Addis Ababa University

College of Natural and Computational Sciences

School of Earth Sciences

Remote Sensing and Geoinformatics

Mapping Agricultural Drought and its Coping Strategies Using Remote Sensing and GIS Techniques in East Shewa Zone, Central Rift Valley Region of Ethiopia

By Hurgesa Hundera

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A Thesis Submitted to the School of Earth Sciences of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Remote Sensing and Geoinformatics

June, 2016

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This is to certify that the thesis prepared by Hurgesa Hundera entitled as Mapping Agricultural Drought and its Coping Strategies Using Remote Sensing and GIS Techniques in East Shewa Zone, Central Rift Valley Region of Ethiopia is submitted in partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and Geoinformatics compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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Abstract

Drought is one of the most complex naturally occurring disasters that results in serious human life, environmental, social and economic costs around the world. Particularly, agricultural drought in developing countries like Ethiopia is very disastrous causing population displacement, food shortage, loss of life and reduction of agricultural output. In order to monitor agricultural drought risk, GIS and remote sensing have a significant role which paves the way for development of drought coping strategies. This research was conducted in East Shewa Zone of Oromia Region of Ethiopia with the objective of mapping agricultural drought risk using GIS and remote sensing. The research was also aimed at identification of major drought coping strategies practiced in the study area. To achieve these objectives, both primary and secondary sources of data were employed. Both satellite remote sensing data and socioeconomic data was utilized in this research. In addition, key informant interviews and focus group discussions were employed to identify drought coping strategies. The result of drought severity index indicated that 2005 and 2009 were years of drought while 2013 identified as wet year. On the other hand based the result of SPI 2005 and 2009 were years of droughts while 2012 wet year. The result also showed that there is an increasing correlation (r = 0.7) between long term NDVI and seasonal rainfalls. The results were supported by the interviews and focus group discussions. Based on the result droughtbrissk map, 5.1% of the zone are under extreme drought risk, 31.9% severe drought, 27.1% moderate drought and 32.5% are under mild drought. Thus, it is only the remaining 3% of the East Shewa Zone that are not vulnerable to drought. The study identified the major drought coping strategies in the area to be receiving of food, water, edible oil, and other food supplements by the government and NGOs. In addition, reducing food intake, petty trading, hoarse cart and daily labor, selling charcoal and dried cow dung were also the coping strategies employed during drought years by the affected communities. It is recommended that for detailed investigation of drought risk assessment using long-term SPOT NDVI characterized by high spatial resolution is good for the study area. Moreover, establishment of formal early warning information centers particularly for rainfall distributions would boost the application of different drought coping strategies to mitigate impacts of droughts.

Key words: Drought risk, coping strategies, GIS, NDVI, remote sensing, SPOT.

List of Acronyms

APO	Adama Project Office
AMS	American Meteorological Society
AVHRR	Advanced Very High Resolution Radiometer
CSA	Central Statistical Authority
ECA	Economic Commission for Africa
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GIS	Geographic Information System
IDW	Inverse Distance Weighted
IPCC	Intergovernmental Panel for Climate Change
MODIS	Moderate Resolution Imaging Spectroradiometer
MSA	Meteorological Service Agency
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
PDSI	Palmer Drought Severity Index
SPI	Standardized Precipitation Index
TRMM	Tropical Rainfall Measuring Mission
UTM	Universal Transverse Mercator
VCI	Vegetation Condition Index
WMO	World Meteorology Organization
YAI	Yield Anomaly Index

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Drought is one of the most complex naturally occurring disasters that results in serious human life, environmental, social and economic costs around the world. Due to its cumulative impacts and widespread over large geographical areas, drought is stronger than other natural disasters (Tadesse *et al*., 2004; Wilhite, 2007; Khalil *et al*., 2013; Golian *et al*., 2015). Again drought is pointed out as dangerous natural phenomena that occur when precipitation is lower than normal period thereby characterized by causing insufficiency for human practices and the natural activities (WMO, 2006). Almost all climatic regions and more than 50% of the planet earth are vulnerable to drought each year (Wilhite, 2000; Renza *et al*., 2010). On average, there is an economic loss of $6-8 billion every year in the world as a result of drought (Huailiang *et al.,* 2009). According to Dai (2011) large amount of droughts have occurred in different parts of the continents in the past three decades. This implies that both developed and developing nations are under the impact of drought.

Agriculture is the dominant economic activity in developing countries. It is very much sensitive to weather and climate variables like temperature, precipitation, light and weather extremes, such as droughts, floods and severe storms (Molua, 2002; Adger *et al.,* 2003; Demeke *et al*., 2012). This indicates that any fluctuation in the variables, largely affects agricultural production. Agricultural drought in developing countries is very disastrous causing suffering, population displacement, food shortage, loss of life, land degradation, death of animals, reduction of agricultural output, diminishing of rivers and lakes, deteriorations of water conditions, wildfires and permanent vegetation failure (FAO, 2011; Huang *et al.,* 2013; Kapoi and Alabi, 2013).

Many of the drought related problems in the developing countries are taking place in Africa with some variation within the regions (Minamiguachi, 2005). In this case, the sub-Saharan part of the region is mostly cited to be the most drought affected area due to the fact that the region is receiving much lower amount of rainfall. Ethiopia as one of the sub-Saharan African countries has been experiencing different degree of droughts in the last decades. The recently released report of Intergovernmental Panel for Climate Change (IPCC) indicated that as a result of climate change and variability, drought conditions are projected to be harsher in the future (IPCC, 2014). Similarly Houghton *et al*. (2002) revealed that the intensity and frequency of drought are likely to increase in several regions which further amplify the need for the current study.

