ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF EARTH SCIENCES

REMOTE SENSING AND GIS BASED CHARACTERIZATION OF AGRICULTURRAL DROUGHT CONDITIONS IN NORTH WOLLO ZONE, AMHARA REGIONAL STATE, ETHIOPIA

A Thesis Submitted to

The School of Graduate Studies of Addis Ababa University

In Partial Fulfillment of the Requirements for the Degree of Masters of Science in Remote Sensing and Geo-informatics

BY

ESHETU GEBRE

(GSR/1374/07)

January 2017

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BY: ESHETU GEBRE

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Chair Person	**Signature**	**Date**
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Examiner	**Signature**	**Date**
Dr. K.v.suryabhagavan	________________	________________
Examiner	**Signature**	**Date**

Declaration

I declare that, this thesis prepared for the partial fulfillment of the requirements for the degree of Master of Science in Remote Sensing and Geo-informatics entitled “Remote Sensing and GIS Based Characterization of Agricultural Drought Conditions in North Wollo Zone Amhara Regional State, Ethiopia” is my original research work prepared independently by my own effort with the close advice and guidance of my adviser. I also declare that this thesis has not been presented in any university and all sources that I have used or quoted have been indicated and acknowledged by means of complete references.

Eshetu Gebre

Signature ——————————

Date ——————————

Certification

Here with I state Eshetu Gebre has carried out this research work on the topic entitled "Remote Sensing And GIS Based Characterization Of Agricultural Drought Conditions In North Wollo Zone Amhara Regional State, Ethiopia" under my supervision and it is sufficient for submission for the partial fulfillment for the award of Degree of Master of Science in Remote Sensing and Geographic Information System.

Advisor: Dr. Getachew Berhan

Signature

Date——————————

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LIST OFACRONYMS

DEM	Digital Elevation Model
DDPC	Disaster Prevention and Preparedness Commission
ANOVA	Analysis of Variance
SAS	Statistical Analysis software
ETo	Reference Crop Evapotranspiration
EWS	Early Warning System
TCI	Temperature Condition Index
GIS	Geographic Information System
IPCC	Inter-Governmental Panel On Climate Change
LSHM	Land Surface Hydrological Models
NDVI	Normalized Difference Vegetation Index
NMSA	National Metrological service Agency
PDSI	Palmer Drought Severity Index
PN	Percent of Normal
RS	Remote Sensing
AET	Actual Evapotranspiration
SPEI	Standardized Precipitation Evapotranspiration Index
VCI	Vegetation condition index
WMO	World Meteorological Organization

ABSTRACT

Drought is the most complex but least understood of all natural hazards. Major food production in Ethiopia, especially in the Amhara Region, North Wollo Zone, is almost fully dependent on rain-fed agriculture and the area is often hit by periodic droughts. This drought causes serious economic, social, food security and environmental problems. Arid climatic conditions in North Wollo Zone are characterized by erratic rainfall and successive drought years together with high rate of moisture deficiency has adversely affected the agricultural production levels. Thereby increases drought risk. In this study, the Standardized Precipitation Evaporation Index (SPEI), Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI), were applied to characterize the agricultural drought conditions in North Wollo Zone from 2000 to 2015. Correlation analysis was performed between NDVI and SPEI, rainfall and NDVI, VCI and rainfall and NDVI and Crop Yield Anomaly and SPEI and Crop Yield Anomaly. SPEI values were interpolated to get the spatial pattern of meteorological based drought. Ground based crop yield data was used to evaluate the drought monitoring index. Finally, the combined drought severity map was generated by overlaying the agricultural and meteorological drought severity maps. The results showed that there was good correlation between rainfall and NDVI (r=0.71), VCI and Rainfall (r = 0.77), NDVI and SPEI (r=0.82) and NDVI and Crop Yield anomaly, (r=0.78) and SPEI and Crop Yield Anomaly (r=8.3). Analysis result of Spatial pattern of long term seasonal average rainfall and NDVI from 2000 to 2015 years, showed that there was a large variation during the main cropping season and the corresponding NDV1 values was also almost similar. The minimum and maximum rainfall observed during this period was found to be 250 to 599 mm where it indicates a large variation in distribution of rainfall in all the weather stations. This might be the effect of altitude among other factors. The drought severity was analyzed from 2000 to 2015 based on satellite and climate data. The two years 2005 and 2015 were considered as drought years and 2009 and 2013 were taken as slight-drought years. The extent of drought severity was increased by increasing time scale. The combined risk map showed that approximately 5% of the area has slight risk, 42.5 % of the area faced by very severe risk, 19.5 % of the area considered as moderate risk and 33 % area face severe risk within the study area. It can be seen severe drought year from 2000 to 2015 because it has received low rainfall at 2005 and 2015. Hence, it is concluded that, the study area was affected by severe drought in year 2005 and 2015 and slight drought in 2009 and 2013 and the drought monitoring indices results almost similar with ground truth data result of crop yield. Drought from socio-economic aspect has not been studied. Besides, delineating areas under drought risk relevancy of risk assessment can be made more meaningful when the human population as well as livestock population under risk will be assessed. Therefore, it is recommended to include the socio-economic data to better understand the vulnerability factors.

Keywords: Agricultural drought, Meteorological drought, SPOT, NDVI and SPEI.

CHAPTER ONE: INTRODUCTION

1.1 Background

Climate change is one of the characteristics of natural atmospheric circulation. The effect of fluctuations in the atmospheric elements such as rainfall and temperature is achieved and environmental phenomena of drought and climate change are integral parts (McKee and Doesken et al., 1997). Major drought events have been reported in the USA, the Horn of Africa, Australia, and Southern Europe over the past few decades (Damberg and AghaKouchak, 2013). Drought is a natural hazard that results from a deficiency of precipitation and water availability from expected or normal amounts, usually extended over a season or longer period of time (Mishra and Singh, 2010). Its occurrence is associated with severe damage of agricultural production and causing an imbalance on food supply and demand. Though, drought occurs in many parts of the world, developing countries are highly vulnerable to drought. So far, Ethiopia is one of the most drought prone countries in Africa (Conway and Schipper, 2011). An estimated proportion of 80 to 85% of the population of the country depends on traditional rain-fed agriculture (Temesgen et al., 2009).

Rain-fed farming is the main form of crop production in Ethiopia; like for many of neighboring regions in Africa. However, it is highly variable in most parts of the country both in terms of length of the rainy season and amount of rainfall (Messay, 2006). Due to rainfall variability, frequent drought has been occurring in various parts of Ethiopia, which affect the crop production, food market prices and ultimately, the cost of living (NMSA, 1996). In addition to these, drought is a period of abnormally dry weather sufficiently prolonged because of a lack of precipitation that causes a serious hydrological imbalance and has connotations of a moisture deficiency with respect to water use requirements (McMahon and Arenas, 1982).The deficiencies have impacts on both surface and groundwater resources and lead to reductions in water supply and quality, reduced agricultural productivity, diminished hydro-electric power generation, disturbed riparian and wetland habitats and reduced opportunities for some recreation activities (Riebsame et al., 1991).There are a number of indicators for drought monitoring and assessment. Every indicator has its successes and limitations in drought detection. Meteorological drought indicators assimilate information on rainfall, stored soil moisture or water supply but they do not express much local spatial detail. On the other hand, the derived drought indicators calculated from satellite-derived surface parameters have been widely used to study droughts. Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation indices. With the advancements in Remote Sensing technology, the historical drought indices were over powered by the newly developed indices from Remote Sensing data that are considered to be real time. Remote Sensing and GIS technique is increasingly being regarded as a useful drought detection technique, as evidenced by its use across many parts of the world (Gujarat, India). The main purpose of this study was to characterized agricultural drought using observed climate data from stations and the satellite images.

1.2 Statement of the problem

There is a concern that the ongoing global warming may increase the severity of droughts in Ethiopia. Dai (2011) has reported that the temperature increase of 1-3°C in 1950 to 2008 has reduced the annual rainfall in most African countries. The key factors to drought occurrence and drought severities are deviations in precipitation and evapotranspiration. Therefore, if climate change results in changes in one or both of these factors it can be expected that drought occurrence and its severity will change as well. A change in the precipitation mean and variability obviously influences the occurrence and severity of drought.

Currently, in Ethiopia use of intensive drought assessment tool is not common, which integrates climate, water and spatial variability of soil and land use properties as well as crop growth and root development. Due to this, it is not possible to fully characterize agricultural drought magnitude, spatial extent and potential impacts. As a result of this, there is inadequate early warning and response mechanism that helps the government in planning drought mitigation strategy and emergency support measures during drought event. Major food production in Ethiopia, especially in the Amhara Region, in North Wollo Zone, is almost fully dependent on rain-fed agriculture and the area is often hit by periodic droughts. This drought causes serious economic, social and environmental problems. According to Ethiopian Government Disaster Risk Management and Food Security Sector of the Ministry of Agriculture (DRMFSS, 2012) report; the dry land semi-arid parts of North Wollo Zone, drought and crop failures have been common and rain-fed agriculture is yet to provide minimum food requirement for rapidly growing population. Conventional methods of drought monitoring and early warning using station point data is time consuming and tedious. Similarly, the data are often incomplete and inconsistent. These problems are even further compounded by limited number and distribution of observation stations which is rather a common concern for most African countries. In the last three decades Remote Sensing has provided a useful tool for drought monitoring and a variety of Remotely Sensed drought indices based on vegetation indices and land surface temperature have been developed (Jain et al., 2009). This technology is currently supporting drought monitoring and early warning in Ethiopia. However, their utilization is limited due to lack of advanced knowledge and accessibility of high resolution satellite image data for agricultural drought monitoring. Also, there is scarcity of the research work on drought assessment in Ethiopia in general and specifically in North Wollo Zone. Due to this, there is a gap between the drought and pre awareness about it. On the other hand, crop production is very sensitive to agricultural drought. Arid climatic conditions in North Wollo Zone characterized by erratic rainfall and successive drought years together with high rate of moisture deficiency has adversely affected the agricultural production levels, thereby, increasing drought risk. Since, there is no much scope to bring additional land under cultivation in North Wollo Zone, evaluation of probable risk arising out of drought in the study area have been help in developing better management plans for mitigating and adopting drought impacts.

In addition to variability in precipitation, a number of factors play a major role in the evolution of a drought. These factors include evapotranspiration, which is affected by temperature and wind, water holding capacity of soils, the depth and presence of groundwater supplies, and vegetation. Some studies undertaken at Eastern parts of Amhara Regional State have been used only vegetation indices and Standardized Precipitation Index (SPI) which cannot fully account agricultural drought severity status. Under climatic conditions with low temporal variability in temperature the SPI is superior to identify different severity of droughts. However, the role of temperature increase on drought conditions was not recognized using the precipitation-based SPI drought index.

To fill these gaps, this research has attempted to use the SPEI drought indicator which accounts the effect of temperature and evapotranspiration in its computation to make the research detail and find a better result at zonal level.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study was characterization of the agricultural drought conditions using remote sensing and Geographic Information System (GIS) based drought indices.

1.3.2 Specific Objectives

- To identify meteorological drought by using SPEI method in North Wollo Zone,
- To identify agricultural drought by using remote sensing image and GIS techniques,
- To evaluate the overall drought modeling approach and relate crop production with SPEI and NDVI index in North Wollo Zone.
- To assess drought of the study area by combining both agricultural and meteorological drought and develop drought risk map of the area

1.4 Significance of the Study

Farmers inhabiting the area experience extreme temporal and spatial variability of rainfall in cropping seasons with frequent and longer dry spells that affect their agricultural productivity. The risks associated with agricultural drought are spatially variable; hence, they require different adaptation strategies and options. In order to adapt to the adverse impacts of drought, agricultural drought assessment and identification of risk Zones have to be the primary tasks. Identification of agricultural drought risk Zone is usually carried out on the basis of analysis of rainfall and evapotranspiration data on longtime basis (Lemma, 1996). Further, collecting sufficient spatial and temporal data is very difficult, especially, in areas with rugged topography and low accessibility. The use of satellite data using advanced techniques such as remote sensing and Geographic Information System can assist in the detection and mapping of agricultural drought prone areas. Agricultural drought risk mapping in turn helps in decision making process for drought monitoring and identifying appropriate site for specific adaptation and mitigation. Hence, agricultural drought risk zone map produced from this study can be useful on one hand for policy makers to prioritize their actions based on the risk level, and on the other, for researchers to generate agricultural technologies and information including selection of drought tolerant and adaptive crops, as well as, generation of crop management and soil moisture conservation practices. Moreover, it may be helpful for development agents and Non-Governmental Organizations to facilitate scaling up of best technologies with success stories from similar risk Zones elsewhere.

This study is important to monitor drought events and their variability, explore their predictability, and determine how they might change under different conditions. The information obtained from this study can be considered in spatial planning to create more optimal land and water management and to eliminate or lessen the increasing drought hazard. Moreover, the result obtained from this study about this hazard drought vulnerability and characterization can become an integral part of drought planning, awareness, and mitigation efforts at the regional and local levels.

1.5 Scope of the Study

The focus of this study was North Wollo Zone, Amhara Regional State. The area has been chosen because for the past decades it has been seriously affected with continuous drought hazard. Due to the high rate of drought and other factors the agricultural production has been decreasing which illustrate the phenomenon and the negative impacts of drought to people. The result of this study could be contributing information about the drought hazard in the zonal for researchers, policy makers and other stakeholders.

1.6 Limitation of the study

Insufficient finance and time series data were major problems that hinders the in depth analysis of the problem. The problem could have been better explained and investigated if enough time series data and finance were available. Unavailability of high resolution satellite data was another problem encountered during implementation of the research study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Seasons and Agro-climatic Zones of Ethiopia and North Wollo Zone

Ethiopia is characterized by two seasons in almost western half, designated as wet and dry seasons decreasing toward north wards from 10 months in south west to only 2 months in the northwest (NMSA, 1996). Similarly three distinct seasons locally known as *Bega* (October to January), *Belg* (February to May) and *Kiremt* (June to September).Three major climatic zones, which have been known since ancient times in Ethiopia due to varied topography are Dega, Weina Dega, and the Kolla. Specifically in North Wollo Zone the Weina Dega (also known as the slight climate Zone). In addition to this, The Ethiopian traditional system uses altitude and mean daily temperature to divide the country into five climate Zones (Gemechu, 1977). Another broad classification can be made using the rainfall distribution through the year which produces uni-modal, bi-modal and a diffuse rainfall region (Haile and Yarotskaya, 1987). However, the most useful for agricultural purposes is the agro-climatic zones which uses the water balance concept, the length of the growing season (including onset dates) at certain probability levels (NMSA, 1996). In this way North Wollo Zone has two distinct zones can be identified namely the areas with a single growing period and areas with a double growing period. This information should be able to form the basis on which to build the seasonal forecasts with particular emphasis on the specific crop choices in each region (NMSA, 1996).

2.2 Drought Definitions

Drought has many definitions, depending on the field considered (i.e. social, economic and agricultural or environmental). For instance, a meteorologist might consider drought as a lack of precipitation, a hydrologist defines it as the period when the water available is less than the water demanded, while a farmer would consider drought as any period of low soil moisture (USGS, 2013). Drought is a disastrous natural phenomenon that had multi-sever impacts on human and environment. The difficulty of studying such phenomena came from the fact that no one can recognize when the drought can be started or even when it is ended. In most cases, its impact persists even after ending of the drought event. Furthermore, the drought concept varies among regions of different climates (Dracup et al., 1980). Drought is mainly and directly linked with lack of rainfall that causes consequences including agricultural and hydrological hazards associated with severity and duration of this lack (Dracup et al., 1980). Drought is the appearance of climate change and a widespread phenomenon in Ethiopia. Ethiopia faces widespread droughts, causing large economical and social damages. 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. The agricultural sector on which around 85 percent of the population depends is by far the largest sector being affected by drought. In dryland semi-arid areas, the major factors that aggravate the impact of drought are poor water management and hence agricultural production is below the potential. Usually, significant deficiency of precipitation from normal over an extended period of time results in plant water stress or agricultural drought in dryland semi-arid areas where most part of the study area is placed.

2.3 Classification of Drought

Droughts can be categorized into four types: meteorological drought, hydrological drought, agricultural drought and socio-economic drought. The meteorological drought can be viewed as the general conception of drought. It occurs when there is a below Norma precipitation amount during an extended period of time (months, years, etc.) over a region. Lack of precipitation is the main cause of a meteorological drought (Mokhtari, 2005). A hydrological drought is characterized by a below normal average of water in a water resource management system (i.e. lakes, water reservoir). Hence, this type of drought can affects the hydrological system. Results from several studies show that, besides lack of precipitation, the geology of an area also plays a crucial role on the hydrological droughts (Vogel and Kroll, 1992). Different studies show that amount ground water reservoirs in an area depend on the physical structure and substance of the location area.

