013	9	1.91	0.21										
SPI-3(F-A)	Gursum	1979	1983	15	6.23	0.42	9.00	4.00	3.00	0.00	16.00	25.71	11.43	8.57	0.00	43.71
		1985	1985	3	1.07	0.36										
		1990	1990	3	0.77	0.26										
		1992	1992	3	0.36	0.12										
		1994	1994	3	1.31	0.44										
		2007	2012	18	2.77	0.15										
SPI-6(Mr-Augs)	Gursum	1989	1983	30	6.27	0.21	14.00	1.00	3.00	0.00	16.00	40.00	2.86	8.57	0.00	51.43
		1985	1986	18	1.05	0.06										
		1990	1990	6	0.75	0.13										
		1992	1992	6	0.41	0.07										

		1994	1994	6	0.7	0.12										
		1996	1996	6	0.52	0.09										
		1998	1999	12	0.08	0.01										
		2003	2003	6	1.46	0.24										
		2007	2007	18	2.37	0.13										
		2012	2012	6	0.76	0.13										
SPI-12(J-D)	Gursum	1972	1987	108	7.97	0.07	18.00	1.00	3.00	0.00	22.00	51.43	2.86	8.57	0.00	62.86
		1990	1990	12	0.51	0.04										
		1982	1992	12	0.49	0.04										
		1994	1994	12	0.68	0.06										
		1996	1996	12	0.86	0.07										
		1998	2001	48	0.89	0.02										
		2007	2009	36	2.37	0.07										

Drought parameter							No. drought years					Drought Frequency				
SPI	Station	start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JY)	chelenko	1987	1987	2	0.17	0.09	3.00	1.00	0.00	1.00	5.00	6.82	2.94	0.00	2.94	14.71
		1992	1992	2	0.53	0.27										
		1995	1995	2	0.47	0.24										
		1997	1997	2	3.11	1.56										
		2000	2001	2	1.06	0.53										
SPI3(JL-Augs)	chelenko	1979	1979	3	0.83	0.28	10.00	3.00	2.00	1.00	16.00	29.41	8.82	5.88	2.94	47.06
		1982	1982	6	1.63	0.27										
		1985	1985	3	0.06	0.02										
		1989	1989	3	1.27	0.42										
		1992	1992	3	0.47	0.16										
		1995	1995	9	4.68	0.52										
		2000	2000	15	3.22	0.21										
		2006	2006	6	0.59	0.1										
SPI-3(F-A)	chelenko	1980	1980	3	0.22	0.07	13.00	1.00	0.00	2.00	16.00	38.24	2.94	0.00	5.88	47.06
		1982	1982	12	2.12	0.18										
		1985	1985	6	0.39	0.07										
		1994	1994	3	0.37	0.12										
		1996	1996	3	0.55	0.18										
		1998	1998	3	2.66	0.89										
		2001	2001	3	0.38	0.13										
		2004	2004	3	2.69	0.9										
		2008	2008	3	0.66	0.22										
2010	2010	9	1.61	0.18												
SPI-6(Mr-Augs)	chelenko	1979	1980	12	0.95	0.08	13.00	4.00	0.00	2.00	19.00	38.24	11.76	0.00	5.88	55.88
		1982	1984	18	1.66	0.09										
		1989	1980	12	0.86	0.07										
		1994	1998	30	3.8	0.13										
		2000	2004	30	5.18	0.17										
2010	2010	6	0.06	0.2												
SPI-12(J-D)	chelenko	1979	1980	24	0.11	0.07	16.00	2.00	2.00	0.00	20.00	47.06	5.88	5.88	0.00	58.82
		1982	1985	60	2.27	0.05										

		1989	1989	12	0.81	0.01												
		1994	1998	60	3.97	0.07												
		2000	2004	60	4.18	0.07												
		2001	2011	36	0.49	0.01												
Drought parameter							No. drought years					Drought Frequency						
SPI	Station	start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought		
SPI 2(J-JY)	Gelemso	1983	1983	2	0.06	0.03	6.00	2.00	10.00	7.00	22.22	7.41	3.70	3.70	0.00	25.93		
		1987	1987	2	0.11	0.06												
		1990	1992	6	2.27	0.38												
		1997	197	2	0.32	0.41												
SPI3(JL-Augs)	Gelemso	1979	1979	3	0.20	0.07	12.00	2.00	1.00	0.00	15.00	44.44	7.41	3.70	0.00	55.55		
		1982	1984	9	1.60	0.18												
		1987	1992	18	5.03	0.28												
		1995	1995	3	0.08	0.03												
		1997	1997	3	0.97	0.32												
		1999	1999	3	0.63	0.21												
SPI-3(F-A)	Gelemso	2011	2012	6	1.53	0.26												
		1983	1983	3	0.36	0.12	11.00	0.00	0.00	1.00	12.00	40.74	0.00	0.00	3.74	44.44		
		1985	1985	3	0.76	0.25												
		1987	1987	6	1.20	0.20												
		1990	1990	6	1.70	0.28												
SPI-6(Mr-Augs)	Gelemso	1989	1998	6	3.88	0.65												
		2011	2012	12	2.41	0.2												
SPI-6(Mr-Augs)	Gelemso	1983	1984	12	1.02	0.09	9.00	3.00	0.00	0.00	12.00	40.74	0.00	0.00	3.70	44.44		
		1987	1991	30	4.54	0.15												