Even though it is difficult to clearly monitor the beginning and the end of an agricultural drought occurrence, it is possible to monitor and analyze its characteristics using different drought indices. This can be done either through traditional climatic drought indices from meteorological data sets or modern remote sensing based drought indices (Palmer, 1965; Abbas *et al.,* 2014; Himanshu *et al.,* 2015). In comparing with conventional weather data, remote sensing approaches are relatively better for monitoring vegetation conditions, agricultural drought and crop yield assessment (Domenikiotis *et al.,* 2004). Therefore, this research is designed to map agricultural drought and its major coping strategies using remote sensing and GIS techniques in East Shewa Zone, Central Rift Valley Region of Ethiopia

1.2 Statement of the Problem

During drought period, it is a common activity for the countries to adjust budget allocations with the intention of supporting the affected societies (Mutua, 2011), which hinder the speed of the development (World Food Programme, 2006). The frequent drought experienced in Ethiopia has negatively impacted its primary economic activity. Though the country has characterized by long history of recurring drought, its magnitude, frequency, and impacts since 1970s have been increasing (Margaret, 2003), which affected largely agriculture dependent economy. On the other hand, this sector is expected to speed up the overall development of the country.

Specifically, during the drought period of 2000 – 2001 and 2002 – 2003, more than 10 millions of people affected by starvation, destroyed many crops and death of animals indicating that the magnitude and share of the problem is increasing (Bramel *et al.,* 2004; ECA, 2005). Furthermore, Ghulam *et al*. (2007) indicated that the existence of drought over time series results in altering of soil moisture, roughness of the land, land use thereby affecting material exchange between vegetation, soil and atmosphere. Hence, agricultural drought is an influential natural force that determines significantly agricultural output of the communities (Cavatassi *et al.,* 2010; Quin *et al.*, 2014).

Several studies have been carried out to monitor agricultural drought using remote sensing and GIS techniques including Huailiang *et al.* (2009), Huang et al. (2013) and Abbas *et al.* (2014) in China, Kapoi and Alabi (2013) in Kenya, Muthumanickam *et al*. (2011) and Himanshu *et al.* (2015) in India, Khalil *et al*. (2013) in Egypt, Biranu (2014) in Tigray, Gizachew and Suryabhagavan (2014) in East Shewa Zone. However, few of them explicitly focused on agricultural drought assessment and not well documented in East Shewa Zone, Central Rift Valley Region of Ethiopia. On the top of this, none of them identified drought coping strategies in study area. Furthermore, Gizachew (2010) recommended that based on identification of drought risk levels, site specific drought coping strategies should be implemented. Therefore, the researcher has been motivated to fill the gap observed at local level by studying agricultural drought mapping and its major coping strategies using remote sensing and GIS techniques in East Shewa Zone, Central Rift Valley Region of Ethiopia.

1.3 Description of the Study Area

1.3.1 General Background and Its Location

Most parts of the present East Shewa Zone, study area of this research, were under the Yerer and Kereyu Awraja before 1988. Geographically, this zone extends from longitudes of 7^{o} 33'50"N to 9^{o} 08'56"N and latitudes of 38^{o} 24' 10"E to 40^{o} 05' 34"E. According to the data obtained from East Shewa Zone Finance and Economic Development Office (2014) the total area of East Shewa zone is 9178km^{2}.

This indicates that the zone is entirely found in tropical zone having its associated climate. It is also found in the rift system and has elongated shape. With respect to its relative location, the Zone has physical contact with three regional states of Ethiopia namely: Southern Nations, Nationalities of Peoples, Afar and Amhara National Regional States of Ethiopia. Therefore, this zone is boarded to the north by Amhara National Regional State, on the Southeast by Afar National Regional State, to the southeast by Arsi Zone, on the west by Southwest Shewa Zone and by West Arsi Zone in the South. The Zone shares the longest and shortest boarder with Arsi Zone and Afar National Regional State respectively. Along the northern and southern portion it is narrow. Based on the May 2007 National Population and Housing Census of Ethiopia, the total population of East Shewa Zone was 1,179,944 with the crude population density of 124 km^{2}