Agricultural drought occurs when there is a soil water deficiency. In this case, water available in the soil is not enough to support growth of crops and other types of plant. Thus, primary consequences of agricultural drought are the damage of vegetation (crops, grass, and plants), though the severity of the damage depends on the specific characteristics of both the plants and the soil in addition to weather conditions (Flood and Climate Basics, 2004). Agricultural drought can also be enhanced by human activities like over-farming, deforestation, excessive irrigation, erosion and poor water management.

Population growth, urban development, the establishment of new industries, tourism, and the development of energy and agricultural sectors also contribute to water scarcity. This kind of drought is called socio-economic drought. Different droughts have different temporal distributions. After a rain shortage, the time at which the impact of a drought will appear depends on the drought type. For instance, it takes a longer time to detect precipitation shortage in groundwater than in soil moisture. Therefore, different time scales are necessary to monitor different droughts. The time scale commonly used for drought monitoring ranges from weeks to 1 or 3 months for agricultural droughts and from 12 to 24 months for hydrological droughts. The present study has been focused on meteorological and agricultural droughts, which are generally measured at three and four month scales. Drought indices are usually used to identify droughts and to classify them according to their intensity, severity, duration and geographical extension. The indices are helpful in extracting drought information from a variety of datasets. The Vegetation Condition Index, Crop Moisture Index (Palmer, 1968) and Drought Monitor Index are common to monitor agricultural droughts.

2.4 Time Sequence of Drought Impacts

The sequence of impacts associated with meteorological, agricultural and hydrological droughts highlights its differences. When drought event begins, the first to suffer is usually the agricultural sector because of it is heavily dependence on stored soil water (Hisdal and Tallaksen, 2000). The latter can be rapidly depleted over extended dry periods. If no precipitation period continues, then people will begin to feel the effects of the shortage. Those who rely on surface water (i.e., reservoirs and lakes) will suffer first and those who rely on subsurface water (i.e., groundwater) are usually the last to be affected. Although, groundwater users, often the last to be affected by drought during its onset, they are the last to experience a return to normal water supply levels. Obviously, the length of the recovery period is a function of the intensity of the drought, its duration and the quantity of precipitation received following the drought period. As schematically illustrated in (Fig 2.1), a drought event is caused by a certain meteorological situation, for instance a persisting anticyclone/ high pressure system. Associated with the prevailing dry and warm weather, a meteorological drought with a rainfall deficit develops. The rainfall deficit and the high evapotranspiration reduce the soil water content, which might cause an agricultural drought if it occurs during the growing season. Due to the precipitation deficit in the catchment, stream flow decreases until it is only fed by ground water and finally the groundwater reservoirs will also deplete. Consequently, hydrological droughts lag the occurrence of atmospheric droughts and depending on the season and the crop also the occurrence of agricultural drought. Water in hydrological storage systems such as surface and groundwater reservoirs is often used for multiple and competing purposes, e.g. flood control, irrigation, recreation, hydropower, navigation or wildlife habitat, further complicating the sequence and quantification of impacts (Wilhite, 2005).

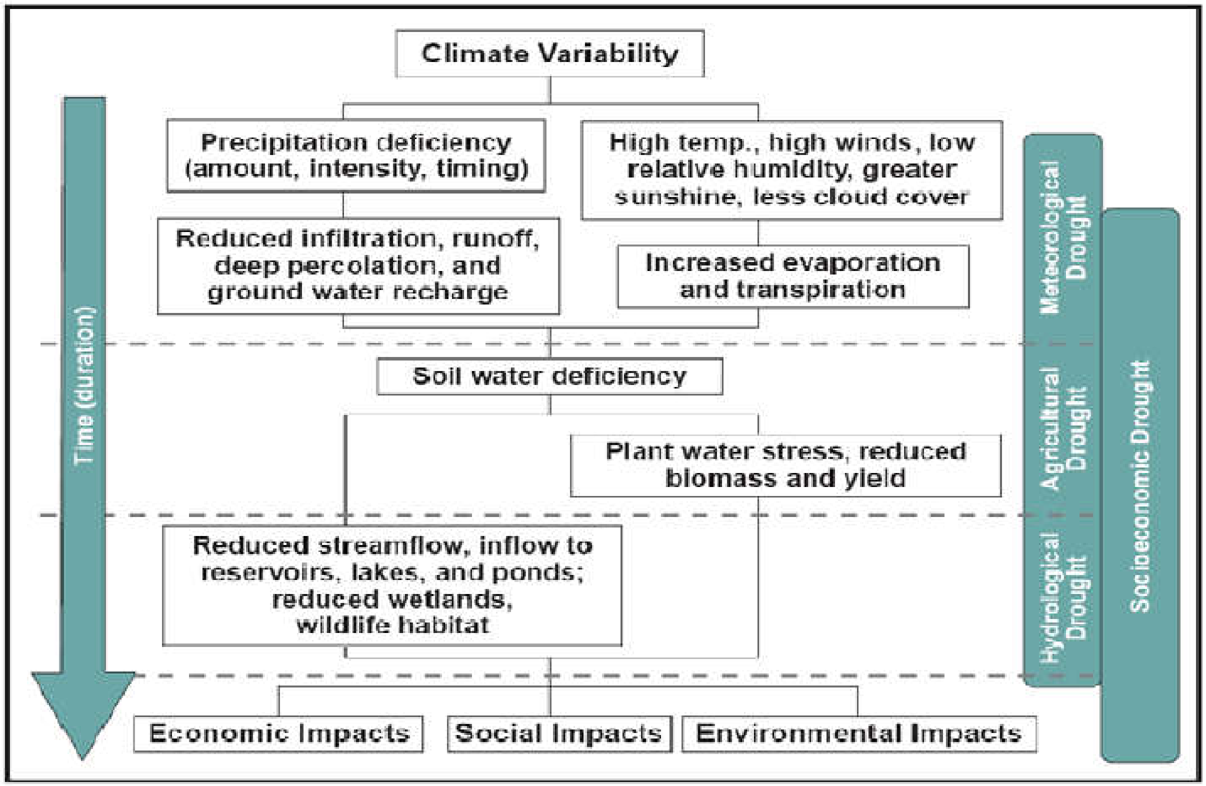

Figure 2.1: The sequence of drought impacts associated with meteorological, agricultural and hydrological drought (Source: National Drought Mitigation Centre, University of Nebraska-Lincoln, USA)

2.5 Drought History in Amhara Region

In general, during recent years, the Amhara Region has suffered from frequent drought phenomena. It is the single most rerunning climatic related natural hazard negatively impacting the region. Furthermore, as the Ethiopian Government Disaster Risk Management and Food Security Sector of the Ministry of Agriculture (DRMFSS, 2012) reported from 105 districts of the region 48 are drought prone among these North Wollo Zone was seriously affected and chronically food insecure.

2.6 Drought Assessment

Assessing and analyzing drought is very important in water resource planning and management. Droughts are assessed under meteorological, agricultural, hydrological, and socio-economic aspects (Nagarajan et al., 2010). Drought assessment depends on the factors that caused the drought and the impact of the drought. Assessing drought requires the understanding of historical droughts and its impact during the drought (Wilhite et al., 2007). Estimating climatological and hydrological parameters such as precipitation, evaporation and temperature are the best ways for assessing drought events (Mishra and Singh, 2010). In the past, drought assessments were done based on simply ground observations. However, the quantification of droughts had lower accuracy due to its distribution in space and time. Satellite remote sensing method is recently used because it enables the observations of variables at local, regional and even global scales (Su et al., 2001). Droughts are mainly assessed based on its intensity or severity, the duration and the areal extent. These parameters are combined into drought indices (Rossi et al., 1992).

2.7 Drought Indicators classification

Drought indices are useful for monitoring drought conditions, because they provide a quantitative method for determining the onset and end of a drought event, and because the index value indicates the level of drought severity. The drought indicators are classified as meteorological, satellite based and process based indicators. Crop moisture index is classified under meteorological based indicator where as vegetation temperature condition index and water deficit index is classified under satellite based indicator. Vegetation temperature condition index is a dimensionless indicator and vary from zero to one. A process based indicator is the result of the modeling of the energy and matter transfer between the atmosphere and the surface. Other indicators are physical and biophysical. Physical indicators of drought includes rainfall, water levels in streams/rivers and flow rates of springs, ground water levels, soil moisture condition, and surface water availability index, where as biophysical indicators includes plant yellowing, animal migration and emergence of plant pathogens (Murray, 2005).

2.8 Standardized Precipitation and Evapotranspiration Index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) was developed by Vicente-Serrano et al. (2010) with the intention of defining a drought index that would be sensitive to climate change. Vicente-Serrano et al. (2010) noted that the main factor influencing drought is precipitation; although other factors such as air temperature, ET, wind speed, and soil water holding capacity can also influence drought. The SPI can detect wet and dry events occurring simultaneously at different time-scales. However, the main shortcoming of SPI is that it uses only one climate variable (rainfall) for monitoring droughts (Sivakumar et al., 2011; Vicente-Serrano et al., 2012). It assumes rainfall has a stronger influence on droughts than other climate variables such as temperature, wind speed and direction, and potential evapo-transpiration; hence these variables are neglected.

Before the early 1980s, this assumption was warranted, because precipitation seemed to be the dominant factor in terrestrial water changes; but, thereafter, other climate variables such as temperature, wind, and humidity have been shown to have equally, or even more, important than rainfall in influencing drought. For instance, if a given region received the same amount of rainfall during two different seasons under different temperatures, it was likely that the region would be drier during the warmer season owing to higher evaporation. However, to overcome the shortcomings of SPI, Vicente-Serrano et al. (2010) recently proposed a new drought index: the Standardized Precipitation Evapo-transpiration Index (SPEI), which depends on the potential evapotranspiration (PET). The Standardized Precipitation Evapo-transpiration Index (SPEI) is a modification of the SPI. Similarly to the PDSI, the SPEI also accounts for the effect of temperature variability in the monitoring of droughts, and like the SPI, it can be computed at different time scales. As a result, the Standardized Precipitation Evapo-transpiration Index can be used to detect the temporal and geographical extension of droughts, and this makes it a good tool for drought analysis and monitoring.

2.9 Various Vegetation Indices

Among various satellites-derived indices, the Normalized Difference Vegetation Index (NDVI) has evolved over a period of time as a primary tool for monitoring vegetation changes and interpretation of the impact of climatic/weather events of the biosphere. For example, Kogan (1995) has developed the Vegetation Condition Index (VCI) using the Advanced Very High Resolution Radiometer (AVHRR) thermal bands images. NDVI was first suggested by Tucker (1979) as an index of vegetation health and density. The relationship between NDVI and rainfall is known to vary spatially, notably due to the effect of variation in properties, such as vegetation type and soil background (Farrar and Nicholson et al., 1994). Many studies have focused on the relationship between the NDVI and rainfall. NDVI showed patterns of vegetative growth from green-up to senescence by indicating the quantity of actively photosynthesizing biomass on a landscape (Burgan et al., 1996).

2.9.1 Normalized Difference Vegetation Index

Remote sensing has been found to be useful for earth observation. 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. By comparing visible and near infrared light, scientists measure the relative amount of vegetation and its vigor using vegetation Index. 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 following formula:

NDVI= (NIR-R) / (NIR+R); Where NIR= near infrared band, R= Red 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). It provides a measure of the amount and vigor of vegetation at the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigor and amounts of vegetation. Tucker first suggested NDVI in 1979 as an index of vegetation health and density (Thenkabail et al., 2004) and it has been considered as the most important index for mapping of agricultural drought (Vogt, 2000 Cited in Mokhtari, 2005). SPOT vegetation historical 10 day syntheses (S10) archive satellite product is one of the most important innovation for agricultural drought monitoring. 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. NDVI is good indicator of green biomass, leaf area index and patterns of production (Thenkabail et al., 2004). Furthermore, NDVI can be used not only for accurate description of vegetation vigor, vegetation classification and continental land cover but is also effective 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). Based on NDVI, the vegetation Condition Index (VCI) was developed to separate the short term weather signal in the NDVI data from the ecological signal. It was found the usefulness of VCI for drought detention, tracking, mapping, and estimating drought impact on vegetation (Kogan, 1995).

2.9.2 Normalized Difference Vegetation Index - Rainfall relationship as indicator of drought

Several studies have been devoted towards drought with the aid of satellite-derived information. Reflectance in the visible, near-infrared and thermal bands was combined into Vegetation Condition Index (VCI).Temperature Condition Index (TCI), and Normalized Difference vegetation Index (NDVI), which considerably improved early drought detection, watch and monitoring of drought's impacts on agriculture. Using NOAA Advanced Very High Resolution Radiometer (AVHRR) data, Researchers have successfully extended satellite data analysis to large-area vegetation monitoring (Kogan. 1990). Since vegetation indices derived from the AVHRR sensor are directly related to plant vigor, Density, and growth conditions, they may also be used to detect unfavorable environmental variables. Vegetation amount and condition are a function or environmental variables such as rainfall. Many studies have focused on the relationship between the NDVI and rainfall. A study by Wang et al., (2003) concentrated on temporal responses of NDVI to precipitation and temperature result showed that the average growing season NDVI values were highly correlated with precipitation received during the growing season. Relations between temperature and rainfall with NDVI were examined within growing season, across growing seasons and across years. It was concluded that precipitation has the primary influence on NDVI and by inference, on productivity.

Many studies performed in arid and semi-arid regions of east Africa (Nicholson and Farrar, 1990), USA (Vang et al., 2006) pointed out that precipitation has the primarily influence on NDVI. Studies on temporal relationship claim that NDVI responds to rainfall with certain time lag from 1 to 12 weeks (1 to 3 months), reflecting the delay in vegetation development after rain. The lag can vary depending on both climatic and non-climatic factors such as air and soil temperature, evaporation, soil or vegetation type (Nicholson and Farrar, 1990).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the Study Area

This study was conducted in North Wollo Zone, Amhara National Regional State of Ethiopia. The North Wollo Administrative Zone is one of the eleven Zones of the Amhara National Regional State. In North Wollo Zone, as in most parts of Amhara region, subsistence agriculture is the main livelihood of the rural population. Geographically, North Wollo Zone is located between 11^{o}N to 12^{0}N latitude and 39^{0}E to 40^{0} E longitudes and has an estimated area of 1,275,514.35 hectares, which covers about 20 percent of the region (Fig 3.1). The altitude of the Zone varies from 913 to 4187 meter asl. It has four agro-ecological zones, namely, lowland (*Kolla*) 500 to 1500 meter asl 38 percent, Mid-altitude (*Woina-Dega*) 1500 to 2300 masl is about 34 percent, Highland (*Dega*) 2300 to 3200 m asl is 21% and *Wurch*>3200 is about 7 percent of the Zone (NMSA,1996).