		1997	1999	18	2.53	0.14											
		2011	2012	12	1.48	0.12											
		2014	2014	6	0.53	0.09											
SPI-12(J-D)	Gelemso	1984	1985	36	1.02	0.06	6.00	4.00	1.00	0.00	11.00	22.22	14.81	3.70	5.56	47.22	
		1987	1987	12	0.94	0.08											
		1990	1991	24	3.03	0.13											
		1997	1997	12	0.33	0.03											
		1999	1999	12	1.16	0.1											
		2011	2013	36	2.51	0.07											
Drought parameter							No. drought years					Drought Frequency					
SPI	Station	start	End	Durationmonths	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought	
SPI 2(J-JY)	Asebe teferi	1981	1981	2	0.38	0.19	10.00	2.00	3.00	1.00	16.00	27.78	8.86	8.33	2.78	4.44	
		1986	1986	2	0.07	0.01											
		1989	1989	2	0.07	0.04											
		1991	1994	6	4.43	0.55											
		1996	1997	4	2.08	0.52											
		1999	2000	4	0.55	0.14											
		2005	2006	4	4.41	0.05											
		2011	2012	4	1.74	0.44											
		2014	2014	2	0.02	0.02											
SPI3(Jy-Augs)	Asebe teferi	1981	1984	12	0.93	0.05	12.00	2.00	3.00	1.00	18.00	33.33	5.56	8.33	2.18	50.00	
		1986	1986	3	0.48	0.16											
		1989	1990	6	1.65	0.28											
		1992	1994	9	2.4	0.27											
		1996	1997	6	1.11	0.19											
		1999	1999	3	0.02	0.01											
		2005	2008	12	4.36	0.36											
		2011	2012	6	3.36	0.56											
SPI-3(F-A)	Asebe teferi	1979	1979	3	0.95	0.32	16.00	1.00	1.00	2.00	20.00	44.44	2.78	2.18	5.56	58.56	
		1981	1983	9	2.87	0.32											

		1985	1989	12	2.77	0.23										
		1990	1990	3	0.3	0.1										
		1994	1994	3	0.18	0.05										
		1998	1998	3	2.01	0.67										
		2003	2004	18	4.03	0.22										
		2011	2011	3	0.17	0.06										
		2013	2014	6	0.54	0.09										
SPI-6(Mr-Aug)	Asebe teferi	1979	1979	6	0.29	0.05	13.00	1.00	2.00	2.00	18.00	35.11	2.78	8.16	5.56	80.00
		1981	1981	6	0.33	0.09										
		1983	1983	6	0.35	0.06										
		1986	1987	12	1.1	0.09										
		1989	1990	12	1.22	0.1										
		1993	1994	12	0.93	0.08										
		1996	1996	6	0.07	0.01										
		1998	1998	6	1.28	0.21										
		2006	2008	24	6.89	0.28										
		2010	2011	12	2.2	0.18										
		2014	2014	6	0.24	0.04										
SPI-12(J-D)	Asebe teferi	1979	1979	12	0.43	0.04	9.00	3.00	1.00	2.00	15.00	25.00	8.53	2.78	8.66	41.67
		1981	1983	36	2	0.06										
		1985	1986	24	0.53	0.02										
		1990	1980	12	0.68	0.06										
		1984	1994	12	1.12	0.09										
		1996	1996	12	0.5	0.04										
		1998	1998	12	0.46	0.04										
		2005	2006	24	4.08	0.17										
		2008	2008	12	1.19	0.1										
		2011	2012	24	2.13	0.09										
Drought parameter							No. drought years					Drought Frequency				
SPI	Station	start	End	Durationmonths	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JY)	kulumsa	1980	1980	2	0.26	0.13	5.00	0.00	0.00	0.00	5.00	13.89	0.00	0.00	0.00	13.89
		1982	1982	2	0.02	0.01										
		1997	1997	2	0.47	0.24										
		2003	2003	2	0.01	0.01										

		2002	2002	2	0.83	0.42										
SPI3(JL-Augs)	kulumsa	1980	1982	9	4.41	0.49	5.00	7.00	1.00	1.00	15.00	16.67	19.44	2.78	2.78	41.67
		1995	1996	6	0.41	0.07										
		1990	1990	3	1.41	0.47										
		1994	1994	3	0.08	0.03										
		1996	1997	6	2.49	0.42										
		2005	2007	12	1.93	0.16										
		2009	2009	3	1.09	0.36										
		2012	2013	6	3.20	0.53										
SPI-3(F-A)	kulumsa	1979	1979	3	0.71	0.24	10.00	4.00	1.00	1.00	16.00	27.78	11.11	2.78	2.78	44.44
		1983	1983	3	0.89	0.30										
		1985	1985	3	1.04	0.35										
		1988	1988	3	1.84	0.61										
		1990	1990	3	0.92	0.31										
		1992	1992	3	0.16	0.05										
		1994	1995	6	1.95	0.33										
		1998	1998	3	0.48	0.16										
		2002	2002	6	2.06	0.34										
		2004	2004	3	1.25	0.42										
		2008	2010	9	1.63	0.18										
		2012	2012	3	0.86	0.29										
		2014	2014	3	1.41	0.47										
SPI-6(Mr-Augs)	kulumsa	1979	1983	60	0.21	0.00	11.00	8.00	1.00	0.00	20.00	30.56	22.22	2.18	0.00	55.58
		1985	1985	6	1.29	0.22										
		1988	1988	6	0.18	0.03										
		1990	1990	6	1.20	0.20										
		1992	1992	6	0.74	0.12										
		1994	1996	18	0.62	0.03										
		1998	1998	6	1.30	0.22										
		2002	2002	6	0.29	0.05										
		2004	2004	6	2.22	0.37										
		2008	2009	12	0.72	0.06										
		2012	2014	18	3.17	0.18										
SPI-12(J-D)	kulumsa	1981	1983	36	2.30	0.06	9.00	4.00	2.00	1.00	16.00	25.00	11.11	3.56	2.78	44.44

