IMPACT OF METEOROLOGICAL DROUGHT ON MAIZE AND SORGHUM PRODUCTION IN FEDIS, DEDER AND SHINILE WOREDAS, ETHIOPIA

BY: TIGABU MUCHE

A THESIS SUBMITTED TO

THE PROGRAM OF APPLIED PHYSICS

SCHOOL OF APPLIED NATURAL SCIENCE

OFFICE OF GRADUATE STUDIES

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

ADAMA, ETHIOPIA

NOVEMBER, 2018

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SCHOOL OF APPLIED NATURAL SCIENCE, ASTU

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ADAMA, ETHIOPIA

NOVEMBER, 2018

APPROVAL SHEET

Adama Science and Technology University

Post Graduate Studies Program

We hereby certify that we have read and evaluated this thesis entitled as "**IMPACT OF METEOROLOGICAL DROUGHT ON MAIZE AND SORGHUM PRODUCTION IN THREE WOREDAS OF EASTERN HARERGHE AND SHINILE ZONES, ETHIOPIA."** This thesis prepared by Tigabu Muche under our guidance. We recommend that it be submitted as fulfilling the thesis requirement.

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As member of the Board of Examiners of the Final MSc Thesis Open Defense Examination**,**
we certify that we have read and evaluated the Thesis prepared by Tigabu Muche
and examined the candidate. We recommend that the thesis be accepted as fulfilling the Thesis requirements for the Degree of Master in Applied physics (Meteorology)

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External Examiner	Signature	Date

Declaration and Statement of the Candidate

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with my approval as university supervisor.

Signature -------------------------- Date --------------------

Place: Adama Science and Technology University, Adama

Date of Submission: November, 2018

ACKNOWLEDGMENTS

I would like to express my heartfelt thanks and appreciation to my family for their interests in my research work, and for their usual advices, guidance and encouragement to accomplish my thesis work successfully.

I have no word to express my deep and heartfelt gratitude to my father, Muche Gebrye and my mother, Ayalnesh Shibabaw who have been helping me from early school age to this day that brings me near to success. I would like to convey special thanks to my wife, Almaz Mitiku and my brother, Moges Muche for their persistent encouragement and support throughout my study.

My sincere thanks go to my major advisor, Mekonen Ayana (Ph.D, Assoc, Prof) and my co advisor, Lisanework Nigatu (Ph.D, Assoc,Prof), Mesfin Asfaw (Ph.D.) and Abebe Belay (Ph.D.) for their valuable comments, guidance and constant encouragement during all phases of this work.

I am also thankful to Eastern Harerghe and Shinile Zones Agricultural and rural development offices, Central Statistical Agency (CSA) and National Meteorological Services Agency (NMSA) for their cooperation in providing me all kinds of information.

Last, I also thank all individuals who have contributed something for the completion of my study.

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List of Acronyms/abbrevation

AVHRR	Advanced Very High Resolution Radiometer
CMIP5	Coupled Model Inter-comparison Project Phase5
CPI	Crop Performance Index
CROPWAT	Crop Water Requerment
CSIRO-Mk	Common Wealth Scientific and Industrial Research Organization
DEM	Digital Elevetion Model
FEDBEHZ	Finance and Economic Development Bureau of Eastern Harargea Zone
FAO	Food Agricultural Organization
FEWS NET	Famine Early Warning System Network
GC	Gregorian Calander
GCM	General Circulation Model
GIS	Geograhpic Information System
ITCZ	Intertropical Convergence Zone
JMBO	Jijiga Meteorology Branch Office
LEAP	Livestock Early Assessment And Protection
Masl	Meter above sea level
MD	Meteorological Drought
NDVI	Natural Difference Vegetation Index
$NDVI_{mean}$	Mean of Natural Difference Vegetetion Index
$NDVI_{max}$	Maximum of Natural Difference Vegetetion Index
NIRB	Near Infrared Band
NMA	National Meteorology Agency
PNP	Percent of Normal Precipitation
PET	Potential Evapotranspiration
P_{mean}	Mean of Precipitation
RB	Red Band
RF	Rain Fall
SPI	Standardized Precipitation Index
STATS	Statistics soft ware
Temp	Temperature
WFP	World Food program
WRSI	Water Requirement Satisfaction Index

Abstract

In order to adapt and/or mitigate the impact of MD, MD assessment has to form one dimension of research to be done; whereas, the use of MD indices and different soft wares provides wide scope in drought risk detection and mapping. Consequently, this study was conducted in Eastern Harerghe and Shinile Zones with the objective of assessing MD risk and preparing MD risk zone map using Rainfall (RF) and Yield data. To assess and examine spatiotemporal variation of seasonal MD patterns and severity, four drought indices namely, Percent of Normal (PON), Water requirement satisfaction index (WRSI), Standard Precipitation Index (SPI) and Natural Difference Vegetation Index (NDVI) anomaly are applied. To characterize temporal MD, onset, cessation, Length of Growth Period (LGP) of Seasons, its impact on maize and sorghum yields with rainfall, the yield data were utilized. A late onset or early termination and duration of sowing can initiate or exacerbate drought conditions. The result derived from indices for the study period cropping seasons experienced enhanced MD with observed spatial difference in severity level over the study areas. The impact of MD on crop production was measured through yield reduction. Generally, the index results are with results of yield reduction depicting that yield reduction is largely attributed to MD. The result revealed that WRSI, SPI and NDVI anomaly express decreased and the grain yield decreased with the time over the study areas. Thus, WRSI can be a good indicator for occurrence of MD. The result indicated that the areas are classified into slight, moderate and severe MD risk zone. Thus, the MD risk mapping can be useful to guide decision making process in drought monitoring and to reduce the risk of drought on agricultural production.

Key words: Meteorological drought, Meteorological drought indices, Rainfall and Geographical information system

1. INTRODUCTION

1.1 *Background*

Climate has always been dynamic, and affects natural systems through the consequences of climate variability and climate change (Bekele, 1997). Because of climate change and variability, drought has become a recurrent phenomenon in several countries across the globe. It is manifested in erratic and uncertain rainfall distribution in rainfall dependent farming areas, especially in arid and semi-arid ecosystems. Frequent and severe drought has become one of the most important natural disasters in sub-Saharan Africa and often results in serious economic, social, and environmental crises (Tadesse et al., 2008). It is marked by the creation of uncertain agricultural economics (Kandji &Verchot, 2006). Droughts are a type of environmental disaster that occur in every climatic zone, no matter if high or low rainfall area. Droughts are usually divided into four different stages. The first stage is a meteorological drought which is defined as the cumulative lack of precipitation in a region over a prolonged period of time. Second a lack of water in the soil causes an agricultural drought, which usually is accompanied by reduced crop yields or shortage of soil moisture. Third a hydrological drought is characterized by a shortage of water in surface or underground water resources (Azorin-Molina, 2012), it can be visible through dried up rivers and lakes. Finally, a socio-economic drought is apparent when the supply of good water does not meet the demand (Sirak, 2015).

According to Jeyaseelan (2004), analyses of time series NDVI data and NDVI derived products help to identify vegetation condition anomalies as a function of rainfall. Water requirement satisfaction index (WRSI) is also one of crop performance index based on a water balance model that simulates the reduction of crop yield due to water deficit. This model is currently operational as yield monitoring and forecasting tools for region wide food security analyses in drought prone countries in Sub-Saharan Africa (Senay and Verdin, 2002). In addition, standard precipitation index (SPI) is meteorological drought index used to quantify the impact of rainfall deficit on soil moisture on which it responds to precipitation anomalies on a relatively short scale. In general, applications of satellite based vegetation, crop performance and climate derived drought indices become the feasible means and acceptable decision tools for timely action against the negative consequences of meteorological drought. Thus, Assessment of meteorological drought by remote sensing or ground data is believed to be very helpful for providing countermeasures as early as possible. GIS and Remote sensing techniques are being widely used for analysis of drought monitoring and assessment using various drought indices (Alemayehu Kassa, 1999; Jeyaseelan, 2004; Chopra, 2006, Amare Degefaw, 2007; Beyene Ergogo, 2007).

Ethiopia is a sub-Saharan country that has been affected by frequent drought. Millions of lives have been lost because of recurring droughts in the past several decades. Due to climatic changes, drought occurs every two years in different parts of Ethiopia (NMSA, 1996; Kandji &Verchot, 2006 ;). In addition, the drought recurrence cycle shortens over time while the affected area is widening, impacting additional parts of the country that were once unaffected (NMSA, 1996). In order to respond to the effects of drought, Ethiopia has been conducting drought assessment and monitoring missions. The Ethiopian National Meteorological Services Agency (NMSA) classified three seasons per year in Ethiopia: rainy season (June to September), dry season (October to January) and short rainy season (February to May) (NMSA, 1996).

Since agricultural activities in the dry land semi-arid areas in general and study area, Fedis, Deder and Shinile woredas in particular, are influenced and controlled by seasonal rain, the study of meteorological drought analysis is carried out season-wise using vegetation based drought index (NDVI), Percent of Normal (PON) and climate based drought index (SPI) as well as crop performance index (WRSI).These indices as proxies of drought , and crop and/or vegetation health condition are vital in drought assessment and hence, they are applied in this study.

1.2 Problem Statement

Ethiopia's climate is influenced by general atmospheric and oceanic factors that affect the weather system (Bekele, 1997) and climatic factors such as drought has significant impact on agricultural output (Tsegaye, 1998). This makes Ethiopia vulnerable to climate variability. Climate variability over the last three decades resulted in drought and famines in Ethiopia and several other countries in Africa (Comenetez and Caviedes, 2002). Due to greater reliance on climate sensitive sectors such as agriculture, Ethiopia is vulnerable to the risk of climate variability and change such as MD. MD is a period of abnormally dry weather sufficiently for the lack of precipitation to cause a serious hydrological imbalance and carries connotations of a moisture deficiency (Mohan and Arena, 1982 cited in Chopra, 2006). In Eastern Ethiopia, the major impact of MD is manifested through rainfall variability and recurrent drought due to climate change. The risks associated with them are generally late onset and early cessations of rainy season that cause reduction in the maize and sorghum crops growing season in Eastern Harargea Zone and Shinile Zone Fedis, Deder and Shinile woredas respectively. The amount and distribution of rainfall in these crops growing season is also very erratic, indeed making crops vulnerable to moisture deficit. Agriculture is one of the most vulnerable sectors to MD impact. The impact is redundantly stronger in the study areas in particular, where agriculture is truly important for the daily subsistence, and where adaptive capacity is low.

Agriculture is the most vulnerable and sensitive sector that is seriously affected by the impact of MD. MD is currently more pronounced in the study area. Farmers inhabiting in the study area are exposed to the impact of MD that resulted from the current climate change. This is due to the fact that most of farmers' cultivars (long duration crop variety) can no longer resist the existing MD and intra seasonal dry spell (NMA agro-meteorological bulletin, 2015). As a result, most of the cultivars have gone obsolete, and yield reduction and crop failure, death of livestock becomes common (Gizachew, 2010).

Therefore, the aim of this research was to study the impact of Meteorological-Drought on maize and sorghum crops (precipitation and crop yields performance), to assess quantitatively climate anomalies in terms of severity, intensity (magnitude of drought), duration, frequency and spatial extent) in the introduction explained areas. Generally, studying of the impact of Meteorological drought (drought severity, intensity, frequency and duration) on crops can be useful in this regard for the decision making process on drought monitoring and to avert its consequences on agricultural production and productivity for study areas.

1.3 Objectives

1.3.1 General objective

The main objective of the study was to investigate the spatial-temporal occurrence of meteorological drought and its impacts on Maize and sorghum production in the study areas.

1.5.2 Specific objectives

Specific objectives of the study are:

- To assess spatial and temporal characteristics of MD in the study area,
- To analyze the trend of meteorological drought
- To determine the impact of meteorological drought on sorghum and maize yields of the study areas.
- To prepare meteorological drought risk zone map for the study area.

1.4 Research Questions

1. How is the meteorological-drought in the study area characterized (in terms of duration, frequency and severity)?
2. How is the trend of the occurrence of meteorological-drought characterized?
3. What is the extent of meteorological-drought impacts on crop yield?
4. How is the meteorological-drought risk zone map prepared over the study area?

1.5 Significance of the Study

Meteorological drought within these study areas was highly impacted and those were the most important climatic variable affecting crop yields. Moreover, this study generated information about impact of MD on these crops and facilitates exchange of this information among societies, field experts, policy makers and researchers.

The study tried to investigate the impact of Meteorological drought spatial-temporal characteristics and their impact on maize and sorghum yields.

1.6 Scope of the Study

The scope of the study areas were in Eastern Harerghe Zone: Deder and Fedis woredas and Shinile Zone: shinile woreda and more than 30 years past rainfall data and also10 years maize and sorghum yields data was used. But, to carry out this research budget, and unavailability of enough yield data and data quality as the result of MD was also the major limitation encountered during implementation of the research study.

2. LITERATURE REVIEW

2.1 General Definitions, types and indices of Drought

Meteorological-Drought is defined as “the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affects land resource production systems” (UNCCD, 1999). Meteorological-Drought is a disastrous natural phenomenon that has significant impact on agricultural, environment and socio-economic conditions of the community.

According to Segele and Lumb (2005), Ethiopia has been ravaged by severe drought for many of the last 35 years, primarily due to the failure of its main (Kiremt) rainy season.

Meteorological-Drought is also defined as a prolonged abnormally dry period when there is not enough water for users’ normal needs, resulting in extensive damage to crops and a loss of yields (Wilhite, 2005). These definitions are conceptual explanations that provide the basis for the operational meaning. The operational definition of Meteorological-Drought focuses on identifying the beginning, end, spatial extent, and severity of the drought in a given region and is based on scientific reasoning. The analysis is conducted by using hydro-meteorological information and is beneficial in developing drought policies, early warning monitoring systems, and preparedness plans (Smakhtin & Hughes, 2004).

Atmospheric drought, which is defined not only in terms of precipitation deficiencies but also in terms of temperature, humidity, or wind speed.

Water-management drought, which is characterized water supply shortage caused by the failure of water-management practice or facilities (Matthai, 1979).

2.1 Types of drought

Generally, the most prominent types of drought are meteorological, agricultural, and hydrological droughts (Obasi, 1994; Wilhite, 2000 ;).

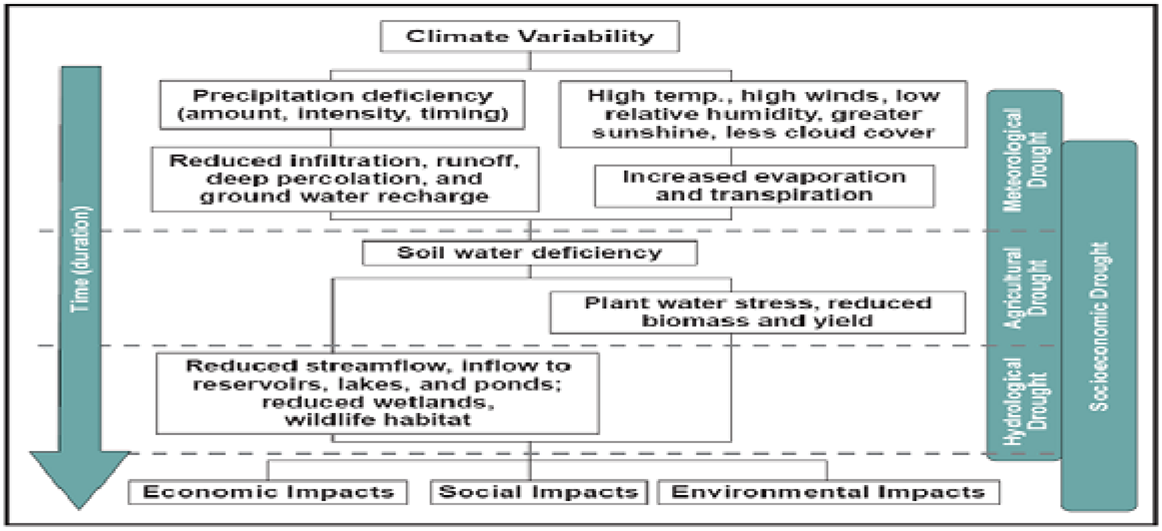

Figure 2. 1 Relationship between different types of drought

(Source: National Drought Mitigation Center, University of Nebraska-Lincoln, USA).

2.1.1 Meteorological drought

Meteorological drought refers to a deficiency of precipitation, as compared to average conditions, over an extended period of time. It basically originates from the deficiency of precipitation and focuses on the physical characteristics of drought (Mokhtari, 2005) rather than impacts associated with shortage of precipitation. Meteorological drought leads to a depletion of soil moisture and has always an impact on crop production. Water deficit is one of the most common environmental stresses that affects growth and development of plants (Aslam et al., 2006). So, meteorological drought is the cause of other types of drought. And we see in detail.

2.1.2 Hydrological drought

Hydrological drought results when precipitation deficiencies begin to reduce the availability of natural and artificial surface and subsurface water resources. It occurs when there is substantial deficit in surface runoff below normal conditions or when there is a depletion of ground water recharge. Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on the surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, and ground water). Hydrological drought is associated with the effects of low rainfall on the water levels of rivers, reservoirs, lakes and aquifers (Wilhite, 2000; Obasi, 1994).

2.1.3 Agricultural drought

Agricultural drought links various characteristics of meteorological and hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, and reduced ground water or reservoir levels (Wilhite, 2000). It is typically occurred after meteorological drought but before hydrological drought (Flood and Climate Basics, 2004). This drought does not depend only on the amount of rainfall but also the correct use of that water. Agricultural drought, or more generally, limited water availability is the main factor limiting crop production.

2.1.4 Socio-economic drought

Socio-economic drought occurs when human activities are affected by reduced precipitation and related water availability. This form of drought associates human activities with elements of meteorological, agricultural, and hydrological drought. A socio-economic drought is apparent when the supply of good water does not meet the demand (Sirak, 2015). This research focuses on meteorological drought analysis and an early warning system.

2.2 Meteorological drought index

Different types of drought require different indices that can be used to quantify the moisture condition of a region and thereby detect the onset and measure the severity of drought events, and to quantify , the intensity, spatial extent of a drought event thereby allowing a comparison of moisture supply condition between regions (Quiring and Papakryiakou, 2003; Beyene, 2007). It has become clear that no single indicator or index is adequate for monitoring drought on regional scale. Meteorological-Drought indices are one of the most important elements of an effective drought monitoring and early warning system (Ji & Peters, 2003). They help to characterize drought and guide appropriate responses to reduce drought impacts. The main advantage of this study was by using indices to find temporal and spatial occurrence of drought (severity, frequency, duration and spatial extent) and its impacts on maize and sorghum production. There are several operational indices in drought assessment and monitoring that are based on rainfall data. These indices are often not easily accessible, nor are they tailored to be conveniently understood by decision makers (Ji & Peters, 2003). The common approach that is used to derive the necessary information of the application of climatic drought indices, such as the Palmer Drought Severity Index (PDSI), which has been widely used by the U.S. Department of Agriculture (Jain et al., 2009), Deciles, Normal Difference vegetation Index (NDVI), Water requirement Satisfaction Index (WRSI) and Percent of Normal Precipitation (PON) are also an indices those are the measurements of different parameters for a location. Another popular climatic drought index is the Standardized Precipitation Index (SPI) that was developed by McKee et al. (1993), which can identify data on emerging drought months for regional and global applications. Mishra and Desai (2005) have adopted the SPI for parts of India and have used that data to compile a drought severity area frequency curve. These drought severity and monitoring indices are based on point and gridded data that are measured at the different meteorological stations located in a wide area.

2.2.1 Standard Precipitation Index (SPI)

Assessment of rainfall is used to identify the pattern and the intensity of drought. SPI, developed by Mckee et al. (1993), is the most widely used index for understanding the magnitude and duration of drought events, risk assessment analysis and making decisions with special ability for adjustments to time periods. According to Thavorntam and Mongkolsawat (2006), SPI is used to examine the severity and spatial patterns of drought in the given region. It is designed to quantify the impacts of precipitation deficit on groundwater, reservoir storage, soil moisture, and stream flow for multiple time scales. Guttman (1998) has made comparison of Palmers Drought Severity Index (PDSI) and SPI, and recommend SPI as drought index, as it is easy to determine and has greater spatial consistence. According to McKee et al. (1993), conditions of soil moisture are reacting to precipitation anomalies in relatively short time period and appearance of drought is happening every time when SPI is negative and its intensity comes to -1.0 or lower, while drought stops when SPI is positive.

2.2.2 Normalized Difference Vegetation Index (NDVI)

In satellite image, vegetation appears very different at different light spectrum particularly in the visible and near infrared wavelengths. Healthy or dense vegetation absorbs most of the visible light that reached on it and reflects a large portion of the near infrared light. Unhealthy or sparse vegetation reflects more visible light and less near infrared light.

NDVI is an index of vegetation health and density and computed from the satellite Image using spectral radiance in red and near infrared reflectance using the formula:

$$NDVI = \frac{\mathrm{NIR} - \mathrm{R}}{NIR + R} \qquad (2.1)$$

Where, NIR= near infrared (730 -1000nm) band, R= Red (550 – 700nm) band NDVI is a powerful indicator to monitor the vegetation cover of wide areas, and to detect the frequent occurrence and persistence of droughts (Thavorntam and Mongkolsawat, 2006).

The advanced very high resolution radiometer (AVHRR) on board NOAA satellite collects the data that are used to produce NDVI. However, there are an increasing number of other applications, e.g., drought monitoring (FEWS net). NDVI is a nonlinear function that varies between -1 and +1 and values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation (FEWS net). NDVI can be used for monitoring rainfall and drought, estimating net primary production of vegetation, crop growth conditions and crop yields, detecting weather impacts and other events important for agriculture, ecology and economics (Ramesh et al., 2003).

2.2.3 Percent of Normal (PON)

The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using percent of normal are very effective when used for a single region or a single season. It is calculated by dividing actual precipitation by normal precipitation typically considered to be a 30-year mean and multiplying by 100%. This can be calculated for a variety of time scales, including monthly, seasonal, annual, or water year. The precipitation for a specific location is considered that the rain fall amount is excess 125% that is above normal, the rainfall is between 75-125% that is normal and the rain fall is less than 75% that is below normal and rain fall is below 50% that is much below normal (Thornthwaite, 1948; Mather, 1978; 1979).

2.3 Impact of Meteorological drought on agricultural sector

Meteorological drought produce a complex web of impacts that span many economic sectors. Among, agriculture is the primary economic sector affected by MD and particularly, short term MD at the critical growth stages has severe impacts on agriculture (Wu and Wilhite, 2004 cited in Mokhtari, 2005). Agriculture is the largest consumer of water and, therefore, the most sensitive to MD. Thus the occurrence of MD during the main rainy season has greater impact on study areas food production. This impact is largely prominent in dry land semiarid areas.

Its impact includes reduced crop yield, rangeland, and loss of biodiversity and forest productivities. The consequence of these impacts result in reduction of income of farmers and agro based industries, increased price for food and other agricultural products such as forest products. Besides, losses in crop production, MD is associated with increases in insect infestation, plant disease and wind erosion (Mokhtari, 2005). The Eastern Harerghe and Shinile

Zones are characterized by diverse topographic features in which high mountainous and deeply incised canyons and gorges, valleys and plateaus with steep slopes dominate its most parts (Coltorti et al., 2007). So, this area impacted by recurrent drought and followed other cases.

2.4 Effect of rainfall variability and trend on crop production

According to Getaneh, (2015), the impacts of rainfall on crop production in Ethiopia are closely related to its variability and occurrence of dry/wet spells during the crop growing periods. The effects of the rainfall variability on crop, however, varies with types and varieties of crops cultivated. A study by Bewket (2009) showed that among cereals grown in the Amhara National Regional State, sorghum exhibited the largest year-to-year variability in terms of area cultivated, total production and yields during the 1994- 2003 period, and this was markedly associated with the high inter-annual variability of rainfall (Bewket, 2009).

Sorghum is a C4 plant and efficient user of soil water and adapted to the unreliable rainfall pattern, as well as to a range of soil types. Moreover, the reasonable performance of the crop under higher temperature ranges (30-35ºC) makes it a suitable crop (Girma, 2005). Sorghum is cultivated mostly at lower altitudes along the country's Western, South-Western, North-Eastern, northern and eastern peripheries. Sorghum is produced in dry lowland, the intermediate and high land altitudes vernacularly named Kola, Woina Dega and Dega respectively with altitude ranging from 500 to 2,300 masl. Sorghum is drought resistant and is grown well at low elevations where rainfall is less reliable. Sorghum doesn't receive much of external inputs except for avian control, which is ecologically regulated pest in the Great Rift Valley System (EIAR, 2011). Sorghum production in Ethiopia is total production 39,498,838.88 (Quintals) per total area coverage 1,923,178.35 (ha) per (CSA, 2012). The national average sorghum productivity in Ethiopia is 2.0 tons/ha (CSA, 2012) which is far below the global average of 3.2 tons/ha (FAO, 2005). This is because of a number of factors. Several production constraints include drought, insect pests… soil fertility decline, inadequate adoption of the existing improved varieties, lack of high yielding and good quality sorghum varieties, and post-harvest management practices.

Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socio-economic conditions typically under rain-fed production. The maize agro-ecologies in Ethiopia can be broadly divided into six major categories (MOA 2005), the Semi-moist and Moist ecologies cover about 75 % of the national maize production area; whereas, the dry ecologies cover the remaining 25 % (MOA 2005).