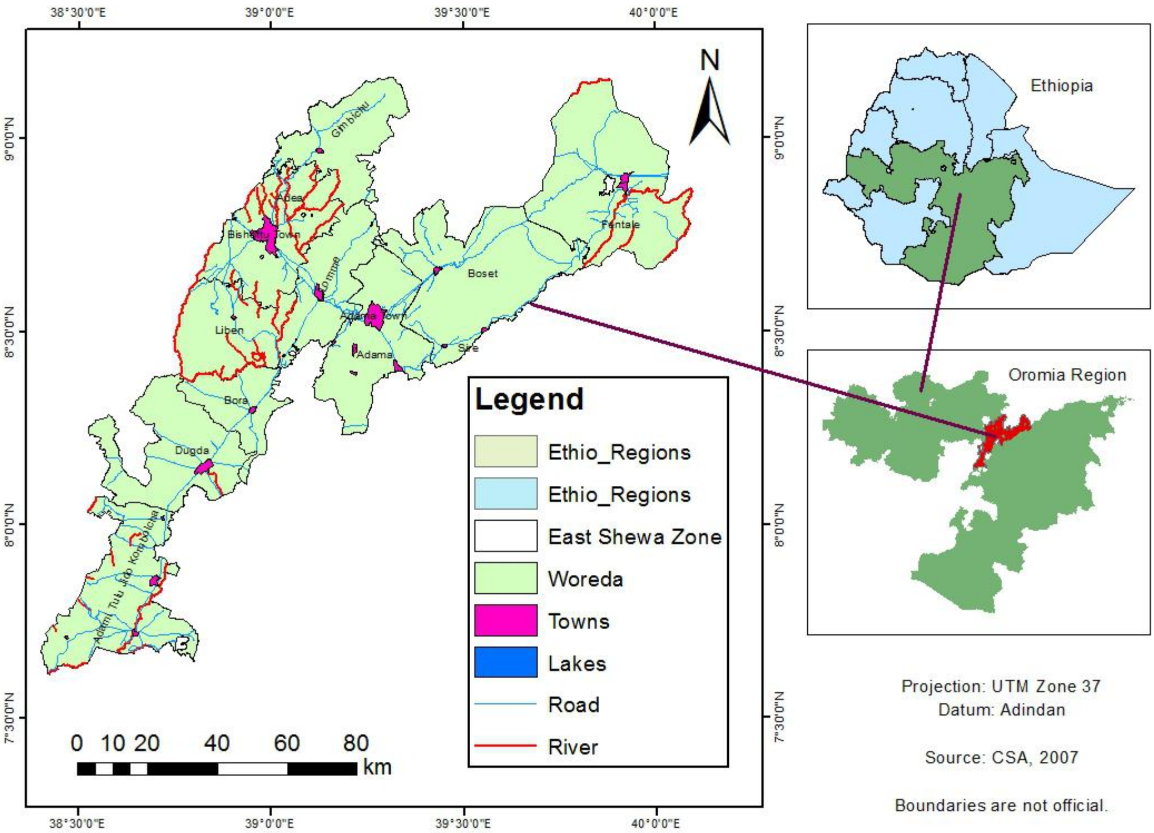

Figure 1.1 Location Map of East Shewa Zone

1.3.2 Climate, Relief and Drainage System

The elevation of East Shewa extends from less than 1000 to above 3000 and thus its altitudinal zones ranges between temperate (Dega, 0.2%) to tropical (Kolla, 38.7%) (East Shewa Zone Finance and Economic Development Office, 2014). The largest land mass of the zone (about 61.1%) is grouped under sub-tropical (Woina Dega). As it is depicted in the fig. 3.2 relative large amount of rainfall was recorded in 2008 and 2012 where as the lower amount of rainfall was recorded in 2005, 2006 and 2009. Accordingly, high altitude parts of the Zone with elevation over 2500 m (parts of Gimbichu highlands) as well as isolated high peaks in the rift floor experience mean annual temperature of 10-15^{o}C, accounting for about 0.2% of the total area of the zone. Furthermore, most parts of the zone, including the lower rift scarps and higher parts of the rift floor (sub-tropical) with elevation 1500-2300 m register mean annual temperature of 15-20^{o}C. The northern extreme parts of the zone including pocket areas of the rift floor with elevation less than 1500 m.a.s.l, being regions of tropical climate, come under mean annual temperature category of 20-25^{o}C. It forms 38.7% of the total land surface of the zone.

The general elevation of this zone decreases from an area that lies some distance to the north of Lake Ziway to the south of the adjacent course of the Awash River. It is a strip of low lying that separates the main basins: the Awash and Lake Basins from each other. The general elevation of the floor thus decreases from this strip of land in both northeast and southwest directions following the general alignment of the rift valley. The falling in elevation continues in the northeast where it drops up to 800 meters above mean sea level around Awash National Park and goes on dropping further in the northeastern direction.

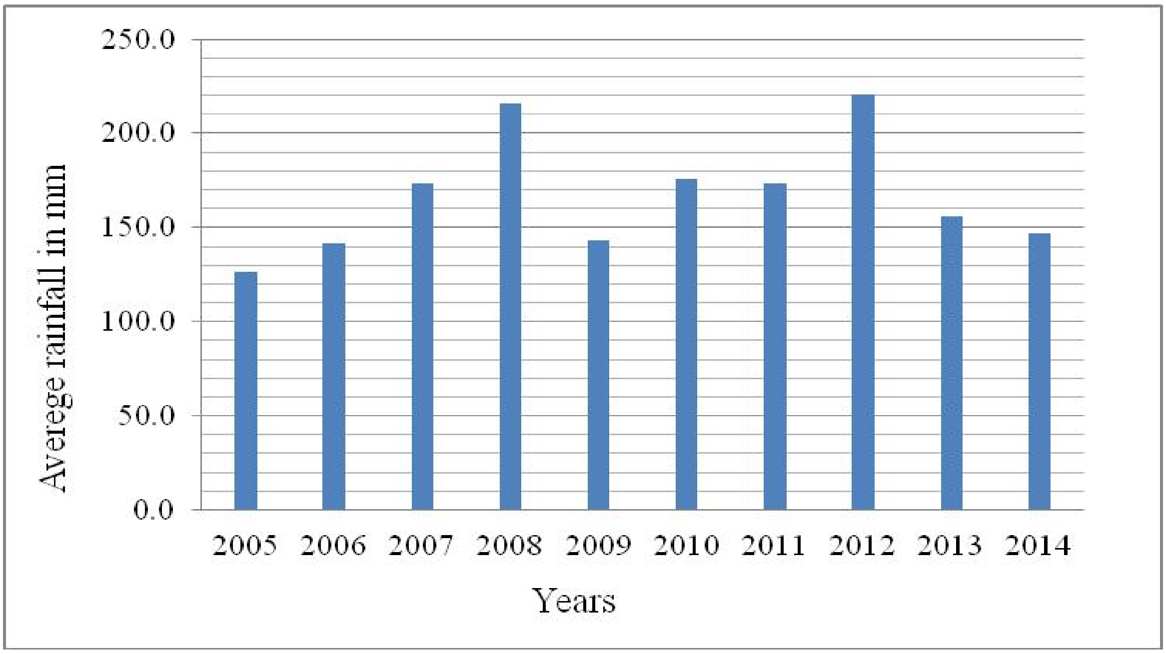

Figure 1.2: Average rainfall of East Shewa Zone of 2005 – 2014.

Awash River drainage system is the major drainage in the zone covering 78.8% of the total area while the Lakes Region basin shares about 22.2% of the total surface of the zone. The two sub-basins of East Shewa Zone are drained by a number of rivers. Among these, Mojo and Kesem are the principal tributaries of the Awash River. The Meki, Bulbula, Jido, Hora Kal'o, Awade and Hulaka are significant streams in the lakes sub-basin of East Shewa Zone.