Drought parameter							No. drought years					Drought Frequency				
SPI	Station	start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-IY)	Gobesa	1989	1989	2	0.33	0.17	9.00	0.00	0.00	0.00	9.00	25.00	0.00	0.00	0.00	25.00
		1991	1991	2	0.03	0.02										
		1997	1998	4	1.25	0.31										
		2000	2000	2	0.31	0.16										
		2003	2003	2	0.82	0.41										
		2005	2005	2	0.06	0.03										
		2008	2008	2	0.58	0.29										
		2014	2014	2	0.28	0.13										
SPI3(JL-Augs)	Gobesa	1979	1979	3	0.43	0.14	15.00	2.00	2.00	0.00	19.00	41.67	5.56	5.56	0.00	52.78
		1982	1982	3	0.58	0.19										
		1986	1990	12	3.09	0.28										
		1993	1998	18	4.47	0.25										
		2000	2000	3	0.38	0.13										
		2007	2007	3	0.61	0.2										
		2010	2012	9	1.84	0.2										
		2014	2014	3	1.7	0.57										
SPI-3(F-A)	Gobesa	1982	1983	6	1.99	0.33	11.00	1.00	5.00	0.00	17.00	30.56	7.78	13.86	0.00	47.22
		1985	1988	12	2.95	0.25										
		1990	1990	3	1.58	0.53										
		1992	1992	3	0.08	0.03										

		1994	1994	3	1.56	0.52										
		1998	1998	3	1.12	0.37										
		2002	2002	3	0.46	0.15										
		2009	2014	18	4.15	0.23										
SPI-6(Mr-Augs)	Gobesa	1982	1983	12	0.60	0.05	14.00	3.00	1.00	1.00	19.00	38.89	8.33	2.78	2.78	52.78
		1985	1990	36	4.3	0.12										
		1992	1992	6	0.21	0.04										
		1994	1994	6	1.64	0.27										
		1997	2000	24	2.42	0.1										
		2009	2012	24	1.77	0.07										
		2014	2014	6	2.31	0.39										
SPI-12(J-D)	Gobesa	1982	1986	60	2.68	0.04	15.00	3.00	1.00	0.00	19.00	41.67	6.33	2.78	0.00	52.78
		1988	1991	48	3.03	0.06										
		1994	1998	60	4.17	0.07										
		2000	2001	24	0.17	0.01										
		2010	2010	12	0.14	0.01										
		2012	2012	12	0.53	0.04										
		2014	2014	12	2.45	0.2										
Drought parameter							No. drought years					Drought Frequency				
SPI		start	End	Duration months	Severity	Magnitude	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JIY)	Bedeno	1982	1982	2	4.26	2.19	3.00	2.00	1.00	3.00	9.00	8.33	5.56	2.78	8.33	28.60
		1988	1988	2	7.03	3.52										
		1991	1991	2	2.15	4.08										
		1994	1994	2	0.01	0.01										
		1997	1997	2	0.81	0.41										

		2001	2001	2	1.78	0.81										
		2003	2003	2	1.01	0.51										
		2011	2011	2	0.2	0.14										
		2014	2014	2	1.07	0.54										
SPI3(JL-Augs)	Bedeno	1979	1999	3	0.12	0.04	15.00	0.00	1.00	2.00	15.00	42.67	0.00	2.76	5.56	41.57
		1982	1982	3	0.48	1.16										
		1985	1985	3	0.07	0.02										
		1988	1988	3	2.43	0.81										
		1984	1985	6	0.50	0.08										
		1987	1987	3	0.11	0.04										
		2001	2003	9	2.2	0.24										
		2006	2008	9	0.04	0.1										
		2010	2014	12	1.1	0.15										
SPI-3(F-A)	Bedeno	1978	1978	3	0.63	0.28	14.00	2.00	1.00	1.00	15.00	38.65	5.66	2.78	2.78	50.00
		1982	1983	6	3.71	0.62										
		1985	1986	3	0.22	0.07										
		1988	1988	3	1.7	0.37										
		1990	1990	3	0.25	0.08										
		1998	1998	3	1.42	0.47										
		2002	2006	15	2.02	0.13										
		2008	2008	3	0.44	0.15										
		2010	2014	18	2.51	0.17										
SPI-6(Mr-Augs)	Bedeno	1980	1980	6	0.22	0.04	18.00	0.00	0.00	2.00	20.00	50.00	0.00	0.00	6.56	89.38
		1982	1983	12	3.72	0.31										
		1985	1985	6	0.15	0.03										

		1988	1998	6	2.64	0.44										
		1990	1990	6	0.17	0.03										
		1997	1998	12	0.5	0.04										
		2001	2003	30	1.28	0.04										
		2008	2008	6	0.53	0.09										
		2010	2014	30	2.37	0.08										
SPI-12(J-D)	Bedeno	1980	1980	12	0.08	0.01	19.00	0.00	0.00	2.00	21.00	32.78	0.00	0.00	5.56	50.33
		1982	1983	24	3.86	0.16										
		1985	1686	12	0.28	0.02										
		1988	1988	12	2.35	0.2										
		1980	1980	12	0.26	0.02										
		1984	1984	12	0.01	0										
		1997	1998	24	0.38	0.02										
		2001	2006	72	1.67	0.02										
		2008	2008	12	0.18	0.02										