These crops are widely grown under rain-fed conditions. Therefore, the productions of these crops were affected by rainfall variability. However, the link between the production of these crops and rainfall variability in the study area is not adequately studied. Hence, the main objective of this study was to investigate the spatial and temporal occurrence of Meteorological Drought and its impacts on these crops in the study areas.

Generally, the use of drought indices using station and satellite data has been more prominent over that of the study areas. According to Beyene (2007), drought assessment and monitoring using conventional method which rely on the availability of weather data are tire some and time consuming. In contrast, the satellite sensor data (NOAA-AVHRR) are consistently available, cost effective and can be used to detect the onset of drought, its duration and magnitude. Hence, it is important to define spatial and temporal occurrence of drought (its frequency, duration and its intensity) for the past and find appropriate criterion for future meteorological drought appearance using these data.

2.5 Seasons and Climate Zones

Understanding the nature of the Ethiopian climate is important for any food security policy in Ethiopia. The Ethiopian National Meteorological Services Agency (NMSA) divides Ethiopia into four climatic zones based on the pattern of rainfall (NMSA 1996, 5). These are:

(1) The two-season type: this includes the western half of Ethiopia, which is divided into distinct wet and dry seasons.

(2) Bi-two season type: the south and southeast of Ethiopia is characterized by double wet seasons that occur between March-May and September-November with two dry seasons in between (Workineh, 1987 bibliog., Haile 1986 quoted by NMSA 1996).

(3) The undefined season mostly has sporadic rainfall between July and February without any defined season. It occurs in the dry northern part of the Ethiopian Rift Valley.

(4) The three-season type: these areas include central and southwestern Ethiopia. The average annual rainfall in the highlands of Ethiopia is above 1000 mm a year and it rises to 2000mm and 3000 mm in the wet southwestern parts of Ethiopia (NMSA 1996, Babu 1999a, 63).

The three seasons in Ethiopia are classified according to the amount and timing of rainfall. They are designated as Kiremt, (June-September), Bega (October-January), and Belg (February-May) (NMSA 1989, 5). These seasons determine the seasonal agricultural activities, such as land preparation, planting, weeding and harvesting by farmers.

Kiremt (June-September) - Kiremt is the main rainy season in Ethiopia. These systems include the Inter Tropical Convergence Zone (ITCZ), the Maskarin High Pressure in the Southern Indian Ocean, the Helena High Pressure Zone in the Atlantic, the Congo air Boundary, the Monsoon depression and Monsoon trough, the Monsoon Clusters and the Tropical Easterly Jet (Kassahun 1999). The ITCZ moves north and south in the tropics following the change of seasons. The ITCZ reaches southern Ethiopia at the beginning of the belg season and moves northward bringing rainfall with it. At the end of August, the ITCZ begins to return southward ending the Kiremt precipitation that corresponds with the maturation of crops. Most Ethiopian rainfall, with the exception of the south and southeastern parts of the country, is caused by the ITCZ (Kassahun 1999).

The High Pressures created in the Maskarin and St. Helena areas are important causes for the moisture-carrying winds to go to Ethiopia and drop their precipitation in the highlands. The weakening of these high pressures reduces the amount of rainfall in Ethiopia. The Congo Air Boundary in the Congo rain forest is a meeting place for the moisture-carrying winds from the Indian and Atlantic Oceans. This boundary pulls the low air pressure from the north and east into Ethiopia. It also pulls the winds originating from the low pressure in the South Atlantic and provides them with moisture to be dumped in southwestern Ethiopia (ibid.). Occasionally, the monsoon clusters also provide rainfall to the Eastern part of Ethiopia (ibid.). Finally, the Tropical Easterly Jet, which moves 13 kilometers above sea level over Ethiopia, strengthens the ITCZ, which is the main system that creates rainfall over Ethiopia. The absence of this strong wind could negatively affect the amount and distribution of rainfall (ibid). The Meher crops in the highlands of Ethiopia depend on the Kiremt rainfall.

The intensity and fluctuation of the rain-producing systems during the Kiremt season influence the amount and distribution of rainfall in Ethiopia (Babu 1999a, 65). The lack of definition of ITCZ, which is the main rain producing system, causes deficient RF over Ethiopia (ibid.). Following Jackson, Abate argues that not all RF in Ethiopia is caused by the movement of the ITCZ; other “dry” and “wet” periods in Ethiopia are influenced by the atmospheric disturbances that create rainfall away from the ITCZ (Jackson 1979 cited by Abate 1984, 18-19). Most of the food is planted during this season. Drought during Kiremt may lead to food insecurity and starvation; with the exception of south and southeastern Ethiopia, most parts of the country receive 60 - 90 percent of their rainfall during the Kiremt season (Babu 1999a, 65).

Bega (October-January) - The Bega season occurs between October-January. Bega is the dry, windy and sunny season in most highlands of Ethiopia. The causes of this dry season are the Sahara and Siberian High Pressures that send dry and cold winds to Ethiopia during the northern winter (Kassahun, 1999). During the Bega, most of highland Ethiopia is sunny during the day and cold during the night and morning, which includes frost in December and January. However, there are some areas of lowland Ethiopia, such as the Ogaden that get some rainfall during this period. A low pressure air that moves from Western to Eastern Europe, occasionally, passes over Ethiopia and interacts with warm and humid air from the tropics creating unseasonable rainfall in Ethiopia during the Bega (Kassahun, 1999). Moreover, the tropical disturbances on the Arabian Sea might move to Ethiopia and drop some rainfall during the Bega season, especially in the pastoral areas of the country (ibid.). The pastoral areas of south and southeastern Ethiopia experience a bi-modal rainfall regime and receive their rainfall between October-January and February-May. The precipitation during the Bega season (October –January) is generally the region, Southeastern Ethiopia receive rainfall associated with the Southward retreat of the ITCZ (Babu 1999a, 64). By the end of November, dry Arabian and Saharan anticyclones replace the Southward shifting ITCZ and bring warm-dry weather to Ethiopia (ibid.). At times this new air circulation meets with tropical air masses and brings untimely and unwanted rainfall to Ethiopia. The wind direction also reverses from wet Westerly to dry Easterlies that bring dry and cold wind to Ethiopia (ibid.). Rainfall in Ethiopia decreases from SW to NE.

Belg (February-May) - The belg season is also known as the small rain period and occurs between February-May. The belg rains begin when the Saharan and Siberian High Pressures are weakened and various atmospheric activities occur around the Horn of Africa. Low-pressure air related to the Mediterranean Sea moves and interacts with the tropical moisture and may bring precipitation to the region. The high pressure in the Arabian Desert also pushes that low-pressure air from South Arabian Sea into mid- and Southeast Ethiopia, which in turn, creates the Belg rains. The beginning of the Belg rain is also the period when the ITCZ begins to reach south and southwest Ethiopia in its South-North movement (Kassahun, 1999). The Belg rains fail when these diverse weather phenomena are not realized. For example, the creation of strong low pressure and cyclones in the southern Indian Ocean reduces the amount and distribution of rainfall in Ethiopia (ibid.). Between 5 and 10 percent of crops in Ethiopia are produced during the Belg season. In some areas, the Belg rainfall may produce up-to fifty percent of local food.

The small rains also contribute to increased pasture for domestic and wild animals. Normal Belg rainfall adds moisture to the soil, easing land preparation for the Kiremt planting. During the dry season, the mass of dry air comes from the Northeast (Abate 1984, 13). The Belg season is influenced by the tropical surface air masses in the Indian and Arabian anticyclones and the Central African cyclones south of Ethiopia (Haile 1987). At the beginning of March, the ITCZ arrives in Southwestern Ethiopia to move Northward which brings rainfall (Babu 1999a, 65). Belg rainfall is brought by the penetration of extra-tropical troughs that replace the Arabian anticyclones (Babu 1999a, 65). The Belg rains normally end in the middle of May and dry weather persists (for a month) until the middle of June. Babu (1999a) argues that the Belg rains may sometimes merge with the Kiremt rainy season without the one-month break. He states, "a Merging Belg and Kiremt rain was observed in 1972, 1977, 1982, 1987 and 1993, which were all El Niño years. So the presence or absence of El-Nino could be used as a predictor to anticipate belg or Kiremt rainfall" (Babu 1999a, 65).

Microclimates in Ethiopia- In addition to the ITCZ, local factors also affect rainfall in Ethiopia. Spatial variations caused by altitude create rainfall variations in Ethiopia leading to the existence of various microclimates. Altitude is an important factor in creating various climatic zones in Ethiopia. The four types of climate zones in Ethiopia are the Dega, Weina-Dega, Kola and Bereha. The Dega is cool and usually receives adequate rainfall. The Weina Dega is temperate and supports most Ethiopian crops. The kola is hot and includes the lowland areas. The Bereha is the desert type area in the peripheral parts of the country in which nomadism is the main economic activity (Tsegaye, 2000).

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study areas are located in the Eastern Harerghe and Shinile Zones of Oromia and Somali Regional states respectively. Their Zonal capital, Harar and Jijiga respectively, are found 525-625 kms South-East of Addis Ababa. They are two of the drought-prone and aid-dependent areas in Oromia and Somali Regional States (Bewket and Conway, 2007). The study area covers Fedis, Deder and Shinile. The altitude of the Eastern Hararge and Shinile Zones range between 1024-2144 meters above sea level (masl), with most areas lying above 1000 (masl).

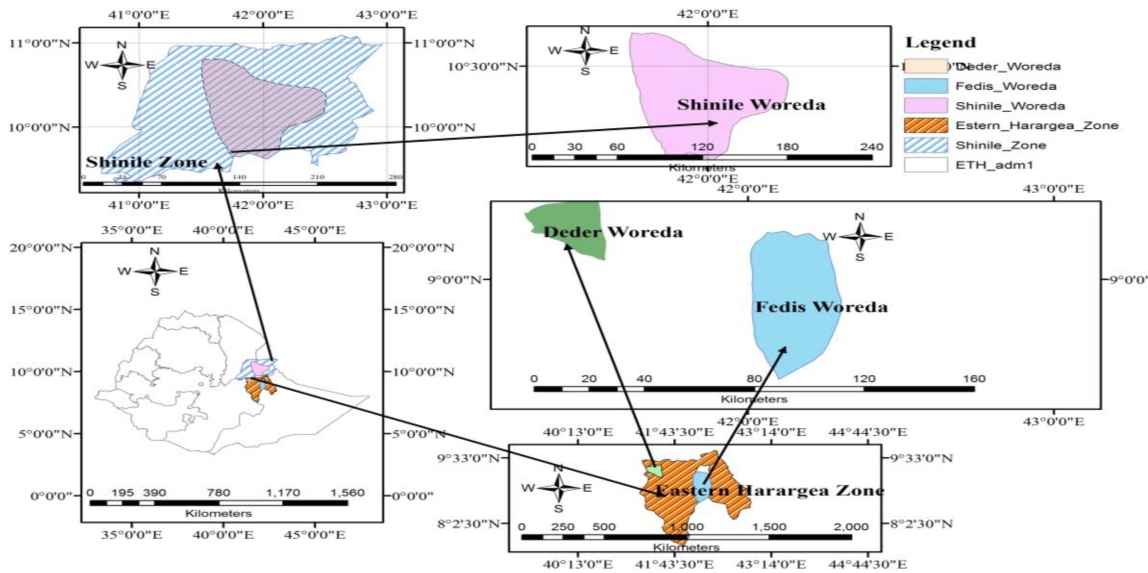

Figure 3. 1 Map of the study areas (by using GIS version 10.3.1 Software)

3.1.2 Topography

Eastern Harerghe and Shinile Zones are characterized by diverse topographic features in which high mountainous and deeply incised canyons and gorges, valleys and plateaus with steep slopes dominate its most parts (Coltorti et al., 2007). Because of the diverse topography, the study area experiences different climatic conditions that range from hot and arid lowlands in the Eastern part to cold and humid highlands in the Western part.

Table 3. 1 Classification of Agro-Ecological zones based on Altitude

Elevation (meter above sea level)	Traditional Zone	Description
>3000	Wurch	Cold Highlands
2500 – 3000	Dega	Cool, Humid Highlands
1500 – 2500	Weina Dega	Temperate, Cool Sub-humid Highlands
300 – 1500	Kolla	Warm, Semi - Arid Lowlands
< 300	Bereha	Hot and Hyper - Arid lowlands

Source: Degefu (1987) and Gissila (2004)

Table 3. 2 Representative Meteorological stations for study areas are:-

Study areas	Latitude(N)	Longitude(E)	Altitude(m)	Area coverage (in Km^2)	Annual RF(in mm)	Annual Mean Temp (in c°)
Shinile	9^0 41' 37.2"	41^0 50' 92.8"	1024	0.50	639.0	25.7
Deder	9^0 19' 79.5"	41^0 26' 71.3"	2144	0.03	1008.1	16.4
Fedis	9^0 07' 94.4"	42^0 04' 49.7"	1699	0.11	526.1	19.5

3.1.3 Climate

The climate of study areas in Eastern Harerghe Zone: Fedis, Deder woreda and Shinile Zone shinile woreda studied by semi-arid and sub-humid climate based on the moisture index classification of climate. The long term average seasonal rainfall that the area receives ranges from 458 to 518 mm and according to NMA study in 1996, the study areas are characterized by bimodal rain fall distribution (those were spring and summer). The warmest temperatures are recorded during February to May, while the coldest was recorded during October to January. High temperatures between 30-35^{o}c are recorded in low altitude areas, however in highland areas the average temperatures are between 20-22^{o}c (Eklundh, 1996 and NMA website map-room, **www.ethiomet.gov.et**).

3.2 Data sources

For this study, the daily historical meteorological gridded (Station + satellite) and station RF data collected from Ethiopian National Meteorological Agency (NMA) for a period of 36 years (1980-2016). The crop yield (Maize and Sorghum yield in Qt/Ha) data for the period of 2006-2015 G.C obtained from the annual agricultural survey data base of the Central Statistics Agency

(CSA) and Eastern Harerghe and Shinile Zones agriculture offices. Three meteorological weather stations shown above in Table 3.2 selected for the study on the basis of spatial representative of the zone.

3.3 Data Collection and Analysis

To achieve the objective of this study the following procedures were followed:-

The ArcGIS version10.3.1 software were used to characterize spatial Meteorological Drought by imputing (analyzing) rainfall data processed by MS Excel including NDVI, WRSI, yield data and yield reduction data, woredas' coordination (latitude and longitude) and woredas' base map data. The study used MS excel 2010, Instant version 3.37 and XL Instat soft wares to characterize temporal Meteorological Drought (i.e. to show rainfall trend, extent, frequency and duration in temporal characteristics of MD as output) by analyzed rainfall and crop yield data ; LEAP version 2.9 software used for this study by inputting RFE2 download from internet in FAO USGS then aggregated into Excel and generate NDVI, Yield reduction and WRSI data products to monitor and investigate crop reduction and RF trends spatially and temporally in MD-prone parts of the study areas; For this study, 3024 dekades seasonal NDVI, Yield reduction and WRSI images products data were analyzed.

Additionally, the study used a time series AVHRR satellite gridded and three stations rain gauges' rainfall, NDVI images, data used to show meteorological–drought characters by helping indices such as SPI_4 based (because they are used to assess meteorological season classification based on Lemaa Gonfa studied), PON, NDVI and WRSI. The data obtained from National Meteorological Agency Jijiga Branch Office (NMA JBO), from internet by using LEAP version 2.9 software and crops yield data attained from Eastern Harerghe and Shnile Zones Agricultural Office or from Central Statistics Agency (CSA). AVHRR gridded rainfall data have 4km by 4km spatial resolution (satellite data) in monthly and seasonally time step basis data for the period of the main rainy season (June - September) and (Mar-may). This gridded obtained from NMA and Famine Early Warning System (FEWS-NET) archive website: (http/:iridl.Ideo.columbia.edu GCM) about 37 years (from 1980 -2016 G.C) that used to fill the missing year data.

So to characterize meteorological drought, the study used long years' meteorological data and different soft wares such as INSTAT 3.37, LEAP, and ArcGIS 10.3.1 techniques, MS Excel 2010, and these woreda base map. Finally, this research is to assess impact of Meteorological drought on Maize and sorghum crops using Meteorological Stations, satellite data and crops yield data based on Meteorological drought indices and by helping different software packages (to assess quantitatively climate anomalies in terms of severity, intensity (magnitude of drought), duration, frequency, temporal and spatial extent of drought).

3.4 Data analyses

To characterize temporal and spatial Meteorological-Drought, its impact and correlations on maize and sorghum yields with rainfall; the yield data, monthly rainfall data for a period of 36 years from (1980-2016) rearranged in a monthly, seasonally and annually time step in Microsoft excel 2010 spread sheet. For the study areas (Fedis, Deder and shinile), the trend and severity of monthly, seasonally and annually rainfall (i.e. maximum, minimum and mean rainfall, onset date, end date, LGP; amount) analyzed. The rearranged data averaged over more than thirty years' time span and analyzed in order to examine monthly, seasonal and annual Meteorological-drought characteristics by using the following indices and different soft wares. NDVI, WRSI and yield reduction data were prepared by aggregating these data from LEAP software to Excel. The parameters used in this study are used described in the following sections.

3.4.1 Percent of Normal (PON)

The formula of PON is used to show drought index of the study area and the formula is Percent of Normal:

$$\mathrm{PON} = \left(\frac{\mathrm{P}}{\bar{\mathrm{P}}}\right) * 100 \qquad 3.1$$

Where: PON is percent of Normal; P is Precipitation and $\bar{P}$ is mean of Precipitation.

It is calculated by dividing actual precipitation by normal precipitation typically considered to be a 30-year mean rain fall data and multiplying by 100%. This can be calculated for a variety of time scales, including monthly, seasonal, annual, or water year. Normal precipitation for a specific location is considered to be 100% (Willeke et al., 1994). By using this index, the study calculated monthly rainfall data and that have identified spatial extent, magnitude, occurrence and characteristics of the meteorological drought.

3.4.2 Water Requirement Satisfaction Index (WRSI)

It is used to monitor crop performance during the growing season and based upon how much water is available for the crop. The WRSI is generated by a crop water balance model in LEAP software. Besides, the model uses soil information from FAO digital soil map and topographical parameter derived from Digital Elevation Model (DEM). WRSI calculated as the ratio of seasonal actual evapotranspiration (AET) to the seasonal water requirement (WR) times 100, in LEAP version 2.9 software and that produce the graphs and images.

$$\text{WRSI} = \left(\frac{\text{AET}}{\text{WR}}\right) * 100 \qquad 3.2$$

Where, WRSI stands for Water Requirement Satisfaction Index; AET is Actual Evapotranspiration and WR is calculated from the Penman-Monteith reference crop evapotranspiration (ETo) in LEAP version 2.9 software and selected the growth seasons (Belg and Kiremt) and crop varieties such as sorghum and maize.

WRSI computed using LEAP version 2.9 software generating data into Excel and imported into GIS environment. The WRSI result is then reclassified based on drought severity classes for each grid cell of the study area.

LEAP version 2.9 software input parameters: were crop development models (USGS), crop coefficients and satellite rainfall data**.** The results based on drought Severity Class were:

Table 3. 3 WRSI based drought severity class (Gizachew, 2010)

WRSI (%)	Drought severity class
80-100	No Drought
70- 79	Slight Drought
60-69	Moderate Drought
50-59	Severe Drought
< 50	Very Severe Drought

So, it used to see the relation between crops yields and drought stress, years and WRSI and also it has shown that the aridity severity, frequency and duration analysis of meteorological-drought.

3.4.3 Standard Precipitation Index (SPI)

SPI is an index that is developed to quantify precipitation deficit at different time scales, and can also help assess drought severity of MD by helping MS Excel and by using ArcGIS version 10.3.1 software analyzed spatial pattern of drought. The SPI is simplicity (only rainfall data is required for calculation).

SPI is also used to analyze the impact of rainfall deficiency on crop development. Different time scales reflect the impact of drought on the availability of the different agricultural crops.

According to Edwards and McKee in 1997, the mean SPI for the location and desired period is represented zero and also it represented water deficit or excess (i.e. positive SPI represents that water has been available to plants; whereas, negative SPI or rainfall deficiency is reflected on crop production through yield reduction). Yield reduction due to moisture deficiency is clearly explained in this issue. The formula of SPI is:

$$SPI_{ij} = (X_{ij} - X_{im})/\sigma_{ij} \tag{3.3}$$

Where, SPI_{ij} is the SPI of the i^{th} month at the j^{th} timescale, X_{ij} is rainfall total for the i^{th} month at the j^{th} time scale, X_{im} and are the long-term mean and standard deviation associated with the ith month at the jth time scale, respectively. X_{ij}= is the seasonal precipitation and, X_{im} is its long-term seasonal mean and δ is Standard deviation. The final results of SPI based drought severity class were:

Table 3. 4 SPI based drought severity class (Gizachew, 2010).

SPI Value	Drought severity class
Above 0	No drought
0.0 to -0.99	Slight drought
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2 and less	Very Severe drought

So, it is used to see the duration, severity, frequency of meteorological-drought.

3.4.4 Normalized Difference Vegetation Index (NDVI)

NDVI is used to analyze the impacts of MD on crops in the study areas. NDVI used to develop the meteorological-drought risk map and to see vegetation greenness by the helping of LEAP software version 2.9 for study areas. According to the study Hendrickson (1986) cited in Beyene Ergogo (2007), it has been shown that NDVI is highly sensitive to an extended rainfall anomaly. In this regard, simple linear regression analysis between decadal rainfall and NDVI is carried out for different lag time periods so as to better understand the influence of rainfall on vegetation growth and development. The formula of NDVI is:

$$NDVI = \left[\left(\frac{NDVI_{\max} - \overline{NDVI}}{\overline{NDVI}max}\right)\right] * 100 \tag{3.4}$$

Where, NDVI maxi=Maximum NDVI in the growing season in i^{Th} year (1980 – 2016) and Mean NDVI max=long term mean maximum NDVI in the growing season. The resulting NDVI anomaly percentage assigned to respective grid cell and it reclassified into five drought severity classes based on drought severity class. The results were:

Table 3. 5 NDVI based drought severity class (Gizachew, 2010).

NDVI Anomaly in %	Drought severity class
Above 0	No drought
0 to -10	Slight drought
-10 to -25	Moderate drought
-25 to -50	Severe drought
Below -50	Very Severe drought

The study has shown impact of meteorological drought on crop production can be largely expressed by yield reduction. In view of this, yield reduction due to water deficiency is computed using LEAP software integrated the data and imported to GIS to show spatially and analyzed by MS Excel to show temporally.

3.4.5 Characterizing the Meteorological-Drought

From the daily of long term rainfall data, the onset and cessation dates, trend analysis, and dry spell risk analyzed. All these Meteorological-Drought indices identified different soft wares, such as INSTAT tools version 3.37, and SPI_4 and the data captured by MS Excel 2010 soft wares.

In order to examine the MD of study areas for more than a thirty years (1980-2016) climatological period Statistical tools like mean, standard deviation, coefficient of determination (R^2), coefficient of variability (CV) and p-value comparison used in ISTANT (v 3.37) statistical software. Coefficient of variability (CV) used to classify the degree of MD (rainfall) events as less, moderate and high. When CV < 20% it is less variable, CV from 20% to 30% is moderately variable, and CV > 30% is highly variable. Areas with CV > 30% are said to be vulnerable to drought (Gebremichael *et al.*, 2014).

Onset is the beginning or the start of the main growing season as the first occasion from the first of month that records 20mm of rainfall amount or more over a 3-day period, and was not be followed by a period of more than 10 consecutive dry days in the following 30 days (Stern *et al.*, 2003; Segele *et al.*, 2005).

Secession date is the end date of the growing season in which the soil water balance is nearly zero and the availability of the soil water to the plant is negligible (Lumb, 2005). It can be computed using first-order Markov chain modeling by considering maximum daily evapotranspiration of 5 mm and soil available water holding capacity of 100mm with the daily reduction of 0.5 mm.

Growing season also determined that it is defined as the period of the year when both moisture and temperature conditions are suitable for crop production and it is calculated from cessation and onset date of the rainy season. The length of the growing period (LGP) is obtained by counting the number of days between the start and the end of the growing period (Chamberlin *et al.*, 2009).

Different statistical parameters determined to indicate the variation of monthly and seasonal rainfall using equation. The coefficient of variation of monthly and seasonal rainfall variability was analyzed by:

$$CV = \left(\frac{SD}{\overline{X}}\right) * 100, \text{where } \overline{X} = \sum_{i=1}^{N} X_{i,} \text{ and } SD = \sqrt{\frac{(X_i - \overline{X})^2}{N-1}} \qquad (3.5)$$

Where from equation (3.5), CV is the coefficient of variation, SD is standard deviation, $\ddot{X}$ is long year mean and N is total number of year during observations, Xi is rainfall of each month or season. The coefficient of determination (R^2) also indicates the variation of the climate variable with time in the linear regression model which is defined as:

$R^2 = SSR/SST$ OR 1 – SSE/SST -- (3.6)

Where, SSE is the Sum of Squared Error, SSR is the Sum of Squared Regression; SST is the Sum of Squared Total. R^2 measured how successful the fit was in explaining the variation of the data. P-value is a statistical measure that used to determine whether the hypotheses were correct. Usually, if the p-value of the dataset was below the pre-determined amount (say 0.05 which is the 95% confidence interval), the variability of the dataset has meaningful effect on the result (Wilks, 2006).