1.3.3 Geology

According to the information obtained from Zonal Atlas of East Shewa (1999), the landmass of East Shewa zone being part of the Rift Valley System belongs to the Tertiary and Quaternary sub-classifications. Hence this Zone comes under the category of recent volcanic and sediments and the Rift Valley System. Pleistocene recent volcanic sediments cover mainly northeast of the zone. This part of the zone is still tectonically unstable, relative to adjacent landmasses. Cinder cones like Mount Fentale are still presumed to be active. The extensive recent volcanic ash that lies on the surface to the west of Mount Fentale and the ever expanding Beseka Lake indicate that the zone is still unstable. The Lakes Region of the Zone is also an area of recent volcanic and seismic activities. The other signal of unstability of the zone is the existence of hot springs and fumaroles in several parts of the zone. In other words, the zone is well known by its geothermal from Gergedi hot spring in the western side of Wonji Gafarsa and the Sodere in Melkasa near Awash River. The main landscape in zone and its surrounding consists of fault controlled depressions covered with sediments and volcanic domes and cones. More importantly, the Zone is endowed with different minerals. These minerals include diatomite, clay, pumice, scoria, sand ignimbrite, volcanic ash (Finance and Economic Development of Adama, 2014). Quaternary sediments, which account for about 21.8% of East Shewa Zone, cover the southeastern part of the zone. Quaternary Volcanic/basalts cover 20.4% of the zone, which cover the northeastern part of the zone including larger portions of Adama, Boset and Fentale districts of the zone. On the other hand, the larger portion of the zone is under Pleistocene-Pliocene complex which includes western part of Arsi Negele, Adami Tulu Jido Kombolcha, Liben Chuqala, Bora, Dugda, Lome and Ade'a districts of the zone.

1.3.4 Soil

Andosols extend over larger portions of Adami Tullu Jido Kombolcha, Boset, Dugda, Adama, Lume and Bora districts of the zone, which accounting for about 23.43% of the land area of the zone. Vertisols cover the larger portion of Ada'a, Liben Chukala and northern Lume and it makes up 14.61% of zonal land surface. This type of soil is mainly used for grazing purposes. Phaeozems cover larger portions of Dugda and Bora, and smaller portions of Ade'a, Adama and Liben Chukala districts of the zone. It covers about 13.14% of the total area of the zone. In East Shewa, fluvisols are found in localized areas of Adama, Boset and Fentale as well as Dugda and Bora districts of the zone, along the valleys of the Awash and Meki rivers, the shores of Lake Ziway accounting for about 5.72% of total area of zone. Cambisols occur in about 15.09% of the total area of the East Shewa zone. They are mainly found in Liben Chukala, Fentale, Boset, Ade'a, Gimbichu and Fentale districts of the zone. Lithosols (13.8%) are soils of limited depth with continuous hard rock within 10cm of the surface. It covers smaller portions of Dugda, Bora, Liben Chukala, Gimbichu, Ade'a, Boset and Fentale districts of the zone.

1.3.5 Vegetation Cover

According to Physical Geography of East Shewa, the zone has generally about four major types of vegetation regions: woodland and savannah, the coniferous forest, broad leafed forest and grasslands. Furthermore, natural vegetations grown in East Shewa Zone are grouped under the Acacia woodland and savannah vegetation grown at an altitude of 1500 to 2200 meters above sea level and mean annual rainfall of 250 to 875 mm and it covers large parts of lakes region and Awash valley. Beside Acacia woodland, grassland areas also occupy lowland parts of East Shewa zone with various species and tall grasses

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of this study is to map agricultural drought and its major coping strategies using remote sensing and GIS techniques in East Shewa Zone, Central Rift Valley Region of Ethiopia.

1.4.2 Specific Objectives

Based on the above stated general objective, the following specific objectives are formulated. Hence, the specific objectives are to:

1. generate the agricultural drought map based on its severity levels using Normalized Difference Vegetation Index (NDVI) and Standardized Precipitation Index (SPI)
2. asses the temporal aspect of drought conditions using Normalized Difference Vegetation Index (NDVI) and Standardized Precipitation Index (SPI) in study area
3. examine the relationship between rainfall and Normalized Difference Vegetation Index (NDVI) in the study area
4. identify major drought coping strategies being undertaken by the communities in response to previous droughts in study area

1.5 Research Questions

Throughout this research work, all the activities that were undertaken focused on finding potential answers for the guiding questions. Thus, depending on the specific objectives formulated above, this research was guided by the following questions.

1. Which part and what percentage of the study area is affected by agricultural drought based on Normalized Difference Vegetation Index (NDVI) and Standardized Precipitation Index (SPI)?
2. How is the temporal aspect of drought conditions using Normalized Difference Vegetation Index (NDVI) and Standardized Precipitation Index (SPI) in study area?
3. What is the relationship between rainfall and Normalized Difference Vegetation Index (NDVI) monthly, seasonally and annually in the study area?
4. What are the major drought coping strategies being undertaken by the communities in response to previous droughts in study area?

1.6 Significance of the Study

It will have a special contribution in identifying the major drought coping strategies being undertaken by the communities in response to previous droughts. It will furthermore identify which part and what percentage of the study area is affected by agricultural drought based on satellite derived indices. In doing so, it is expected that the final outcome of this research will help governmental and non-governmental organizations as well as policy and decision makers that work on agricultural drought monitoring issues. Hence, it will enable them to revise and prioritize their actions based on the risk level of the area in an informed manner. Development agents and other stakeholders may also use it as an input to facilitate scaling up of best technologies with success stories from similar water limited areas elsewhere.

1.7 Scope of the Study

The scope of this study is limited to only the assessment of agricultural drought together with its identification of major coping strategies in East Shewa Zone. Temporally, the study is also limited to 10 years (2005 – 2014).

1.8 Limitation of the Study

One of the limitations of the study was lack of historical record of drought from the districts. Crop yield data over the past ten years from districts, zone, Office of Finance and Economic Development and Central Statistical Authority was inconsistent. An additional challenge relates to the respondents' in recalling drought historical events and its coping methods. Nevertheless, this study provides valuable information and insight that can be of great importance for the relevant information regarding drought risk assessment and the study was not affected by the limitations.

CHAPTER 2: LITERATURE REVIEW

2.1 Basic Concept and Definition of Drought

The concept and definition of drought varies according to the causes and transaction phases for which it occurs. This is due to the fact that its definition which is appropriate for one field does not address basic understandings in another field. Similarly, being it is relative term drought conditions for a specific region might be considered as wet conditions for another region. As a result, there is no universally accepted definition of drought that satisfies all the fields and scientific communities.