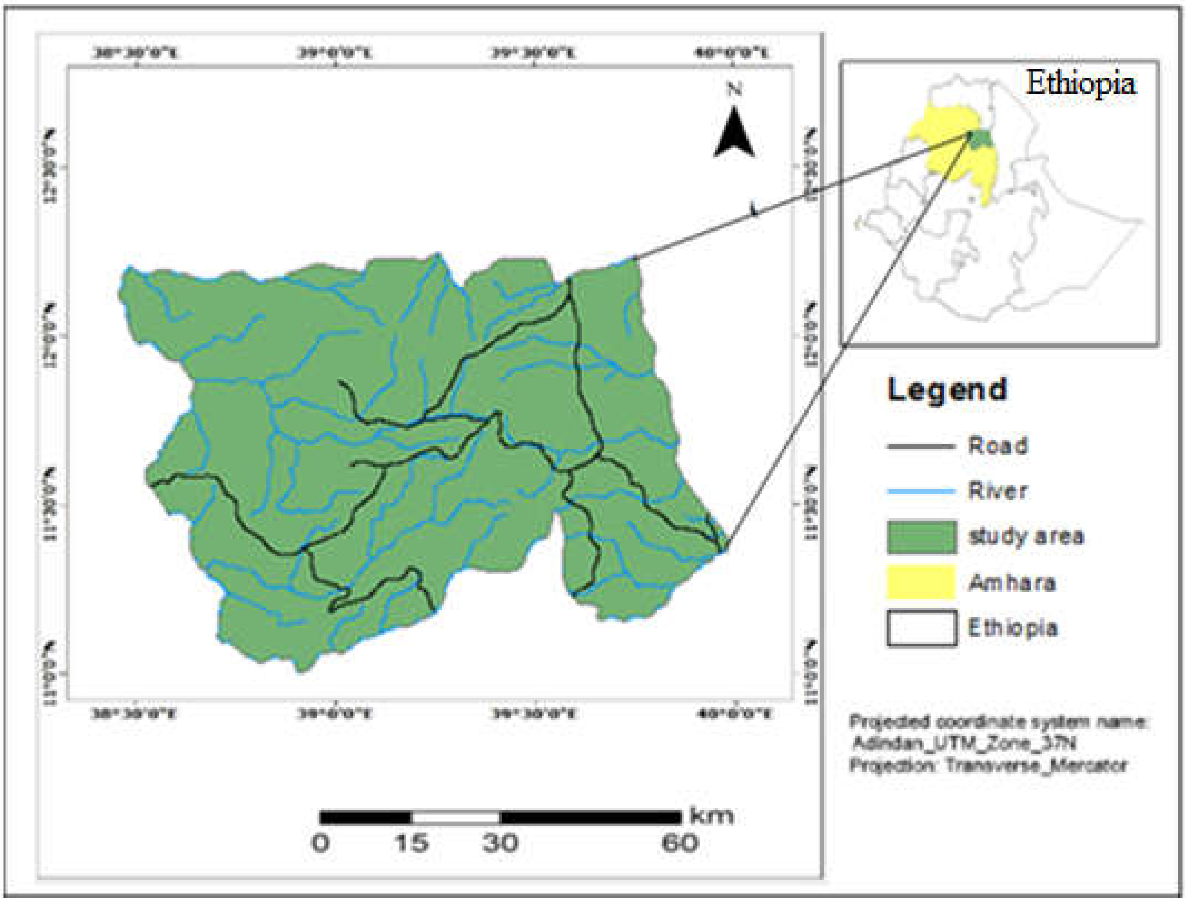

Figure 3.1: Location map of the study area

3.2 Climate and Rainfall Distribution

According to the air temperature data collected by Ethiopia National Meteorological Service Agency from seven weather stations, the mean minimum and maximum annual temperature at study area was found between 13^0C and 26.4^0C, respectively. A bi-modal nature characterized rainfall is common in most parts of the study area. The short rainy season (*Belg*) extends from February to April while long rainy season (*Meher*) that ranges from June to September. In most cases, the highland areas (*Dega*) are mainly dependent on *Belg* rain whereas, the Woina dega and Kolla areas are *Meher* rain dependent for crop production (NMSA, 1996).The principal feature of rainfall in most parts of North Wollo Zone is its seasonal character, poor distribution and variability from year to year. For the past decades, an erratic distribution of rainfall has been the major climatic factor affecting crop yields in the study area. The highest amount of rainfall was recorded during the months of July and August. On the other hand, the *Belg* rain (February-April) was inadequate for crop cultivation. The late season rain (September-October), which is essential for crop development, was also insufficient for the crops to grow. Such an erratic nature of rainfall has been a contributing factor to the declining crop production, which affects most farmers in the study area (NMSA, 1996).

Table 3.1Average maximum and minimum temperature of North Wollo Zone

Year	Max	Min	Year	Max	Min
2000	26.3	13.2	2008	25.1	13.2
2001	25.7	13.9	2009	25.81	12.9
2002	27.2	14.3	2010	24.5	13.2
2003	26.6	13.7	2011	25.7	13.8
2004	28.0	13.8	2012	26.8	13.4
2005	28.6	13.9	2013	27.2	14.1
2006	26.1	13.6	2014	26.0	13.4
2007	26.1	13.3	2015	27.9	14.2

Source: (NMSA, 2015)

3.3 Soil and Vegetation Cover

Soils are one of the most valuable life supporting natural resources for the society since they produce food, fiber and fodder, which are basic to our existence. The wide diversity in climate, topography and vegetation in the area has given rise to marked variations in soils. Soils in depressions and at the foot of the mountains tend to be black and liable to water logging during the rainy season, while those in elevated areas are likely to be highly leached, acidic and deficient in phosphorus and nitrogen. Erosion is the major problem on steep slopes. The management of soil fertility and other agronomic practices vary according to each soil type. Two types dominate all the agro-ecological zones: walka and keyate. Walka is a relatively fertile black cotton soil, but it has physical limitations similar to vertisols, cracking when dry and becoming waterlogged and difficult to work when wet. It covers an extensive area in the mid-altitude zones and the lower parts of the mountains (Murphy, 1968 World Bank, 1983 FAO, 1986.

Large parts the study area also has very shallow soils and excessive drainage conditions. The land degradation due to steep slope is major constraint for crop production in the study area. It is generally not rectifiable unless at great cost, by means of physical structures (e.g. terraces) and even then only in places where the conditions allow the construction of the structures required. It can thus generally be considered a permanent limitation. The physical potential for small-scale rain-fed crop production is seriously constrained in the larger part of the Zone. Approximately 31% of the Zone is classified as suitable for small-scale rain-fed crop production. Out of this 31%, 7% is considered moderately suitable and the remainder (62%) is classified as marginal. Highly suitable land does not occur in the Zone. Major limitations include lack of adequate moisture and the steepness of the terrain (DRMFSS, 2012).

3.4 Major Crops Cultivated in North Wollo

With regards to crop production, the administrative zone is dependent on both the *Belg* and *Meher* seasons. According to the available data from the Zonal Agriculture office, the major crops cultivated during the short rain (*Belg*) season, in order of importance are Barley, Teff and Lentils, while during the main rain (*Meher*) season the most important cultivated crops are Sorghum, Teff, Maize, Wheat, Barley, Chick peas, Faba beans and Lentils. The study area also benefited from irrigated crop production, although the total area is small as compared with other rain-fed fields.

3.5 Data Collection

Since, agricultural activities in the dryland semi-arid areas of Ethiopia in general and study area, North Wollo Zone in particular, are influenced and controlled by seasonal rainfall and temperature variability. Agricultural drought analysis was carried out seasonal wise using different drought indices with the objectives of characterizing agricultural drought using remotely sensed image based vegetation condition and climate data. Agricultural drought characterization was conducted by considering the entire dry and wet years because such consideration explains well agricultural drought characterization in drought risk zone map by comparing their vulnerability. In order to accomplish this study the following primary and secondary data have been collected.

3.5.1 Field Investigation

The field investigation was conducted to assess ground truth by using GPS for study area weather station point data capturing and informal interview for drought monitoring indices validation, and also for intensive analysis that to be used as an input to Remote Sensing image processing and interpolation of SPEI value. The major/dominant land use of study area was investigated by field observation.

3.5.2 Satellite Data Acquisition and Analyses Methods

3.5.2.1 SPOT vegetation NDVI

SPOT vegetation historical 10 day syntheses (S10) archive is freely available through SPOT Vegetation Program meat distribution server (http://free.vtvito.be/). SPOT vegetation NDVI data can be obtained for the whole continent of Africa (38°N to 35°S. 26°w to 60°E) in a geographic projection, with a spatial resolution of 0.00892857 degree (i.e. approximately 1 km) for agricultural drought monitoring. The size of image is 9633 x 8177 pixels. Ten-day composite data are processed by selecting pixels with the maximum NDVI during a 10 day period. Choosing pixels with the maximum NDVI is fundamental because it decreases cloud cover and water vapor contributions that negatively impact the NDVI value. Therefore, for this study, NDVI products were downloaded from 2000 to 2013.The 10-day composite per month is computed from the first of the month to the 10th, from the 11th to the 20th, and from the 21st to the end of the month. From these dekadal NDVI values of the continent Africa, the values for the study area, North Wollo Zone has been extracted. The raw data of NDVI value was not given in standard range (3 to 255). Then, it has been rescaled it in to normal NDVI range (-1 to +1) as.

To convert the RAW values in to normal NDVI:

Actual NDVI= Coefficient a*DN plus coefficient b (1)

NDVI = Coefficient a*DN + b,

Where; Coefficient a = 0.004, Coefficient b = −0.1

Then, actual NDVI was calculated from the raw data as (Raw data pixel value * 0.004) − 0.1 using Raster map algebra in ArcGIS. For this study, 192 dekadal seasonal NDVI images were analyzed and used as an input data for VCI and NDVI anomaly drought index.

3.5.2.2 PROBA-V Data Acquisition

PROBA-V vegetation data were also used for this study with 1km spatial resolution similar with that of SPOT vegetation data but of two days temporal resolution. PROBA vegetation data were also downloaded for 2014 and 2015 of the June, July, August and September months from the freely accessible website hosted by Vito. The PROBA-V vegetation is successor of SPOT vegetation since May, 2014 (http://proba v.vgt.vito.be/content/mission). PROVA-V vegetation data, rescaling is different from SPOT vegetation data processing. The PROVA-V vegetation data was rescaled to obtained the standard range of NDVI value (-1 to +1). Raw digital value ranges from 3 to 255, which was similar with that of SPOT vegetation data but its offset value is different. Therefore, the rescaling value is expressed as:

Actual NDVI=$(\text{Digital Number}/\text{Coefficient a})$ – Coefficient b (2)

Where, coefficient a = 250 and Coefficient b = −0.08

Therefore, $\text{Actual NDVI} = (\text{Raster}/250) - 0.08$

3.5.2.3 NDVI Anomaly

NDVI can be used as an index to assess vegetation condition through analysis of NDVI anomaly (Murali et al., 2008). Vegetative drought index has been calculated using NDVI values. Maximum NDVI and long term mean maximum NDVI in the growing season (June to September) were computed in order to derive seasonal NDVI anomaly. NDVI anomaly percentage was derived using the following formula for the study area.

NDVI Anomaly i= [(NDVI max i - Mean NDVI max)/ (Mean NDVI max)]*100 (3)

Where NDVI max i=Maximum NDVI in the growing season in i^{th} year and Mean NDVI max=long term mean maximum NDVI in the growing season during the period of study. The NDVI Anomaly values have been used for this study to identify agricultural drought risk and it presented in (Table 3.2).

Table 3.2: Agricultural drought risk classification using NDVI anomaly

NDVI anomaly (%)	**Drought severity class**
Above 0	No drought
0 to - 10	Slight drought
-11 to - 25	Moderate drought
-26 to - 50	Severe drought
Below - 50	Very Severe drought

Source: Gizachew Legesse and Suryabhagavan, K.V. (2014).

3.5.2.4 Vegetation Condition Index (VCI)

Although the NDVI has been extensively used in the past for vegetation monitoring, it is often very difficult to interpret in relation to vegetation condition, especially when comparing different ecosystems. Vegetation condition index was first suggested by Kogan (1995). VCI captures rainfall dynamics better than the NDVI particularly in geographically non homogeneous areas. The VCI not only permits the description of land cover and spatial and temporal vegetation change but also allows quantifying the impact of weather on vegetation status. The VCI have been used to estimate the climate impact on vegetation. It is defined as:

VCI= ($NDVI_J$ - NDVI min)/ (NDVImax - NDVI min) *100 (4)

Where, NDVImax and NDVI min is calculated from long-term recorded for a particular year and j is the index of the specific year. The VCI values between 50% and 100% indicates slight or optimal/normal conditions where as VCI values close to zero percent reflects an extreme dry season (Thenkabail 2004).The VCI was reclassified into five clusters as shown in (Table 3.3).

Table 3.3: Classification of vegetation condition index values in term of drought

VCI value (%)	Category
0 to 20	Very Severe drought
21 to 35	Severe drought
36 to 50	Moderate drought
51 to 60	Slightly drought
61 and above	Optimum/normal

Source: (Kogan, 1995)

3.5.2.5 Digital Elevation Model (DEM)

The digital elevation model has been used for this study, it is 30 m resolution. The DEM of study area showed that the high altitude areas located in the central part of study area at 4187 m in (Fig.3.2) (B). The boundary area of the study area, where elevation down to around 913 m, it's highly susceptible to agricultural drought that might be due to the elevation factor for rainfall distribution and temperature variability.

3.5.2.6 Land-Use /land-Cover

Land use / Land cover map of the study area was prepared from Landsat image. The study area was classified into different land use types. The information contained in the land use map tells us how the different uses of the surface are distributed inside the area under study. In (Fig. 3.2) (A) and the appendix (Table 2) it can be seen that the study area is mainly occupied by cultivated land with more than 34% of the study area. There is also 55.59 % of the area covered by bare and forest lands. The rest of 10.41 % is mainly settlement, shrub and grassland. Agricultural activity is concerned on land use pattern which is an important factor that influences crop production and productivity.

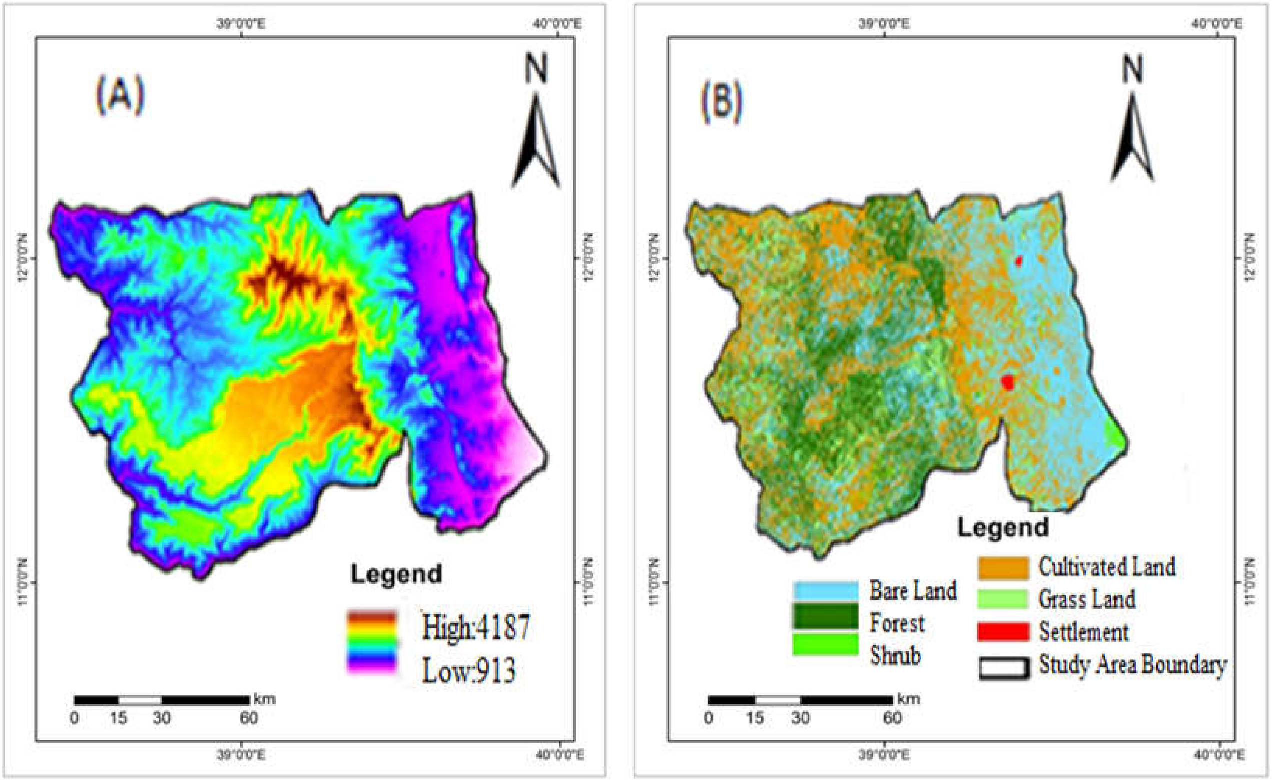

Figure 3.2 Elevation (A) and Land-use/Land-cover (B) map of North Wollo Zone

3.5.3 Meteorological data

Rainfall and temperature data was collected from National Meteorological Service Agency (NMSA) of Ethiopia from all weather stations of study area, which have been used to derive Standardized Precipitation and evapotranspiration Index (SPEI). Vicente-Serrano et al. (2010) proposed a new drought index called the Standardized Precipitation and Evapotranspiration Index (SPEI). The SPEI based on precipitation and temperature data, and has the advantage of combining a multi-scalar character with the capacity to include the effects of temperature variability on drought assessment. The procedure to calculate the index is detailed, and involves a climatic water balance, the accumulation of deficit/surplus at different time scales, and adjustment to a Log-logistic probability distribution. Mathematically, the SPEI is similar to the Standardized Precipitation Index (SPI), but it includes the role of temperature. The values are accumulated to different time scales, following an approach similar to that of the SPI drought index. The SPEI has the advantage of being multi-scalar, which is crucial for drought analysis and monitoring. The SPEI's main advantage over the other widely used drought indices lies in its ability to identify the role of evapotranspiration and temperature variability on drought assessment in the context of global warming (Vicente et al., 2010).