Dry spell is another climatic variable which is potentially damaging crop production if it coincides with the most sensitive stages such as flowering and grain filling (Stern and Coe, 1984). According to NMA, a value of just under 1mm is defined a day to be dry if rainfall amount is less than this threshold. The dry spell is the consecutive of dry days (<1mm) more than 7 days within 30 days (FAO, 2007). It also calculated using first-order Markov chain modeling. So, the onset of rainfall and dry spell risk were very crucial to farmers as it answers the vital question "when to plant? And what would be frequency of dry spell expectation for the coming season? The LGP determined by subtracting onset date from end date.

3.4.6 Trend analysis

For trend analysis, the monthly and annually data series of the study areas weather station more than 30 years long year data analyzed and test for the existence of significant trend by correlation and regression analysis and using INSTAT software. To determine the trend of rainfall in the study areas, sequential plot time series analysis used. This can be mathematically denoted using the functional relationship below:

Y = f (I) -- 3.7

Where, Y is the value of the variable under consideration at time i.

Suppose that Y_i is the estimated value of the dependent variable Y_i at time i, then Y_i can be predicted from the simple linear equation.

The model can be written as

$Yi = \beta o + \beta 1Xi + \varepsilon i$ -- 3.8

Y_i = the estimated value of the dependent variable(maize yield); βo = the Y intercept measuring the value Y_i at time i, $\beta 1Xi$ = the slope of the line measuring the change in the variable Y_i that results from a units change in time i, i = the independent variable (time) *i* =1, 2, 3, 4…30 and Ɛi = Random error. It hypothesized that there is no trend in the amount of rainfall over time. Thus the null hypothesis is stated as; H0: $\beta 1 = 0$. Variability of annual and seasonal rainfall assessed using CV and Analysis of Variance (ANOVA) techniques (Mann_Kendall). Standard rainfall plotted against time (in years) to visualize the time series variation of annual and seasonal rainfall.

From the rainfall data collected, Date(s) of onset of the rainy season (in days), date(s) of end of the rainy season (in days), and length of the rainy season (in days) parameters derived. Correlation and simple linear regression analysis are the statistical tools which are used to establish the relationship and effect of rainfall and maize and sorghum yields. The regression model for the study rain fall effect computed as:

Y= a+ bx --- 3.9

Where, *Y* = the value of the dependent variable (maize and sorghum yield/ ha), *a* = *Y* intercept,

b = regression coefficients (each b represents the amount of change in *Y* (yield) for one unit of change in the corresponding x-value when the other *x* values are held constant; *x* = the rainfall independent variables (*i.e.* rainfall onset, cessation, duration, and seasonal rainfall totals) and *e* = the error of estimate or residuals of the regression.

Pearson Correlation coefficient (r) analyses used to analyze the correlation between crop yields (maize yield expressed in Qt/ha) with rainfall characteristics, value of r ranges between -1 to +1, a correlation coefficient close to +1 indicates a strong positive correlation, a correlation coefficient close to -1 indicates a strong negative correlation similarly a correlation coefficient of 0 indicates no correlation.

3.4.7 Meteorological drought risk map

Meteorological drought risk zone map of the study area was produced from the output derived from Satellite based vegetation in LEAP version 2.9 software, climate and crop performance drought indices by using multi criteria evaluation (MCE) techniques. In order to compute the frequency of drought occurrence, drought class image from each index was reclassified into Boolean image based on their threshold value and images were generated for each drought index. These binary images were added to obtain the frequency map showing the frequency of drought occurrence at each pixel level.

The seasonal frequency maps derived from each drought indices were reclassified into common scale based on the frequency of drought occurrence. According to Lemma Gonfa (1996), the probability of drought occurrence in a given area can be classified into high, moderate and low drought probability zones when drought occurs in more than 50 percent, 30 to 50 percent and less than 30 percent of the years, respectively. Based on these criteria, the frequency maps of each drought classes are reclassified into five classes based on the frequency of drought occurrence in study periods: 0-2 classified as no drought; 3-4 classified as slight drought; 5-6 classified as moderate drought; 7-10 classified as severe drought; 11-13 classified as very severe drought. Finally, maps from each drought indices were weighted according to the percentage of influence using GIS software, and then combined using weighted overly analysis. The schematic representation of the methodology has been depicted in the following figure.

$$\mathrm{RZM} = \frac{(\mathrm{WRSI} + \mathrm{SPI} + \mathrm{NDVI})}{3} \qquad 3.10$$

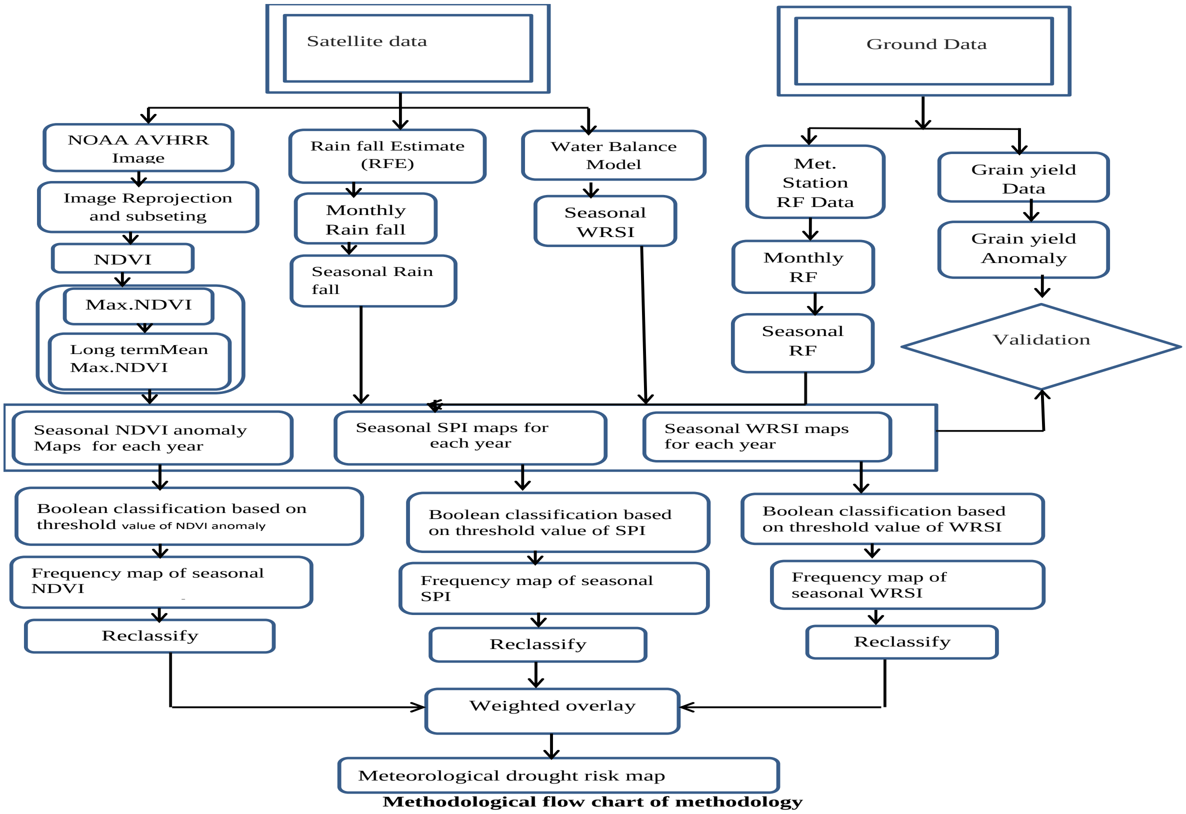

Figure 3. 2 Methodological flow chart of the study areas.

4 RESULTS AND DISCUSSION

4.1 Spatial and temporal patterns of drought Conditions using Indices

4.1.1 Standard Precipitation Index (SPI)

Drought characteristics included various drought conditions, such as duration, severity, and intensity. The SPI was determined based on seasonal classification of Ethiopian (NMSA 1996, Babu 1999a, 63) which mainly include Belg (Feb-May), Bega (Oct – Jan) and Kiremt (Jun- Sep). The results of SPI_4 analysis are given below in Table 5.1 and Figure 4.1. The point RF was used to take woreda based because the NMA station RF data represent about fifty Kilo meter radius coverage. SPI values are normally distributed; the frequencies of extreme and severe drought events for any location and timescale are consistent (WMO, 2010).

The analysis of SPI_4 for Shinile woreda showed that drought has occurred at different level from 1980 to 2016 rainy season. As it can be shown in Figure 4.1, the drought happened in the years 1980, 1981, 1984, 1985, 1988 - 1991, 1995, 1999, 2000, 2002 - 2005, 2008, 2009, 2011 and 2015 (see Appendix 5). Severe droughts years were 1984, 2000, 2005, 2009, 2011 and 2015 respectively; those were explained with their SPI values that range from -2 to -1. The results indicated that there was rainfall deficit in the growing season. Therefore, there was the worst dry season. SPI can be used to identify not only drought years but also wet years. In this regard, using SPI analysis, wet years were identified. As the maps were shown in the Figure 4.1, the years 1982, 1983, 1986, 1987,1992 - 1994, 1996 - 1998, 2001, 2006, 2007, 2010, 2012 and 2013 were very wet years in Shinile woreda, and based on $SPI_{4,}$ among these years the extreme wettest years were 1983, 1996, 1997, 1998 and 2010. Besides analysis of the 36 years (1980-2016) annual RF showed a coefficient of variation ranging from 70.4 – 157.2 %. That is highly variable. So, the yields were vulnerable to meteorological drought.

The analysis of SPI_4 based for Deder woreda, from Figure 4.1, the years 1984, 1985,198, 1987, 1991, 1994, 2004, 2005 and 2007 to 2015 were droughts. On the other hand, the severe droughts years were 1984, 1994 and 2007 to 2013 with their SPI values ranges from -1.0 to -1.5. The results indicated that during those years there was rainfall deficit in the growing season; therefore, there were the worst dry years. Considering of the most severe droughts years above mentioned period was a better illustration of the drought extent and intensity in this area, especially recent years frequented to drought. So based on this index, the extreme wet years were 1999, 1998, and 1997 with SPI values greater than 1.0. Besides analysis of the 36 years (1981-2016) annual RF showed a coefficient of variation ranging from 70.8 – 139.0 %. This was highly variation of RF that indicated vulnerable of yields to MD.

The result of the analysis of SPI_4 for Fedis woreda is given in Figure 4.1. As it can be seen, the droughts occurred in the years 1980, 1982 - 1986, 1990, 1991-1993, 2005, 2007, 2010 – 2012 and 2015. The very severe droughts years were 1980, 1982 - 1985, 1986, and 2010 with SPI values in range from -1.5 to -2.0. The results indicated that these years were rainfall deficit in the growing season; therefore, there were the worst dry seasons in Fedis woreda and the earliest years were frequented MD. The years 1988, 1989, 1995 - 1997, 2009 and 2014 were also extreme wet with SPI values greater than 1.0. Besides analysis of the 36 years (1981-2016) annual RF showed a coefficient of variation ranging from 75.6 – 202.7 %.

During Kiremt season (Jun – Sep), in the Figure 4.2, based on SPI_4 for Deder in the years 1984, 1987, 1991, 2010 and 2013 were found to be the extreme drought; whereas, during this season the years 1983, 1988 and 1998 to 2002 were found to be extreme wet and based on vegetation (NDVI index) trend data these years were good production years. As the Figure 4.5 indicates, most years have shown more frequent drought than wet years and also drought occurrence was frequent in 1980s and 2010s;this indicates the earliest time is returned now and the RF performance is shown decreasing trend. The recent years were frequented MD.

During Kiremt season (Jun – Sep) in the Figure 4.2, based on SPI_4 for Fedis woreda in the years 1980-1986, 1990-1993, 2001, 2005, 2007, 2010, 2012 and 2015 were shown droughts (the SPI_4 values range from -0.1 to -2.0). Among these years, 1980, 1984,1985 and 1986 were very severe droughts (SPI_4 values range from -1.6 to -2.0); whereas, the years 1987-1989, 1994-2000, 2002, 2006, 2008, 2009, 2011, 2013 and 2014 were wet (the SPI_4 values range 0.3 to 1.6). Among these years, 1988 and 2009 were good cropping years because these years were found to be extreme wet years than others. As the below Figure 4.2 has shown more frequented droughts years than wet years and also drought occurrence was frequent in the first years (1980's).

During Kiremt season (Jun – Sep) in the Figure 4.2, based on SPI_4 for Shinile woreda, in the years 1980-1982, 1984-1987, 1989-1991, 1993, 1995, 1997, 2002, 2004, 2009 and 2015 were the droughts (the SPI_4 values range from -0.2 to -2.1). Among these years, 1991 and 1987 were very severe droughts (the SPI_4 values range from -1.6 to -2.1); whereas, the years 1984, 1996, 1998, 2001 and 2010 were extreme wet and these years were good cropping years because these years were more wet years than others. So, as the below Figure 4.2, based on SPI_4 has shown frequented drought years which were less than wet years and also drought occurrence was frequented in the first years (1980's).

During Belg season (Feb – May), in the Figure 4.3, based on SPI_4 for Deder woreda, in the years 1984, 1986, 1988, 1992 to 1994, 2000 to 2005, 2007 to 2009 and 2011 to 2015 were shown drought. Among these years, the years 1988, 1994, 2007, 2009, 2011 to 2013 were shown from moderate to severe drought (the SPI_4 values range from -1.0 to -1.6). The recent years were more frequent the drought years; whereas, from Figure 4.3, the years 1981 to 1983, 1985, 1987, 1989 to 1991, 1995 to 1998, 2006 and 2010 were wet (the SPI_4 values range from 0.1 and 3.3). Among these years, in 1997 was the wettest year and expected good cropping season.

During Belg season (Feb – May), in the Figure 4.3, based on SPI_4 for Fedis woreda, in the years 1980, 1982 to 1986, 1991, 1999, 2001, 2002, 2005, 2008, 2010, 2011 and 2015 were shown droughts (the SPI_4 values range from -0.1 to -1.5). Among these years, the years 1980, 1982-1986, 1999, 2008, 2010 and 2015 were shown moderate droughts (the SPI_4 values range from -1.0 to -1.5); especially 1984 were severe drought. The earliest years (1980's) were more frequent the drought years; whereas, in the Figure 4.6, the years 1981, 1988 to 1990, 1995 to 1998, 2000, 2003, 2004, 2007, 2009 and 2014 were wet (the SPI_4 values range from 0.1 and 2.0). In line with this, 1998 and 1989 were found to be the extreme wet years and there were expected good cropping season.

As it can be seen from Figure 4.3, the SPI_4 values for Belg season (Feb – May), ranged from -0.1 to -1.6 for Shinile woreda, during the years 1980, 1984, 1985, 1988, 1992, 1994, 1999-2005, 2007, 2009, 2011-2013 and 2015. These values indicate drought of different levels. Based on the classification given by equation 3.3, SPI values between -1.5 and -1.6 are considered as severe droughts. In line with this, the years 2000, 2009, and 2011 are classified severe droughts. The earliest years (2000's) were characterized with more frequented drought events; whereas, the years 1981, 1983, 1986, 1987, 1996 and 2010 were wet and there were good cropping season.

So, the implication of the above result indicated that the drought pattern such as drought frequency, severity and intensity explained by using SPI_4 index in study areas. It used to know the drought years, its frequency time and its magnitude in study areas.

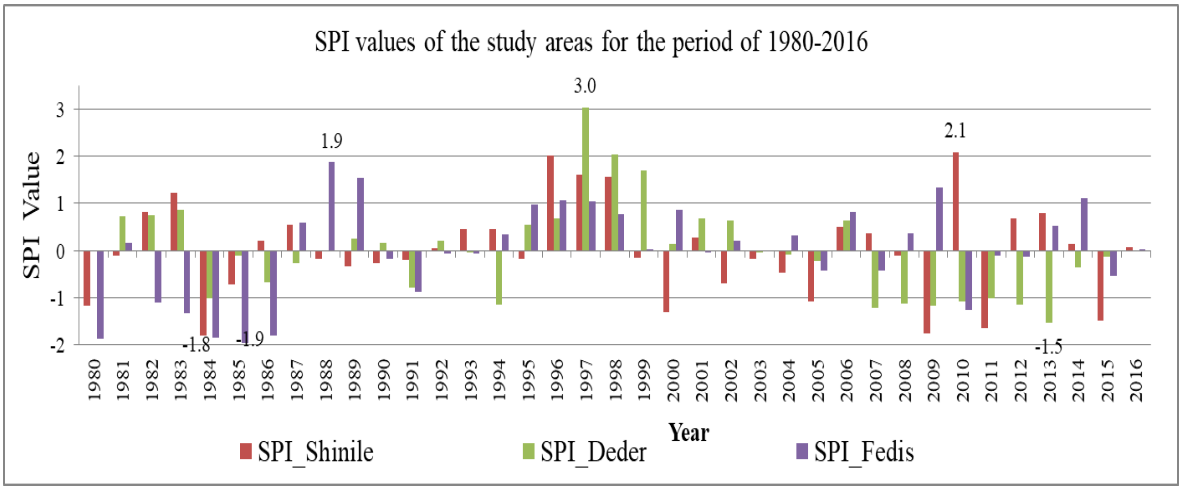

Figure 4. 1 SPI RF values of Shinile, Deder and Fedis woredas for the period of 1980-2016

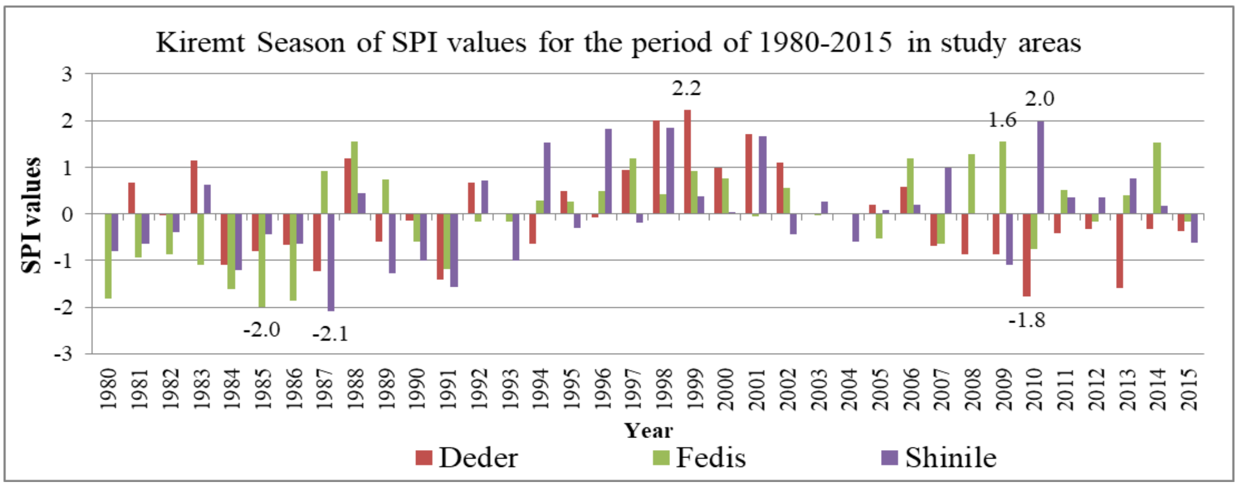

Figure 4. 2 Kiremt Season (Jun – Sep) RF SPI of Deder, Fedis and Shinile woredas

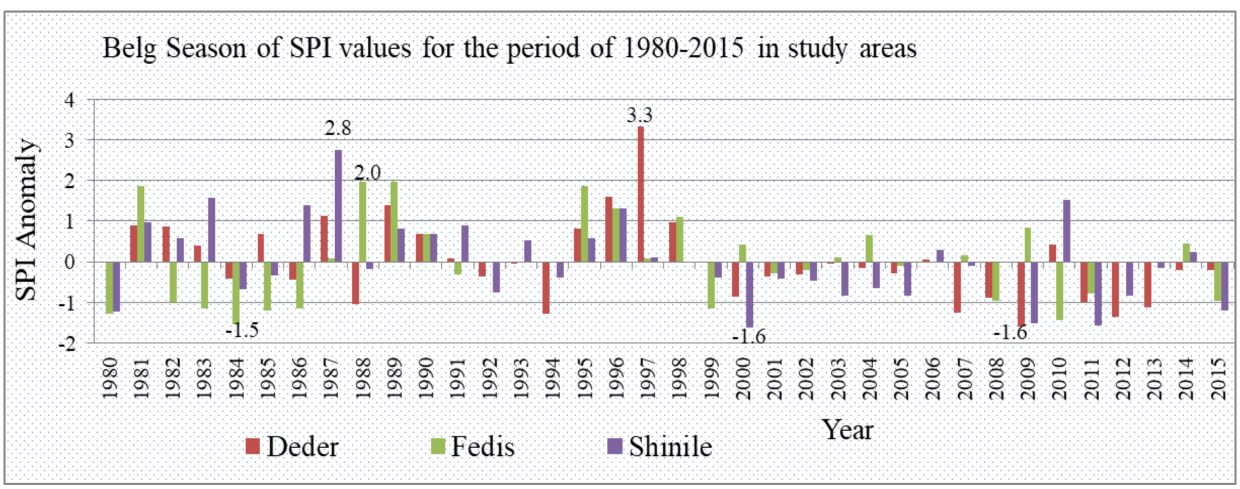

Figure 4. 3 Belg Season (Feb - May) RF SPI of Deder, Fedis and Shinile woredas

4.2 RF Trend Analysis in the study areas

Figure 4.4 shows, annual total rainfall trend in Fedis woreda for the period 1980 to 2016 was positively increased with the time. Based on the result in Figure 4.4, during the above mentioned period, the highest amount of RF was 923.3 mm in the year 1988; whereas, the lowest total amount of rainfall was 89.4 mm in the 1985 and also the mean total RF was 514.7mm (see Table 5.2 and Appendix 2). The trend of total rainfall amount was increased with the time. Whereas, the annual total rainfall trend, in Figure 4.4, for Deder woreda for the period of 1981 to 2016 was decreased and the highest total RF recorded in the year 1997 with the value 1933.7mm but the minimum total amount of rainfall recorded in 1985 with the value 425.0 mm. The mean total RF was 992.95 mm (see Table 5.3 and Appendix 2). As shown in Figure 4.4, the annual total rainfall trend in Shinile woreda for the period of 1980 to 2016 decreased and the maximum total rainfall was 965.9 mm in 2010; whereas, the minimum total amount of rainfall was 348.6 mm in 2015 and the mean total RF was 639.0mm. The study showed that the trend of total rainfall amount decreased with the time. Statistically, significant all trends were detected for precipitation on annual based (see Table 5.1 and Appendix 2). The trends of annual RF showed in Table 4.1.

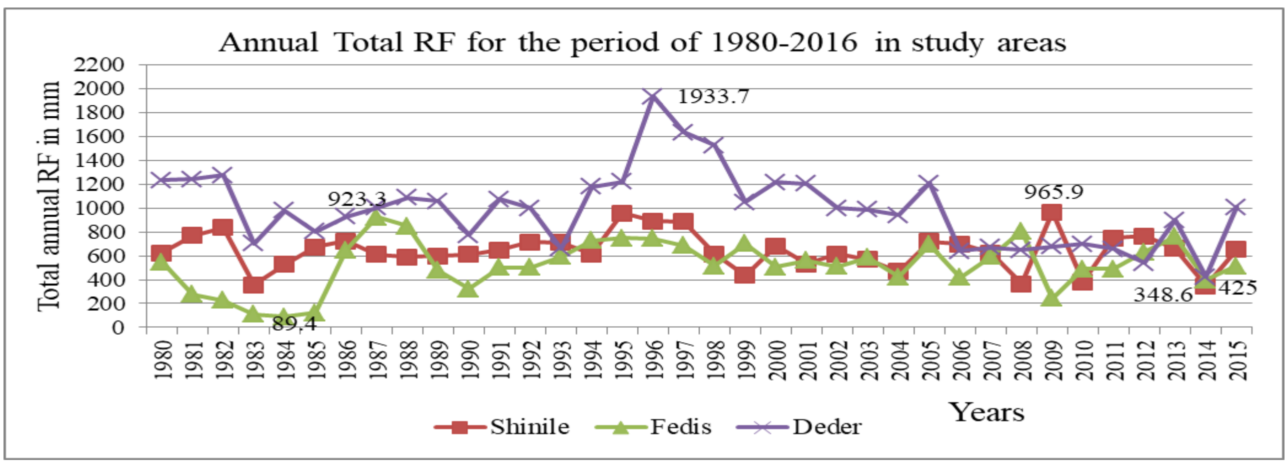

Figure 4. 4 Total Annual RF Trend of Shinile, Fedis and Deder woredas

4.3 Monthly total RF Trend Analysis

As can be seen from Figure 4.5, the monthly total rainfall trend of Shinile woreda is decreased with time. The maximum RF recorded in the month of April and August during Belg season (Feb-May) and during Kiremt season (Jun –Sep) with value average 107.9 mm and 115.3 mm respectively. The minimum total RF recorded in December with value 12.4mm and the monthly mean value was 53.3 mm.