SPI	Station	start	End	Drought parameter	No. drought years	Drought Frequency	MD	MoD	SD	ED	Total	%MD	%MoD	%SD	%ED	%All Drought
SPI 2(J-JIY)	Bisidimo	1991	1992	4	1.49	0.37	10.00	4.00	3.00	0.00	17.00	40.00	16.00	12.00	0.00	68.00
		1994	1997	8	3.66	0.46										
		2000	2003	8	3.64	0.45										
		2005	2005	2	0.11	0.06										
		2008	2013	12	5.46	0.46										
SPI3(JL-Augs)	Bisidimo	1995	1996	6	2.04	0.34	10.00	1.00	1.00	1.00	13.00	40.00	4.00	4.00	4.00	52.00
		1999	2001	9	2.56	0.28										

		2007	2014	24	4.49	0.19										
SPI-3(F-A)	Bisidimo	1990	1990	3	0.72	0.24	10.00	1.00	1.00	1.00	13.00	40.00	4.00	4.00	4.00	52.00
		1994	1995	6	1.88	0.31										
		1998	1998	3	0.84	0.28										
		2000	2000	3	0.62	0.21										
		2002	2002	3	0.62	0.21										
		2007	2012	15	4.52	0.3										
		2014	2014	3	1.3	0.43										
SPI-6(Mr-Augs)	Bisidimo	1990	1990	6	0.01	0.00	13.00	0.00	0.00	1.00	14.00	52.00	0.00	0.00	4.00	56.00
		1994	1995	12	1.44	0.12										
		1998	1998	6	0.52	0.09										
		2000	2002	18	1.62	0.09										
		2008	2014	42	8.39	0.13										
SPI-12(J-D)	Bisidimo	1990	1990	12	0.63	0.05	12.00	2.00	1.00	0.00	15.00	48.00	8.00	4.00	0.00	60.00
		1994	1996	36	1.91	0.05										
		1998	1998	12	0.21	0.02										
		2000	2001	24	1.4	0.06										
		2005	2005	12	0.17	0.01										
		2007	2008	24	1.54	0.06										
		2010	2014	60	3.96	0.07										

## **APPENDIX C**

SUMMARY OF DROUGHT FREQUENCY AND INTENSITY

**Table C 1 Summary Drought Frequency and Intensity SPI-3 (kiremt)**

	station	Number of year drought intensity				%MoD	%SD	%ED	%all drought
		moderate	severe	extreme	total				
1	FEDIS(36 YEARS)	2	2	6	10	5.6	5.6	16.7	27.8
2	GURSUM(35 YEARS)	5	0	0	5	14.3	0	0	14.3
3	CHELENKO (34 YEARS)	3	2	1	6	8.8	5.9	2.9	17.6
4	BEDENO(36 YEARS)	0	1	2	3	0	2.8	5.6	8.3
5	ALEMAYA(36 YEARS)	2	1	1	4	5.6	2.8	2.8	11.1
6	KERSA(25 YEARS)	2	0	1	3	8	0	4	12
7	BISIDIMO(25 YEARS)	1	1	1	3	4	4	4	12
8	KOBO(36 YEARS)	1	1	2	4	2.8	2.8	5.6	11.1
9	MEISO(36 YEARS)	2	0	3	5	5.6	0	8.3	13.9
10	BEDESSA(34 YEARS)	1	0	0	1	2.9	0	0	2.9
11	GELEMSO(27 YEARS)	2	1	0	3	7.4	3.7	0	11.1
12	HIRNA(36 YEARS)	2	0	0	2	5.6	0	0	5.6
13	ASEBE TEFERI(36 YEARS)	2	3	1	6	5.6	8.3	2.8	16.7
14	KORA(26 YEARS)	1	0	1	2	3.8	0	3.8	7.7
15	GOBESSA(36 YEARS)	2	2	0	4	5.6	5.6	0	11.1
16	DIKSIS SUDE(27 YEARS)	2	3	0	5	7.4	11.1	0	18.5
17	KULUMSA(36 YEARS)	7	1	1	9	19.4	2.8	2.8	25
18	TICHO(26 YEARS)	0	0	1	1	0	0	3.7	3.8
19	ADELLE(25 YEARS)	7	1	1	9	28	4	4	36
20	ROBE (36 YEARS)	3	1	1	5	8.3	2.8	2.8	13.9
21	ABOMSA (25 YEARS)	1	0	2	3	4	0	8	12
22	INDETO(36 YEARS)	4	2	0	6	11.1	5.6	0	16.7