3.5.3.1 Standardized Precipitation and Evapotranspiration Index

The calculation of SPEI is similar to SPI except that the function is fit to precipitation minus potential evapotranspiration (P-PET) values. The PET value can be calculated using different equations that link it to the temperature value. Vicente et al. (2010) recently showed that the use of simple or complex methods to calculate the PET provide similar results when a drought index such as the PDSI and SPEI is calculated. Vicente et al. (2010) stated that although, some methods in general provide better results than others for PET quantification. Droogers and Allen (2002), the purpose of including PET in the drought index calculation is to obtain a relative temporal estimation, and therefore the method used to calculate the PET is not critical. Therefore, the simplest approach to calculate PET (Thornthwaite, 1948) is used, which has the advantage of only requiring data on monthly mean temperature. Following this method, the monthly PET (mm) is obtained by:

$$PET = 16\mathrm{k}\left(\frac{10T}{i}\right)^{\mathrm{m}} \tag{5}$$

In the above equation T is monthly mean temperature in degree Celsius i is heat index derived from 12 monthly index values calculated as a sum of 12 monthly index values i, which is calculated as given in the equation:

$$i = \left(\frac{T}{5}\right)^{1.514} \tag{6}$$

m is a coefficient depending on i, and k is a correction coefficient computed as a function of the latitude and month. The difference between precipitation and potential evapotranspiration provides a measure of water surplus or deficit for the month and this is compared over time and standardized to get the value of SPEI.

$$d_i = P_i - PET_i \tag{7}$$

d_i- a difference of precipitation and potential evapotranspiration for month i. The probability distribution of cumulative D i is aggregated at different time scales following the same procedure as that for the SPI. The difference $D^{k}_{i,j}$ in a given month j and year i depends on the chosen time scales, k. In quantifying the SPEI is needed to use a three parameter distribution, since in two parameter distributions the variable (x) has a lower boundary of zero (0> x <∞), whereas in three parameter distributions x can take values in the range (γ>x <∞, where γ is the parameter of origin of the distribution), consequently, x can have negative values, which are common in D series. To model D_i values at different time scales are used the probability density function of a three parameter Log-logistic distribution:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\left(1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right)^{-2} \tag{8}$$

Where α, β and γ are scale, shape and origin parameters, respectively, for D values in the Range (γ>D<∞).The Log-logistic distribution adopted for standardizing the D series for all time scales is given by:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{9}$$

F (x) value is then transformed to a normal variable by means of the following approximation:

$$SPEI = W - \frac{C_0+C_1W+C_2W^2}{1+d_1+d_2W^2+d_3W^3} \tag{10}$$

Where C_o, C_1, C_2, d_1, d_2, d_3 is similar constants as for SPI and W is probability-weighted moments:

$$W = \sqrt{-2\ln(P)} \tag{11}$$

P≤0.5 and P is the probability of exceeding a determined D value. The average value of SPEI is zero, and the standard deviation is one. The SPEI is a standardized variable, and it can therefore be compared with other SPEI values over time and space. For each time scales, each drought event (period in which SPEI is continuously negative and SPEI ≤ -1), can be defined through its duration (time from the beginning to the end), severity (SPEI value for each month following the classification), magnitude (SPEI sum for each month and for the duration of the severity), intensity (magnitude/duration ratio of the event). For this study Computer software have been used to compute the values of SPEI. The software is automatically calculates the SPEI value over a wide range of time scales. It is freely available in the web repository of the Spanish National Research Council (available online at http://digital.csic.es/handle/10261/10002). This software can be calculates the SPEI values by using the observed climate variables data to detect historical drought. The software can be runs for 3, 6, 12, 24 and 48 month time scales for this study 3 month time scale climate data have been used. These time scales can reflect the impact of drought on the availability of water resources. In order to get spatial pattern of drought condition in the study area, interpolation of SPEI value was done using Inverse distance weighted (IDW) method using ArcGIS software. As the SPOT Vegetation NDVI data is from 2000 to 2015, so SPEI was interpolated for this time period of the main crop growing season. Latitude and longitude of all weather stations were taken and a point map was created. Then, each month SPEI value was added to the point map and interpolated for the study area and reclassify based on the drought severity classless as shown in the (Table 3.4).

Table 3.4: Categorization of SPEI for drought severity classes

SPEI value	**Drought severity class**
$1.5 < SPEI \leq 2$	Normal
$1 < SPEI \leq 1.5$	Slight
$-1 < SPEI \leq 1$	Moderate
$-1.5 < SPEI \leq -1$	Severe drought
$-2 < SPEI \leq -1.5$	Very Severe drought

Source :(Vicente, 2010)

3.5.3.2 Weather Station Map

Point map of seven weather stations in North Wollo Zone was prepared from the latitude/longitude file (Appendix table 1). It has been used to interpolate SPEI values from rainfall and temperature distribution in the study area (Fig 3.3).

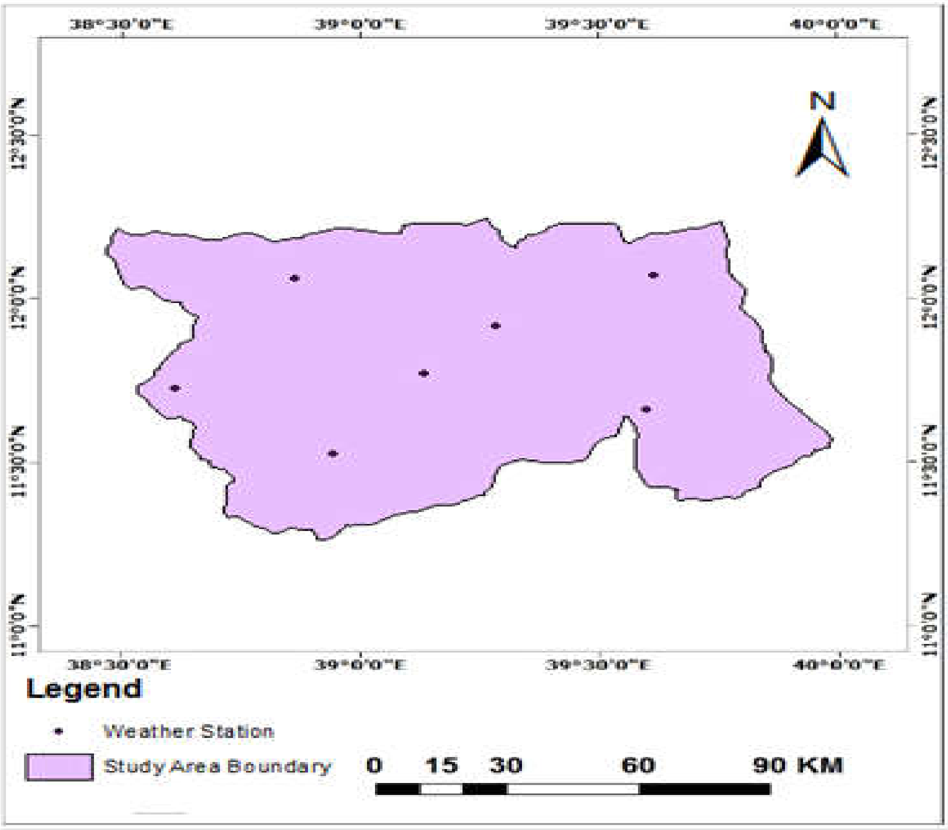

Figure 3.3: Weather stations Map of North Wollo Zone

3.5.4 Crop yield Data

The characteristics of Satellite derived hydro-meteorological parameters and the derived drought indexes must be validated by ground truth data. In this study, the data used for relation and validation purpose is mainly crop yield data. The crop production statistics were taken for the study area from Central Statistical Agency. Different information related to agricultural drought hazard and their impacts on agricultural activities as well as cropping practices were collected from different scientific papers, journal, Ministry of Agriculture, Zonal and Woreda agricultural and rural development office, early warning and food security bureaus and informal interview and group discussion with zonal agriculture office experts (Appendix 1). It also used for the evaluation of the drought indices result that obtained from satellite and climate data. Crop yield data have been obtained for 16 years starting from 2000 to 2015. Yield anomaly has been calculated in the same way as the computation of NDVI anomaly.

3.6 Data Analysis Using Drought Indices

In this study the Standardized Precipitation and Evapotranspiration Index (SPEI) were used to assess the degree of drought in terms of severity and scope using observed climate data from Climate weather stations. In addition to this Satellite images based drought indices was used to detect agricultural drought condition. Correlation analysis has been done to understand the response of climate and satellite based drought monitoring indices result on crop yield. The relationship between NDVI Anomaly, VCI and SPEI results from each seasonal year with corresponding grain yield anomaly was computed to validate the derived indices. Finally, the combined agricultural drought severity map was generated by overlying the agricultural and meteorological drought severity maps. During this study ArcGIS 10.3, Excel, ErdasImagine and other tools were intensively used.

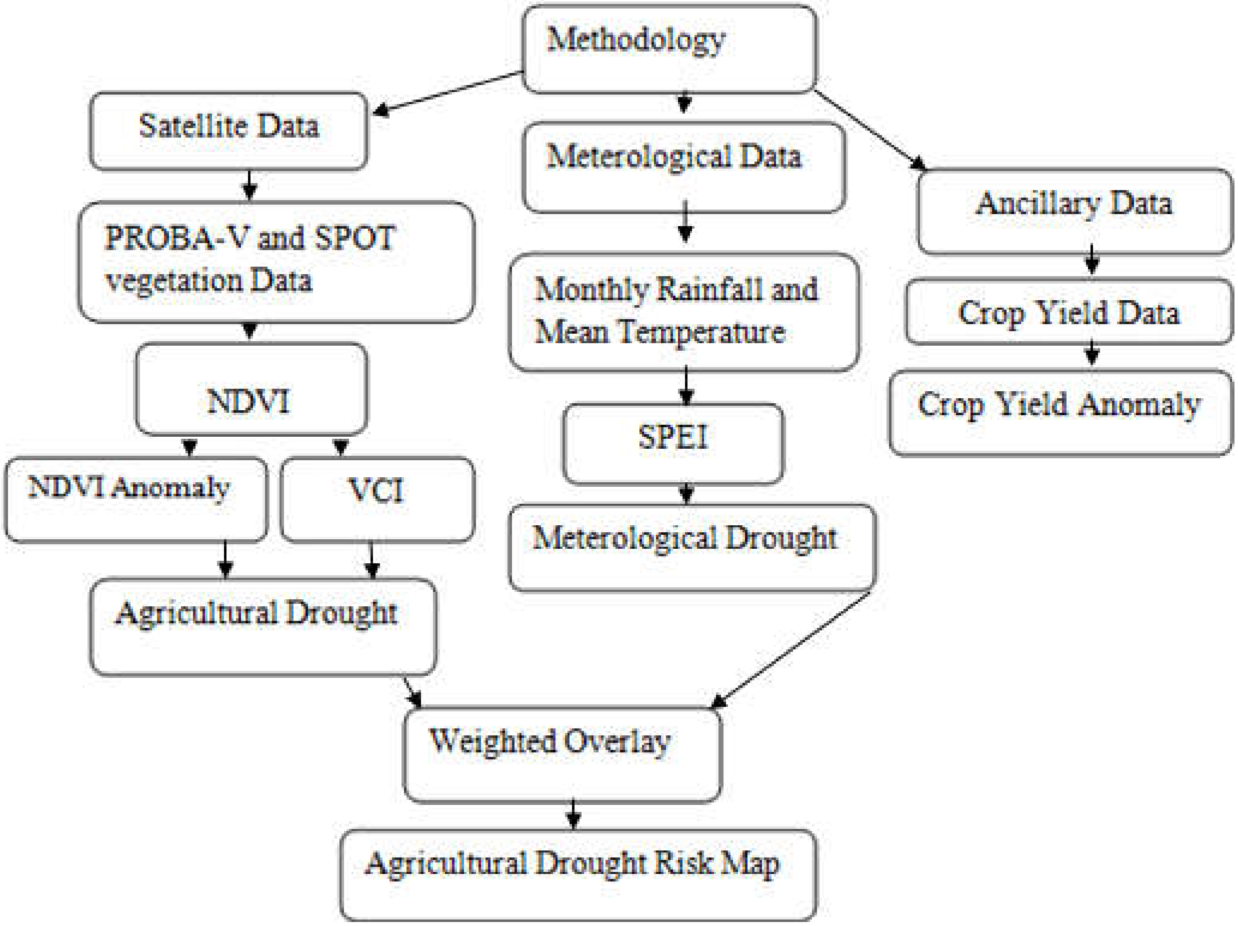

Figure 3.4: Methodological flow chart of the study

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Relationship between Seasonal Rainfall and NDVI

The seasonal analysis of historical rainfall and the response of vegetation are very vital generally in the country and particularly in the study areas because most of cropping system is rain-fed. Its production/yield affected by seasonal rainfall. Accordingly, seasonal rainfall and NDVI patterns of the entire study area for a period from 2000 to 2015 have been studied. The result have been showed that there was good correlation (r=0.71) between rainfall and NDVI (Fig 4.1). During the sixteen years (2000 to 2015), there was considerable year to year variation in precipitation and NDVI (Fig 4.3).It revealed that, there was increasing trend both in rainfall and NDVI. Also they have better association that indicating with in16 year's data, 51 % percent of NDVI variability can be explained by seasonal rainfall (R^2 value 0.514). The result of this study lines with the findings of Aynamba and Tucker (2005), Beyene (2007) and Gizachew (2010) who have reported the strong correlation between NDVI and seasonal rainfall.

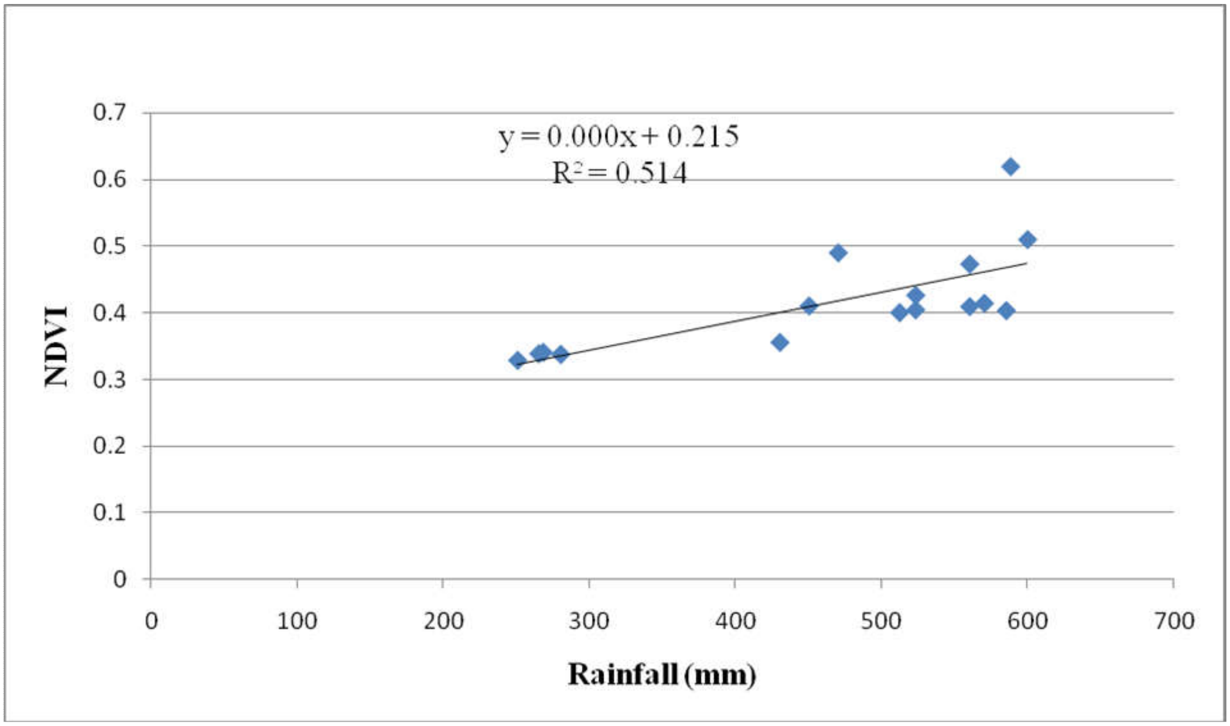

Figure 4.1: Seasonal (June-September) patterns of rainfall and Normalized Difference vegetation Index (2000 to 2015)