As can be seen from Figure 4.5, the monthly total rainfall trend in Deder woreda is slightly decreased with time increased and the highest total RF is also recorded on the month April and August. The highest value on average recorded 128.2 mm and 216.7 mm during Belg season (Feb-May) and Kiremt season (Jun –Sep) respectively. The minimum total RF is recorded 11.0 mm in December and the monthly mean value was 84.4 mm.

As can be seen from Figure 4.5, the monthly total rainfall trend, in Fedis woreda can be shown the increased trend with the time; and the maximum total RF recorded 128.2 mm during Belg season (Feb-May) and 216.7 mm during Kiremt season (Jun –Sep). The highest value on average was recorded in the month of April and August. The minimum total RF recorded 11.0mm in December and the monthly mean value was 84.4 mm (see Appendix 2).

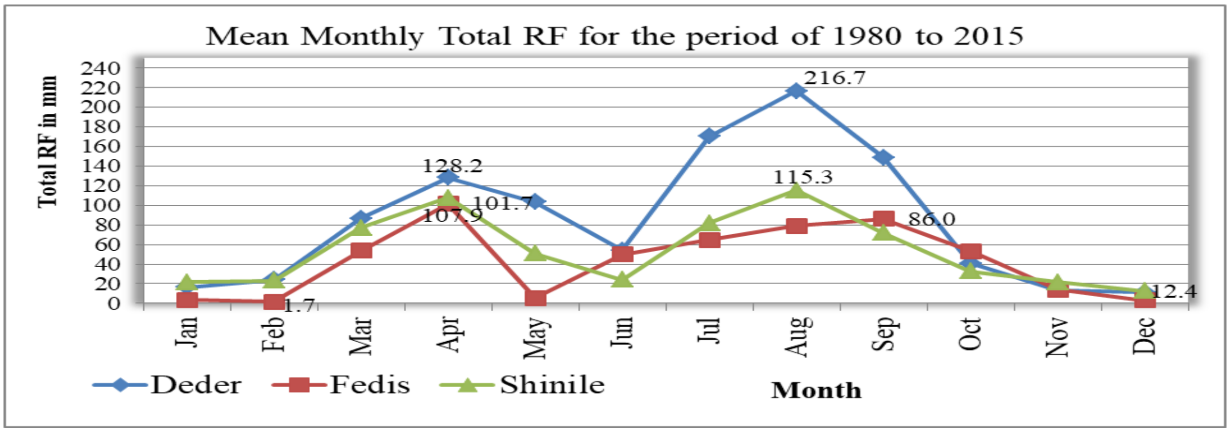

Figure 4. 5 Monthly Total RF Trend of Deder, Fedis and Shinile woredas

Analysis of Variance (ANOVA) techniques

The above data tasted by this techniques and it showed the total rainfall trends increasing and decreasing in the study areas. In Shinile and Deder, the RF trend decreased; whereas, the RF trend increased with time.

Table 4. 1 ANOVA of Study Areas

St. Name	MK_Slope	Season	Mann_Kendal's Trend Test		
			Kendall's Tau	Sen's Slope	P Value
Shinile	-111	Belg	-0.19	-0.075	Sig
	-76		-0.12	-0.841	Sig
	-114		-0.18	-1.919	Sig
	-101		-0.16	-0.767	Sig
	161	Kiremt	0.26	0.538	NonSig
	188		0.30	1.580	NonSig
	73		0.12	0.737	Sig
	23		0.04	0.206	Sig
Deder	-197	Belg	-0.34468	-0.82857	NonSig
	-63		-0.10734	-0.74	Sig
	-106		-0.17921	-1.5167	Sig
	-117		-0.20144	-1.55333	Sig
	90	Kiremt	0.154003	0.447815	Sig
	6		0.010179	0	Sig
	-52		-0.08791	-0.75	Sig
	-53		-0.0903	-0.26496	Sig
Fedis	4	Belg	0.007057	0	Sig
	49		0.0795	0.1579	Sig
	-65		-0.10443	-0.6057	Sig
	190		0.308521	0.126798	NonSig
	123	Kiremt	0.197605	0.815302	Sig
	170		0.271135	1.432248	NonSig
	165		0.263372	1.837037	NonSig
	5		0.008007	0	Sig

Sig: significant, NonSig: Non significant, MK: Mann Kendall

4.4 MD Characteristics Onsets, Cessation, LGP and Dry spell of Seasons

Most prediction studies focus on the total seasonal rainfall amount, however, the time of that rainfall is equally important to agriculture. For example, pastoralists in northern Kenya and southern Ethiopia have identified the spring onset date as the single most desirable piece of forecast information (Luseno, 2003). The time of the seasonal transitions can also be an important control on drought, since a late onset or early termination and duration of sowing can initiate or exacerbate drought conditions. The magnitude of drought impact is closely related to the time of the onset of the precipitation shortage, its intensity, and the duration of the event. As droughts extend from one season to another and from one year to another, potential impacts are magnified since surface and subsurface water supplies continue to be depleted and a larger number of users are affected. Frequent and multi-year drought events offer no opportunity for natural and managed systems to recover, a critical problem for fragile arid and semiarid ecosystems (Edward M. Mugalavai, Dirk Raes, Manchiraju S. Rao, (2008)).

So, in the Figures (4.6 and 4.8), the Starting of Season (SOS) of Belg (Feb to May) for Fedis woreda most of years was started during third dekad of February and the End Of rainy Season (EOS) was ended during May third dekad, and from Figures (4.6 and 4.8) the Starting of Season (SOS) of Belg (Feb to May), for Deder woreda most of the years was started during first dekad of March and the End Of rainy Season (EOS) was ended during May third dekad. In the Figures (4.6 and 4.8) the Starting of Season (SOS) of Belg (Feb to May) for Shinile woreda most of years was started during third dekad of February and the End Of rainy Season (EOS) was ended during May third dekad.

On the other way, the starting of rainy Season (SOS) of Kiremt (Jun to Sep) for Fedis woreda from Figure (4.7 and 4.9) most of the years was started during first dekad of Jun and the End Of rainy Season (EOS) was ended during September third dekad; the starting of rainy Season (SOS) of Kiremt (Jun to Sep) for Deder woreda from Figure (4.7 and 4.9) most of the years was started during third dekad of Jun and the End of rainy Season (EOS) was ended during September third dekad and the starting of rainy Season (SOS) of Kiremt (Jun to Sep) for Shinile from Figure (4.7 and 4.9) most of the years was started during second dekad of Jun and the End Of rainy Season (EOS) ended during September third dekad.

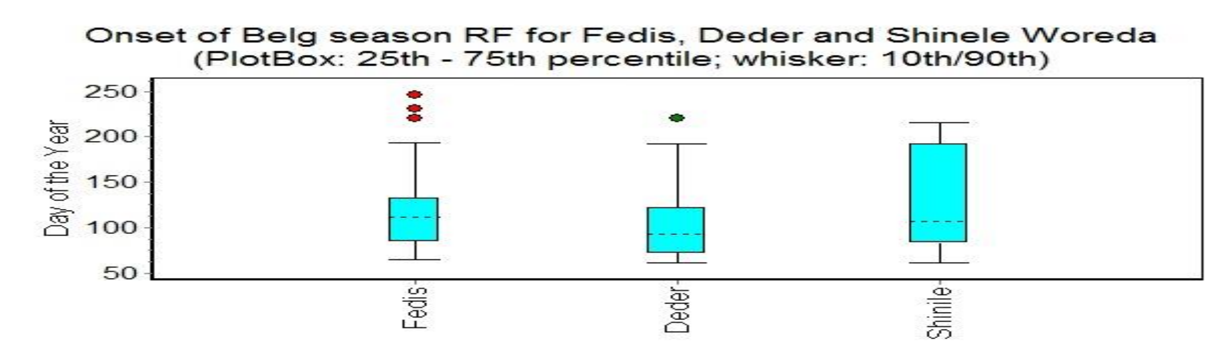

Figure 4. 6 Belg season onsets of rains in days for Fedis, Deder and Shinile woreda

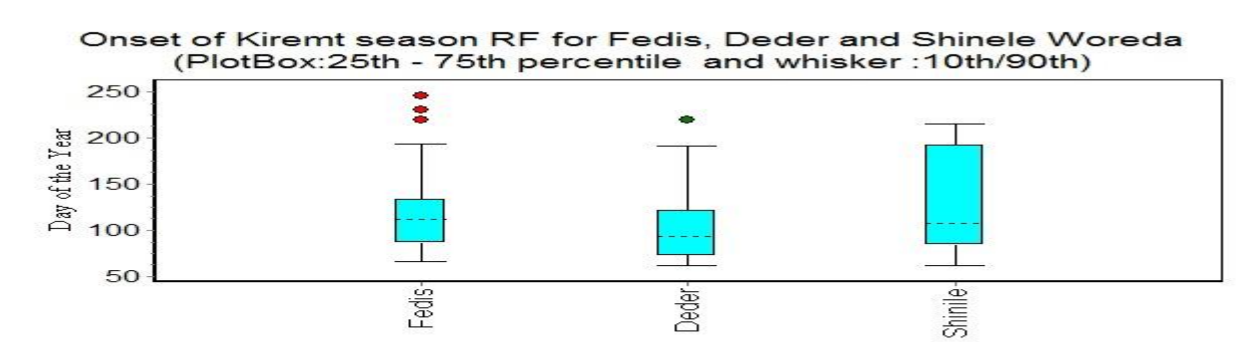

Figure 4. 7 Kiremt season onsets of rains in days for Fedis, Deder and Shinile woreda

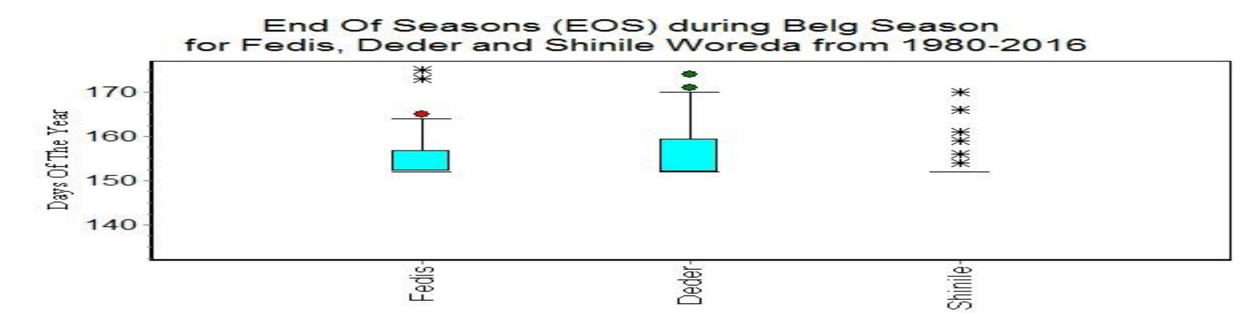

Figure 4. 8 Belg season End of rains in days for Fedis, Deder and Shinile woreda

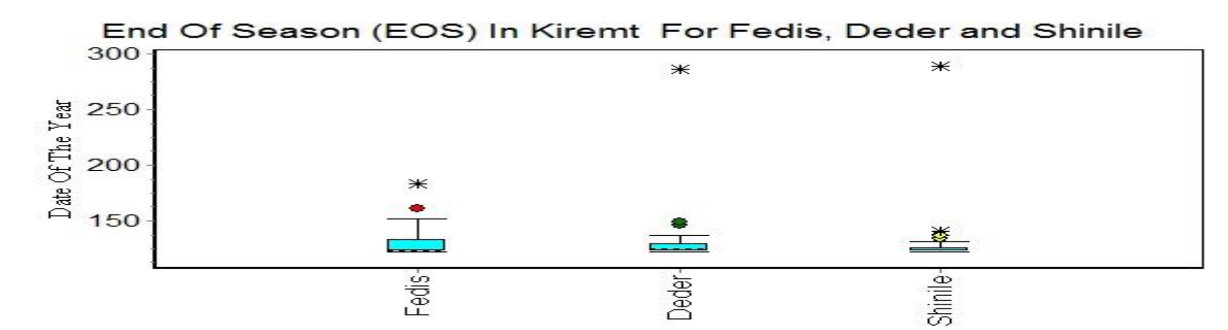

Figure 4. 9 Kiremt season End of rains in days for Fedis, Deder and Shinile woreda

The duration of the rainy season was defined as the difference of the onset and cessation dates of rainfall (length = cessation−onset). Length of Growing Period (LGP) or rainy length time (from Figure 4.10), during Belg season for Shinile was 40-80 days, for Deder about 80 – 100 days and for Fedis woreda there was about 100 – 120 days. Length of Growing Period (LGP) or rainy length time (from figure 4.11) during Kiremt season for Shinile 70 – 90 days, for Deder about 80 – 100 days and for Fedis woreda there was about 100 – 120 days.

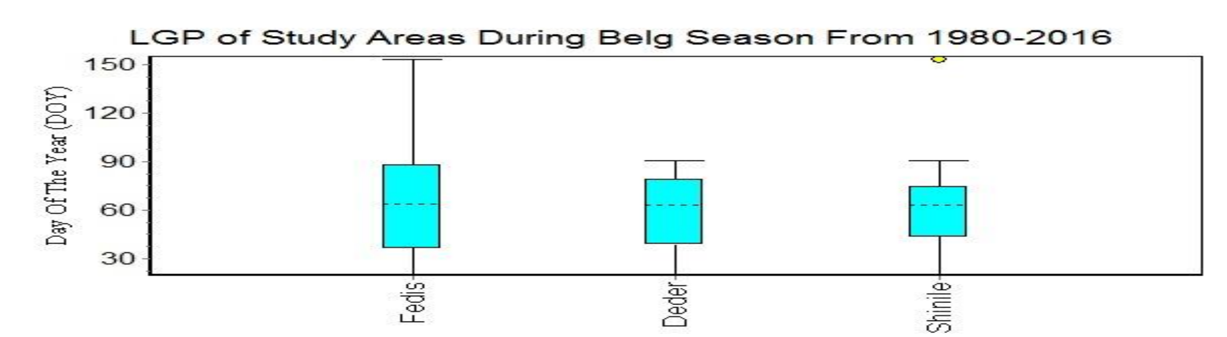

Figure 4. 10 LGP during Belg season in the study areas

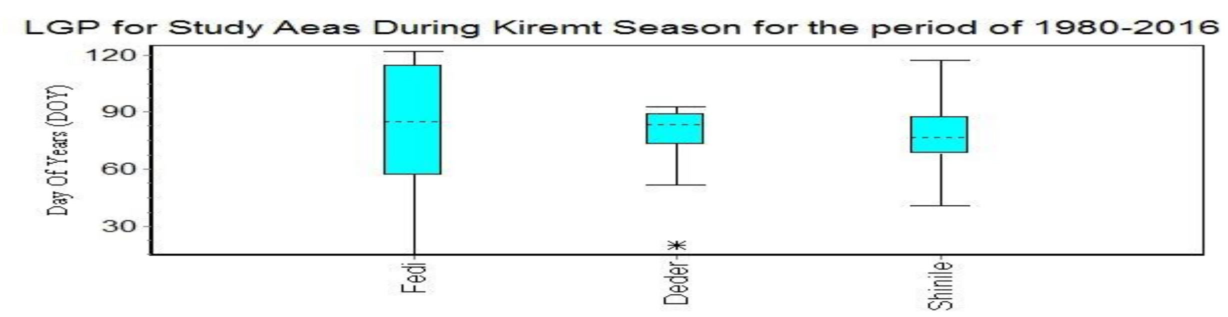

Figure 4. 11 LGP during Kiremt season in the study areas

As it can be seen from Figure 4.12, the dry spell of the Fedis woreda decreases at the end of April and starting of May in range 0-20%, 40-60%, 75-80%, 85-100% in 15, 10, 7 and 5 days respectively. With line this, the dry spell also decreases at the end of August and starting of September in range 0-15%, 20-30%, 50-60%, 80-90% in 15, 10, 7 and 5 days respectively. But during June and September, the dry spell days increased about more than 20% in all days.

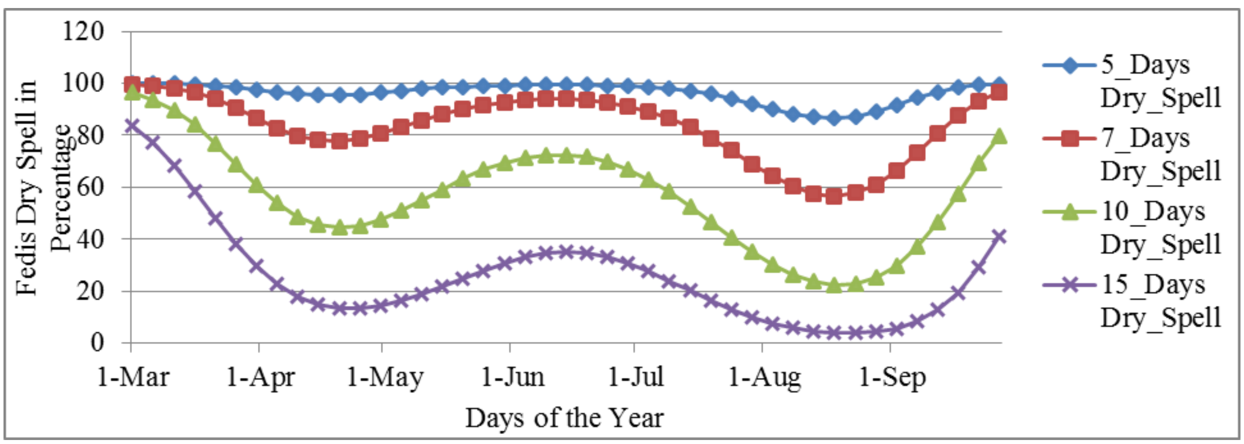

Figure 4. 12 Dry spell in percentage in Fedis Woreda for the period of 1980 – 2016

As it can be seen from Figure 4.13, the dry spell of in Deder woreda decreases at the end of March and starting of April in range 0-20%, 30-40%, 60-70%, 85-100% in considering 15, 10, 7 and 5 days respectively. In line with this, the dry spell also decreases at the half of July and end of August in range 0%, 0%, 0-20%, 40-45% in 15, 10, 7 and 5 days respectively. But during May and September, the dry spell days increases about more than 30% in all days. In general, the dry spell in Fedis woreda was less than others woreda; whereas, in Shinile woreda it was more than others woreda.

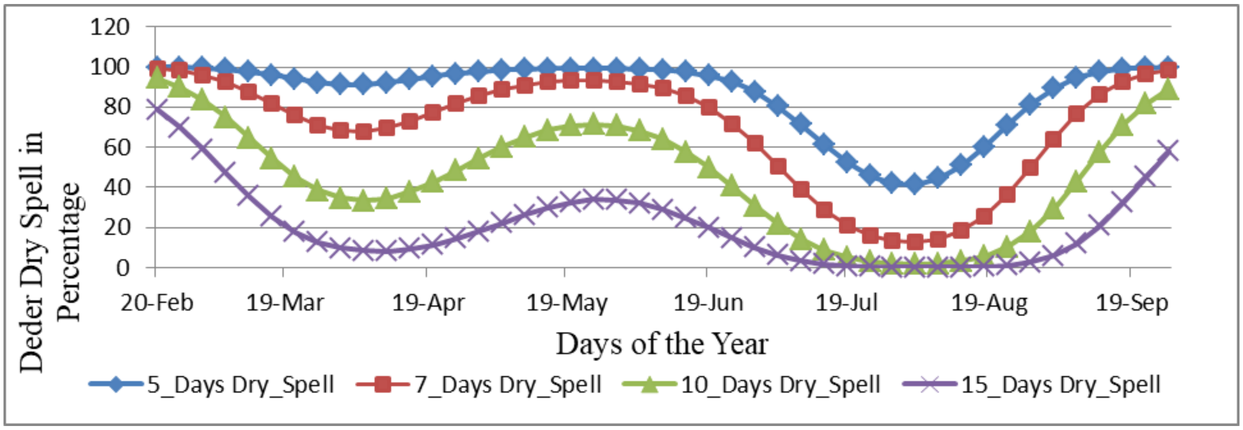

Figure 4. 13 Dry spell in percentage in Deder Woreda for the period of 1981 – 2016

As it can be seen from Figure 4.14, the dry spell of Shinile woreda decreases at the end of March and starting of April in range 20%, 50-60%, 80-90%, 95-100% in 15, 10, 7 and 5 days respectively. In line with this, the dry spell also decreases at the month of August and end of August in range 0%, 5%, 20-25%, 55-60% in 15, 10, 7 and 5 days respectively. But during May, June and September, the dry spell days was increased about more than 60% .

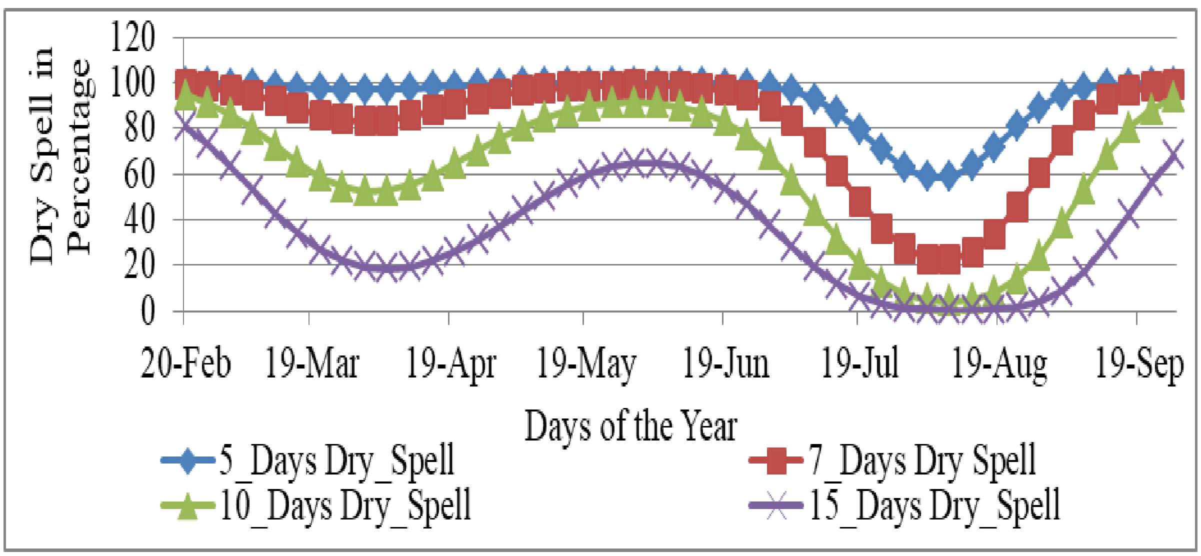

Figure 4. 14 Dry spell in percentage in Shinile Woreda for the period of 1981 – 2016

4.5 Relationship between Kiremt rainfall and crop yield

The relationship between annual RF and the yield, the meteorological station and grain yield of agricultural production are the main ground truth data. Therefore, it is crucial to analyze the relationship between RF amount and grain yield to quantify the impact of Meteorological drought on agricultural production. When SPI is positive, grain yield anomaly also turns positive revealing a good positive correlation; Since SPI is an index that represents water deficit or excess, positive SPI represents that water has been available to plants so that grain yield become above normal condition, Whereas, negative SPI or rainfall deficiency is reflected on crop production through yield reduction and yield reduction due to moisture deficiency is clearly explained (Gizachew, 2010). The relationship between RF amount extracted only area from land use/ land cover map of Deder Woreda and grain yield productivity were analyzed and from scatter plot (Figure 4.15), it can be observed that the two variables have established weak correlation (r = 0.105). This may be the others factors for contribution of crops development in this area such as soil types, pests and insects, moisture condition. This indicates that there may be others factors. The result revealed that the relationship established between the two variables was considering others factors; mean of total RF amount decreases so do agricultural yield and vice-versa. Thus the strength of the total RF amount to explain the existence of meteorological drought through agricultural yield is relatively good sorghum yield is strongly related with RF than Maize yield.

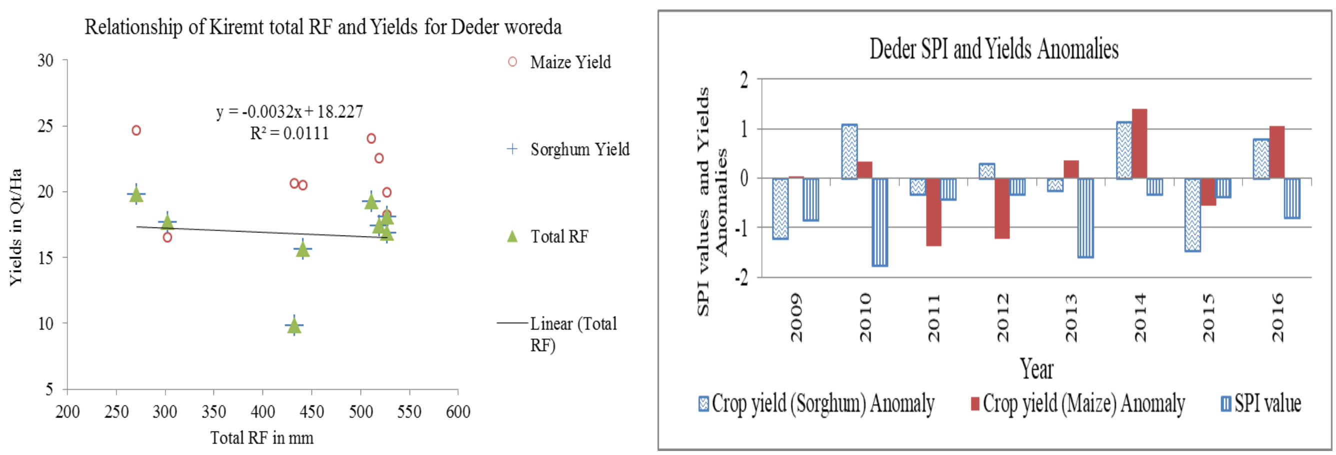

Figure 4. 15 Relationship of RF with Yields and SPI with Yields Anomalies

As it can be seen From Figure 4.16, the relationship between RF amount and grain yield productivity were analyzed and from scatter plot (Figure 4.16), it can be observed that the two variables have established weak positively correlated (r = 0.38). The result revealed that the relationship established between the RF and yields is positive for crops; mean of total RF amount increases so do yields vice-versa. Thus the strength of the total RF amount to explain the existence of meteorological drought through agricultural yield was relatively good. Maize yield was strongly related with RF than Sorghum yield. Here, the study noticed that the maize crop production was increased more than sorghum crop.