SUMMARY OF DROUGHT FREQUENCY AND INTENSITY

**Table C 2 Summary Drought Frequency and Intensity SPI-3 (Belg)**

	Station	Number of year drought itensity				%MoD	%SD	%ED	%all drought
		moderete	sever	extreme	total				
1	FEDIS(36 YEARS)	3	2	2	7	8.3	5.6	5.6	19.4
2	GURSUM(35 YEARS)	4	3	0	7	11.4	8.6	0	20
3	CHELENKO (34 YEARS)	1	0	2	3	2.9	0	5.9	8.8
4	BEDENO(36 YEARS)	2	1	0	4	8.3	2.8	2.8	11.1
5	ALEMAYA (36 YEARS)	1	1	0	2	5.6	2.8	0	5.6
6	KERSA (25 YEARS)	3	2	1	5	4	8	0	20
7	BISIDIMO(25 YEARS)	1	1	2	3	2.8	4	4	12
8	KOBO(36 YEARS)	1	1	0	3	2.8	2.8	2.8	8.3
9	MEISO(36 YEARS)	1	0	2	3	0	0	5.6	8.3
10	BEDESSA(34 YEARS)	0	0	0	0	0	0	0	0
11	GELEMSO(27 YEARS)	0	0	1	1	16.7	0	3.7	3.7
12	HIRNA(36 YEARS)	6	1	0	7	2.8	2.8	0	19.4
13	ASEBE TEFERI (36 YEARS)	1	1	2	4	15.4	2.8	5.6	11.1
14	KORA(26 YEARS)	4	0	0	4	12.9	0	0	15.4
15	GOBESSA(36 YEARS)	1	5	0	6	2.8	13.9	0	16.7
16	DIKISS SUDE (27 YEARS)	0	3	1	4	0	11.1	3.7	14.8
17	KULUMSA(36 YEARS)	4	1	1	6	11.1	2.8	2.8	16.7
18	TICHO(26 YEARS)	2	0	1	3	7.7	0	3.7	11.5
19	ADELLE(25 YEARS)	3	0	1	4	12	0	4	16
20	ROBE(36 YEARS)	3	1	1	5	8.3	2.8	2.8	13.9
21	Abomsa (25 YEARS)	1	3	0	4	4	12	0	16
22	INDETO(36 YEARS)	5	2	0	7	13.9	5.6	0	19.4

SUMMARY OF DROUGHT FREQUENCY AND INTENSITY

**Table C 3 Summary Drought Frequency and Intensity SPI-12 (Annual)**

	Station	Number of year drought intensity				%MoD	%SD	%ED)	%all drought
		moderate	sever	extreme	total				
1	FEDIS(36 YEARS)	0	1	3	4	0	2.8	8.3	11.1
2	GURSUM(35 YEARS)	1	3	0	4	2.9	8.6	0	11.4
3	CHELENKO (34 YEARS)	2	2	0	4	5.9	5.9	0	11.8
4	BEDENO(36 YEARS)	0	0	2	2	0	0	5.6	5.6
5	ALEMAYA (36 YEARS)	1	0	0	1	2.8	0	0	2.8
6	KERSA (25 YEARS)	0	3	0	3	0	12	0	12
7	BISIDIMO(25 YEARS)	2	1	3	3	8	4	0	12
8	KOBO(36 YEARS)	2	2	2	6	5.6	5.6	5.6	16.7
9	MEISO(36 YEARS)	2	1	2	5	5.6	2.8	5.6	13.9
10	BEDESSA(34 YEARS)	0	0	0	0	0	0	0	0
11	GELEMSO(27 YEARS)	4	1	0	5	14.8	3.7	0	18.5
12	HIRNA(36 YEARS)	2	0	0	2	5.6	0	0	5.6
13	ASEBE TEFERI (36 YEARS)	3	1	2	6	8.3	2.8	5.6	16.7
14	KORA(26 YEARS)	0	0	1	1	0	0	3.8	3.8
15	GOBESSA(36 YEARS)	3	1	0	4	8.3	2.6	0	11.1
16	DIKSIS SUDE (27 YEARS)	3	1	1	5	11.1	3.7	3.7	18.5
17	KULUMSA(36 YEARS)	4	2	1	7	11.1	5.6	2.8	19.5
18	TICHO(26 YEARS)	0	0	1	1	0	0	3.7	3.7
19	ADELLE(25 YEARS)	1	0	2	3	4	0	8	12
20	ROBE(36 YEARS)	3	1	1	5	8.3	2.8	2.8	13.9
21	Abomsa (25 YEARS)	2	1	1	4	8	4	4	16
22	INDETO(36 YEARS)	5	0	2	7	13.9	0	5.6	19.4