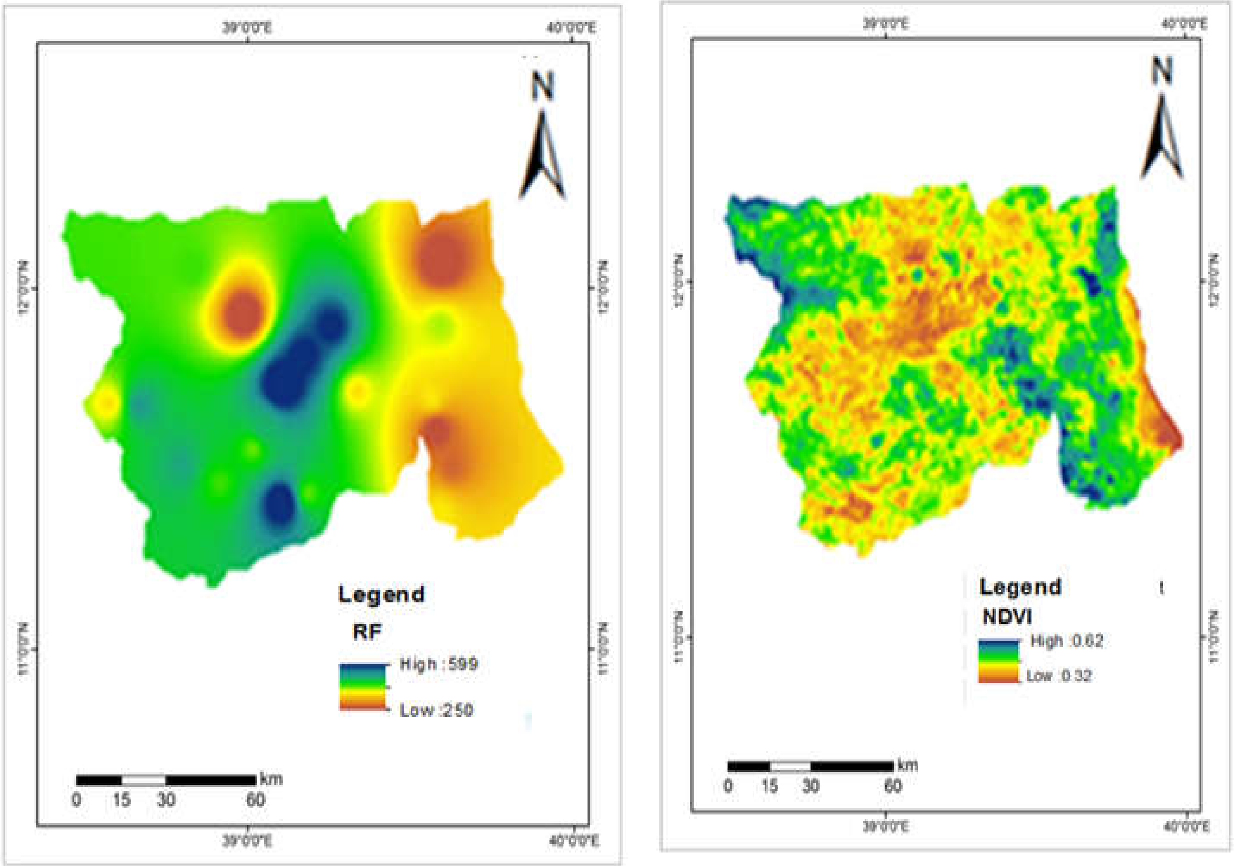

Figure 4.2: Spatial pattern of long term Seasonal (June to September) Average rainfall and Normalized Difference vegetation Index (2000 to 2015)

The NDVI during main crop growing period from 2000 to 2015 was shown in (Fig 4.2), it can be seen that vegetation has a spatial pattern that was clearly constrained by precipitation. The seasonal pattern of rainfall and NDVI, as presented on (Fig 4.3), showed that the higher rainfall variation in the study area. The low rainfall area, where rainfall amounts to 250 mm for the main crop growing season and the corresponding NDVI values is also relatively low whereas if one moves towards the central and south western parts of the study area comparatively high rainfall areas can be identified where rainfall shoots up to 599 mm. It is evident from the (Fig 4.3) that during the low rainfall years NDVI values were also low and two major dips in 2005 and 2015 relatively showed low rainfall and NDVI compared to slight drought year, which clearly marks that these were the drought years.

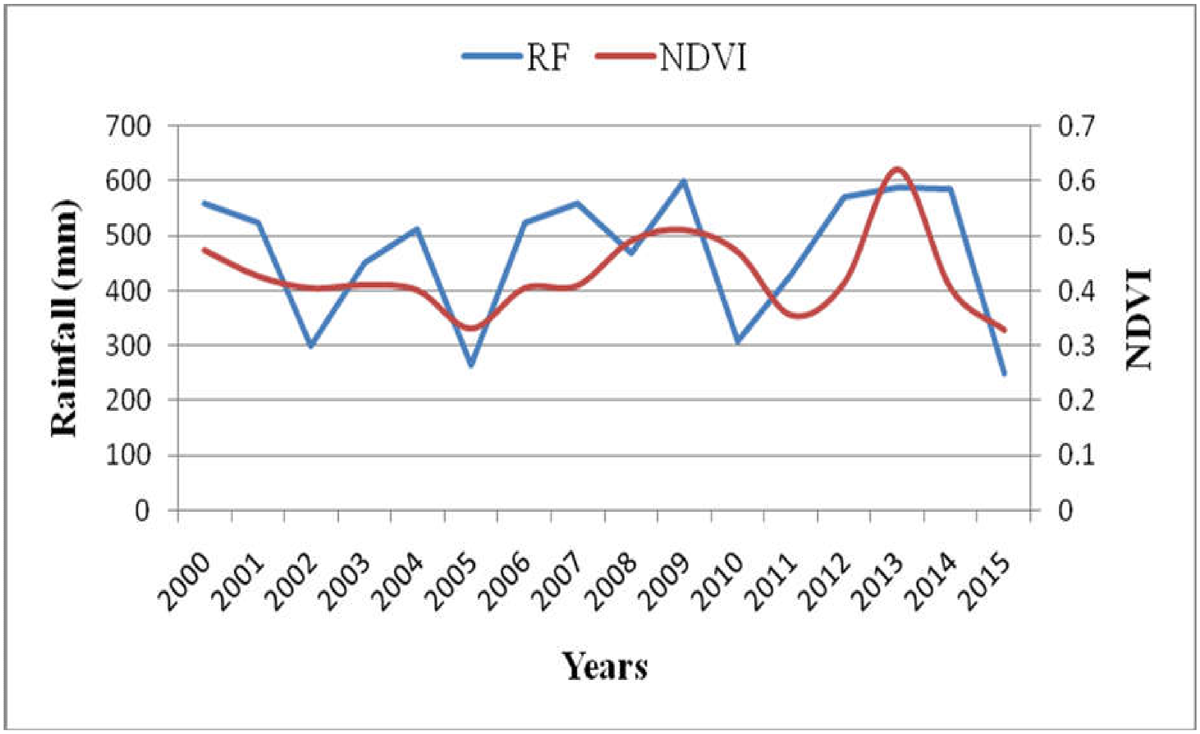

Figure 4.3: Temporal trends of seasonal Average Rainfall and Normalized Difference vegetation index (2000 to 2015).

4.2 Normalized Difference Vegetation Index Anomaly and Agricultural Drought

The NDVI is useful indicator as a measure of agricultural drought when compared to normal plant health. NDVI anomaly is one of agricultural drought index that shows the drought severity level. Based on this drought monitoring index, 2005 and 2015 years were considered as a drought years during the main cropping season in (Fig 4.4).The result provided the spatial patterns of agricultural drought events and the level of drought severity ranges from very severe to slight drought in both 2005 and 2015 drought years. However, the extent of moderate and slightly drought covers small pocket. The majority of the study area was suffering by Very severe and severe agricultural drought (Fig 4.4).

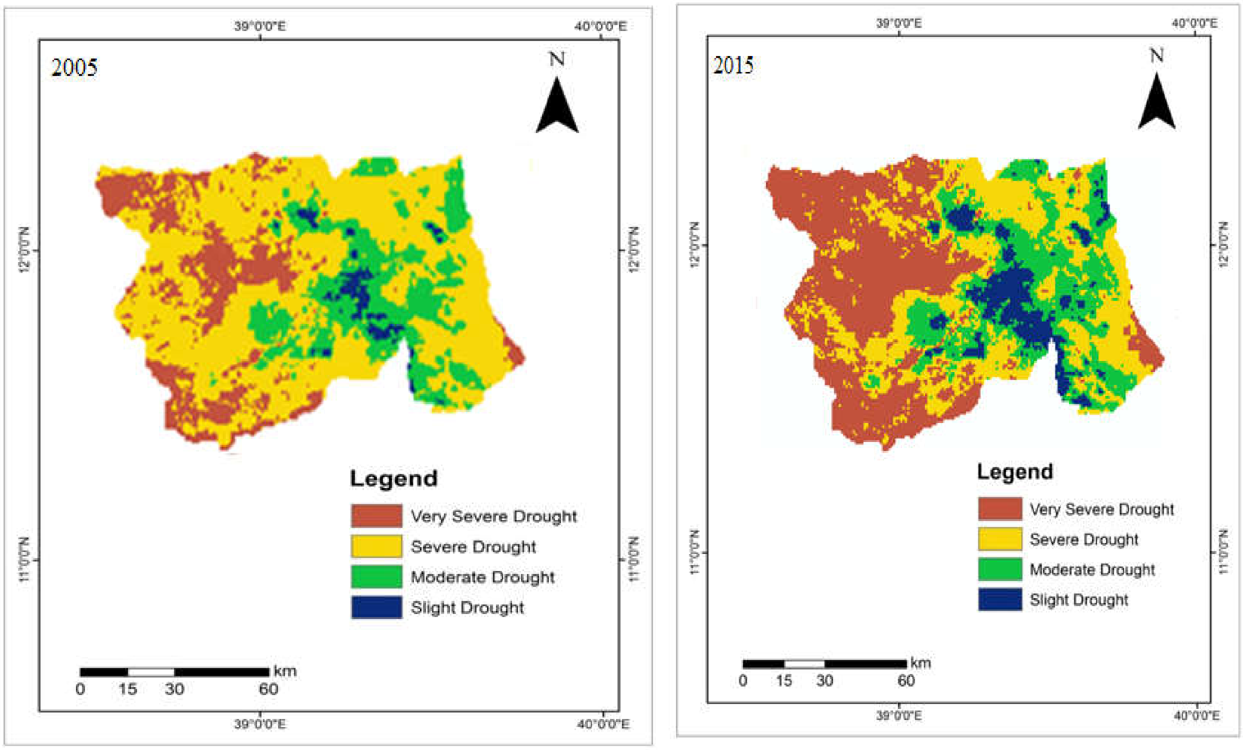

Figure 4.4: Normalized Difference vegetation Index Anomaly for drought years 2015 and 2005

Regarding the wet years, it can be observed from the map depicted in (Fig 4.5) that some very small areas were hit by very severe level of agricultural drought while the majority of the areas under the influence of slight and moderate agricultural drought. Higher value of NDVI anomaly indicates greater vigor and health vegetation (Herrmann and Anyamba, 2004).

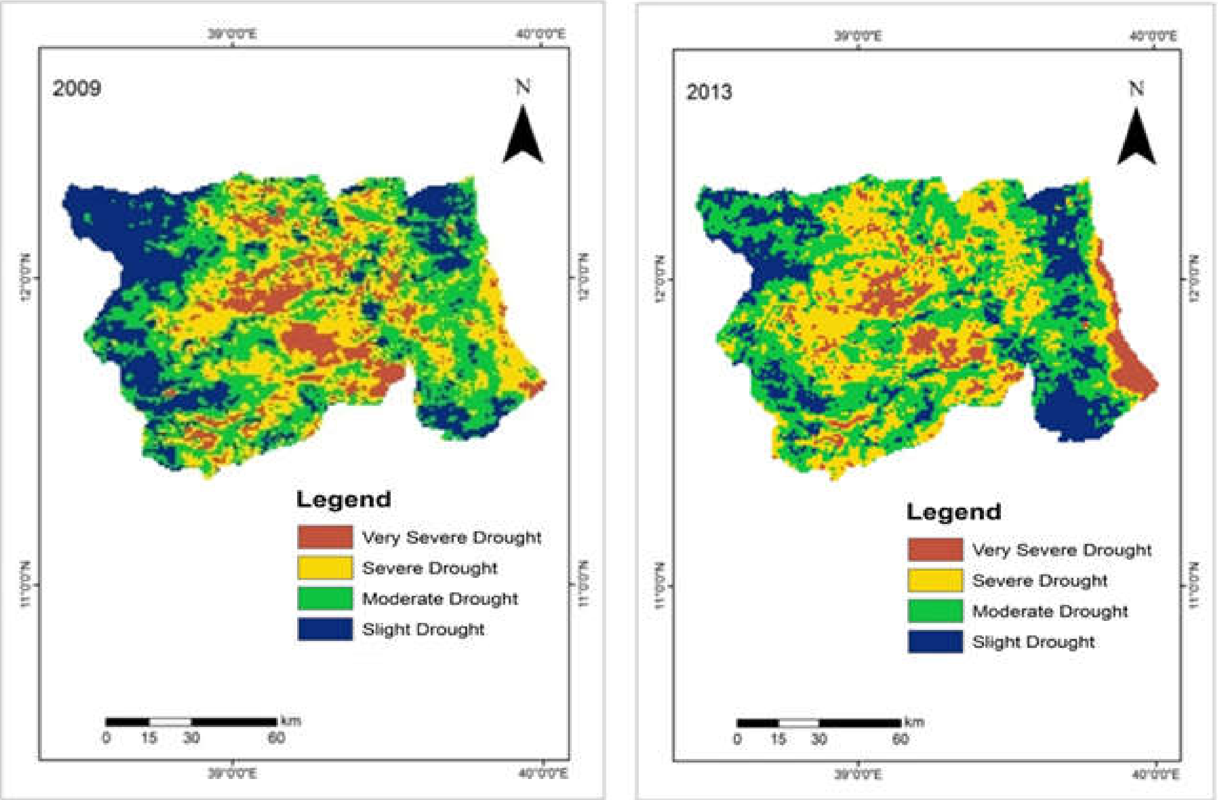

Figure 4.5: Normalized Difference vegetation Index Anomaly for Wet years 2009 and 2013

4.2.1 Relationship between NDVI Anomaly and Crop Yield Anomaly

Trend was computed to recognize the pattern of crop production and NDVI anomaly from 2000 to 2015. Correlation analysis between NDVI and crop yield anomaly was conducted in order to evaluate how the crop yield changes with relation to NDVI for rain-fed cropping systems. There was positive relation(r=0.78) between NDVI and crop yield Anomaly (Fig 4.6). This result confirmed that 62 % of crop yield Anomaly variability can be explained by NDVI Anomaly. The highest yield reduction occurred in 2005 and 2015 due to agricultural drought event (Fig 4.7). This might be attributed by fluctuation of rainfall amount to satisfy minimum crop water requirement. Crop yield is generally correlated with vegetation condition; this index can be used to develop a relationship with yield. The result of this study lines with the findings of Beyene (2007), who have reported the good correlation between NDVI and crop yield anomaly.