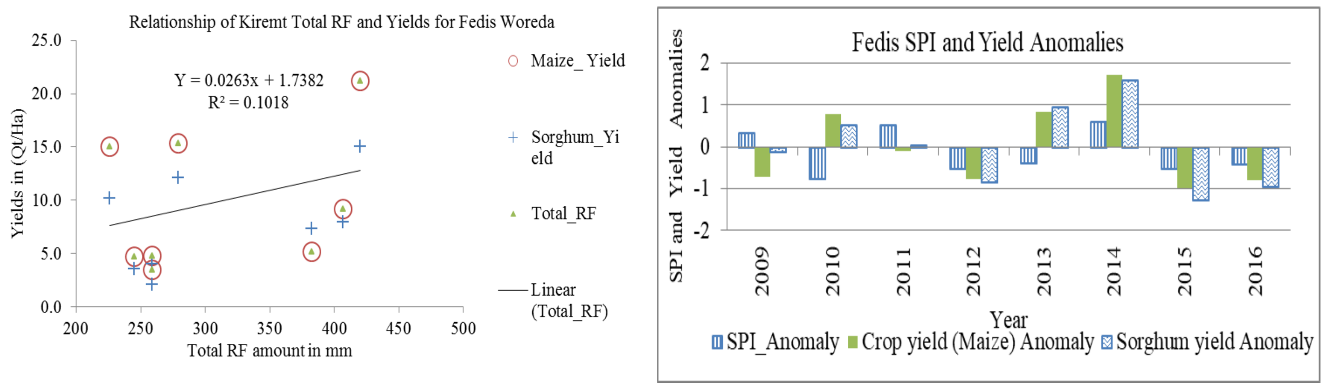

Figure 4. 16 Relationship of RF with Yields and SPI with Yields Anomalies

As can be seen from Figure 4.17, the relationship between total RF of Shinile Woreda and grain yield were showed (Figure 4.17), it can be observed that the two variables have established weak positively correlated (r = 0.29). The total RF increases so do agricultural yield and vice-versa. Thus the strength of the RF amount to explain the existence of meteorological drought through agricultural yield is relatively good. Whereas, sorghum yield is better related with RF than maize yield related with RF. So, sorghum crop is also more drought resistance than maize crop. Here the study noticed that the sorghum crop production is better to be sow than maize crop.

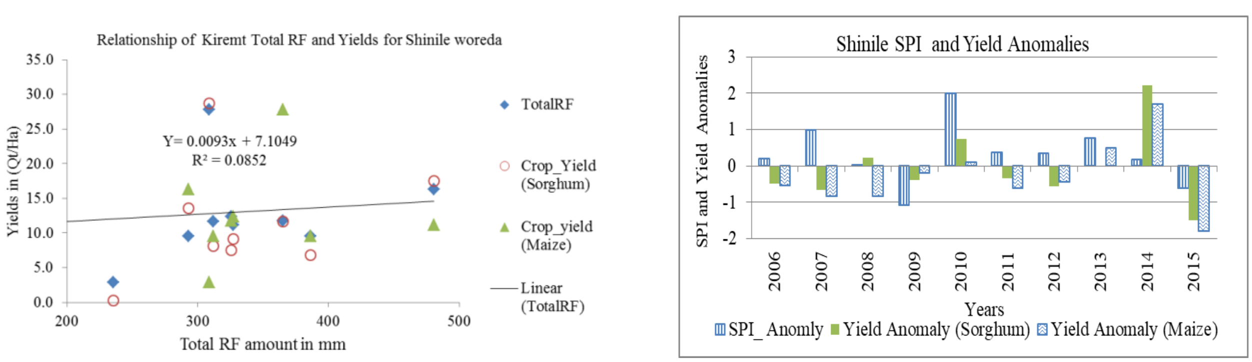

Figure 4. 17 Relationship of RF with Yields and SPI with Yields Anomalies

As the above result shown from Figure 4.15, the sorghum yield anomaly of Deder woreda from the period of 2009 to 2016, there was low yield in the years 2009 and 2015; whereas, there was high yield performance in the years 2010, 2014 and 2016 and others years were medium. Its coefficient of variation was 28% i.e. there was moderately variable. In Figure 4.25, the Maize yield anomaly of Deder woreda, from the period of 2009 to 2016, there was low yield in the years 2011, 2012 and 2015; whereas, there was high yield performance in the years 2010, 2013, 2014 and 2016. As it can be seen above the RF showed a coefficient of variation ranging from 70.8 – 139.0 % and maize crop coefficient of variation was 69% i.e. there was maize yield highly variable than Sorghum yield. This indicates that there was highly variation of RF.

As it can be seen from Figure 4.16, the Maize yield anomaly of Fedis woreda from the period of 2009 to 2016, there was high yield in the years 2009, 2013, and 2014; whereas, there was low yield performance in the years 2009, 2012, 2015 and 2016 and others years were medium. Its coefficient of variation was 58% i.e. there was highly variable yield. Figure 4.26 the sorghum yield anomaly of Fedis woreda, from the period of 2009 to 2016, there was low yield in the years 2012, 2015 and 2016; whereas, there was high yield performance in the years 2010, 2013 and 2014. Its coefficient of variation was 66% i.e. there was highly variable than Maize yield.

In the Figure 4.17, the Maize yield anomaly of Shinile woreda, from the period of 2009 to 2016, there was low yield in the years 2007, 2008, 2011 and 2015; whereas, there was high yield performance in the years 2013 and 2014 and others years were medium. Its coefficient of variation was 58% i.e. there was highly variable yield. The sorghum yield anomaly of Shinile woreda from the period of 2006 to 2015, there was high yield in the years 2008, 2010 and 2014; whereas, there was low yield performance in the years 2007, 2012 and 2015. Its coefficient of variation was 66% i.e. there was highly variable than Maize yield.

4.6 Spatial Pattern of RF Distribution in Fedis, Deder and Shinile woredas

As it can be seen from Figure 4.18 (A), the annual spatial distribution of RF coverage increased both from Western part of Fedis woreda that is large portion of woreda covered no drought from long term mean annual RF (470 mm), and from North to central part of Fedis was shown slight RF distribution and small areas was shown decreased RF or moderate drought the existence of some RF performance (Figure 4.18 (A)). The annual spatial distribution of RF coverage was decreased or high drought frequency mainly concentrated in the Eastern some areas of Fedis.

From Figure 4.18 (B), the spatial pattern of most parts of the areas was slight decreased RF and the mean RF amount was (178 mm) from Northern to South parts of the District and also some areas the RF coverage increased in the North Western; and the RF coverage was shown decreased in some areas in the Eastern parts of the district. From Figure 4.18 (C), the spatial pattern of most parts of the areas the RF distribution was slightly decreased and the mean RF amount was (238 mm) in the North central parts of the District and also there was increased in some areas in the North Western and some areas in the Eastern parts of the district.

As the result can be seen from Figure 4.18 (D), the annual spatial distribution of RF increased in the Eastern part of Deder woreda that is large portion of woreda (was shown wet) from long term mean of annual RF (754 mm); whereas, in the Western and central parts of Deder, the RF distribution slightly decreased; and it also decreased in the Western tip and Southern tip. From Figure 4.18 (E), the Belg (Feb-May) the RF distribution was the same as annually RF distribution occurrence and the long term mean of Belg RF amount was 239 mm. From Figure 4.18 (F), the Kiremt (Jun-Sep), there was good RF performance in the South Eastern parts of Deder; whereas, from central to Western parts of Deder, there was slightly decreasing of RF performance and the long term mean of Belg RF amount was 456 mm.

As the result can be seen from Figure 4.18 (G), the annual RF distribution decreasing expanded from North to central and Eastern part of Shinile woreda that is large portion of woreda covered shortage of RF (was shown dry) from long term mean of annual RF (639 mm); whereas; it was increased from central to South parts of Shinile (wet area). From Figure 4.18 (H and I), the Belg (Feb-May) and the Kiremt (Jun-Sep) drought frequency were the same as annually RF distribution occurred and the long term mean of Belg and Kiremt RF amount were 258.9 and 292.9 mm respectively.

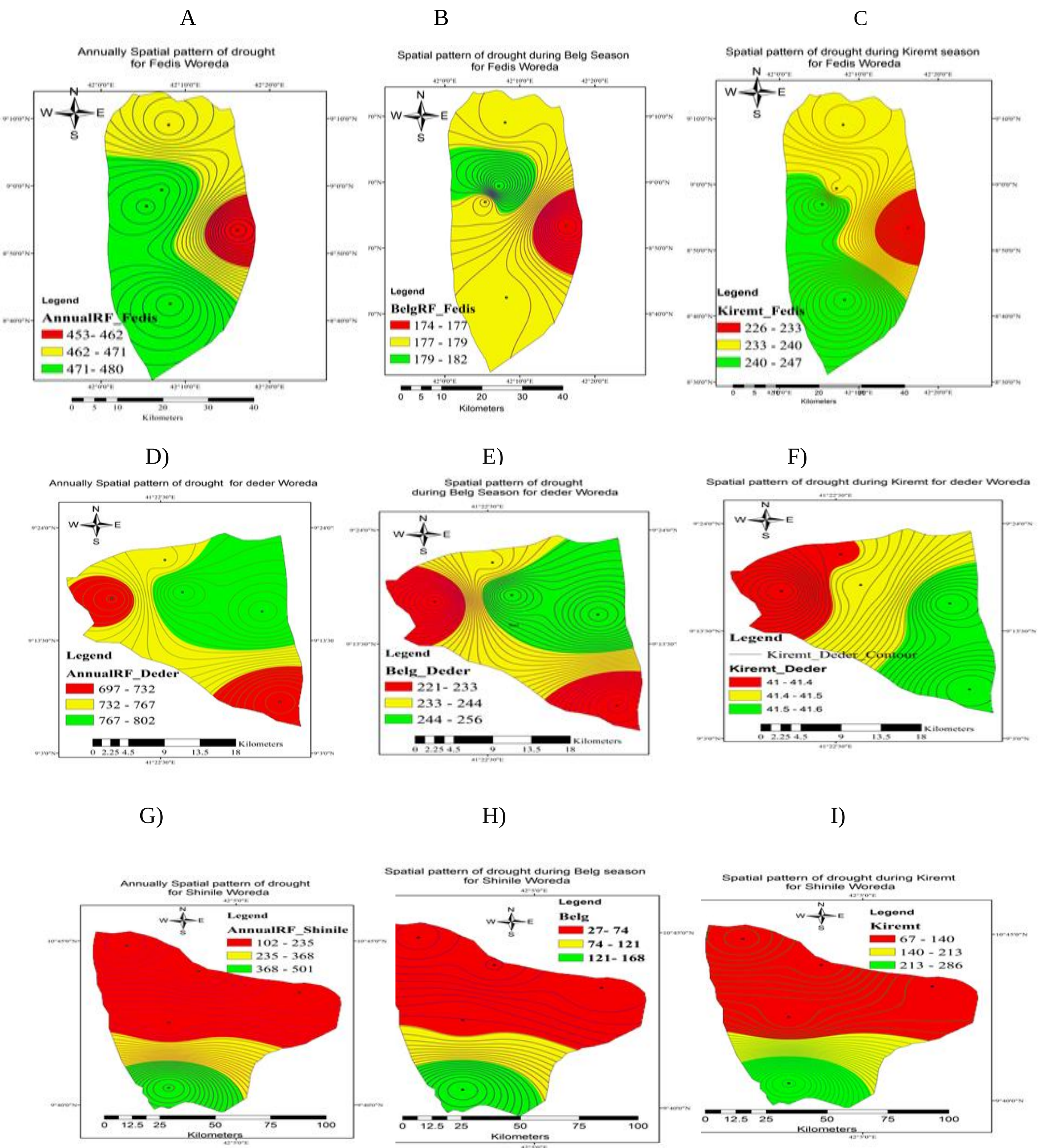

Figure 4. 18 Annually, Belg and Kiremt Spatial coverage of RF for Fedis, Deder and Shinile

4.7 Spatial pattern of drought for study areas expressed in SPI index

As shown below from Figure 4.19 (A), the SPI index of annually (Jan-Dec) result most areas of the district was wet (no drought) in the South Western areas; from North to central part of areas was shown slight drought; whereas, some areas in the Eastern part was shown the most drought (moderate drought). From Figure 4.19 (B), most areas during Belg (Feb-May) was shown slight drought in the Northern; and South Western parts of areas and some areas in Eastern parts of Fedis was moderate drought; whereas, from central to Western parts of Fedis was shown wet (areas had no drought). From Figure 4.19 (C), most areas during Kiremt (Jun-Sep) also covered by slight drought in the Northern and central parts of Fedis; and some areas in Eastern parts of Fedis was moderate drought; whereas, in the South Western parts of Fedis was shown wet (areas had no drought).

The study have be seen as the following Figures by using SPI index anomaly most of the results was observed the same as the above observed Figures but for further explanation from Figure 4.19 (D), annually spatial pattern most of areas was shown no drought (low drought frequency) from Eastern to the central parts of areas; whereas, from South to West part of Deder were observed slight to moderate drought. From Figure 4.19 (E), Belg season spatial pattern in SPI index most of area was shown wet (no drought); from central to South and Western part of areas in SPI index were observed slight to moderate drought respectively. From Figures 4.19 (F), Kiremt season spatial pattern in SPI index most of areas was shown wet (no drought) Eastern to Central part of areas; from Western part of areas in SPI index was observed slight drought and moderate drought was observed in the Southern parts of areas.

The study have be seen as the following Figures, by using SPI index anomaly most of the results were observed the same as the above observed Figures but for further explanation from Figure 4.19 (G), annually spatial pattern small areas of Shinile woreda was shown no drought (low drought frequency) in the South parts of areas; whereas, from South to North tip part of Shinile were observed slight to moderate drought respectively. In this time large portion of areas was covered by moderate drought and more drought patterns during Kiremt and Belg seasons was shown similar to Figures 4.19 (H and I).

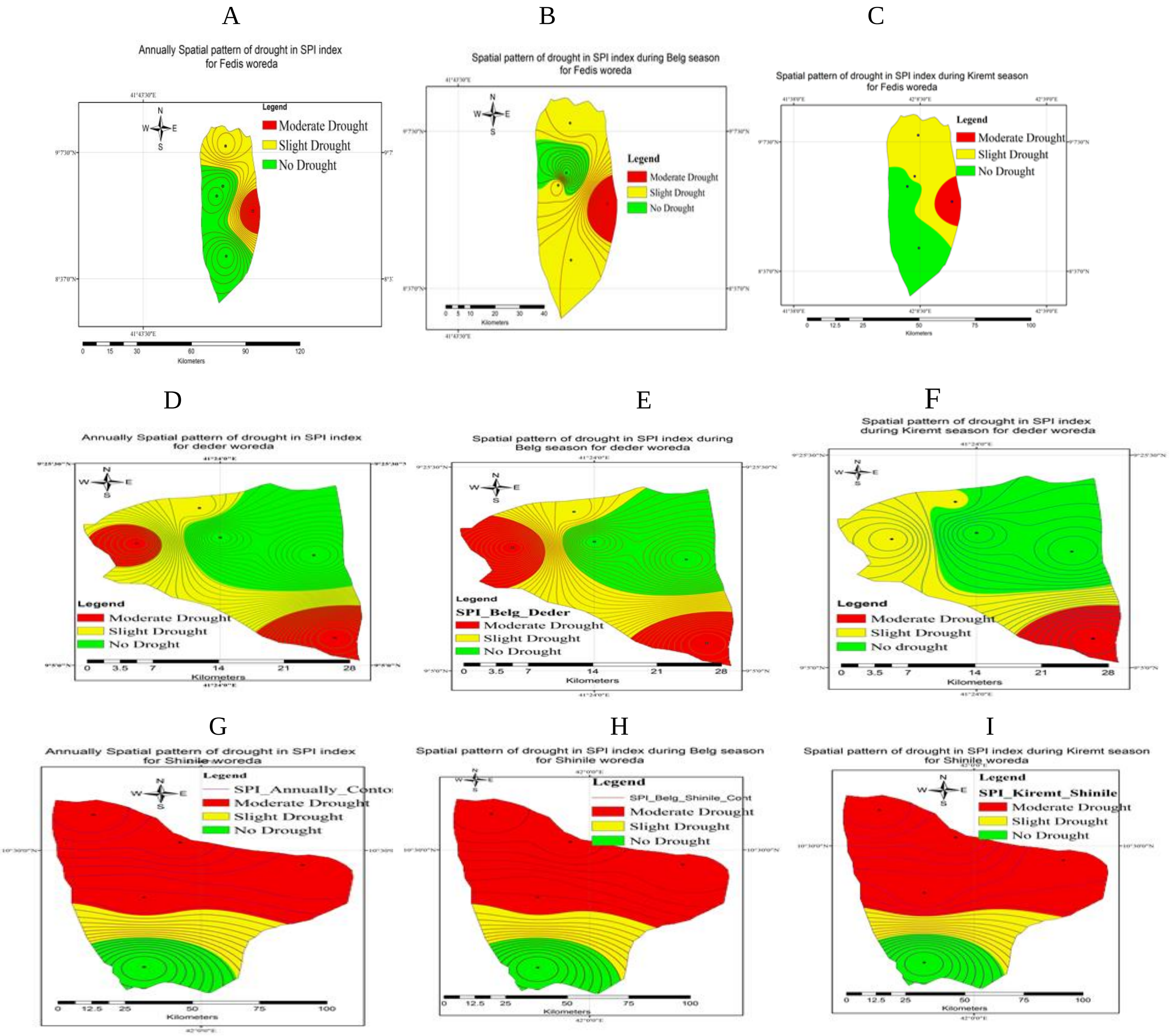

Figure 4. 19 Spatial pattern of drought severity for Fedis, Deder and Shinile expressed in SPI index

4.8 Spatial pattern of Crop production in study areas

The spatial pattern of maize crop productivity, in Fedis woreda, for the period of 2009 to 2016 from Figure 4.20 (A), there was shortage of grain (moderate drought) due to decreasing of precipitation in the South Eastern and Northern parts of District specially in the years 2009, 2012 and 2015; whereas, in the central and Western parts of area was attained slight grain and some area in Western was good rain (no drought). On the other way, the spatial pattern of Sorghum yield productivity in Fedis woreda showed that the same pattern as that of Maize Figure 4.20 (B).

The spatial pattern of maize crop productivity in Deder woreda for the period of 2009 to 2016 (Figure 4.20 (C)), there was shortage of grain (very drought) due to decreasing of precipitation in the Eastern some area and from North expanded to Southern parts of District; there was also some shortage of grain (moderate drought); from North to Western parts of area was covered by slight shortage of grain (slight drought) to good grain (no drought) respectively. On the other way in Figure 4.20 (D), the Sorghum yield productivity of the spatial pattern in Deder woreda was very poor grain yield (very drought) in the South tip; there was also some shortage of grain expanded from Eastern to Western in range slight shortage of grain (slight drought) to good grain (no drought) was observed respectively.

The spatial pattern of maize crop productivity, in Shinile woreda, for the period of 2006 to 2015 (Figure 4.20 (E)), there was shortage of grain (very drought) due to decreasing of precipitation in most parts of area from South to Eastern and Western. From North expanded to central parts of District, there was also covered by slight shortage of grain (slight drought) to good grain (no drought). On the other way in Figure 4.20 (F), the Sorghum yield productivity, of the spatial pattern was very poor grain yield (very drought) in the south tip of part to Eastern and Western, slight shortage of grain (slight drought) to good grain (no drought) was observed in the North Eastern to Central parts of area respectively; but this area was better for sorghum yield than maize due to shortage of precipitation. On the other way, in SPI index, the areas affected by drought was no drought (Yield Anomaly>0.0 Green), Slight drought (Yield Anomaly 0.0 to -0.99 Yellow), Moderate drought (Yield Anomaly -1 to -1.49 Red.

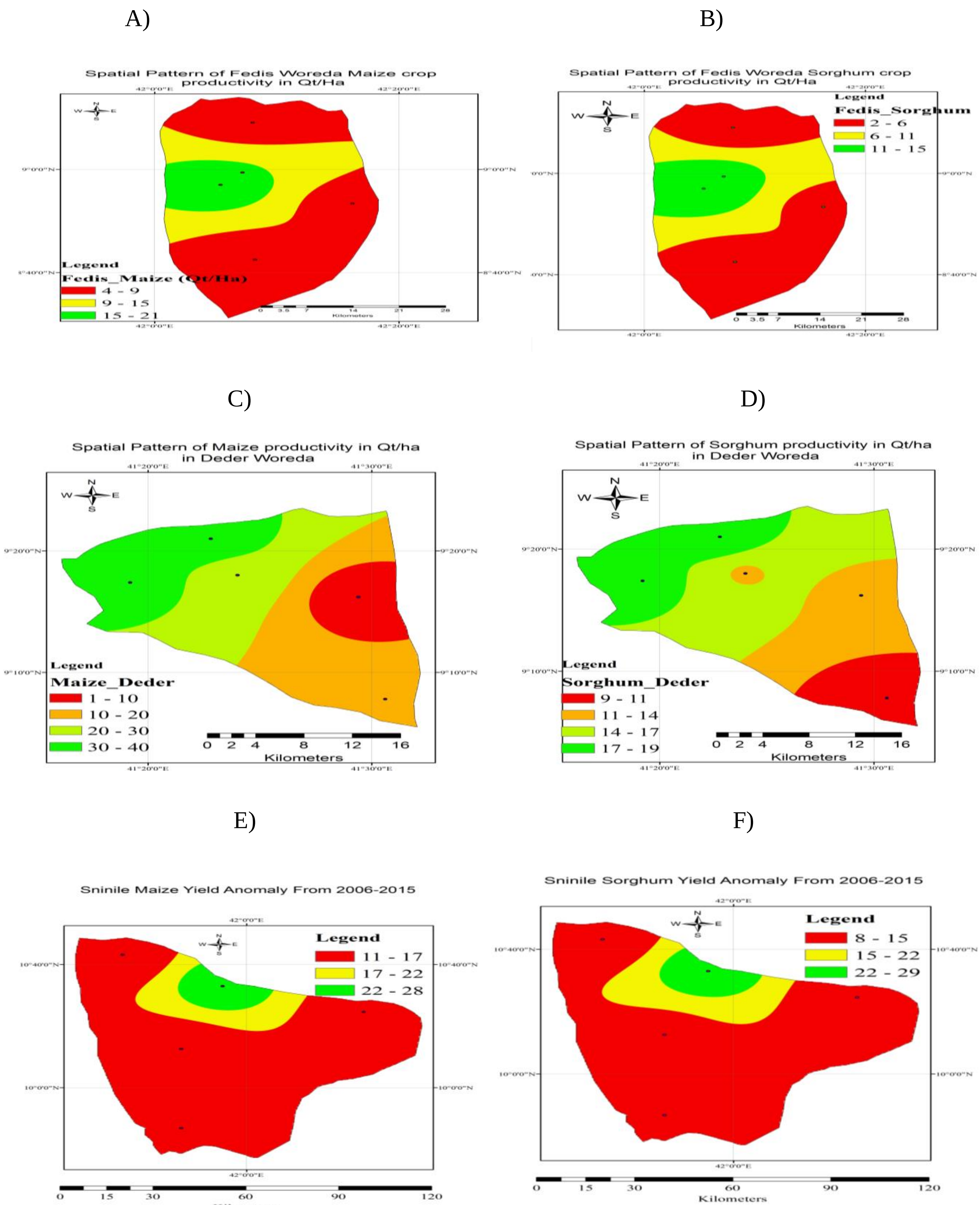

Figure 4. 20 Maize and Sorghum crop yields of Fedis, Deder and Shinile woredas

4.9 Percent of Normal (PON) for Fedis, Deder and Shinile Woredas

The precipitation for a specific location is considered that the rain fall amount is excess 125% that is above normal, the rainfall is between 75-125% that is normal and the rain fall is less than 75% that is below normal and rain fall is below 50% that is much below normal (Thornthwaite, 1948; Mather, 1978; 1979).