According to the Meteorological Glossary drought is a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrological imbalance in the affected area (Huschke, 1959). Broadly, drought is also defined by Hammouri and Naqa (2007) as a disastrous natural phenomenon that has complex impacts on human and environment. This definition implies that drought is naturally occurring which leads to several damages to human activities and natural resources. Again, drought is perceived as unpredictable Earth`s climate systems which results in significantly lower precipitation availability in comparing with the normal condition (Mokhtari, 2013).

The Encyclopedia of World Climatology (2004) also differently defined drought as "the consequence of a natural reduction in the amount of precipitation received over extended period of time, usually a season or more in length, although other climatic factors (such as high temperature, high winds, and low relative humidity) are often associated with it in many regions of the world and can significantly aggravate the severity of the event". Article 1 of the United Nations Convention to Combat Desertification (UNCCD) also defines drought as the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.

Another concept given by the American Meteorological Society (AMS) (1997) is that drought is classified into four categories such as meteorological, agricultural, hydrological and socioeconomic drought. Even though they are interrelated to each other, each type of drought has specific characteristics and affects different aspects of society differently. This concept is almost similar with the definition given by American National Drought Mitigation Center (NDMC) (Fig 2.1). Almost all definitions presented by different scholars emphasized the deficiency of precipitation from the normal amount.

2.2 Types of Drought

According to scientific communities of climatology, there are four basic categories of drought: metrological, hydrological, agricultural and socioeconomic droughts (Wilhite and Glantz, 1985; Wilhite, 2000) (figure.1). Accordingly, the first three types are dealing with drought as physical phenomenon. The last mainly talks about the impacts of physical oriented drought on socioeconomic systems. In other words, it deals with nature of supply and demand of several commodities as a result of physical phenomena of drought. Even though there are specific concepts to each of the drought categories, the origin of all droughts is precipitation deficiency (Camaro, 2015). The four types of drought are briefly explained in the following sections.

2.2.1 Meteorological Drought

The meteorological drought refers to the degree of dryness specified by deficiencies of precipitation and the duration of the dry period at specific time and place (WMO, 2006). In this type of drought, metrological measurements are mainly used to indicate the degree of drought. Thus, atmospheric characteristic that leads to deficiency of precipitation is region specific. If meteorological drought continues for a long period of time, it has negative impacts on the remaining types of drought.

2.2.2 Agricultural Drought

Agricultural drought occurs when moisture in the soil is insufficient to ensure optimal crop growth (Gizachew, 2010). Agricultural drought results in impairment of growth of crops there by reducing yields. According to Wilhite (2000) both meteorological and hydrological droughts have significant impact on agricultural drought as insufficient rainfall, soil water deficit and decreased ground water reduces agricultural yields. Hence, this thesis focuses on mapping agricultural drought and identification of major drought coping strategies.

2.2.3 Hydrological Drought

Hydrological drought is viewed as the deteriorations in water availability in all its forms (Khana, 2009). This definition includes stream flow, ground water, surface water, Lake Reservoir and other forms of water that closely associated with hydrological cycle. Similarly, according to Getachew et al. (2011) hydrological drought is perceived as the event occurring as a result of low rainfall. This perception agree with the fact that hydrological drought is closely related with long term absence of precipitation increased evapotranspiration.

2.2.4 Socioeconomic Drought

The socioeconomic drought happens when human activities at individual level are affected by decreased precipitation (Wilhite and Glantz, 1985). This implies that the demand for economic goods exceeds its supply. Specifically, very limited supply of food item, forage, water, fish, hydroelectric power and other that are related to daily activities if the communities lead to socioeconomic drought as they are depends on weather conditions (Camaro, 2015). The existence of socio economic drought is mainly manifested by affecting the daily activities of the communities due to the creeping characteristics of drought.