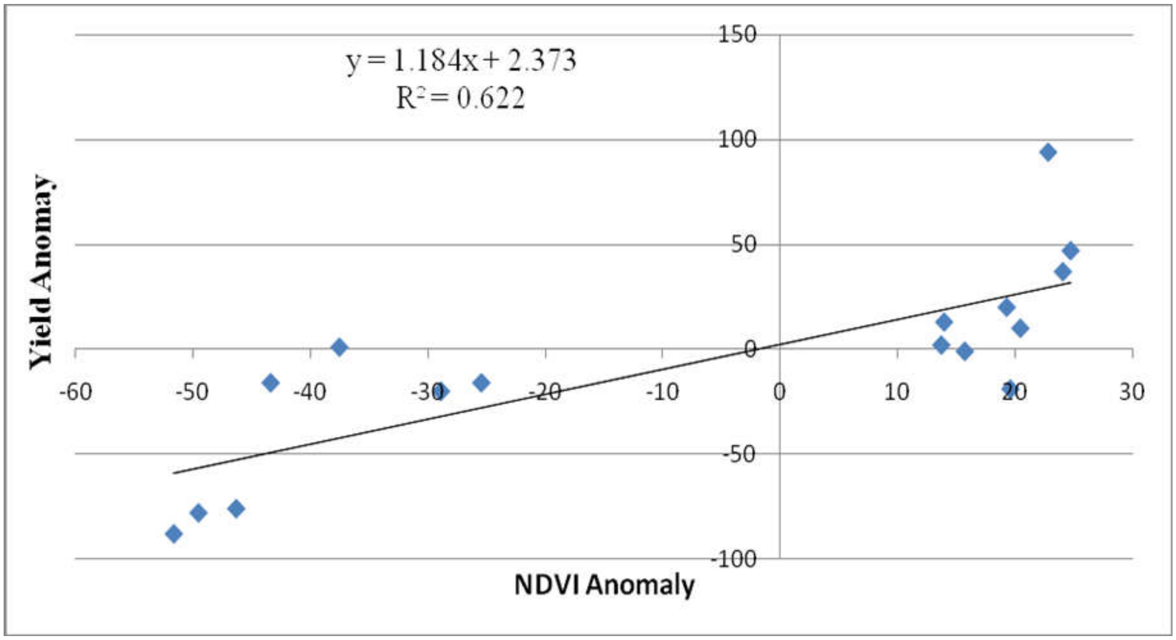

Figure 4.6: Relationship between Normalized Difference vegetation Index and Yield Anomaly

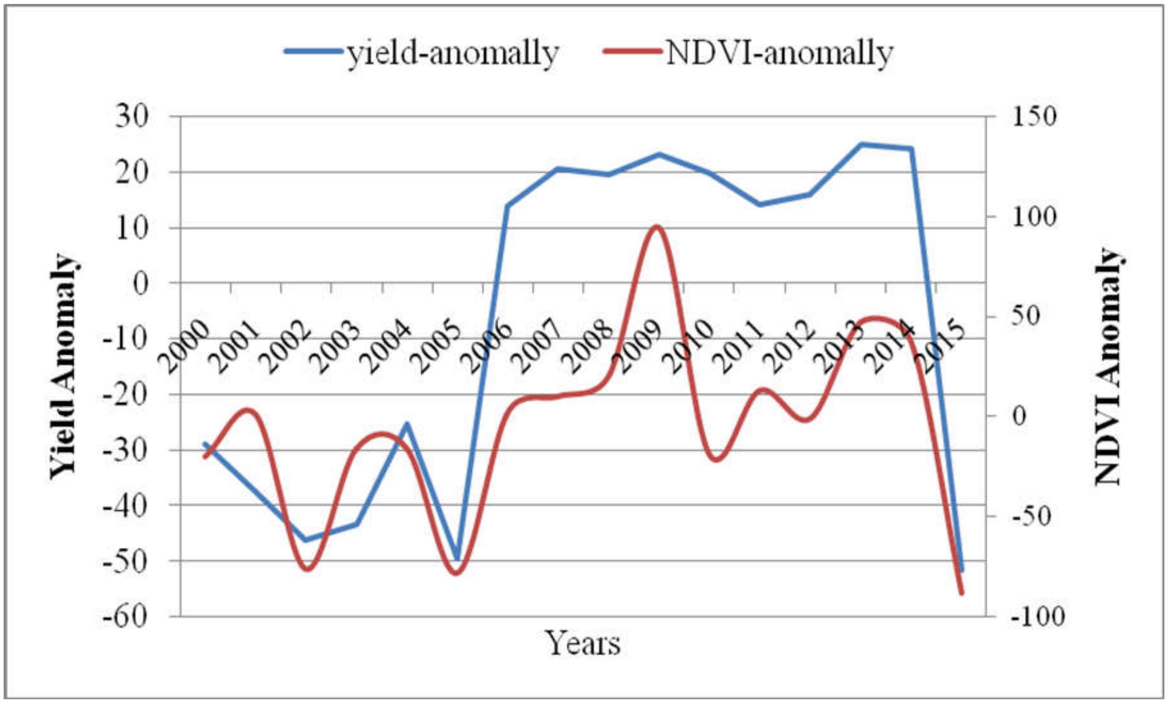

Figure 4.7: Temporal trends of seasonal Yield and Normalized Difference vegetation Index Anomaly (2000 to 2015)

4.2.2 Relationship between NDVI Anomaly and SPEI

Simple correlation analysis was conducted to evaluate the relationship between NDVI Anomaly and SPEI. The result obtained from the correlation analysis of the two parameters indicates there was positive strong correlation(r=0.82) between them (Fig. 4.8), which is in lines with findings of Vicente-Serrano et al. (2012) who reported that the strong correlation between the SPEI and NDVI Anomaly. In this study, R^2 value 0.67 percent indicates that 67 % of NDVI variability can be explained by SPEI. Wang et al. (2001) concluded that NDVI Anomaly was more strongly related to climate variables (precipitation and temperature).

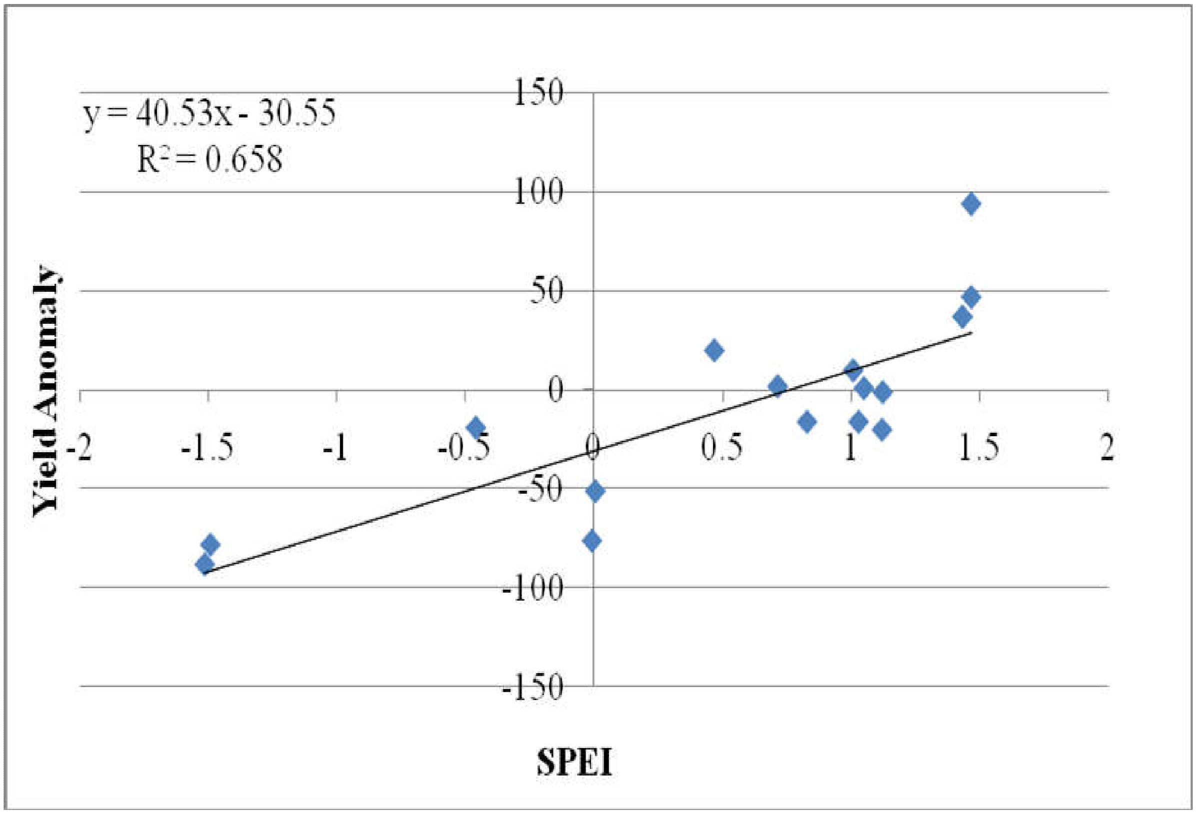

Figure 4.8: Relationship between Normalized Difference vegetation Index Anomaly and Standardized Precipitation and evapotranspiration Index

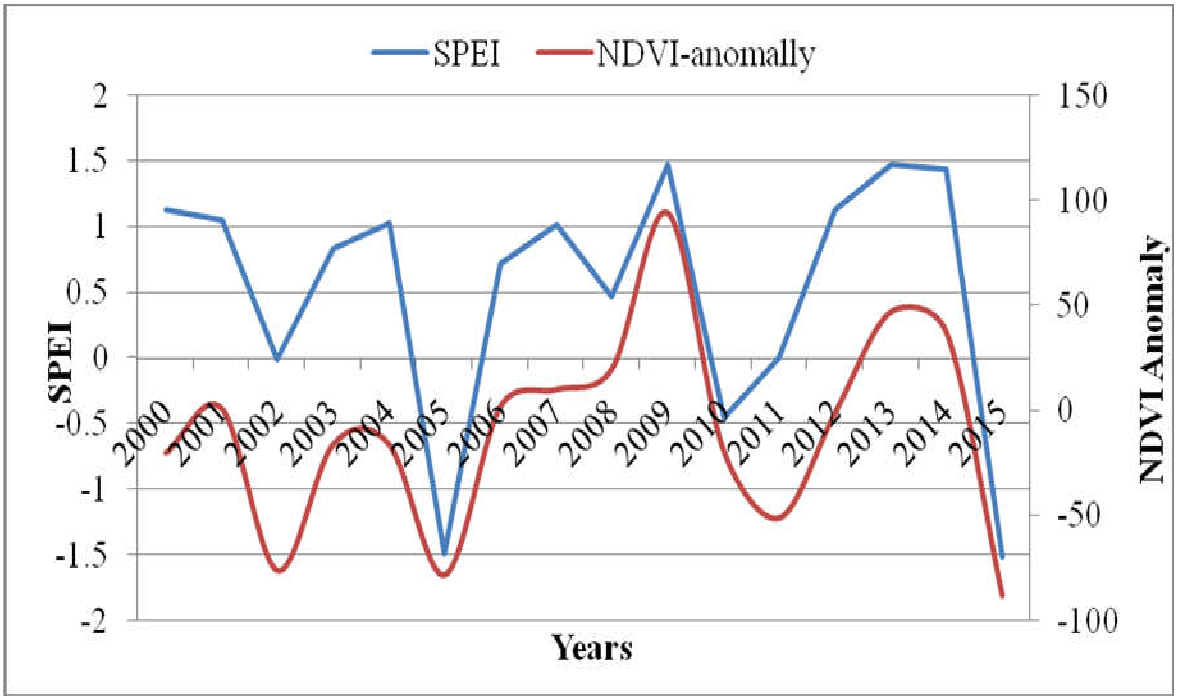

Figure 4.9: Temporal trends of seasonal Standardized Precipitation and evapotranspiration Index and Normalized Difference vegetation Index Anomaly (2000 to 2015).

4.3 Spatio-temporal Patterns of SPEI and Drought Severity

SPEI was computed during the main crop growing season in North Wollo Zone from 2000 to 2015. Drought risk was identified using SPEI by interpolating SPEI values over 16 years. The analysis of SPEI revealed that drought has been occurred at different level of severity from 2000 to 2015 during the main cropping season. The result showed that the drought years of 2005 and 2015 and normal years of 2009 and 2013. It can be seen that during the drought years of 2005 and 2015 the SPEI values was very low in the study area. This indicates low rainfall distribution and high temperature during the main crop growing season and it, therefore, was the worst dry seasons. Spatio-temporal drought severity map showed that Western and Eastern parts of the study area are vulnerable to both very severe and severe drought event while the central part of the study area was less vulnerable to the drought event.

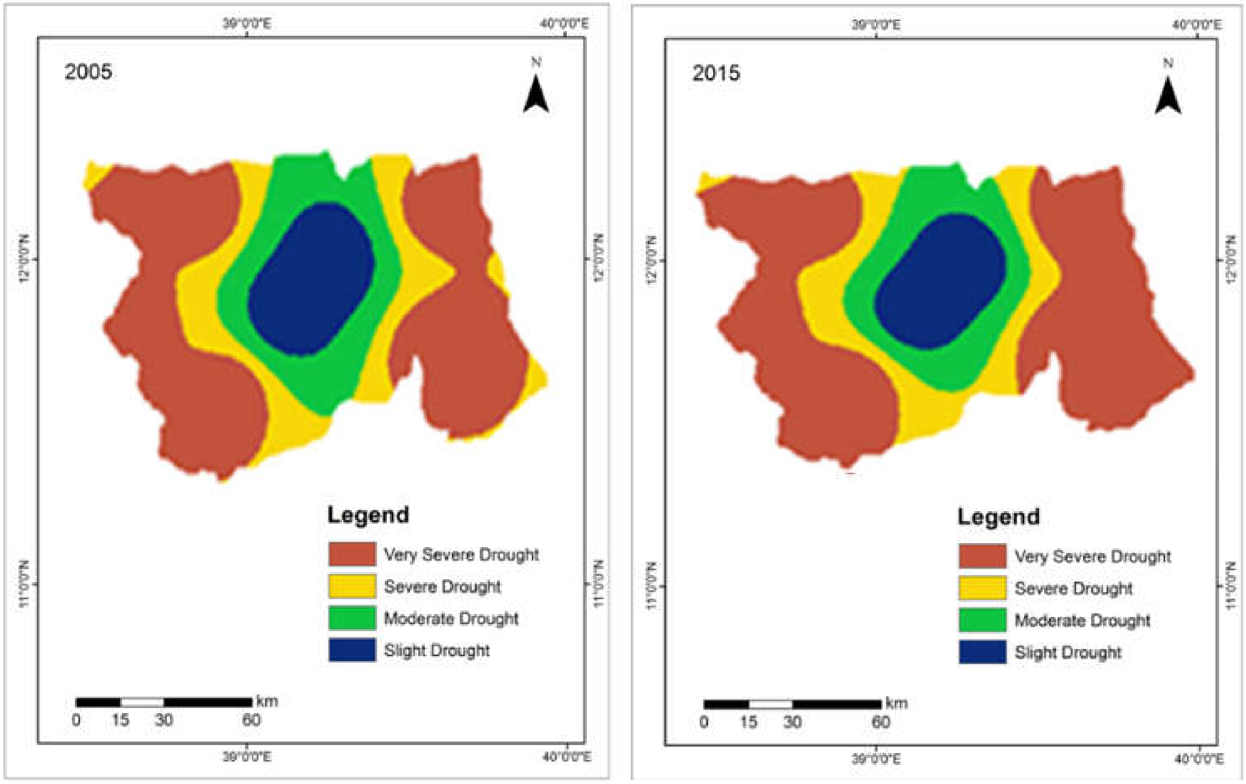

Figure 4.10: Standardized Precipitation and evapotranspiration Index for drought years 2005 and 2015

In addition to this, the spatial pattern of the SPEI value can be used to identify not only drought years but also wet years. In this regard, using SPEI value, wet years were also identified. As the maps showed in the (Fig 4.11), the year 2009 and 2013 were wet years in the study area. The highest SPEI value was observed in the year of 2009 and 2013 and the range of severity was from slight drought to no drought. Although good seasonal rainfall helped almost the whole area to avoid drought during 2009 and 2013, some small areas affected with slight drought from the total area. This might be occurred due to the influence of the bad distribution of rainfall and temperature.

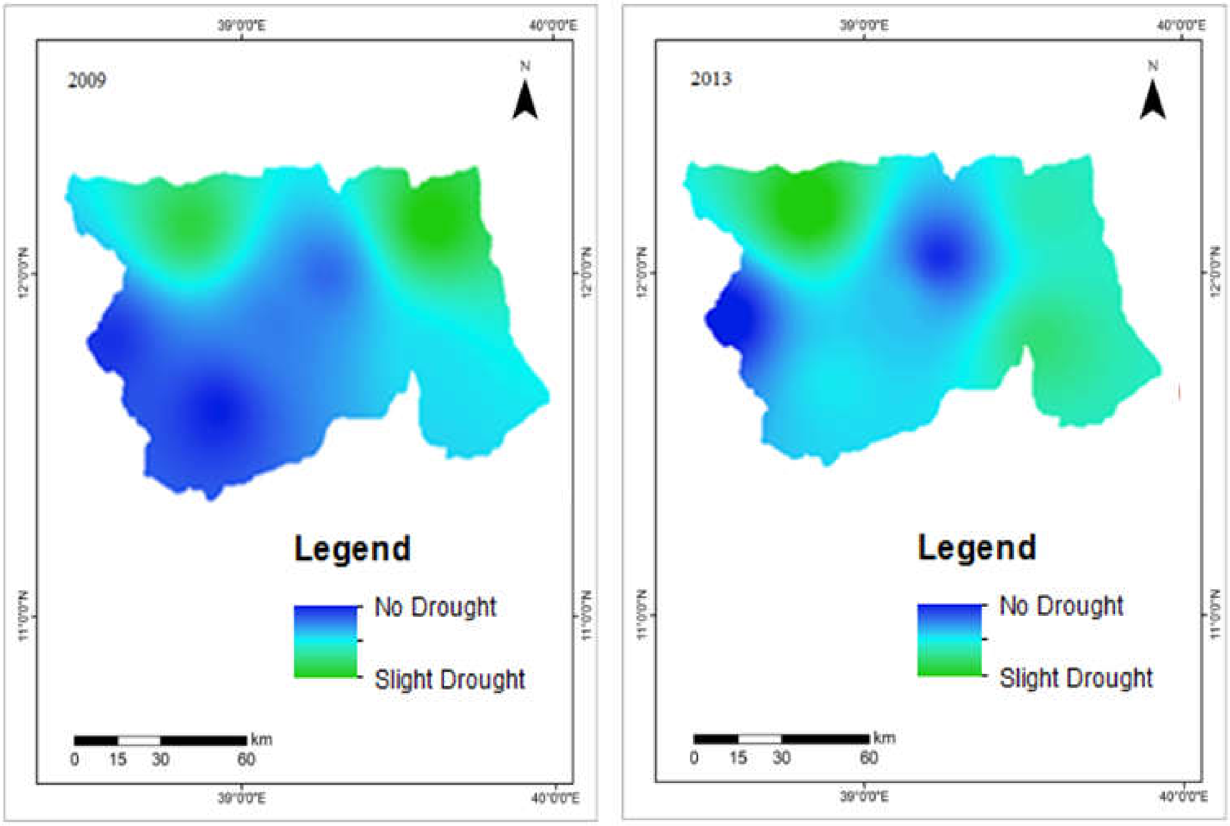

Figure 4.11: Standardized Precipitation and evapotranspiration Index for wet years 2009 and 2013

4.3.1 Standard Precipitation and evapotranspiration Index (SPEI) and yield anomaly

Agriculture is one of the most important sectors that humans rely on and can be significantly affected by droughts. Due to the fact that crop production is a function of rainfall, crop failure is most often associated with moisture deficit or agricultural drought. Thus, the Correlation analysis between SPEI and yield anomaly is vital for validation. In view of this, SPEI and yield anomaly were correlated and the result has shown that when SPEI is positive, yield anomaly also turns positive revealing a good positive correlation (r=0.83). Since SPEI is an index that represents water deficit or excess, positive SPEI represents that water has been available to plants so that yield become above normal condition (Fig 12), Whereas, negative SPEI is reflected on crop production through yield reduction. Similarly, Taotao et al., (2016) reported the strong correlation between Yield Anomaly and SPEI.