The precipitation distribution of Fedis woreda, in PON index, during annually from Figure 4.1 (A): some areas in the Eastern was observed moderate drought, slight drought was observed from Eastern to expand to North wards; whereas, also wet or no drought was covered by large areas from South to Western areas. From Figure 4.21 (B), during Kiremt (Jun-Sep) season, the PON index was observed no drought (wet area) in small areas in the Eastern; whereas, the slight drought expanded from central to North wards and moderate drought was expanded from Western to South parts of area. From Figure 4.21 (C), during Belg (Feb-May) season, the PON index observed moderate drought small areas in the Eastern; whereas, the slight drought was covered most areas and it expanded from North to South wards and no drought (wet area) observed in Western and central parts of area.

The precipitation distribution of Deder woreda, in PON index, during annually from Figure 4.21 (D): some small areas in the Western and Southern tip was observed moderate drought; slight drought was observed in the North and Western areas; whereas, also wet or no drought was covered large areas from Eastern to central areas. From Figure 4.21 (E), during Kiremt (Jun-Sep) season, moderate drought observed in small areas in the South and the slight drought expanded from South to West wards; whereas, no drought (wet area) was expanded from North to central parts of area. From Figure 4.21 (F), during Belg (Feb-May) season, the index showed moderate drought over small areas in the Western and South; and the slight drought was covered in the Southwestern and North; whereas, no drought (wet area) was expanded from North to central parts of area.

The precipitation distribution of Shinile woreda, in PON index, during annually from Figure 4.21 (G): large areas in the Northern, Eastern and central was observed moderate drought; the slight drought was observed in the North and Western areas; whereas, no drought (wet area) was observed in the South small area. From Figure 4.21 (H and I), during Kiremt (Jun-Sep) and Belg (Feb-May) seasons, the PON index was observed the same features that during annually occurred.

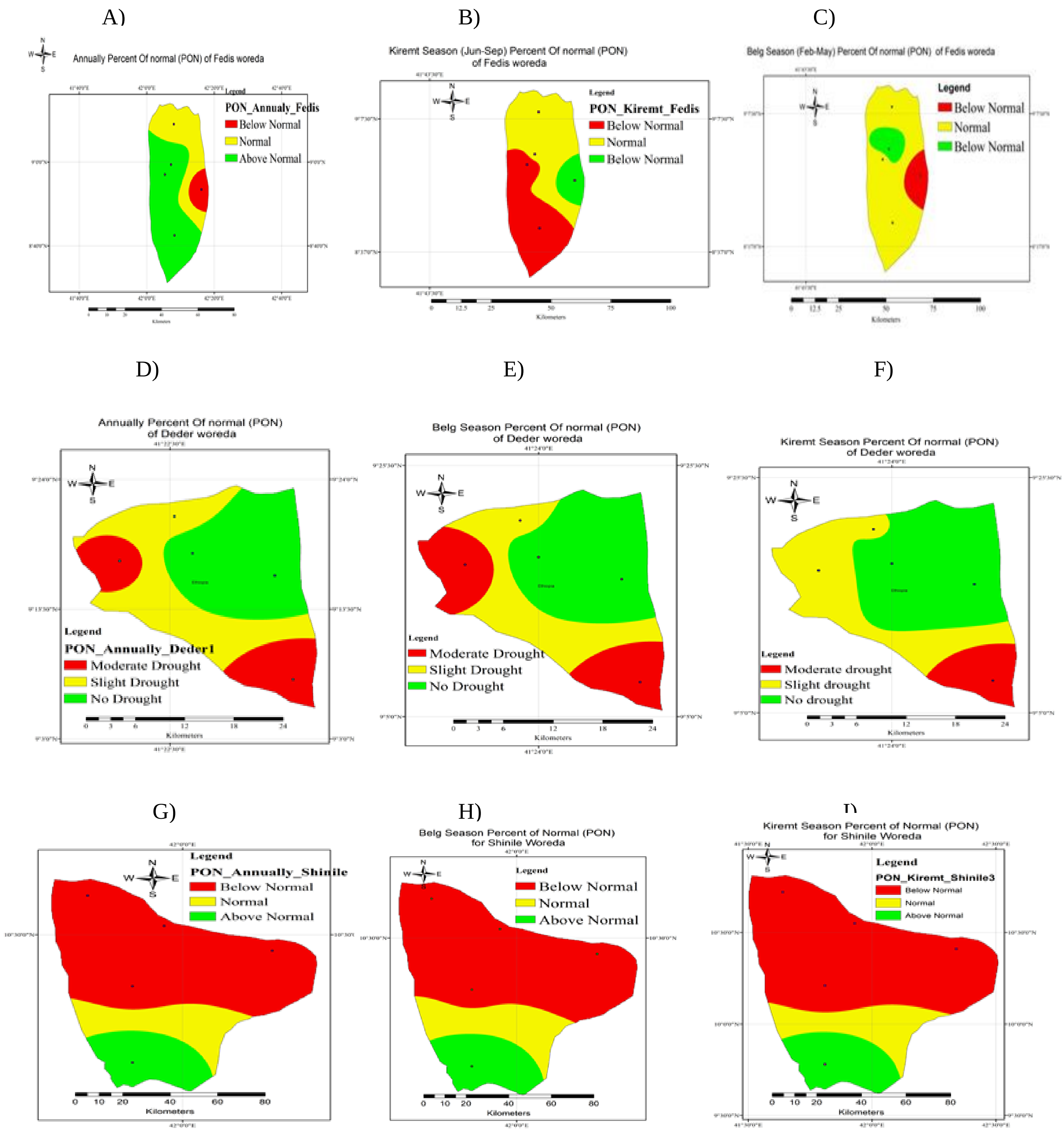

Figure 4. 21 Annual, Kiremt and Belg seasons of study areas expressed in PON Index

4.10 Temporal and Spatial characteristics of MD in NDVI Index

4.10.1 Spatial NDVI, RF and NDVI with Yields reduction in Shinile and Deder

It can be observed from the map depicted in the Figure 4.22, that some very small areas in Shinile were hit by slight and moderate MD while the majority of the areas under the influence of severe and very severe level of MD. The total area was hit by no drought, slight, moderate, severe and very severe level of severity respectively during 1996 to 2014 cropping season; and the distribution of rainfall might be another factor that affected the response of vegetation to the existing rainfall. During Belg (February – May) and Kiremt (June – September), NDVI index was shown severe drought to very severe drought in South –Western parts of area. This may be due to long intra seasonal dry spell or bad distribution of rainfall that affect the growth and development of vegetation. This resulted from mismatch between seasonal rainfall distribution and crop water requirement at critical developmental stages. In Kiremt (June – September), NDVI index was shown severe drought in small areas in the East; whereas in Belg (February – May) the index was shown no drought in the East. In the Northern Parts of areas was shown from moderate to slight drought. The yield of agricultural production was the main ground truth data. Therefore, it is crucial to analyze the trends of NDVI anomaly and yields to quantify the impact of meteorological drought on agricultural production.

In view of Figure 4.23, in Shinile, the lowest vegetation coverage was -178 percent during belg season in 2004; whereas, the highest vegetation coverage also was 160 percent in 2002; but, in this season the sorghum yield was not grown in this area. In this Figure, the lower maize yield reduction was 1996 and 2005 with -10 and 0 percent respectively; whereas, the highest yield reduction was recorded 100 percent in the year 2001. The highest RF was 480 mm in 2010; whereas, the lowest RF was 30 mm in 2000. During Kiremt season, the highest NDVI (vegetation coverage) recorded in 2001 with the percent 200% (no drought); whereas, the lowest NDVI was in the years 2000 and 2009 with the percent -170% (very severe drought). The highest maize and sorghum reduction were in 2009 with 80 percent and 50 percent respectively; whereas, the lowest maize and sorghum reduction were in1996 with 45 percent and 25 percent respectively. The highest RF was 490 mm in 2000; whereas, the lowest RF was 185 mm in 2009. So, the maize yield reduction was better than sorghum yield and also the trends of NDVI and RF decreased with time; but the trend of yields reduction increased with time in two seasons.

In view of Figure 4.24, the NDVI spatial coverage in Belg season, was in range from severe to very severe drought for some small areas in the East Deder; whereas, large areas was covered by the range slight to moderate drought. During Kiremt season, the NDVI spatial coverage was in range severe to very severe drought small areas and large areas in the North and East respectively. Other areas was covered by in range no drought to moderate drought (Figure 4.24). As it can be seen from Figure 4.25, during Belg season, the highest NDVI was recorded in 2008 with the percent of 140%; whereas, the lowest NDVI was recorded in 1998 with the percent -200 %; Within line this, the highest yield reduction of sorghum and maize was recorded in 1998 with the percent of 50 and 70% respectively; whereas, the lowest yields reduction were recorded in 1996 with the percent of 5% and 10% respectively. The highest RF was recorded 860 mm in 1997; whereas, the lowest yields RF were recorded 95 mm in 2009.

In this Figure (Figure 4.25), during Kiremt season, the highest NDVI was recorded in 1997 with the percent of 240% (No drought); whereas, the lowest NDVI was recorded in 2000 with the percent of -200% (very severe drought); in line With this, the highest yield reductions of sorghum and maize were recorded in 2001with the percent of 50 and 32% respectively; whereas, the lowest yields reduction of sorghum and maize were recorded in 1996, 1999, 2006, 2007, 2010 with the percent of 0%. The highest RF was recorded 985 mm in 1999; whereas, the lowest RF were recorded 270.1 mm in 2010. The trends of NDVI and RF decreased with the time; whereas, yields reduction increased with the time. In this area, the maize yield reduction was higher than sorghum yield in Kiremt season; whereas, the sorghum yield reduction was higher than maize yield in Belg season. So, the farmers should be sowing sorghum yield in Kiremt and maize yield in Belg to reduce drought impacts.

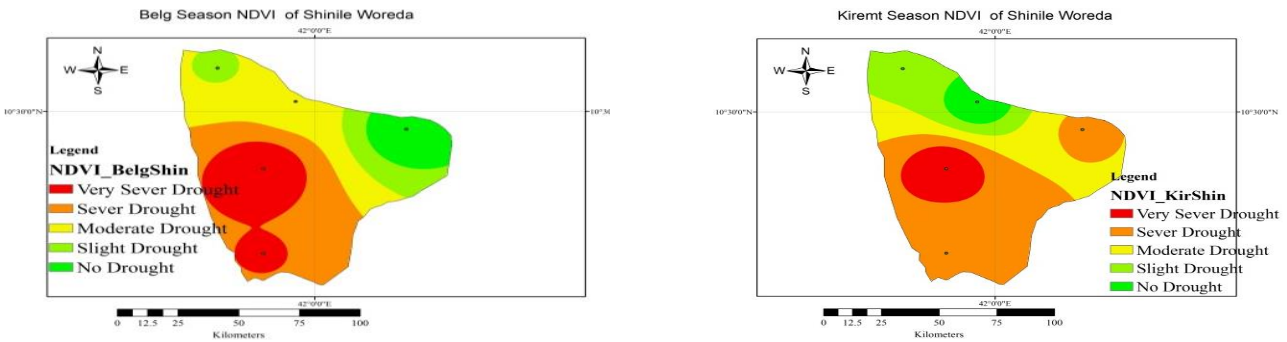

Figure 4. 22 Belg and Kiremt Seasons NDVI coverage for the period of 1996 – 2014

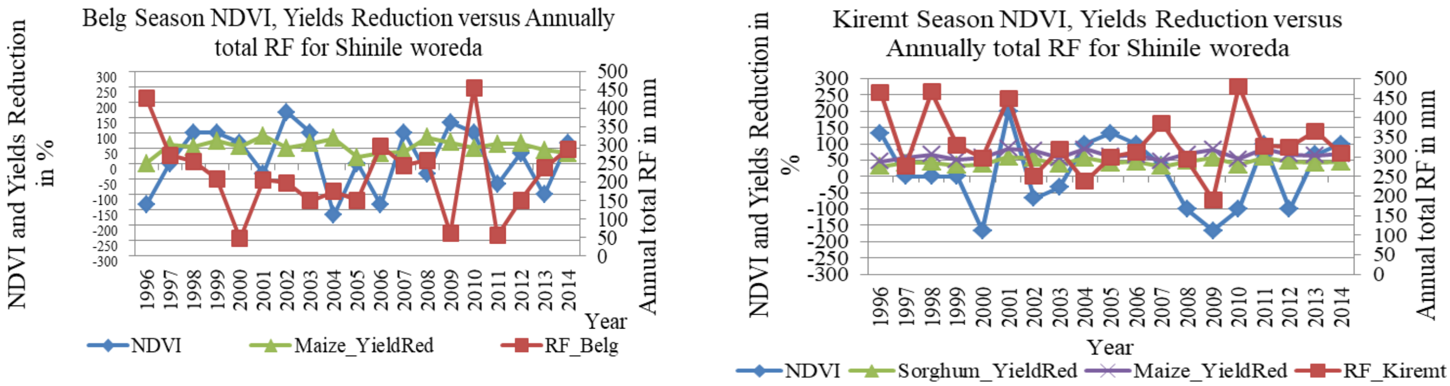

Figure 4. 23 Belg and Kiremt seasons NDVI, Yields reduction versus Total RF

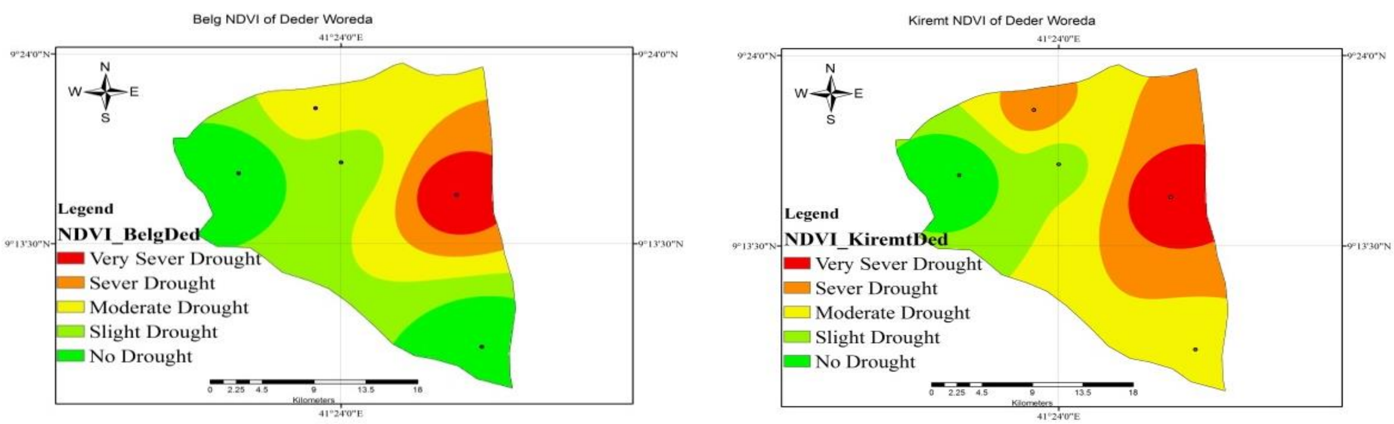

Figure 4. 24 Belg and Kiremt Seasons NDVI coverage for the period of 1996 – 2014

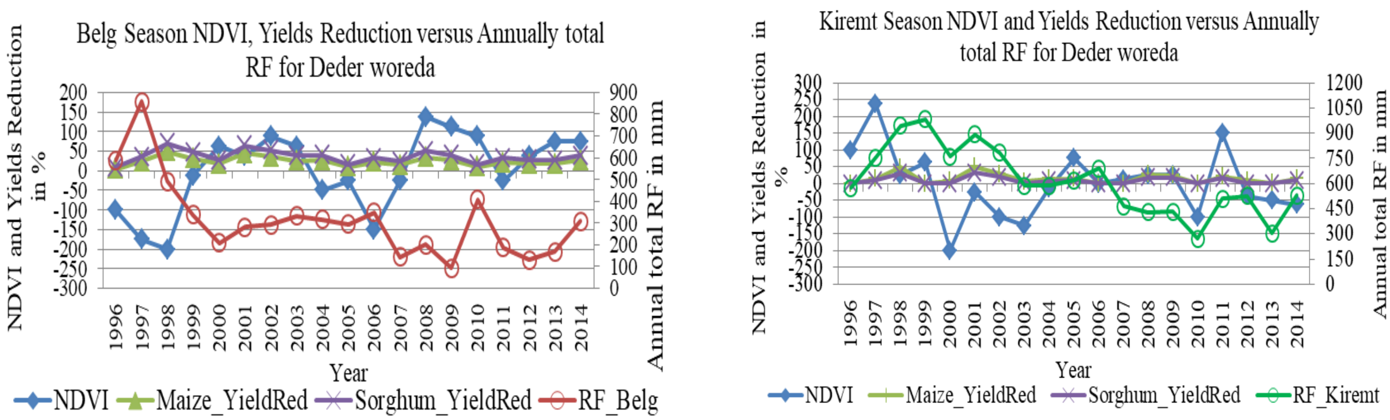

Figure 4. 25 Belg and Kiremt seasons NDVI, Yields versus Total RF

4.10.2 Spatial NDVI and yields reduction with NDVI index for Fedis

According to the result from Figure 4.26 (A), during Belg season, the large areas were covered by severe to very severe drought in the South Western and South Eastern areas; whereas, other small area was covered by in range from moderate drought to no drought in the North areas. Figure 4.26 (B), during Kiremt season, large areas were covered by in range moderate drought to no drought in the South Eastern and North Eastern areas respectively; whereas, small areas in the West were covered by severe to very severe drought.

In view of Figure 4.27, during Belg season, the highest vegetation coverage (NDVI) recorded in 2002 with the percent of 220%; whereas, the lowest vegetation coverage (NDVI) recorded in 1998 with the percent of -270%. In this season, the highest maize and sorghum yields reductions were in 2008 with the percent 60% for two yields; whereas, the lowest maize and sorghum yields reductions were zero percent in the years 1996, 1997, 2003, 2007, 2010, 2013. The highest RF was recorded 420 mm in 2014; whereas, the lowest RF were recorded 200 mm in 2005. The trends of NDVI and RF increased with the time; whereas, yields reduction trends decreased with the time. In this Figure (Figure 4.27), during Kiremt season, the highest vegetation coverage (NDVI) was recorded in the years 1996 and 2007 with the percent of 180% (No drought); whereas, the lowest NDVI was recorded in the years 2002 and 2009 with the percent of -220% and -290% (very severe drought) respectively; in line With this, the highest yield reductions of maize and sorghum were recorded in the years 2002 and 1998 with the percent of 40 and 60% respectively; whereas, the lowest yields reduction of maize and sorghum were recorded in 1996 and 2007 with the percent of 0%. The highest RF was recorded 290 mm in the years 1996; whereas, the lowest RF were recorded 10 mm in 2010. The two parameters (NDVI and RF) were better performance in Belg season than Kiremt season. The trends of NDVI and RF decreased with the time; whereas, yields reduction trends constant with the time (30%). In this area, the sorghum yield reduction was higher than maize yield in Kiremt season; whereas, the maize yield reduction was higher than sorghum yield in Belg season. So, the farmers should be sowing maize yield in Kiremt and sorghum yield in Belg to reduce drought impacts.

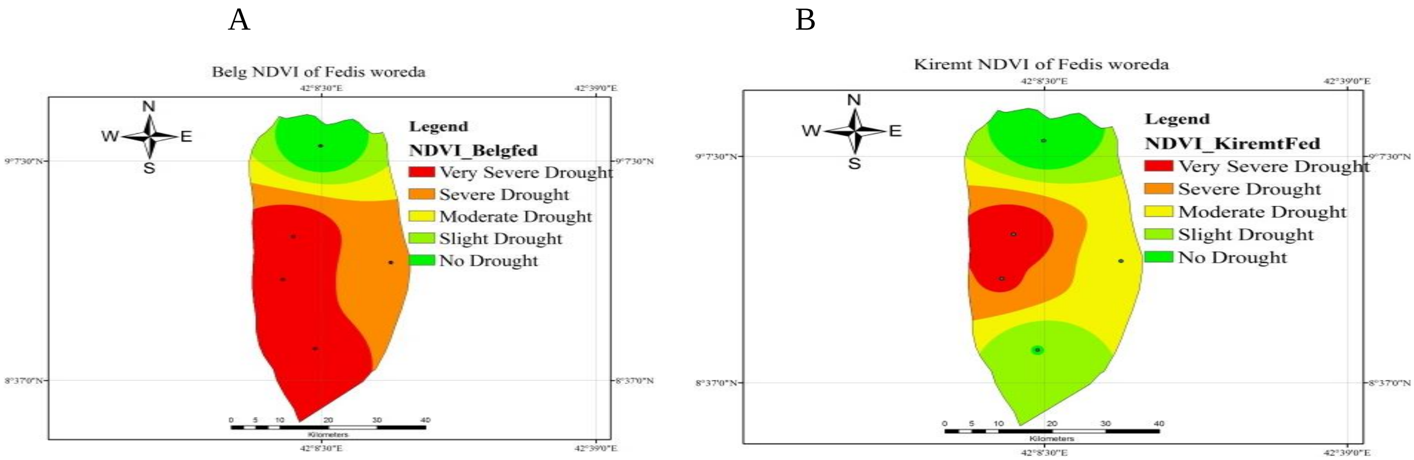

Figure 4. 26 Belg and Kiremt Seasons NDVI coverage for the period of 1996 – 2014

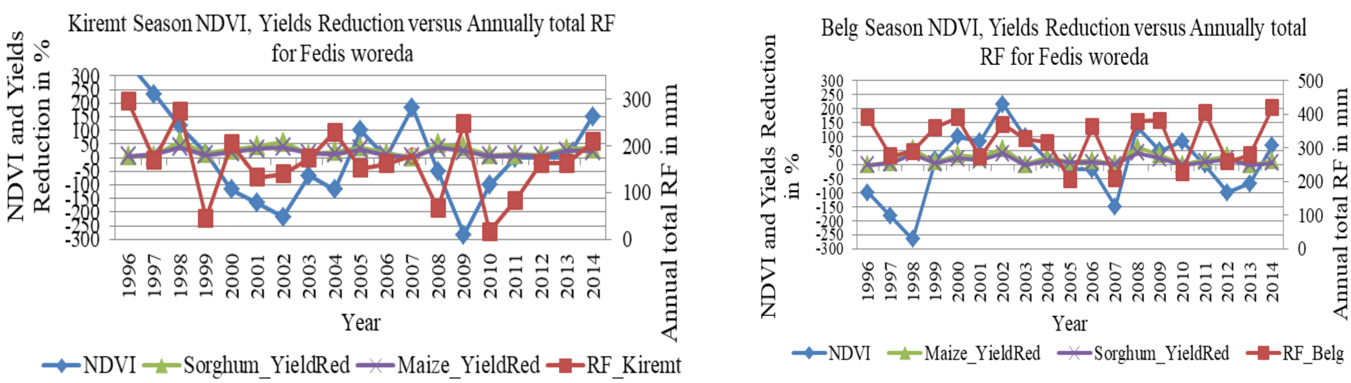

Figure 4. 27 Belg and Kiremt seasons NDVI, Yields versus Total RF

4.11 Temporal and Spatial Characteristics of MD Using WRSI

4.11.1 Spatial WRSI and yields reduction with WRSI for Shinile and Deder

The performance of crops of yields growing in the study areas estimated using WRSI index, for the period of 1996 to 2014. According to the result spatially depicted in Figure 4.28, during Belg season, the MD was prevalent in South and East parts of large areas (class revealing that less than 50%). According to Smith (1992) cited in Senay and Verdin (2002), seasonal WRSI value less than 50% is regarded as a complete crop failure condition due to moisture deficit. As the result, the index has revealed that high yield loss encountered in the area due to MD.

In view of Figure 4.28, during Kiremt season, MD was shown severe to very severe drought in Eastern some areas; whereas, large areas were in range from no drought to moderate drought in South, Central and Northern parts of areas.

According to the result from Figure 4.29, during Belg season, the highest and the lowest WRSI values were recorded in 1996 and in 2001 with the percent of 100% and 30% respectively. In line with this, in this season, the lowest maize yield was 0% in 1996 and 2010; whereas, the highest maize yield was recorded in 2001 with percent of 90%; so, the trend of WRSI were increased but the maize yield reduction decreased with the time r; and in this season the sorghum yield was not grown in this area.

As the result was shown from Figure 4.29, during Kiremt season, the highest and lowest WRSI values were recorded 80% and 40% in 1996 and 2007, and 2001 respectively. In this season, the maize and sorghum yields reduction were recorded less than 90% (in 2001) and 60% (in 2001 and 2011) respectively. This area was more suitable for sorghum production than maize production. In line with this, the trends of WRSI decreased; but, the yields reduction increased with the time. The drought in Kiremt season decreased than Belg season.

According to the result spatially depicted from Figure 4.30, during Belg season, some areas in South tip and North Western Deder was covered by severe to very severe drought (high moisture deficit); whereas other large areas were covered by in range no drought to moderate drought in Central, West and East.

In view of Figure 4.30, during Kiremt season, large areas were covered by no drought to slight drought; whereas, small areas in the North tip parts of areas were covered by in range moderate drought to severe drought. So the moisture stress for this area was more decreased in Kiremt season than Belg season.