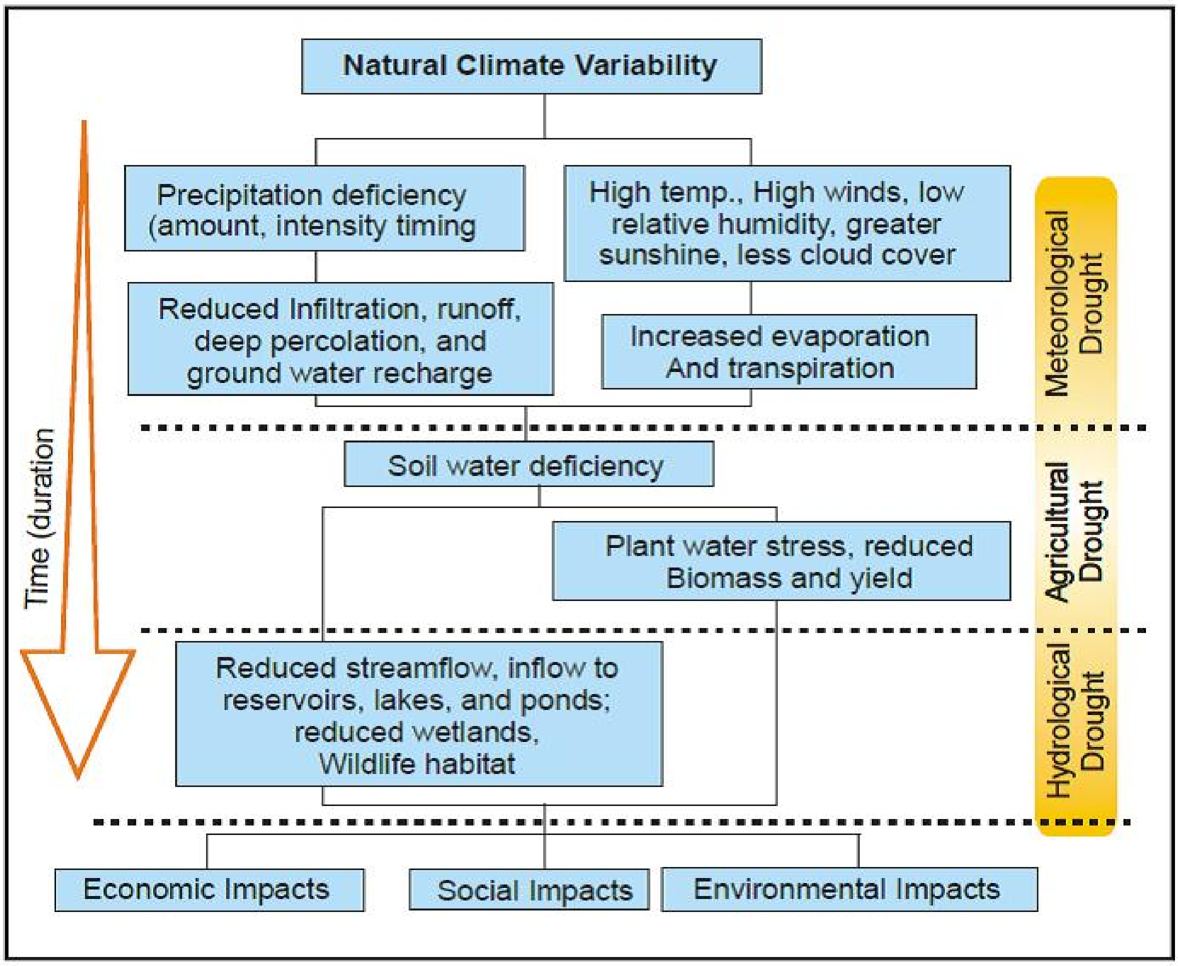

Figure 2.1: Relationship between Different Types of Drought Source: National Drought Mitigation Center (2006)

2.3 Impacts of Drought

Drought is one of the natural disasters that significantly affect almost all world communities and environmental system. These impacts are either direct or indirect. Accordingly, some of the direct impacts are decreased water levels, reduced crop yield, pastures, death of livestock, problems associated to wildlife and fish habitat (Wilhite, 1992; Camaro, 2015). On the other hand, the consequences of these direct impacts result into indirect impact including reduced income for farmers, increased prices for food, unemployment, reduced tax revenues, foreclosures on bank loans to farmers and businesses and migration (Ferrer et al., 2007; Wilhite et al., 2007).

In addition to duration, intensity and spatial extent of drought, the vulnerability of the society and sector to the event determine the extent of the impact (Aghrab *et al*., 2008). For instance, according to Wilhelmi and Wilhite (2002) the nature of climate, land use, soil characteristics, access to irrigation and conservation practices are some of the biophysical and societal factors determine agricultural drought vulnerability. Thus, in any attempt to reduce the impacts of drought, all its components need to be considered. Economic, environmental and social impacts are indicated at the bottom of figure 1, signifying that such impacts can happen at any stage during a drought. They are briefly explained as follows:

Economic impacts of drought are mainly manifested by reducing the businesses of the communities. More specifically, it results in shortage of capital, aggravates risk for financial institutions, unemployment, losses of crop yields, deaths of livestock and reduction of their products, increase prices for food, energy and higher level risk for human and wildlife populations (Murad and Islam, 2011; Camaro, 2015). This finally impairs the economic development of the country by reducing GDP and tax revenue for governments.

Environmental impacts, the second category of the drought impact are mainly realized following the happening of hydrological drought. In this context some of the impacts related to environment are depletion of biodiversity and natural habitat, loss of soil fertility and deterioration of water bodies thereby affecting the overall aspects of land productivity (Kapoi and Alabi, 2013).

The third aspect of drought impact is social related impacts. Even though the impacts included in the first and second classifications have social dimensions, the main social impacts are conflicts between drought sensitive resource users, migration, anxiety about economic losses, health related problems and generally deterioration of quality of life (Ferrer et al., 2007; http://threeissues.sdsu.edu/three_issues_droughtfacts02.html)

2.4 Drought in Ethiopia

According to Webb et al. (1992) since 250 BC droughts have occurred in different parts of Ethiopia at different times. Its frequency has increased over the past few decades particularly in the lowlands (NMS, 2007). Similarly Gebrehiwot and his colleagues said that throughout the human history, the country is frequently exposed to drought and famine (Gebrehiwot et al., 2011). Drought is a major problem affecting social, economic and environmental aspects of the country. This disaster mainly affects the agricultural production and livelihoods of the farming and pastoral communities. This is due to the fact that the sector is highly depends on the availability of rainfall. In line with this World Bank (2003) reported that drought occurrence in Ethiopia can reduce farming output by up to 90% of normal year output. It can also lead to the death of human beings and livestock. According to available literatures Ethiopia was attacked by drought 1964 – 1966, 1972 – 1973, 1978 – 1979, 1983 – 1984, 1987 – 1988, 1992, 1993 – 1994, 2000, 2002/2003, 2008/2009 (Degefu, 1987; Webb and Braun, 1994; Government of Ethiopia, 2009; Temesgen *et al*., 2010) and the currently occurring drought. These droughts were took place with different magnitude and spatial coverage.

2.5 Drought Monitoring Indices

In drought monitoring, the most commonly used approaches are ground based, satellite based and combined approaches. They have their own indices that help us to assess drought characteristics from different point of view. The approaches are briefly highlighted hereunder.

2.5.1 Standardized Precipitation Index (SPI)

The accuracy of drought monitoring using ground based climatic data largely depends on the number of available stations, the nature of their geographical distribution, quality of data itself and analytical methods employed for extrapolation. The most commonly employed index in meteorological drought assessment using ground based data is the Standardized Precipitation Index (SPI). Scientific communities indicated that SPI has been criticized largely due to uneven distribution of observation site, losing of regional information when points were used to represent regions, contain errors, high cost and time consuming (Ramos *et al*., 2009; Renza *et al*., 2010; Getachew *et al*., 2011; Muthumanickam et al., 2011; Himanshu *et al*., 2015). However, according to Mokhtari (2013) ground based SPI is relevant for the assessment of temporal extent of drought.

2.5.2 Satellite Based Agricultural Drought Indices

Available literature reveales that satellite based approach covers large area and continuous real time thereby providing effective techniques for large scale and long time series spatiotemporal variation analysis of drought (Kogan, 2001; Huang *et al.,* 2013; Mokhtari, 2013). For instance, Abbas *et al.* (2014) have recently undertaken study on characterization of drought development through remote sensing in central Yunnan, China. The findings of the study indicate that Tropical Rainfall Measuring Mission (TRMM) images and *in situ* rainfall data are highly correlated (R= 0.97). Using this correlation, they also recommend the use of image-based rainfall estimates in integrated drought indices.