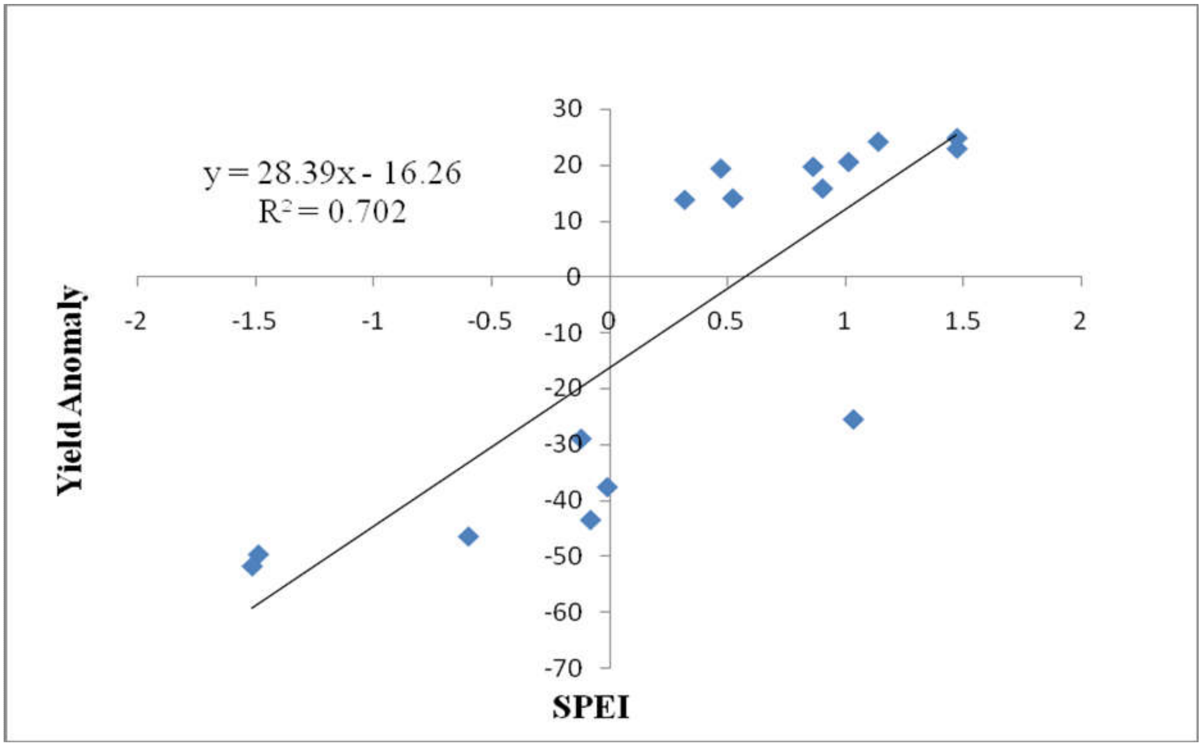

Figure 4.12: Relationship between Standardized Precipitation and evapotranspiration Index and Yield Anomaly

4.4 Drought Monitoring through Vegetation Condition Index

Vegetation Condition Index (VCI) is used to monitor agricultural drought and is derived from NDVI. In this study, the Vegetation Condition Index (VCI) has been computed for the year from 2000 to 2015 from Spot Vegetation NDVI and Prova-v vegetation data. The VCI is better indicator of water stress condition than NDVI (Kogan, 1995). The VCI value between 50% and 100% indicate optimal or above normal condition. It can be seen from the (Fig 4.13) that the Vegetation Condition Index (VCI) values were below 50% in years 2005 and 2015 in the study area. It indicates that the occurrence of very severe drought situation during main crop growing season in the study area. It might be due to deficiency of rainfall and temperature variability. Kogan (1997) illustrated that the VCI value of 35% can be identified as very severe drought condition, which is in line with this findings.

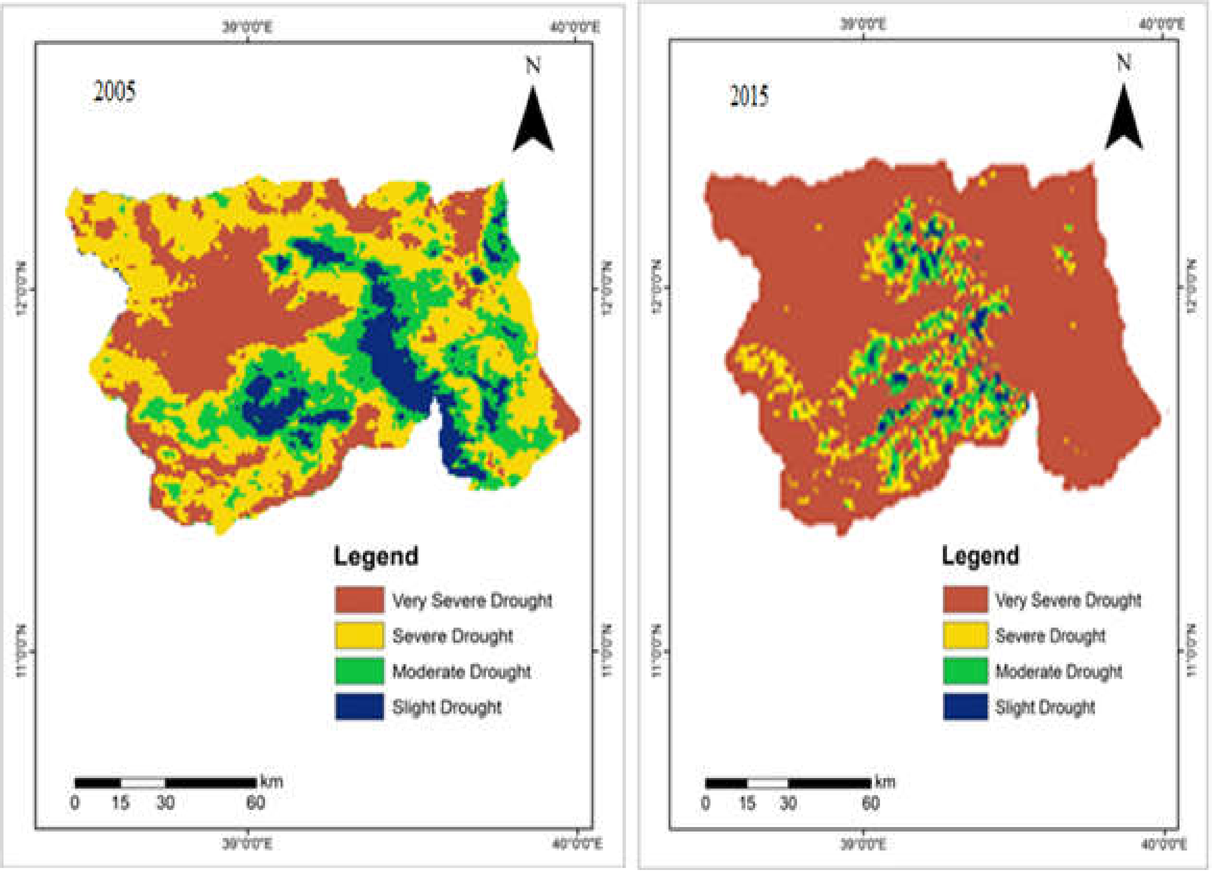

Figure 4.13: Spatial pattern of vegetation condition Index for drought years 2005 and 2015.

The Vegetation Condition Index (VCI) result in 2009 and 2013 year showed that better vegetation condition during the main crop growing season (Fig 4.14). In these years also the vegetation Condition Index was above 50% in most of the study area. It indicates that the vegetation was not severely affected with water stress. As VCI values for the growing season was fairly high during the main crop growing season compared to that of the very severe drought years. The highest yield occurred in years 2009 and 2013, it might be due to good vegetation condition result (Fig 4.14).These results were verified by in situ data of precipitation, mean temperature and crop yield collected from the CSA.

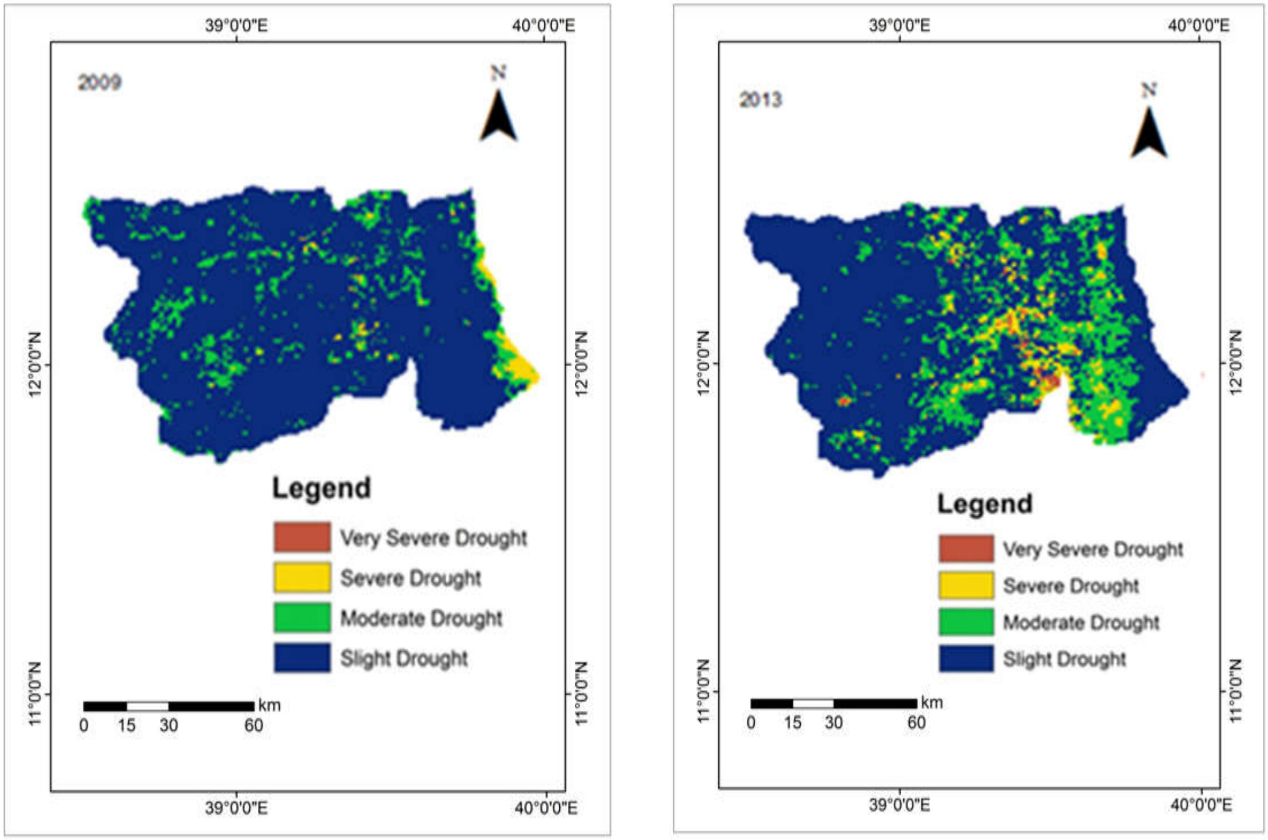

Figure 4.14: Spatial pattern of vegetation condition index for normal year (2009) and (2013)

4.4.1 Relationship between rainfall and VCI

As it is explained in the review literature part of this paper, seasonal analysis of historical rainfall and the response of vegetation interims of VCI are very vital. In (Fig 4.15) showed that there is good correlation between VCI (dependent variable) and Rainfall (independent variable). It is observed that there is a significant positive relationship between VCI and Rainfall (r = 0.77). Furthermore, it is observed after correlation analysis that there is a significant relationship between the VCI and Rainfall (R of Determination indicates that 60 % of VCI can be explained by the variation in rainfall and the other 40 % of the variability in VCI was due to other unidentified factors. Similarly**,** the current results were in accordance with Beyene (2007) who reported that fairly good relationship between Vegetation Condition Index and precipitation. Several studies have been compared the vegetation drought index with meteorological conditions. My observations was consistent with those of (Gebrehiwot et al., 2011), who found a strong correlation between VCI and precipitation.