Based on the result depicted from Figure 4.31, in Belg season, the highest and lowest of WRSI values were recorded in the years 1996, 2003, 2010, 2013 (with the percent of 100%) and 1998,2002 and 2008 (with the percent of 50%) respectively. In line with this, the sorghum and maize yield reduction were less than 70% and 50% respectively.

In view of Figure 4.31, during Kiremt season, the WRSI values were lower in the years 1998 and 2001(with the percent of 60%); whereas, the WRSI values were higher in the years 1996, 1999, 2006, 2007, 2010 and 2013 (with the percent of 100%). In line with this, the maize (50%) and sorghum (30%) yield reduction were highest (for both yields) in the years 1998 and 2001; whereas, the lowest yields reduction were 0%; and the trends of WRSI were increased; but, yields reduction decreased with time in both seasons.

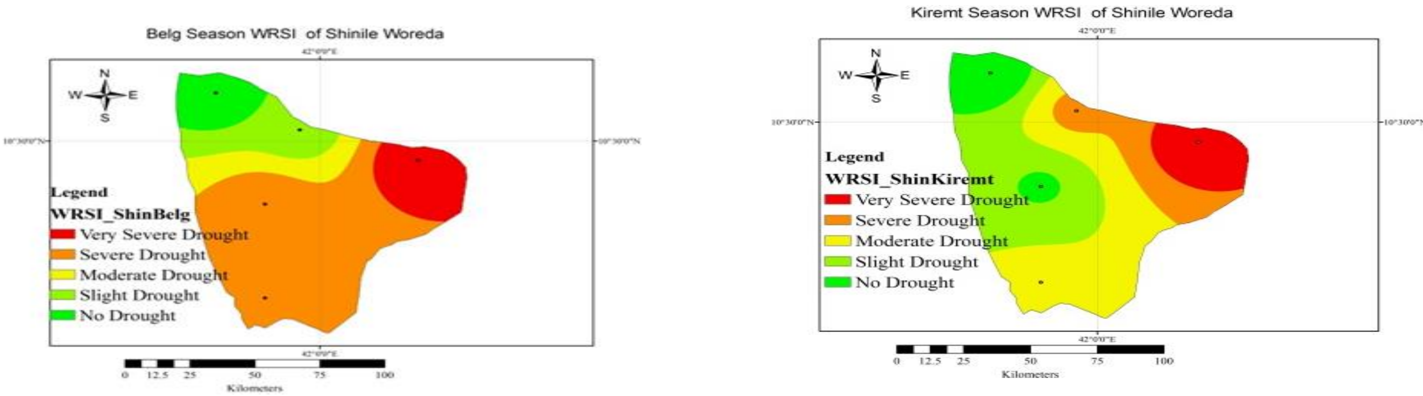

Figure 4. 28 Belg and Kiremt Seasons WRSI coverage for the period of 1996 – 2014

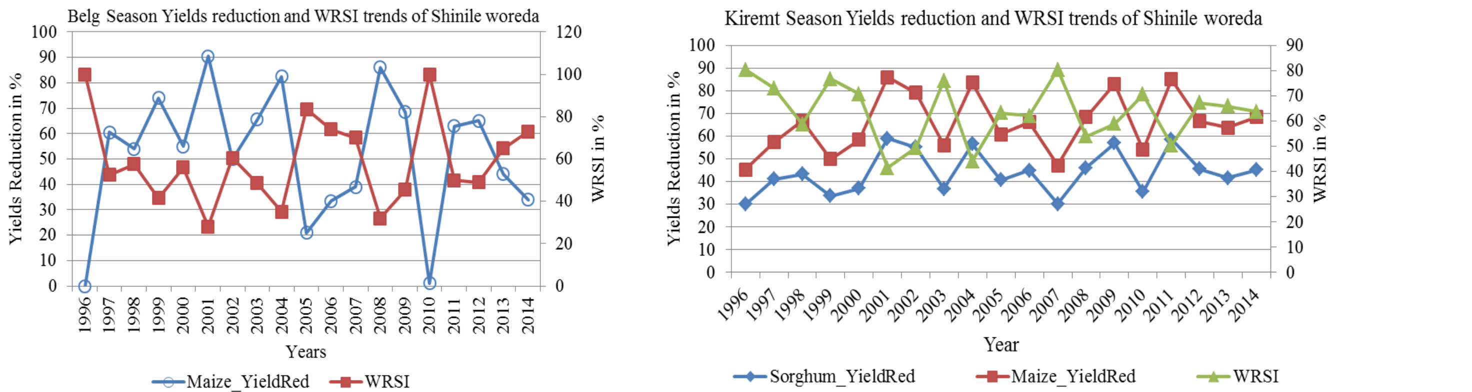

Figure 4. 29 WRSI with Yields reduction trends of Belg and Kiremt Seasons

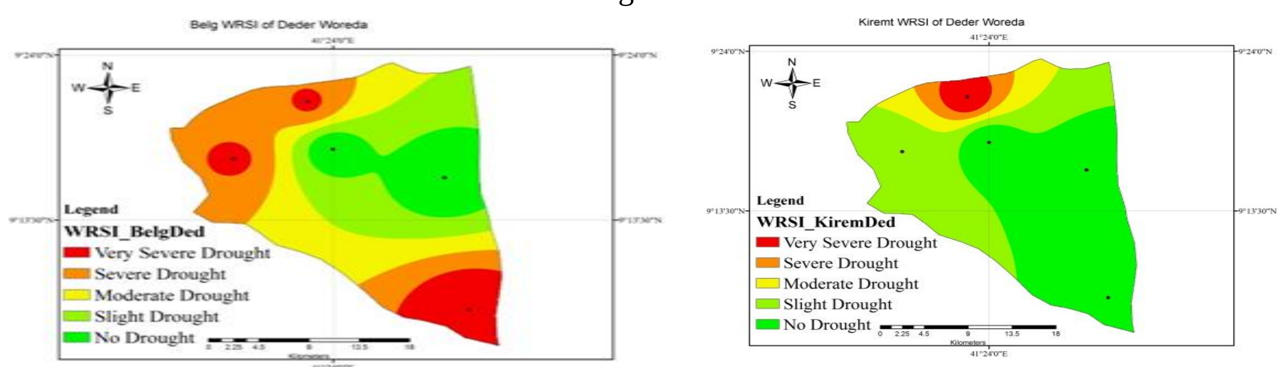

Figure 4. 30 Belg and Kiremt Seasons WRSI coverage for the period of 1996 – 2014

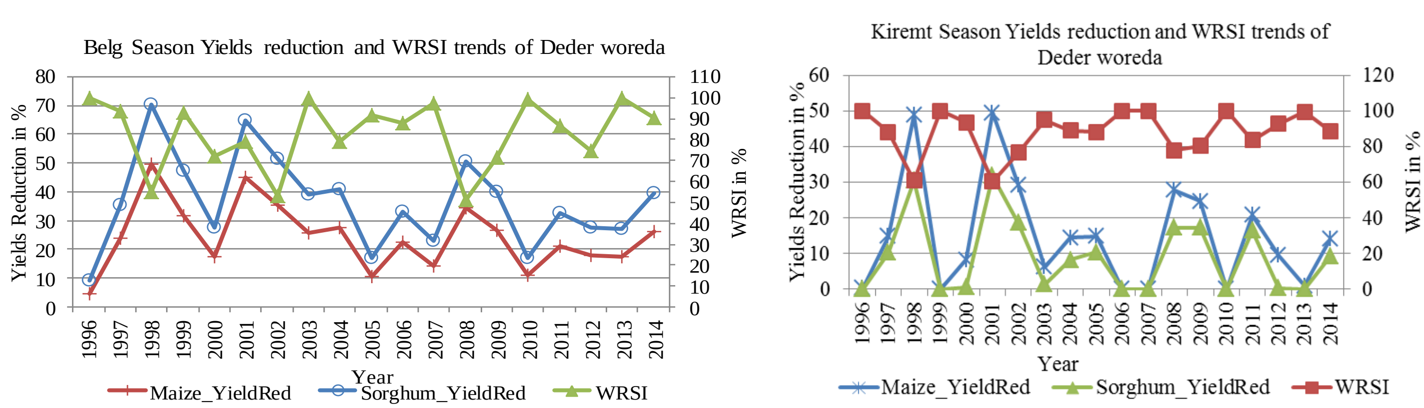

Figure 4. 31 WRSI with Yields reduction trends of Belg and Kiremt Seasons

4.11.2 Spatial WRSI normal and yields reduction with WRSI for Fedis

According to the result that spatially depicted in Figure 4.32, during Belg season, large areas were covered by the WRSI in range no drought to moderate drought (less moisture deficit) in South, central, East and North; whereas, small areas in West covered by severe and very severe drought.

In view of Figure 4.32, during Kiremt season, in South Western large areas were covered by severe and very severe droughts; whereas, much areas in North Eastern were covered by in range no drought to moderate drought. In this season, the drought frequency was more increased than Belg season for this area.

Based on the result that depicted in Figure 4.33, during Belg season, higher WRSI values were recorded in the years 1996, 1999, 2003, 2007, 2010 and 2013 with the percent of greater than 90%; whereas, lower WRSI values recorded in the years 1998, 2002 and 2008 with the percent of less than 60%. In line with this, higher maize and sorghum yields reduction were recorded in the years 1998, 2002 and 2008 (with the percent of greater than 60% and greater than 45% respectively); whereas, lower maize and sorghum yields reduction were recorded in the years 1996, 2003, 2007, 2010 and 2013 (with the percent of 0%).

In the last view of the result that depicted in Figure 4.33, during Kiremt season, the highest and the lowest WRSI values were recorded in the years 2007 and 1998 with the percent of 95% and 55% respectively. In this season, lower WRSI values were recorded in the years 1998, 2002 and 2008; whereas, higher WRSI values were recorded in the years 1996,1999, 2007, 2010 and 2012 with the percent of greater than 80%. In line with this, the sorghum and maize yields reduction were recorded less than 60% and 40% respectively. The highest of sorghum and maize yields reduction were recorded in the years 1998 with the percent of 60% and 40% respectively; whereas, the lowest values of these yields were recorded in the years 2007 with the percent of 0%. In general, trends of WRSI were increased; but yields reduction decreased with the time that temporally depicted in two seasons.

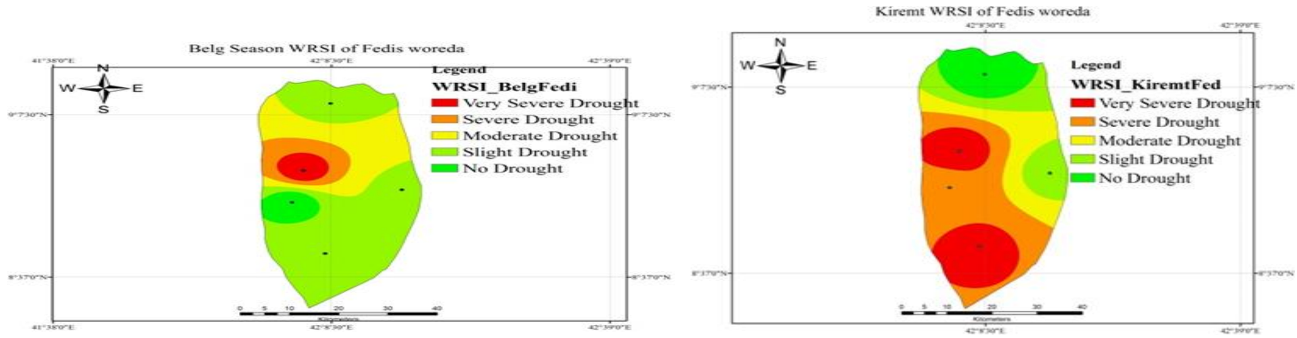

Figure 4. 32 Belg and Kiremt Seasons WRSI coverage for the period of 1996 – 2014

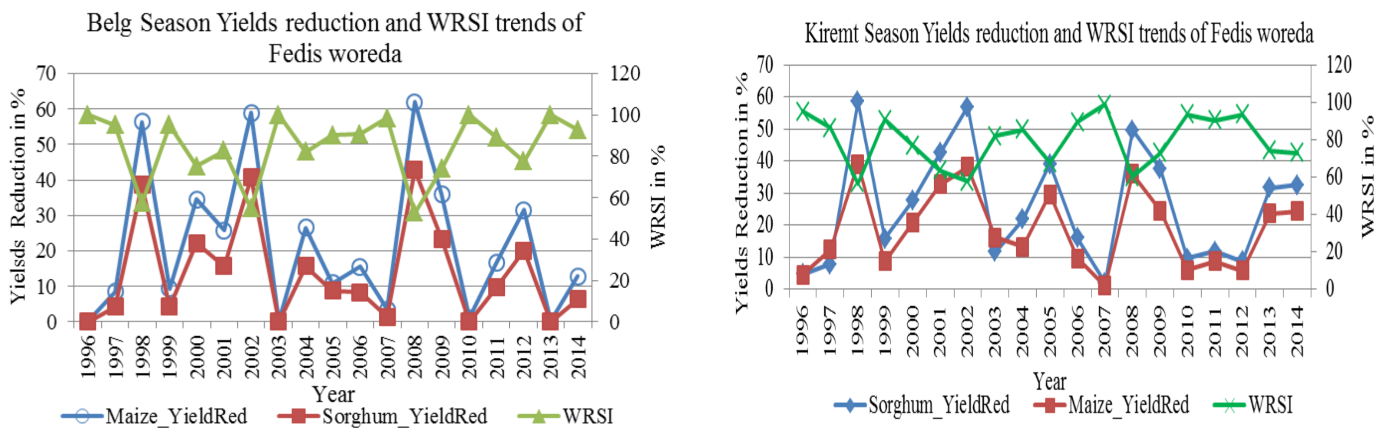

Figure 4. 33 WRSI with Yields reduction trends of Belg and Kiremt Seasons

4.12 Risk Zone Map of Meteorological Drought using indices

The meteorological drought risk map has been prepared by integrating all drought frequency maps generated from the three drought indices SPI, WRSI and NDVI anomaly (Figure 4.34). The three above mentioned representing drought indices were prioritized according to their degree of influence using pair-wise comparison. According to the result derived from the integration of all droughts in Belg and Kiremt seasons were shown the following:

Frequency maps in Shinile woreda, in two seasons are classified into 0 – 2 for no drought, 3 – 4 for slight, 5 – 6 for moderate, 7 – 10 for severe and 11- 13 for very severe drought risk zones. Meteorological drought risk map depicted in Figure 4.34, in Belg season showing that the frequency area affected by no drought, slight, moderate, severe and very severe MD risk encompasses large areas in East and central, South and west, North Western, Northern and North the total geographical area of Shinile woreda respectively. The probabilities of occurrence of MD ranges were from 3 to 13 times for no drought to very severe drought severity level. Thus, the Eastern and most of central part of East area is categorized into no drought (0 – 2), and North western and South is categorized Slight drought (3 – 4), while most of Central to North is categorized moderate drought (5 – 6) and severe drought (7 – 10), and in the tip of North small area is categorized very severe drought (11 – 13). In Kiremt season, in Figure 4.34 in the South small area and Eastern some area were categorized no drought (0 – 2), large area in the South, central and South Eastern were categorized Slight drought (3 – 4), from North Western to North tip areas were categorized in range moderate drought (5 – 6) to very severe drought (11 – 13). So, in both seasons, there were very severe droughts in North.

Meteorological drought risk map depicted in Figure 4.35, in Belg season, showing that the frequency area affected by no drought, slight, moderate, severe and very severe MD risk for Deder woreda. In line with this, some areas in central was shown no drought (0 – 2), large area from central to Western was shown slight drought (3 – 4), some area in the North tip and from north Eastern to central were shown moderate drought (5 – 6), from South Eastern to South western was shown severe drought (7 – 10) and South tip part of areas was shown very severe drought (11 – 13). In Kiremt season, in South Eastern and small area in the center were shown no drought (0 – 2), in Western, center and North Eastern areas were shown slight drought (3 – 4), in the North Western area were shown moderate drought (5 – 6), and was shown severe drought (7 – 10). So, based on the result that depicted in Figure 4.76, in South tip part of area was very severe drought in Belg season; whereas, in North West parts of area was observed severe drought during Kiremt season.

Meteorological drought risk map depicted in Figure 4.36, in Belg season, showing that the frequency area affected by no drought, slight, moderate, severe and very severe MD risk for Fedis woreda. In Belg season, in North tip area was shown no drought (0 – 2), large area South-Western and from East to West in North part were shown slight drought (3 – 4), some area from West expanded to East was shown moderate drought (5 – 6) and small area in East part of area was shown severe drought (7 – 10). In Kiremt season, some small areas in North and East were shown no drought (0 – 2); in the North-Eastern was observed slight drought (3 – 4); and in West part of area was observed moderate drought (5 – 6); small area in center and South tip area were shown severe drought (7 – 10). So, based on the result that depicted in Figure 4.80, in East some part of area was severe drought in Belg season; whereas, in South tip and in western small parts of areas were observed severe drought during Kiremt season.

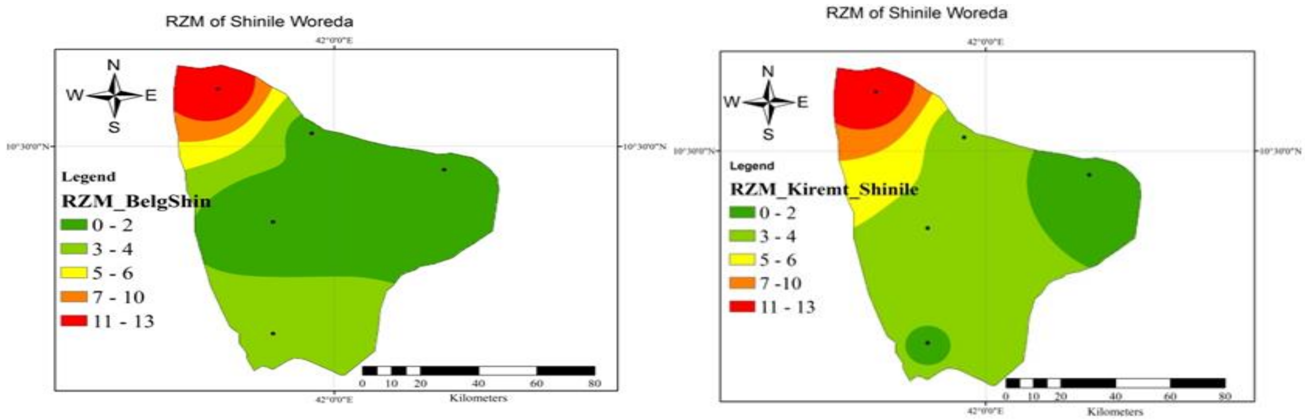

Figure 4. 34 Frequency of MD risk map using WRSI, NDVI and SPI in Belg and Kiremt Seasons

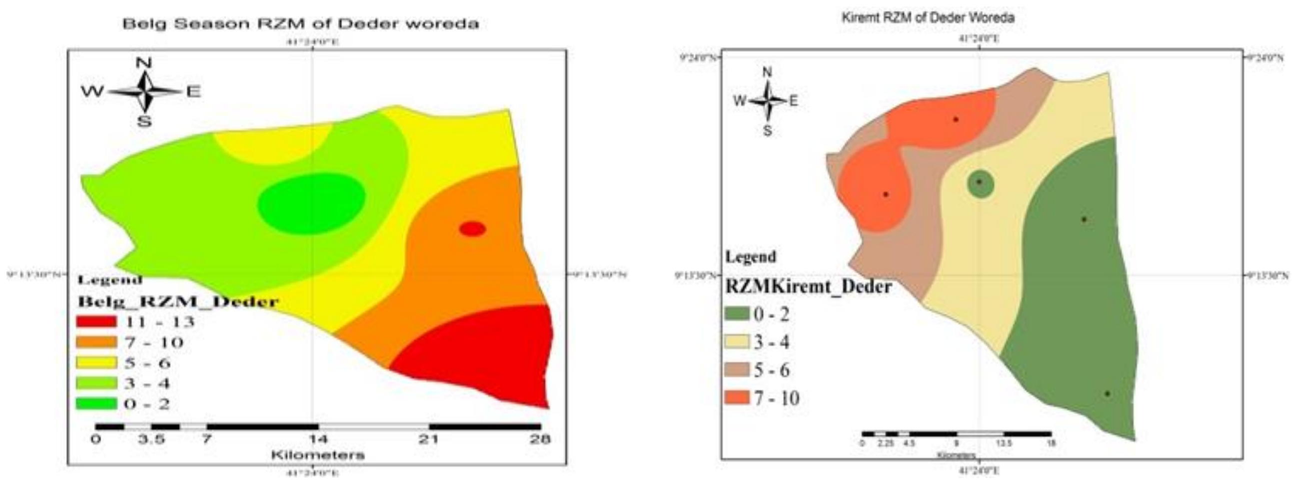

Figure 4. 35 Frequency of MD risk map using WRSI, NDVI and SPI in Belg and Kiremt Seasons

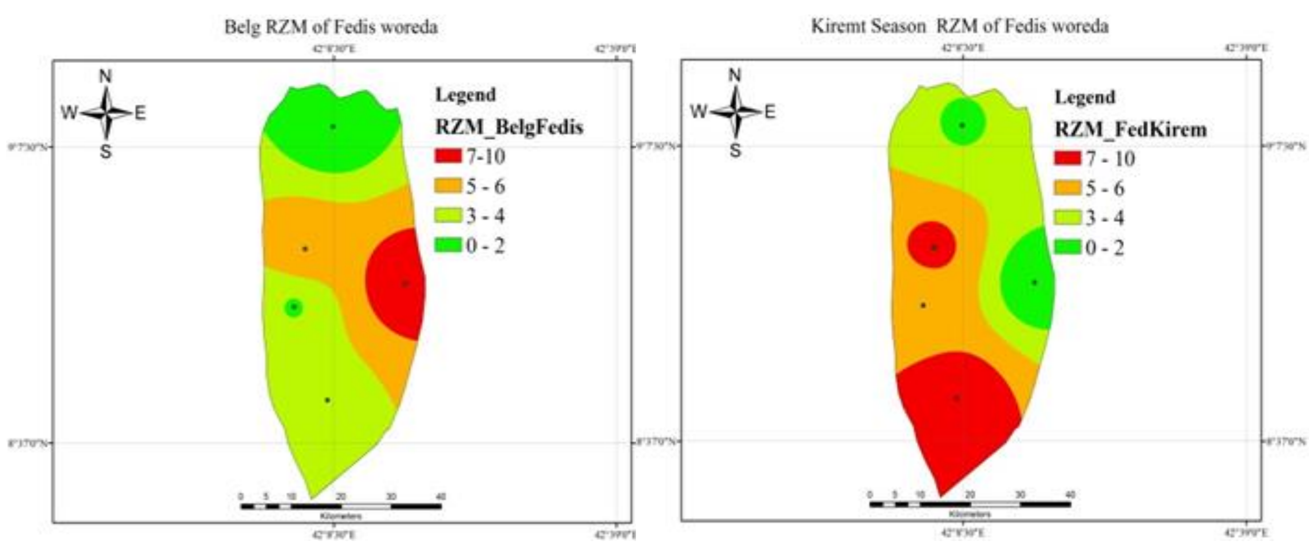

Figure 4. 36 Frequency of MD risk map using WRSI, NDVI and SPI in Belg and Kiremt Seasons

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

Climate has always been a dynamic, and it can affect natural systems through the consequences of climate variability and climate change, which is usually manifested through in erratic and uncertain rainfall distribution. Rainfall is one of the climatic variables that largely determine the occurrence of drought and also influences the growth and development of vegetation which is reflected by NDVI. The analysis of the 36 years (1980-2016) annual RF showed a coefficient of variation ranging from 75.6 – 202.7 %, 70.8 – 139.0 % and 70.4 – 157.2 % over Fedis, Deder and Shinile Woredas respectively. The trends of annual and monthly total rainfall of the period 1980 to 2016 showed positive trends for Fedis and decreasing trends for Deder and Shinile. The highest annual RF was recorded in Deder compare to other study areas. The maximum total RF recorded in the month of April and August during Belg season (Feb-May) and Kiremt season (Jun –Sep) respectively over the study areas.

The Starting of Season (SOS) and the End Of rainy Season (EOS) of Belg (Feb to May) was started during third dekad of February to March first dekad and ended during May third dekad respectively for all study areas. On the other way, the starting of rainy Season (SOS) of Kiremt (Jun to Sep) and the End Of rainy Season (EOS) started during first dekad of Jun to Jun third dekad and ended during September third dekad respectively for all study areas. Length of Growing Period (LGP) or rainy length time, during Belg season for Shinile, Deder and Fedis woredas were 40-80, 80 – 100 and 100 – 120 days respectively. LGP, during Kiremt season for Shinile, Deder and Fedis woredas were 70 – 90, 80 – 100 and 100 – 120 days respectively. However, the dry spell of the study areas, in Belg season were decreased at end of March to the starting of May in 15, 10, 7 and 5 days respectively. In line with this, the dry spells in Kiremt season were also decreased at the end of August to starting to third dekad September in 15, 10, 7 and 5 days respectively over the study areas. But, the dry spell days, during June and September were increased about more than 20% in all days. In general, the dry spell in Fedis woreda was less than others woreda; whereas, in Shinile woreda it was more than others woreda.