Hence, in recent years several authors have employed satellite based drought indices to monitor drought pattern including (Huailiang *et al.*, 2009; Renza *et al.*, 2010; Gebrehiwot et *al.*, 2011; Muthumanickam *et al.*, 2011; Huang *et al.*, 2013; Khalil *et al.*, 2013; Kapoi and Alabi, 2013; Biranu *et al.*, 2014; Gizachew and Suryabhagavan, 2014; Himanshu *et al.*, 2015). Most of these studies utilized NDVI taken from NOAA, MODDIS and ASTER which are characterized by relatively course resolution. In addition, almost all of them did not identify drought coping strategies utilized by the affected communities. The current study is aimed at analyzing spatiotemporal pattern of drought using SPOT NDVI data based drought indices which has relatively better spatial resolution. To this end, this research applies the most commonly employed satellite based indices in agricultural drought assessment such as Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI). After identification of agricultural drought severity, the study also examines major drought coping strategies being implemented by the communities.

2.5.3 Combined Approach

Combining both ground based and satellite based approaches together in drought monitoring is essential as it makes use of the advantages of the approaches. For instance, the existence of environmental parameters like flooding, plant disease, fire and other anthropogenic factors limits the use of satellite based indices for monitoring the impact of drought on vegetation (Goetz *et al.,* 2006; Franke and Menz, 2007). This calls for the ground information to discriminate the drought impacted areas from the locations where the vegetation is being influenced by other factors (Brown *et al*. 2008). Research undertaken by Mokhtari *et al*. (2013) also indicated that it is very hard to find data relatively with both high spatial and temporal resolution due to satellite technical limitations. Considering this, they further revealed that reasonable drought monitoring needs an integration of ground data with high spatial and temporal resolution of indices derived from satellite images. This approach makes the assessment very complete as it tries to integrate both ground data and satellite imageries.

Obtaining NDVI data from landsat satellite image and rainfall from ground rainfall stations, Himanshu et al. (2015) studied monitoring of drought in Jamnagar District of India with the objective of examining the relationship between NDVI and rainfall. The result of the study indicated that temporal variations of NDVI are convincingly associated with precipitation and there exist a strong linear relationship between NDVI and precipitation. However, the authors failed to indicate the severity of drought and the level of the relationship between rainfall obtained from ground stations and NDVI derived from the landsat image.

2.6 Drought Coping Strategies

Abbasi (2014) carried out research on adaptation to drought in Saskatchewan rural Communities, Canada. The result of the study indicated that changing farming practices, diversification in terms of types of crops grown, off-farm employment, and participation in business risk management programs were some of the adaptive actions taken to counteract the adverse effect of the drought. According to the findings of the recently carried out research on responding to crop failure and understanding farmers' coping strategies in Southern Malawi by Coulibaly et al. (2015) indicated that most of the coping methods were ex-post measures. Specifically, the authors identified major coping strategies adopted by the households of the area like engaging in casual labor, small businesses and the sale of forest products.

Yaffa (2013) has also conducted research in Gambia on drought coping strategies collecting data from questionnaire survey of 373 households, 60 focus group discussions and six expert interviews. In his findings, he identified the drought coping strategies like rely on support from other people, rely on support from organizations, earn extra income to buy food, migration of household members, reliance on social networks, sell assets (livestock) to buy food, reduce food consumption and reduce expenses (school fees). Mentioning that these strategies were not enough to offset the negative impacts of the drought, he said that more should be done by the government and NGOs to help people at the time of drought event.

Vilane et al. (2015) in their study on drought coping strategies at Lonhlupheko community, semi-arid rural area in Swaziland, divided drought coping strategies into two based on the source of the strategies. The first strategies were those employed by the household themselves. These methods include marketing and selling, preparing and selling traditional brew, providing labor for food and money, dressmaking, selling second hand clothes, carpentry, cutting and selling of building timber. The second strategies were those received from external and institutional support such as receiving food rations and food farming inputs from NGOs, receiving crop seeds and fertilizer, forming cooperatives, subsidized tractor service and benefiting from extensional services. The authors also indicated the drought coping strategies proposed by the respondents like provision of water for irrigation, construction of dams and structures for rainwater harvesting, revival of agricultural extension services, access to loans for small and medium enterprises and promotion of drought tolerant crops.

Opiyo et al. (2015) in their study on drought adaptation and coping strategies among the Turkana pastoralists of Northern Kenya pointed out the major drought coping strategies such as increased livestock and livestock product sales, old/weak livestock slaughtered for consumption, labor migration to towns, household splitting (e.g. sending children to relatives), seeking agricultural employment, increased bush/wild product collection and sale, livestock migration/herd splitting, minimization of food consumption, reduction of meals and expenses, reduction of gifts to the poor by richer households, increased wild food consumption, seeking relief assistance, grain/fodder storage (mainly for wealthier households) and social support systems. In the same vein the authors also identified some of the major limitations to their strategies, which include inadequate cash income and capital, insecurity, lack of affordable credit facilities and access, illiteracy and lack of technical knowledge, inadequate markets and lack of inputs and equipment for agricultural practices

Collecting primary data from 123 sample households in Borana Zone, Diriba and Jema (2015) have conducted research with objective of identifying drought coping strategies. Hence, their findings revealed several drought coping strategies utilized by the households such as heard splitting destocking, livestock migration and grazing based on rotation between dry and wet season, early matured and drought resistant crop farming, hay making, conservation and feeding on crop residue, intercropping, communal grazing land management, borrowing money from friends, remittance, depending on assistant from other relatives or aid organization, sending children to other relatives, labor work, charcoal and firewood sell and petty trades, reducing food intake, feeding on wild fruits and roots. Even though the authors identified numerous drought coping strategies, they didn`t categorize them into ante and post strategies.