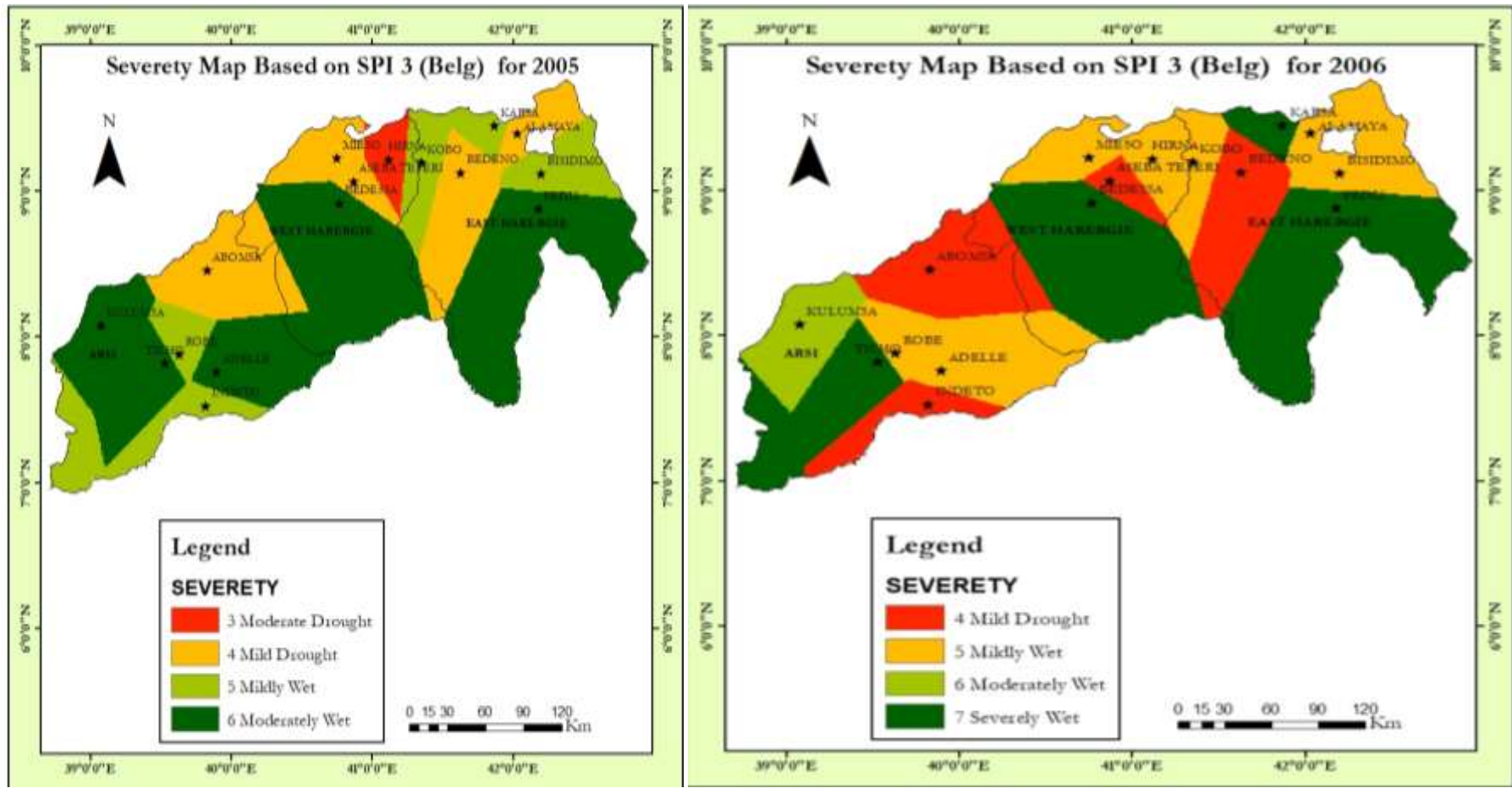


Figure C

Figure C 1. Severity maps based on SPI -3(Belg for 2005-2006)

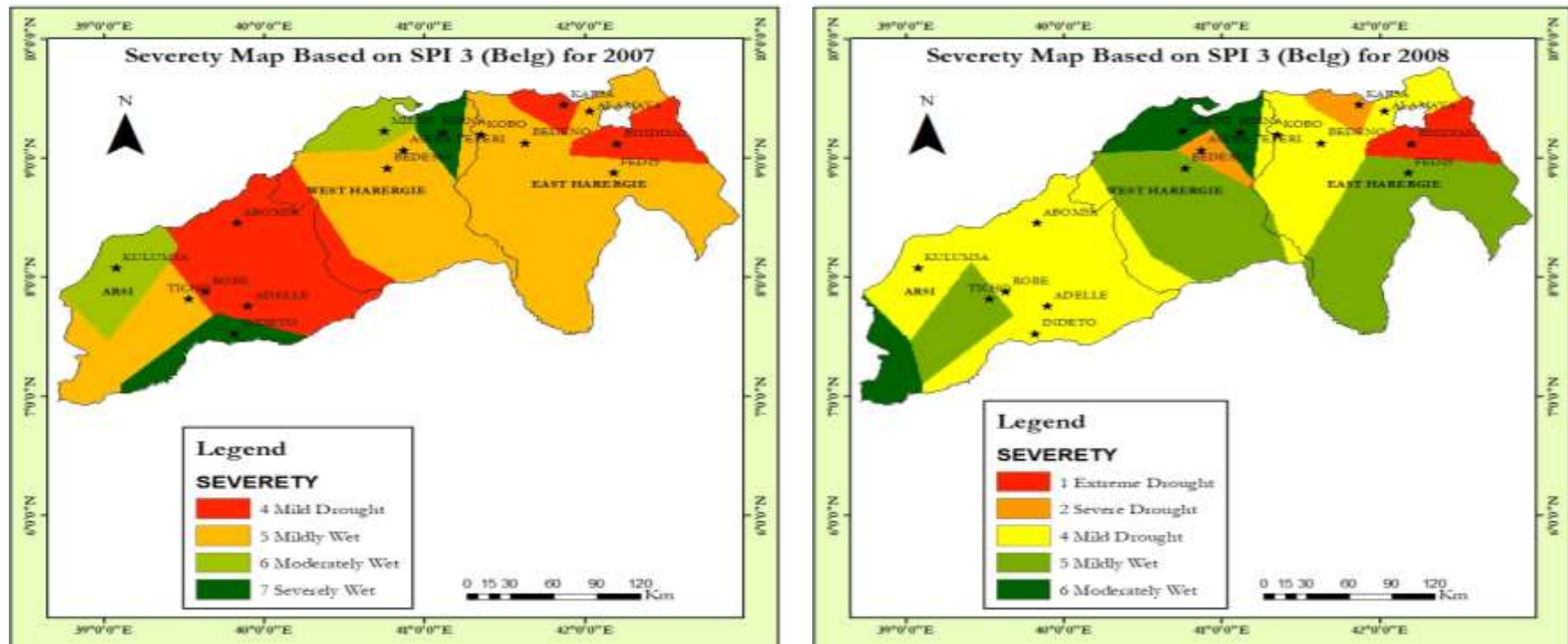


Figure C 2 Severity maps based on SPI -3(Belgs for 2007-2008)