The relationship between RF amounts and yields (maize and sorghum) in Deder woreda have established weak negative correlation. Thus, there were other factors for contribution of crop production. For instance, there was low yield (sorghum) in the years 2009 and 2015; and there was low yield (maize) in the years 2011, 2012 and 2015. The relationship between RF amount and yields, in Fedis was established weak positive. But, maize yield was better strongly related with RF than Sorghum yield; and there was low yield (maize) performance in the years 2009, 2012, 2015 and 2016; and there was low yield (sorghum) in the years 2012, 2015 and 2016. The relationship between RF and yields, in Shinile has established weak positively correlated; but sorghum yield is strongly related with RF than maize yield because most of the time in this district there is shortage of total RF and the existence of diffused pattern of rainfall. There was low yield (maize) in the years 2007, 2008, 2011 and 2015; and, there was low yield (sorghum) performance in the years 2007, 2012 and 2015. Thus, total RF increased so do agricultural yield and vice-versa.

So, the annual high drought frequency mainly concentrated in the Eastern some areas of Fedis. From South to West part of Deder were observed slight to moderate drought. During Belg season, spatial pattern in SPI index, from central to South and Western part of Deder areas were observed slight to moderate drought respectively. In Kiremt season, spatial pattern in SPI index, Western part of areas was observed slight drought and in the Southern parts of areas was observed moderate drought. The annual drought frequency expanded from North to central part of Shinile woreda, large portion of area covered by moderate drought (was shown dry).

The spatial pattern of maize crop productivity, in Fedis woreda, for the period of 2009 to 2016, there was shortage of grain (moderate drought) in the South Eastern and Northern parts of District; especially in the years 2009, 2012 and 2015. The spatial pattern of maize crop productivity, in Deder was shortage of grain (very drought) in the Eastern some areas and from North expanded to Southern parts of District; and the Sorghum yield productivity was very poor grain yield (very drought) in the south tip of part. The spatial pattern of maize crop productivity in Shinile; there was shortage of grain (very drought) in most parts of area from South to Eastern and Western; and Sorghum yield productivity was very poor grain yield (very drought) in the South tip to Eastern and Western.

The RF distribution of Fedis woreda, in PON index, during annually from some areas in the Eastern was observed moderate drought; slight drought was observed from Eastern to expand to North wards. Some areas in the Western and Southern tip of Deder woreda was observed moderate drought; slight drought was observed in the North and Western areas. Large areas in the Northern, Eastern and central part of Shinile woreda was observed moderate drought, slight drought was observed in the North and Western areas.

The spatial NDVI, total RF and yields reduction, in Shinile woreda, for some very small areas were hit by slight and moderate MD while the majority of the areas under the influence of severe and very severe level of MD. During Belg (February – May) and Kiremt (June – September) was shown severe drought to very severe drought in South Eastern parts of area. This may be due to long intra seasonal dry spell or bad distribution of rainfall that affect the growth and development of vegetation. The maize yield reduction was higher than sorghum yield; and during Belg and Kiremt seasons, both yields reductions increased with in percentage, but the NDVI and the total RF decreased with the time in these seasons. Spatial NDVI and yields reduction with NDVI, for Deder woreda was in range from severe to very severe drought for some areas in the East; whereas, large areas was covered by the range slight to moderate drought. During Belg season, the lowest NDVI and yield reduction were recorded in the years (1998 and 1996) respectively; whereas, the highest NDVI and yields reduction were recorded in 2008 and 1998 respectively while during Kiremt season, the lowest NDVI and yield reduction were recorded in the years (2000 and 1996) respectively; whereas, the highest NDVI and yields reduction were recorded in 1997 and 2001 respectively. The trends of NDVI and the total RF decreased with the time; whereas, yields reduction trends increased with the time in two seasons; and also the trends of NDVI vegetation coverage were better than compare to others woreda in two seasons. Spatial NDVI and yields reduction with NDVI index, for Fedis woreda, the western parts of areas were shown severe to very severe droughts in two seasons. During Kiremt season, the highest vegetation coverage (NDVI) was recorded in the years 1996 and 2007; whereas, the lowest vegetation coverage (NDVI) was recorded 2002 and 2009. The highest the maize and sorghum yields reductions were recorded in 2002 and 1998; whereas, the lowest yields reductions were recorded in 2007 and 1996. The trends of NDVI and the total RF decreased with the time; whereas, yields reduction trends was constant with the percent of 30%. During Belg season, the highest vegetation coverage (NDVI) was recorded in the years 2002; whereas, the lowest vegetation coverage (NDVI) was recorded 1998. The highest the maize and sorghum yields reductions were recorded in 2008; whereas, the lowest yields reductions were recorded in 1997 and 1996. The trends of NDVI and yields reduction trends were increased with the time; whereas, yields reduction trends was decreased with time.

The performance of crops of yields growing in the study areas estimated using WRSI index, for the period of 1996 to 2014. The result revealed that less WRSI value was shown moisture deficit during the drought season. In Shinile woreda, the trend of WRSI was increased but the maize yield reduction decreased with the time. The drought in Kiremt season decreased more than Belg season. In Deder woreda, the sorghum and maize yield reduction were less than 70% and 50% respectively; and the trends of WRSI was increased but yields reduction was decreased with time. In Fedis woreda, the highest WRSI values were recorded in the years 1996, 1998,1999, 2003, 2007, 2010 and 2013 with the percent of greater than 90%; whereas, the lowest WRSI values were recorded in the years 1998, 2002, 2007 and 2008 with the percent of less than 60%. In general, the trends of WRSI increased but yields reduction decreased with the time in two seasons.

The Meteorological drought risk map has been prepared by integrating from the three drought indices, SPI, WRSI and NDVI. The probabilities of occurrence of MD ranges were from 3 to 13 times for no drought to very severe drought severity level. In Shinile woreda, during Belg season, in the tip of North small area is categorized very severe drought (11 – 13); in Kiremt season, from North Western to North tip areas were categorized moderate drought (5 – 6) to very severe drought (11 – 13). In Deder woreda, in Belg season, from South Eastern to South western was shown severe drought (7 – 10); and South tip part of areas was shown very severe drought (11 – 13); whereas, during Kiremt season, in North West parts of area was observed severe drought. In Fedis woreda, in Belg season, in East some part of area was severe drought (11 – 13); whereas, during Kiremt season, in South tip and in Western small parts of areas were observed severe drought (11 – 13). So, Meteorological drought risk can be viewed as a product of both exposures to the climate hazards and the vulnerability of farming or cropping practices to drought conditions. Thus, Meteorological drought risk mapping can be useful to guide decision making process in drought monitoring and to reduce the impact of drought on agricultural production and productivity, while identifying appropriate sites for specific adaptation and mitigation actions.

In general, this information is in agreement with the result obtained from the analysis climate and yields data to reduce the impact of drought on agricultural production in study areas.

5.2 CONCLUSIONS

There have been many climate related disasters, such as drought, that have led to famine in Ethiopia. The experience has led to the evolution of an excellent early warning and response mechanisms in Ethiopia. The NMSA provides weather forecasts and the DPPB provides the famine early warning system and assesses the food supply in the country.

The situation of the 1980 to 2016 case teaches us that drought studies are very important for study areas because these areas are aid dependent and recurrent drought experienced. Drought early warning based on onset, secession, LGP and dry spell information obtained in study for study areas. So with credible drought information with a longer lead time, the national government can use it to manage the national food supply. The findings of this study have implications for drought management, early warning system, preparedness and contingency planning and climate change adaptation. In real sense, drought is a climatic event that cannot be prevented very easily, but interventions and preparedness to drought can help to cope with drought by developing more resilient ecosystems, improving resilience to recover from drought and taking various adaptation strategies like water harvesting, making irrigation system more efficient and a geographical shift of agricultural system. It can advise farmers to produce more food instead of cash crops; it can also advise farmers what, where and when to plant and help reduce losses of crops during the process of replanting when the rain returns.

The spatial distribution of drought using SPI in Fedis, during Belg season, there was slight to moderate MD in North, South-Western and East parts of area; and during Kiremt season, there was moderate MD in Northern, Central and Eastern parts of area. In Deder, there were slight to moderate MD in South and West parts of area in both seasons. In Shinile, there was moderate MD in North large portion of area in two seasons.

The spatial distribution of drought using NDVI in Fedis, the trends of RF and NDVI increased but Yields reduction decreased with the time; but the NDVI and RF performance were better in Kiremt than Belg season. In Deder and Shinile, the reverse in Fedis occurred; so, the NDVI and RF performance were better in Belg than Kiremt season. The temporal trends of NDVI vegetation coverage were better for this area than others study areas. The spatial distribution of drought using WRSI in Fedis, during Belg season, there was MD for small pocket area in the West; and there was MD in the South-western large part of area in Kiremt season. So, the WRSI increased; whereas, yields reduction decreased with time. The MD frequency was more increased in Kiremt than Belg season. In Deder, during Kiremt season, there was MD for small area in the North; and there was MD in the South and North-Western for some part of area in Belg season; so, the moisture stress was more decreased in Kiremt than Belg season; and also the trend of WRSI increased; but the yields reduction decreased with time. In Shinile, during Kiremt season, MD was prevalent for small pocket area in the East; and MD was also prevalent in South and East parts of area during Belg season. The MD frequency was greater in Belg than Kiremt season; and the moisture stress decreased in Kiremt. The trends of WRSI decreased; but the yields reduction increased with time in this area in two seasons. So WRSI is Robustness index because it is much related to crops and showed good results in study areas.

The Meteorological drought risk map prepared by integrating from the three drought indices, SPI, WRSI and NDVI; and there were different classes of MD frequency occurred in study areas. Severe (7-10) times MD was frequented some parts of area in East Fedis; whereas, very severe (11-13) times MD in South and North parts of Shinile and Deder respectively.

In general, droughts may be due to long intra-seasonal dry spell or bad distribution of RF or resulted from mismatched between seasonal RF distribution and crop requirement at critical developmental stages that affect the growth and development of vegetation and crops. In this study, the MD indices showed that the drought severity, frequency, trends, spatial pattern and its intensity of MD patterns by analyzing seasonal RF time scale. The resulted showed that there was impact of MD on yields in Deder and Shinile woreda; and there was also in small percent in Fedis woreda; and when the study evaluated droughts performance by helping the indices in spatially and temporally; the WRSI expresses the real picture of MD followed by SPI, PON and NDVI respectively. Therefore, WRSI based MD assessment was better capture drought events or it is robust index than others.

This study provides the foundation data for reducing impact of drought or vulnerability to future droughts (to identify drought risk zone maps), and reducing the perception that drought is not an issue to study areas. We should learn that one of the reasons for the containment of the 1980 to 2016 drought impact on yields was because of a positive economic condition in study areas, open-mindedness on the part of government and donor support.

5.3 Recommendations

Based on the findings of the study, the following recommendations are suggested:

- Since meteorological drought severity levels vary spatially, so, for further study the selection of agricultural technologies and information (drought tolerance crops, the type of crop variety, other weather parameters and soil moisture conservation practices) should be made to fit in to the MD severity levels.
- The methods as well as results of MD assessment and risk mapping are believed to be highly important for decision makers and stakeholders, who have a stake in the study area. However, it is recommended that further studies can build up on this work by including real time seasonal drought forecasts as model parameter so that stakeholders can get early warning information that helps to take necessary adaptation and reduce the impact of MD.
- Implementation of the results of the study areas (onset, Cessation, Dry spell and LDP) used to get early warning information for farmers in study regions in deciding on crop types to cultivate, to plan sowing dates, to harvest water at the time of dry spell and others and reduce the impact of MD on crops.
- The spatial distribution of seasonal crop moisture deficiency will be different if changes in cropping patterns occur. Therefore, if used on an operational basis for drought risk and vulnerability assessment, the crop–climate database will need to be updated periodically as the distribution of crops changes in response to economic factors, climate trends, and government programs.

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Appendices

Appendix 1 Questionnaire

1. What are the others factors those have contribute to define the study areas of yields for common maize and sorghum sowing in future?
2. How is a rainfall characteristic in terms of amount and distribution as well as time of occurrence related to crop requirement?
3. Is there yield reduction due to mismatch of rainfall and crop water needs at different growth stage? How was the impact of MD on yields in study areas?
4. How was rainfall pattern in terms of amount and distribution in study areas about the last 36 years? How was the LGP, Onset, Cessation, LGP and Dry spell of RF in study areas?
5. How the pattern of meteorological drought was looks like in the past growing seasons?

Appendix 2

Table 5. 1 Long year monthly and annually RF statically summary over Shinile woreda

Shinile													
Sum. Stas	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annully*
Mean	21.5	22.5	75.8	112.1	51.0	24.1	82.5	114.5	71.4	31.0	20.8	11.7	639.0
St. Error	5.06	5.39	9.02	11.92	7.71	3.66	7.23	7.42	6.15	7.81	7.66	4.19	25.83
Median	7.4	5.5	69.8	107.9	40.8	16.8	81.1	112.4	69.6	17.7	4.7	0.1	624
St. Deviation	30.77	32.77	54.89	72.52	46.91	22.25	43.95	45.13	37.43	47.48	46.57	25.47	157.13
SampVariance	947	1074	3013	5259	2201	495	1932	2037	1401	2254	2169	649	24689
Kurtosis	3.23	3.12	-0.21	-0.72	6.93	-0.10	1.19	0.43	5.47	16.95	24.62	12.77	-0.11
Skewness	1.79	1.81	0.73	0.39	2.14	1.08	0.70	0.79	1.62	3.64	4.65	3.30	0.05
Range	128.2	135.2	212.5	266.1	243.5	75	204.6	189.9	215.2	266.9	271.9	129.8	617.3
Minimum	0	0	9.5	0	0	0	2.3	51.6	0	0	0	0	348.6
Maximum	128.2	135.2	222	266.1	243.5	75	206.9	241.5	215.2	266.9	271.9	129.8	965.9
Sum	796.6	832.8	2805.6	4149.3	1887.1	890.4	3052.8	4237.2	2641.7	1147.3	768.8	433.3	23642.9
Count	37	37	37	37	37	37	37	37	37	37	37	37	37
CI(95.0%)	10.26	10.93	18.30	24.18	15.64	7.42	14.65	15.05	12.48	15.83	15.53	8.49	52.39
Long Year RF Statistical Summary of The Study Areas													

Table 5.2 Long year monthly and annually RF statically summary over Fedis woreda

Long Year RF Statistical Summary of The Study Areas													
Fedis													
Sum. Stas	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annually*
Mean	3.4	1.8	54.9	103.7	5.7	50.9	66.0	80.5	87.8	54.5	14.2	3.1	526.1
SE	0.8	0.5	7.7	12.5	0.6	5.1	6.5	9.1	9.1	8.9	3.4	1.4	34.5
Median	0.6	1.4	53.5	101.7	5.6	49.8	64.5	77.0	86.0	50.9	6.3	0.0	515.4
Mode	0	0	53.5	101.7	5.6	49.8	64.5	58.3	86	51.5	0	0	502.4
SD	5.0	3.2	46.3	75.0	3.6	30.8	38.8	54.8	54.6	53.1	20.1	8.1	207.0
SV	25.1	10.0	2139.4	5632.4	13.0	946.3	1502.3	3001.8	2985.9	2819.8	405.0	65.8	42863.4
Kurtosis	-0.1	17.4	1.1	0.3	1.9	2.1	0.0	0.3	1.8	1.9	1.9	23.7	-0.2
Skewness	1.3	3.8	1.1	0.8	1.2	0.9	0.6	0.8	0.8	1.4	1.7	4.7	-0.4
Range	13	17.4	175.2	284.7	16.9	152.2	155.4	215.9	263.1	223.7	71.8	46.0	833.9
Minimum	0	0	0	0	0	0	3	0	0	0	0	0	89.4
Maximum	13.0	17.4	175.2	284.7	16.9	152.2	158.4	215.9	263.1	223.7	71.8	46.0	923.3
Sum	124.1	64.0	1977.5	3734.3	205.5	1833	2375.4	2896.7	3160.8	1960.5	497.7	111.2	18940.3
Count	36	36	36	36	36	36	36	36	36	36	35	36	36
CI (95.0%)	1.7	1.1	15.6	25.4	1.2	10.4	13.1	18.5	18.5	18.0	6.9	2.7	70.1

Table 5.3 Long year monthly and annually RF statically summary over Deder woreda

Long Year RF Statistical Summary of The Study Areas													
Deder													
Sum. Stas	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annually*
Mean	16.1	24.5	84.6	128.2	103.3	54.0	171.9	214.1	146.6	40.2	13.2	11.5	1008.1
St. Error	5.0	6.3	9.4	12.2	11.1	6.4	11.0	17.9	11.7	8.4	2.9	2.8	50.1
Median	4.8	21.7	76.0	128.0	103.3	52.3	168.7	214.1	146.6	35.9	13.2	9.3	999.5
SD	29.7	37.7	56.6	72.9	66.8	38.4	65.8	107.2	70.3	50.7	17.2	16.6	300.5
SV	884	1421	3209	5317	4457	1475	4331	11497	4937	2570	297	276	90282
Kurtosis	14.3	16.7	-0.5	0.9	3.7	6.4	-0.4	0.2	2.7	8.4	6.0	9.8	1.5
Skewness	3.5	3.7	0.3	0.8	1.5	2.1	0.2	0.3	1.2	2.7	2.2	2.8	0.9
Range	156.1	209.3	208.4	318.5	340.0	202.6	268.8	462.6	375.0	239.9	80.9	83.4	1393.3
Minimum	0	0	0	0	4.1	2	30.2	0	0	0	0	0	540.4
Maximum	156.1	209.3	208.4	318.5	344.1	204.6	299	462.6	375	239.9	80.9	83.4	1933.7
Sum	580.4	882.7	3047.2	4614.0	3718.6	1945	6187.6	7707.1	5276.4	1447.0	474.3	413.2	36293.3
Count	36	36	36	36	36	36	36	36	36	36	36	36	36
CI(95.0%)	10.1	12.8	19.2	24.7	22.6	13.0	22.3	36.3	23.8	17.2	5.8	5.6	101.7

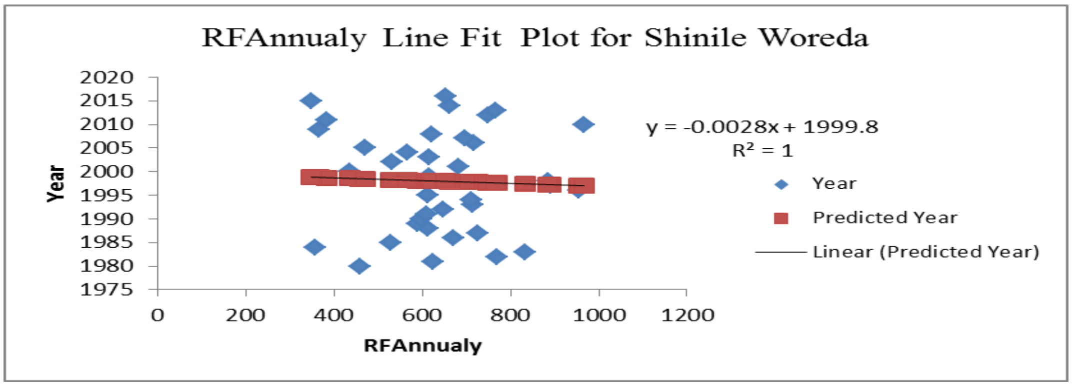
SD: Standard Deviation, StdE: Standard Error, SV: Sample variance, CI: Coefficient of Interval, CV Coefficient Variance

Simple linear regression between rainfall and years starts from 1980-2016 in Shinile
Fitted equation: y = -0.0028 * RF + 1999.8
R-squared: 1.0

ANOVA Shinile District

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.908	6.908	0.0574	0.812028
Residual	35	4211.092	120.317		
Total	36	4218			

	Coeff	*SE*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1999.781	7.650	261.403	0.000	1984.251	2015.312	1984.251	2015.312
RFAnnualy	-0.003	0.012	-0.240	0.812	-0.026	0.021	-0.026	0.021



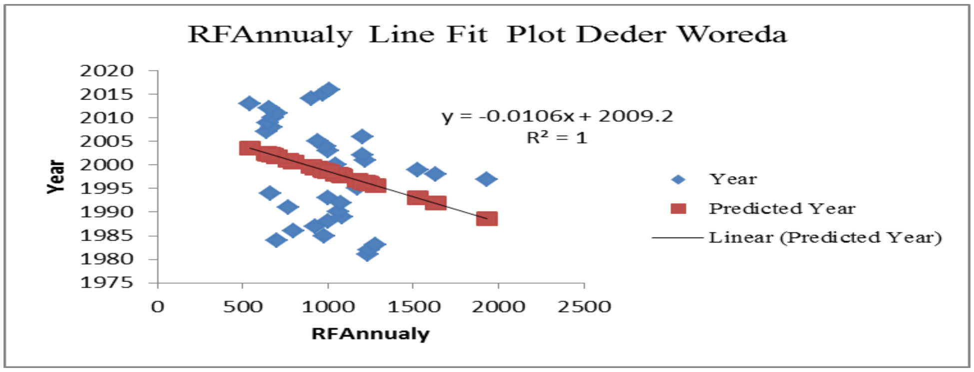
Appendix 3

Simple linear regression between rainfall and years starts from 1980-2016 in Deder.
Fitted equation: y = -0.0106 * RF + 2009.2
R-squared: 1.0

ANOVA Deder Woreda

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	357.2	357.2	3.4426	0.072222555
Residual	34	3527.8	103.759		
Total	35	3885			

	Coeff	*SE*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	2009.219	6.021	333.686	0.000	1996.982	2021.456	1996.982
RFAnnualy	-0.01063	0.006	-1.855	0.072	-0.022	0.001	-0.022



Appendix 4

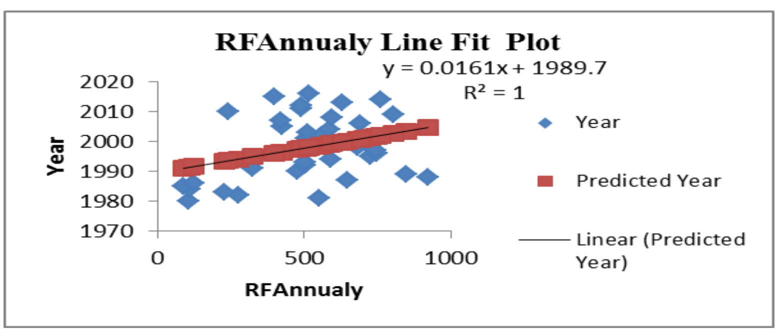
Simple linear regression between rainfall and years starts from 1980-2016 in Fedis woreda.

Fitted equation: y = 0.0161 * RF + 1989
R-squared : 1.0

ANOVA Fedis Woreda RF

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	433.7415	433.7415	4.011605	0.052981051
Residual	35	3784.259	108.1217		
Total	36	4218			

	Coeff	*SE*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	1989.71	4.48	444.37	0.00	1980.62	1998.80	1980.62
RFAnnualy	0.02	0.01	2.00	0.05	0.00	0.03	0.00



Appendix 5

Drought Years in study areas using different Indices							
SN	Period Analyzed	Parameters	Study areas	Season	Drought Years	Index Values	Index
1	1980 – 2016	RF	Fedis	Kiremt	1980-1986,1990-1993, 2001,2003,2005, 2007,2010,2012 &2015	< 0, 0 to -0.99, -1 to 1.49, -1.5 to -1.9, < -2.0	SPI
				Belg	1980,1982-1986,1991,1999,2001,2002, 2005, 2008,2010,2011 &2015		
2	1980 – 2016		Shinile	Kiremt	1980-1982,1984-1987,1989-1991,1993, 1995,1997,2002,2004,2009 &2015		
				Belg	1980,1984,1985,1988,1992,1994,1999-2005, 2007,2009, 2011-2013 &2015		
3	1981 – 2016		Deder	Kiremt	1984-1987,1989-1991, 1994,2007-2015		
				Belg	1984,1986,1988,1992-1994, 2000-2005,2007-2009, 2011-2015		
4	1996 – 2014	Vegetation coverage	Fedis	Kiremt	2000, 2001, 2002, 2000, 2004, 2008, 2009 and 2010	< 0, 0 to -10, -10 to -25, -25 to -50, Below -50	NDVI
				Belg	1996, 1997, 1998, 2005, 2006, 2007, 2012 and 2013		
5	1997 – 2014		Shinile	Kiremt	2000, 2002, 2003, 2008, 2009, 2010 and 2012		
				Belg	1996, 2004, 2001, 2006, 2008, 2011, 2013		
6	1998 – 2014		Deder	Kiremt	2000, 2001, 2002, 2003, 2004, 2010, 2012, 2013 and 2014		
				Belg	1996, 1997, 1998, 1999, 2004, 2005, 2006, 2007 and 2011		
7	1996 – 2014	Moisture stress	Fedis	Kiremt	1998, 2000, 2001, 2002, 2005, 2008, 2009, 2013 and 2014	70 - 79, 60 - 69, 50 - 59, Below 50	WRSI
				Belg	1998, 2000, 2002, 2008, 2009 and 2012		
8	1997 – 2014		Shinile	Kiremt	1998, 2000, 2002, 2008, 2009 and 2012		
				Belg	1997 - 2004, 2006 - 2009, 2011 – 2014		
9	1998 – 2014		Deder	Kiremt	1998, 2001, 2002 and 2008		
				Belg	1998, 2000, 2002, 2008, 2009 and 2012		