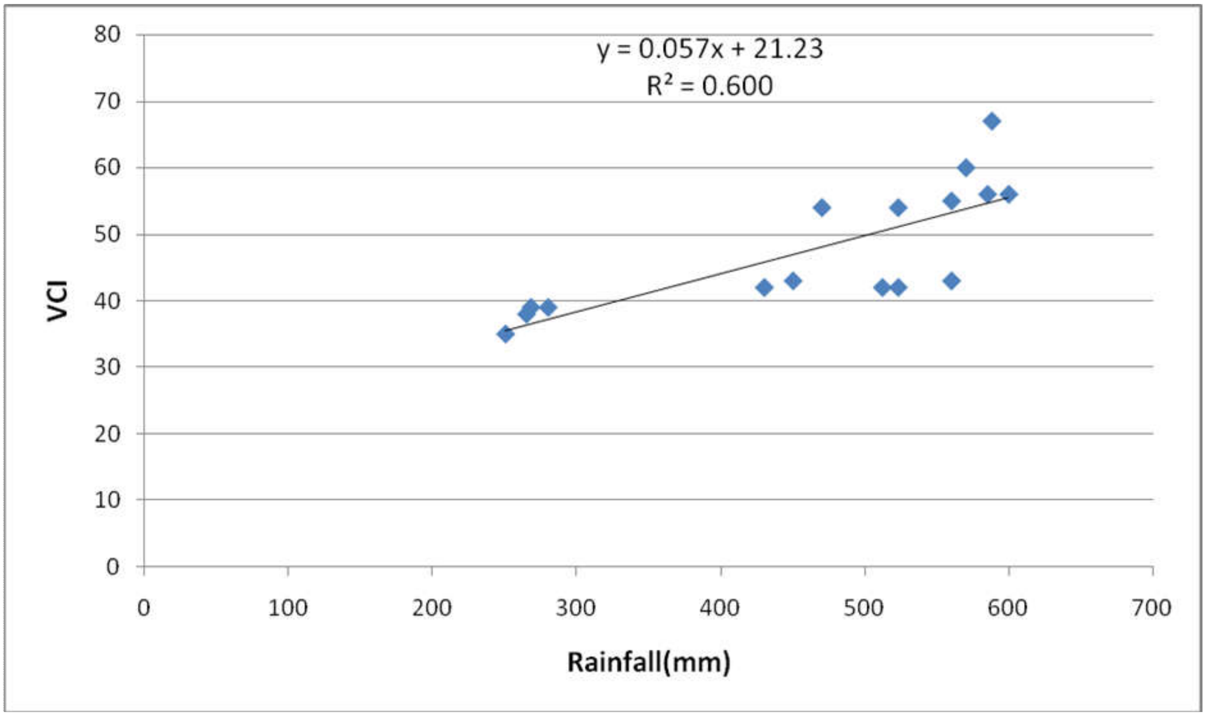

Figure 4.15: Relationship between Vegetation Condition Index and Rainfall

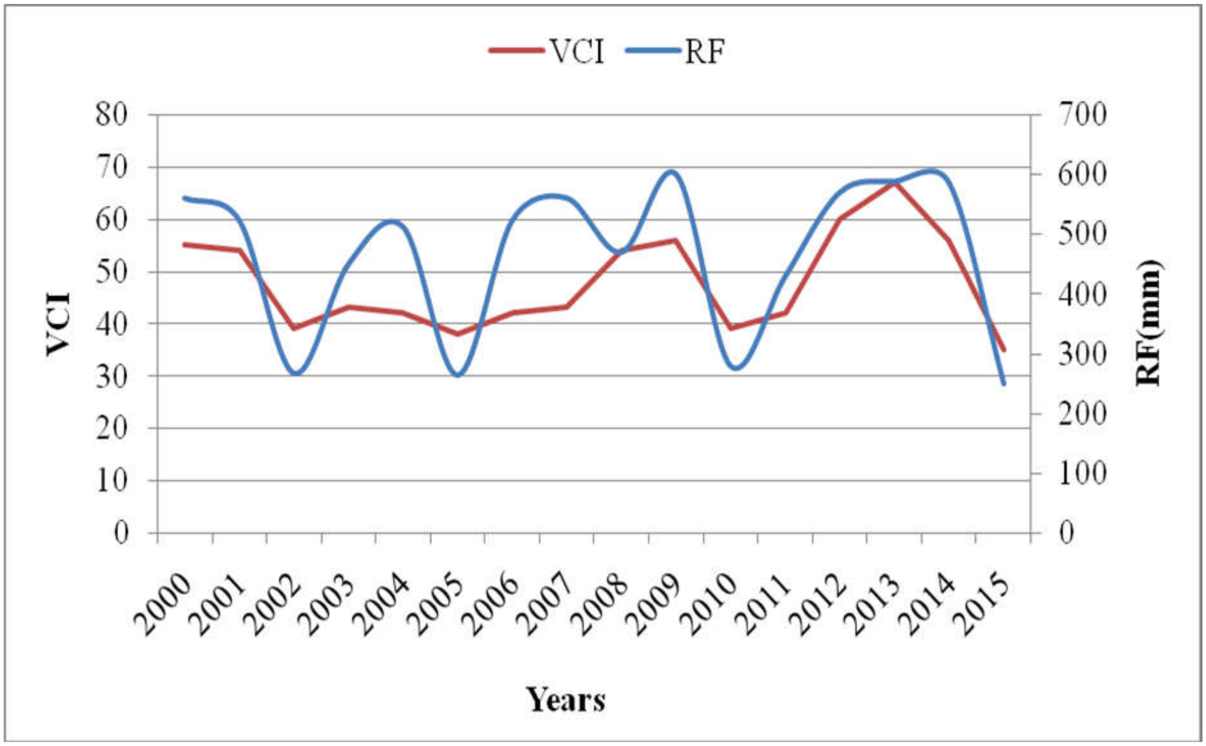

Figure 4.16: Temporal trends of seasonal Vegetation Condition Index and Rainfall (2000 to 2015)

4.5 Drought Severity Extent

The drought severity was analyzed from 2000 to 2015 based on satellite and climate data. Both droughts monitoring indices showed that the two years 2005 and 2015 were considered as drought years and 2009 and 2013 were taken as slight-drought years. The extent of drought severity was increased by increasing time scale (Fig 4.4 and 4.5). In 2005 the area under very severe drought and severe drought was less than as compared to 2015. Similarly, for 2009 and 2013 (slight drought years) the extent of slight drought class had been decreased while the area under moderate drought has increased in 2009 as compare with 2013. These trends indicated that with increasing in time scale the drought tend to be more severe.

4.6 Combined Drought Risk Map

The combined drought severity map was generated by overlying the agricultural and meteorological drought severity maps. The weight was given according to their degree of influence using pair-wise comparison. According to the combine drought map (Fig 4.17) very severe and severe drought primarily occurred in West, North West, South West, East, South east and North east parts of the study area while other study area experienced different type of drought. The area under severe to very severe drought conditions was 33.5% and 42%, respectively (Appendix figure 1) from the total study area, which indicated that almost 75% of the area was prone to drought. The moderate and slight drought succeeded to 19.5 % and 5 %, respectively. Therefore, Drought Mitigation and adaptation practices are unquestionable to meet food security. Adaptation is adjustment in natural or human systems in response to actual or expected drought effects, which moderates harm or exploits beneficial opportunities whereas mitigation of drought is a human intervention aimed at reducing the climate variability to improve livelihood of the community. The intervention might be irrigation based agriculture practices development, drought tolerated crop species adaptation and wisely resource conservation and utilization system.

No	Drought category	Area(ha)	Area (%)
1	Very severe drought	537758.65	42%
2	Severe drought	422794.83	33.5%
3	Moderate drought	249508.27	19.5%
4	Slight drought	65452.6	5%

Table 4.1: Area under Different Drought Conditions

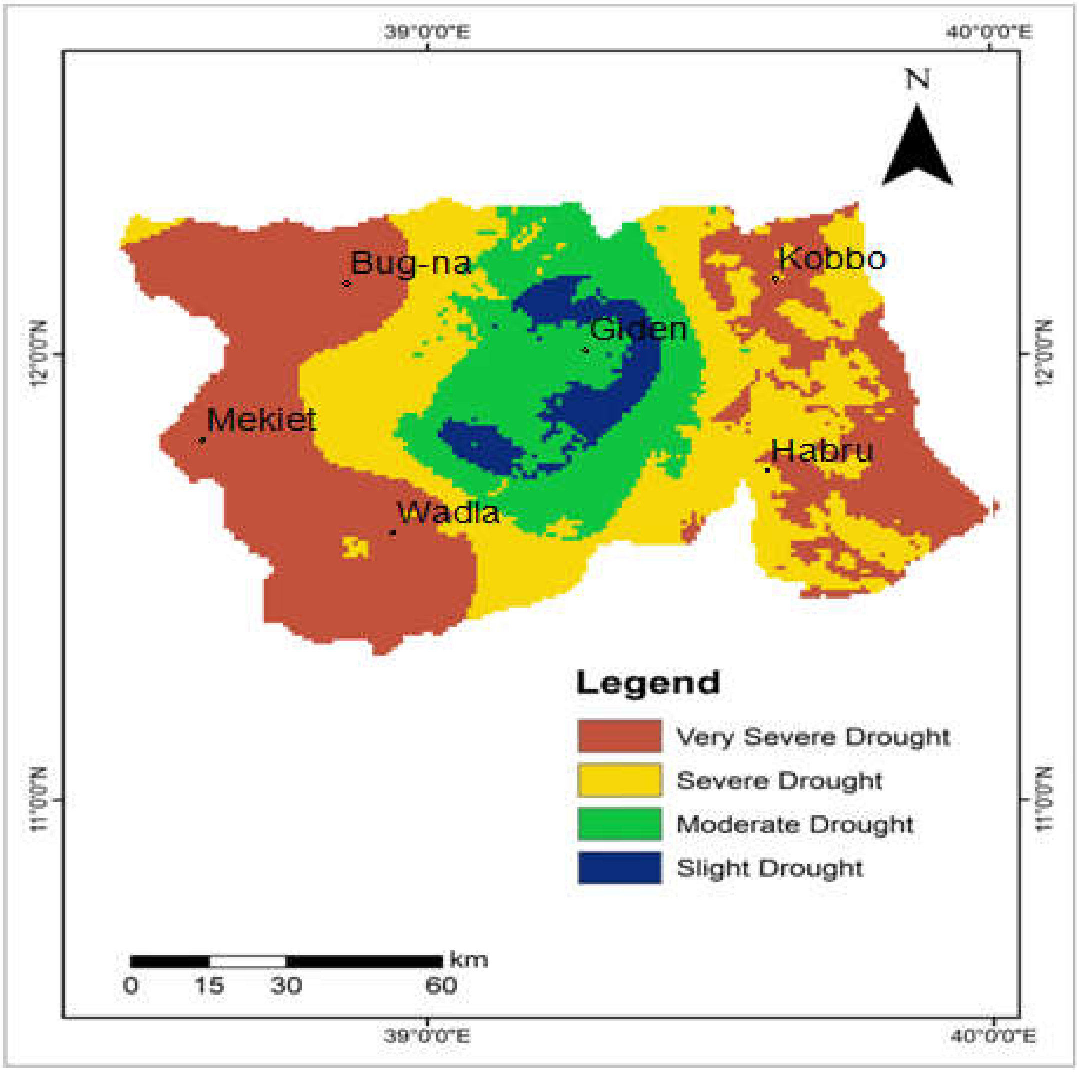

Figure 4.17: Combined drought risk map (2015)

4.7 Validation of Drought Indices using Agricultural Production

In the study area, since agriculture is mostly dependent on rain-fed practices, it is the most impacted system by drought. The crop yield data analysis result showed that there was similar trend like droughts monitoring indices analysis result. In addition to this, the informal interview with zonal agriculture expert's result showed that there was drought in the past 15-20 years. They explained that the fluctuation of rainfall and temperature are no unusual for them that it affect considerably human life, animals, crops as well as other natural resources. Furthermore, information obtained from different published and unpublished sources confirms that every alternate year or after each 2 to 3 years cropping seasons, there was severe agricultural drought in study area, and consequently complete crop failure occurred in most of the study area. Similarly, Alemu (2011), who reported that years with climatic extreme events in the area were 1993, 1997/98, 2001/02 and 2004/05 and 2006 droughts have been occurred. The trend of temperature and rainfall was increasing and decreasing, respectively and numbers of rainy days in seasons are shrinking. In the study area drought was one of climate related disaster that causes damage to crops and livestock. However, the impact of drought was different in the study area. In the central part of the study area the drought occurrence was moderate which might be the result of altitude for rainfall distribution. Rahel (2007) concluded that the fluctuation of rainy season, low rainfall of the small rainy season and late onset of the main rainy season can affect agricultural production and cropping system in East Amhara region, particular north Wollo zone, which is in lines with findings of our study.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Drought is a climatic hazard that occurs in almost every region of the world. It causes physical suffering, economic losses, and degradation of the environment. Agricultural drought occurs when there is not enough soil moisture to meet the needs of crops at a particular time. Agriculture is the most vulnerable and sensitive sector that is seriously affected by the impacts of climate variability and climate change. Identifying patterns of drought and finding its associations with various indices derived from GIS and Remote Sensing techniques are becoming important for monitoring of this natural hazard. Remote sensing and GIS techniques were applied to characterize agricultural drought with the integration of satellite, meteorological and other ancillary data in the study area. The result of this study confirmed that rainfall and temperature were one of the climatic variables that largely determine the occurrence of drought and also influences the growth and development of vegetation's, which was reflected by NDVI anomaly, VCI and SPEI. The study area weather station rainfall data result from 2000 to 2015 years, showed that there was a large variation during the main cropping season. The minimum and maximum mean rainfall observed during this period was found to be 250 to 599 mm where it indicates a large variation in distribution of rainfall in all the weather stations. This might be the effect of altitude among other factors.

The identification of drought and wet years identified by NDVI anomaly, VCI and SPEI drought severity index showed that similar level of variations with ground truth data analysis result of crop yield. This was also supported by the result obtained from informal interviews, group discussion, Published and unpublished documents source of information. The analysis results were showed that, the drought severity was very high in North Wollo Zone. The two years 2005 and 2015 were considered as drought years and 2009 and 2013 were taken as slight and non drought years. The extent of drought severity was increased by increasing the time scale. The relationship between NDVI and yield anomaly, NDVI and rainfall, NDVI and SPEI and VCI and rainfall during the main crop growing season was found to be positive and significant, which can be applied for forecasting the yield reduction in a case of drought situation.

Final resultant risk map was obtained by integrating agriculture and meteorological drought risk maps, which indicate the areas, were facing a combined drought. The combined risk map showed that approximately 5% of areas were found in slight risk, 42.5 % of areas in very severe risk, 19.5 % of areas in moderate risk and 33 % of areas in severe risk in the study area. Agricultural impacts of droughts are the result of short-term precipitation shortages, temperature anomalies that increase evapotranspiration demand and soil water deficits that could adversely affect crop production. Agricultural drought risk can be viewed as a product of both exposure to the climate hazards and the vulnerability of farming or cropping practices to drought conditions. In view of this, agricultural risk zone map produced by integrating all drought maps derived from all drought indices indicates that North Wollo Zone is classified into slight, moderate and severe and very severe agricultural drought risk Zone, respectively. Thus, Agricultural drought risk mapping can be constructive 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 measures.

5.2 Recommendations

Establishment of formal early warning information centers particularly for agricultural drought monitoring would boost the application of different drought coping strategies to overcome impacts of drought. This situation enhances the accessibility of farmers` to drought forecasts which could lead them to timely adoption of effective drought coping strategies. Moreover, drought analysis from socio-economic point of view has not seen in this study. In addition to identifying the drought affected areas in the North Wollo Zone, the study could be more meaningful if effects of drought on human and livestock population have been assessed. Therefore, it is recommended to include the socio-economic data to better understand the vulnerable factors. Prioritization and implementation of site specific adaptation and/or mitigation projects should be made based on such identification of risk levels of specific locations. Since agricultural drought severity levels vary spatially, selection of agricultural technologies and information (drought tolerance crops, the type of crop variety and soil moisture conservation practices) should be made to fit in to the agricultural drought severity levels.

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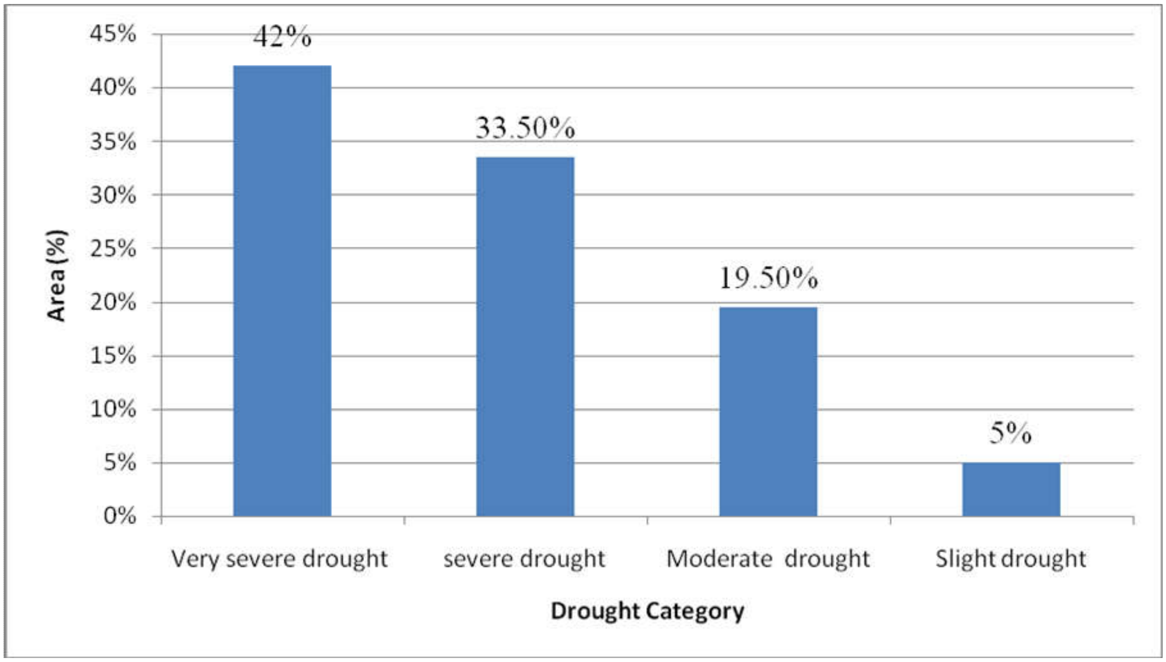
APPENDICES

Appendix .

Check lists for informal focus group discussion with zonal agricultural experts

- ✓ Do you know what climate variability means? Is the pattern of weather is changing? How do you explain the change? What would be the cause?
- ✓ In the past 15-20 years how would you describe the rainfall pattern in terms of -
  - Rainfall on-set and Cessation
  - ii. Rainfall amount
  - iii. Rainfall seasonal distribution.
  - Temperature
- ✓ When agricultural drought occurs between 2000. 2015 G.C in the area? Which one the most devastating one?
- ✓ How the frequency of agricultural drought was looks like in the past growing seasons (low, Medium, high)?
- ✓ What are the major effects that the climate variability and change has caused? Indicate in the area of
  - Agriculture
  - Forest cover
  - Social aspects(conflict, migration, etc)
- ✓ What are the major crops growing in the Meher season?
- ✓ How do you explain the agricultural potential, crop productivity, soil fertility, and total Crop yield in this area?



Appendix figure 1: Total percentage of area faced a combined drought risk

NO	Station Name	X_coordnate	x_ coordinate
1	Wadila	39.22122	11.59034
2	Kobo	39.48289	12.14997
3	Bugna	38.91528	11.46192
4	Lalibela	39.29147	12.01077
5	Debre Zebet	38.93061	11.81878
6	Sirinka/woldia	39.61428	11.7510
7	Birafaf	38.91528	11.46192

Appendix table 1: Study area weather station point data