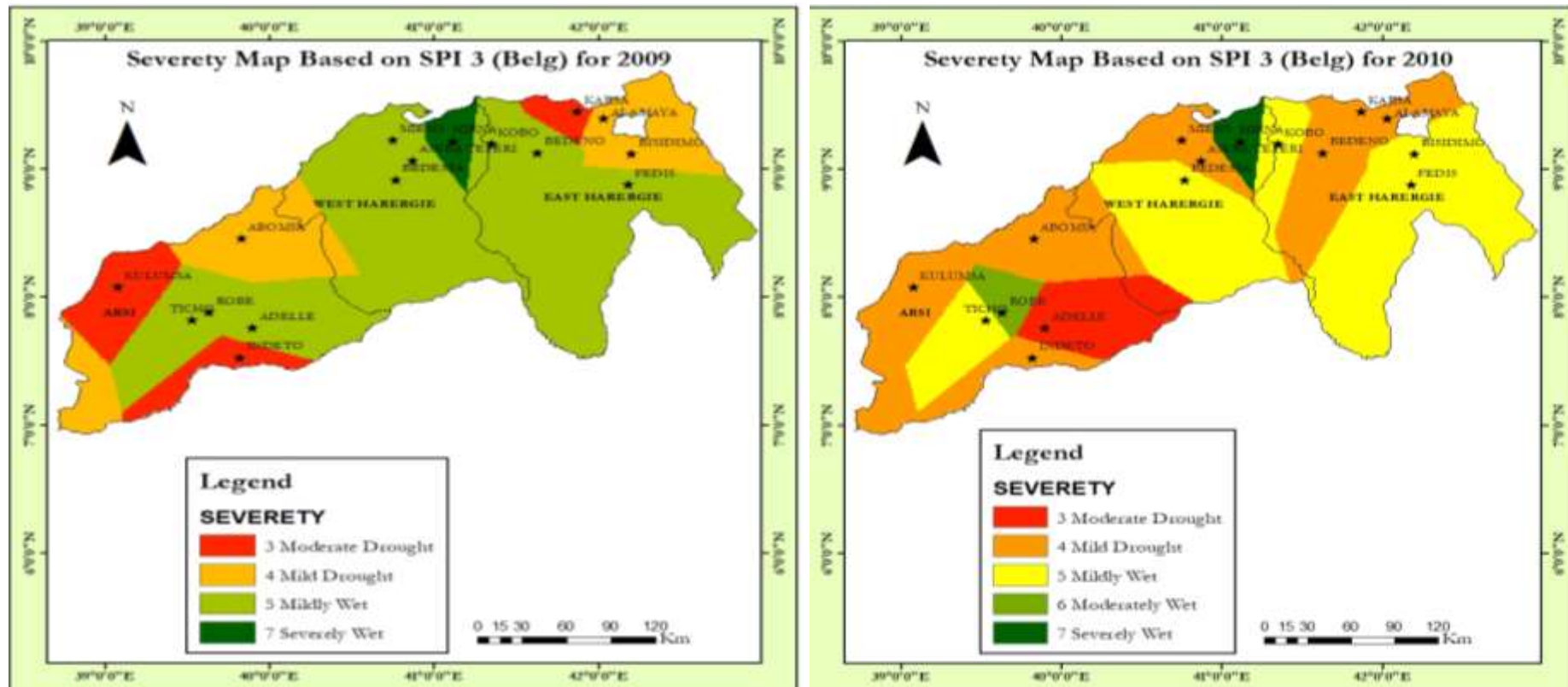


Figure C 3. Severity maps based on SPI -3(Belg for 2009-2010)

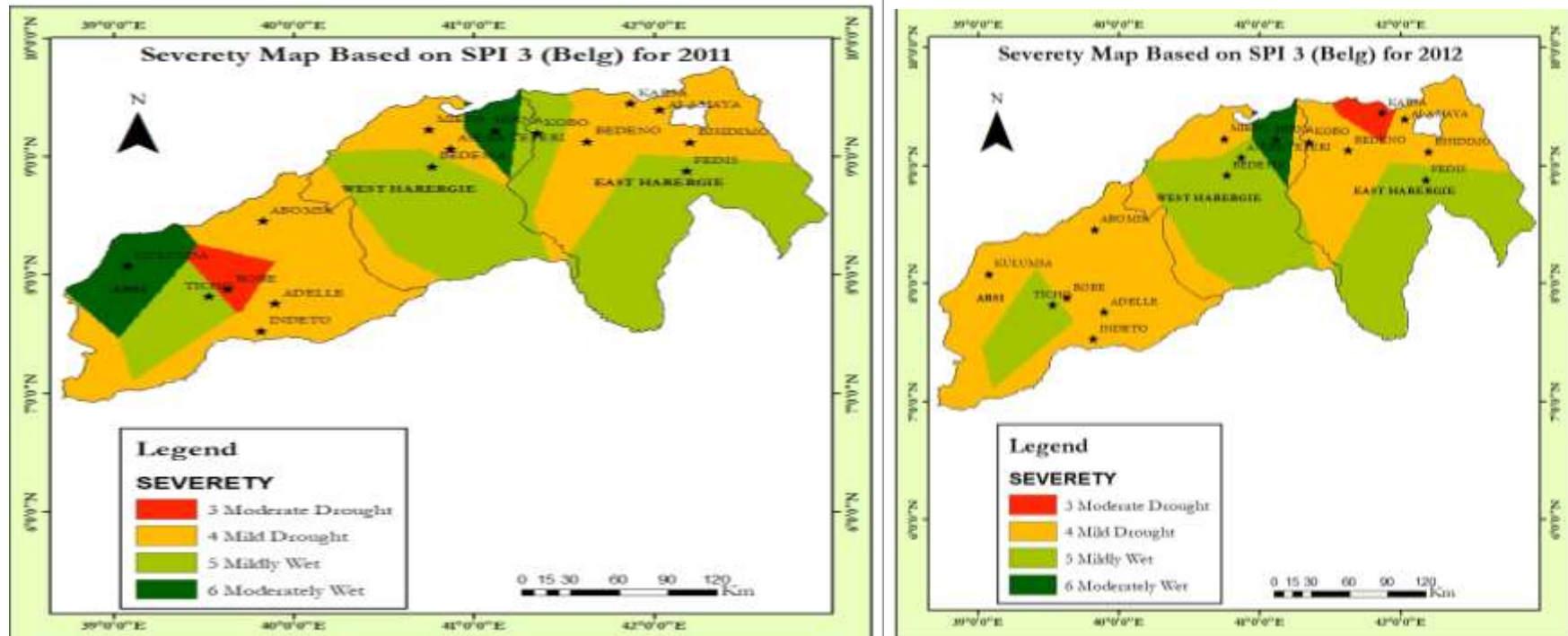


Figure C 4 Severity maps based on SPI -3(Belg for 2011-2012)

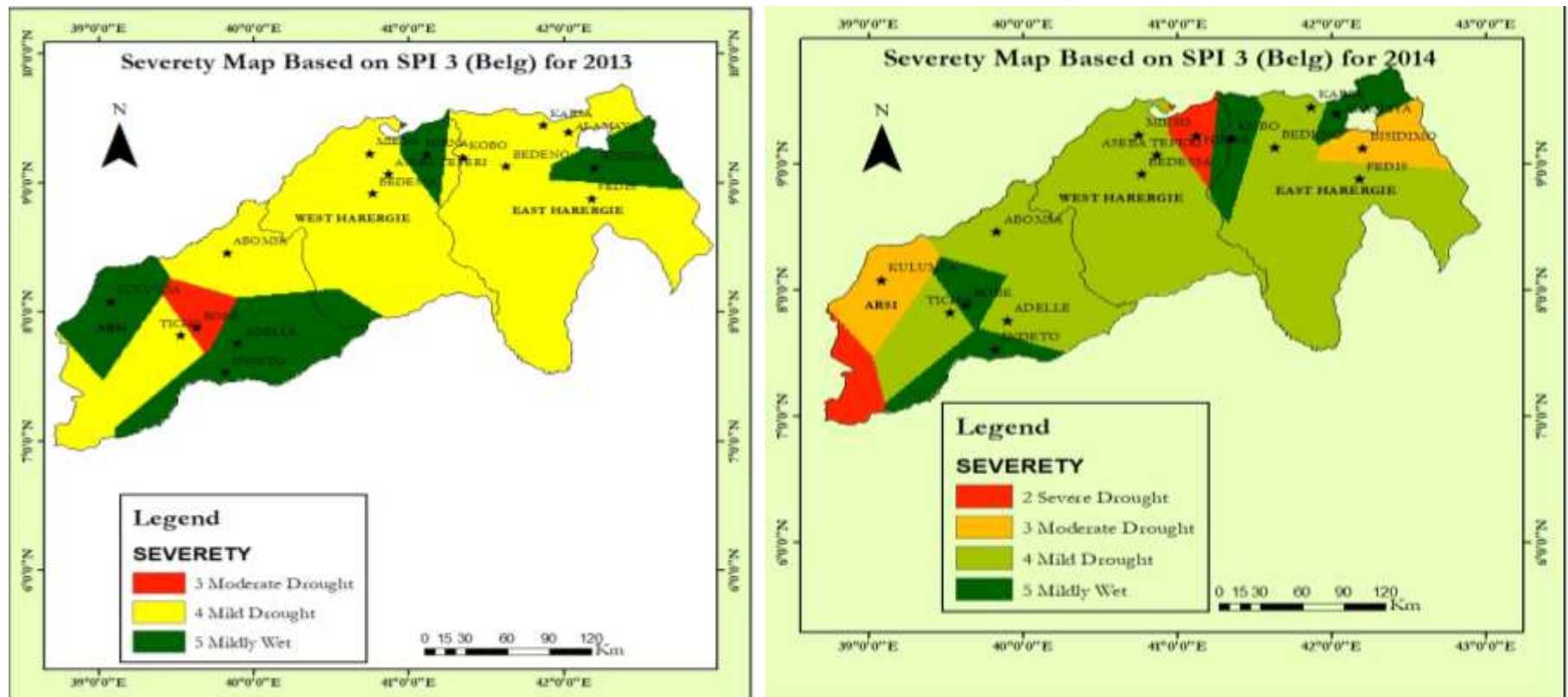


Figure C 5 Severity maps based on SPI -3(Belg for 2013-2014)