In the same vein, an assessment of coping strategies for drought induced food shortages in Fedis District; East Hararghe Zone, Ethiopia has been conducted by Anteneh (2013). He employed field observation, household survey, key informant interview and focus group discussions as the principal means of generating primary sources and analyzed using SPSS software. Hence the identified coping strategies were borrowing, eating wild foods, migration to surrounding urban areas, selling fuel wood and charcoal, pulling children out of school and petty trading. Similarly, even though it is not comprehensive, Ministry of Finance and Economic Development (2007) of Ethiopia in its study identified drought coping strategies carried out by the farmers. The strategies include sale of crop outputs, loan from relatives, sale of animals and own cash.

Most of the reviewed papers identified some of the drought coping strategies in different parts of places though they didn`t use satellite derived drought indices. However, this study focuses on monitoring of drought using satellite based drought indices and identification of major drought coping strategies. Almost all of the reviewed papers did not include drought coping strategies took place as a result of this year drought. However, in this research drought coping strategies being implemented and practiced are included. Moreover, some authors mixed up the coping and adaptation strategies together. They pointed out adaptation measures which are relatively long term and planned approach, as coping strategies.

CHAPTER 3: MATERIALS AND METHODS

3.1 Research Design and Approach

For drought coping strategies part of this study, descriptive method was used. Descriptive questions like "what", "how" and "when" are commonly observed in descriptive research method. This helps to get detailed and valuable insights of the problem under investigation. For triangulation purpose, this study also employed both qualitative and quantitative approaches. In fact this study made use of more of qualitative and some of quantitative approach in integrated system. The approaches helped the researcher to harness diverse ideas about drought coping strategies and assisted in cross-checking the results which increase the validity and reliability of the findings.

3.2 Data Acquisition, Source and Software Package

3.2.1 Sources and Type of Data

Both primary and secondary sources were employed in undertaking this study. Primary data regarding drought coping methods were collected from focus group discussion, field observation and key informant interviews with government officials, local administrative and development agents. Using the methods indicated in this section, data related to drought coping strategies were collected from households and institutions working on the drought related issues and used for analysis. In addition, secondary data were obtained from published and unpublished documents of different sources.

Concerning the satellite data sets, the vegetation 1 instrument on board SPOT4 (launched 1998) and vegetation 2 on board SPOT5 (since 2002) provides measures of land surface reflectance in the visible and in the infra-red domains up to May 2014. These sensors offer a daily global coverage with a spatial resolution of about 1km. Reflectance measurements are performed within four spectral window: blue, Red, Near Infra-red and Medium Infra-red. Zipped decadal SPOT Vegetation NDVI datasets were downloaded from http://www.vito-eodata.be/[1] for the study period 2005 – 2013. However, the 2014 image was downloaded from Copernicus Global Land Service (http://land.copernicus.eu/global[2]). In this process

[1] http://www.vito-eodata.be/PDF/portal/Application.htm

[2] http://land.copernicus.eu/global

about 120 decadal images were downloaded for this study and all the images were rescaled to +1 and -1. For years 2005 – 2014, month of June, July August and September were included. The NDVI data set contains 10-days maximum value NDVI composites at 1km resolution. The ten day composites are distributed and generated by Vlaamse Instelling voor Technologish Onderzoek (VITO) using maximum value composites (MVC) algorithm. MVC aims at reducing the effects of atmospheric interferences such as clouds.

3.2.2 Software Package

In the present study Google Earth, Erdas Imagine 2014 and ArcGIS 10.2 were employed. Erdas Imagine 2014 remote sensing software was used for NDVI and VCI analysis. Similarly ArcGIS 10.2 software was utilized to draw the composite map and extent of agricultural drought in the study area. The composite map of agricultural drought was derived from the aggregate score of various satellite based indices. Finally reclassification into various drought severities was done by overlying maps of the indices.

3.3 Sampling

As it is not viable and economical for the researcher to survey all the districts of the zone, four districts were purposively selected. Purposive selection was done based on the severity and frequency of drought so far occurred in the Zone. This was done in consultation with the Zone`s Disaster Prevention and Preparedness Office. The selected districts were representative in reflecting the character of the remaining parts of the district. Accordingly, Adama, Adami Tulu Jido Kombolcha and Bosat districts were selected. Considering the variations of kebeles interims of the frequency of drought, again purposive sampling was employed in order to select focus group discussants. In this processes about three focus group discussions were carried out. In addition document analysis was also employed in analyzing the drought coping strategies practiced in the study area.

3.4 Data Collection

As stated in source and type of data section, focus group discussions and key informant interviews with concerned officials and experts were employed for collection of data about drought coping strategies.

Focus group discussions were held in study communities to get detailed information regarding drought coping strategies. This technique mainly used to extract information in participatory manner so that the perceptions and views of respondents specific to research objective were captured and interpreted. Accordingly, there were a total of four focus group discussions and each group consisted of five to seven individuals who were not involved in interviews. The participants were individuals who represent different group of the households. To guide the discussion, semi-structured checklists were designed specific to the research objective.

Key informant interviews with government experts such as Zonal and District Rural and Agricultural Development Offices, Zonal and District Disaster Prevention and Preparedness Office were carried out by the researcher to elicit data regarding drought coping strategies.

3.5 Data Processing and Analysis

3.5.1 Preprocessing of Data

Information of the images related to projection parameters (Spheroid name, datum name, latitudes of standard parallels, longitudes of central meridian, latitudes of origin of projection, false easting at central meridian and false northing at origin were incorporated in the raw images. Projection of the data was adjusted to Adindan UTM_Zone_37N. In addition, masking, rescaling of the NDVI, generation of monthly means, seasonal means, monthly long term, seasonal long term, deviations of monthly long term means, seasonal long term means and the respective maximum and minimum were done using Arc tool box.

3.5.2 Normalized Difference Vegetation Index (NDVI)

This index is widely used for determining water stress levels in vegetation and assessment of agricultural drought (Singh et al., 2003 & Son et al., 2012) thereby enabling to monitor changes in vegetation over time. The basic idea of NDVI as a measure of agricultural drought and healthiness of vegetation is that near-infrared portion of the radiation reflected while greater amount of red portion of energy is absorbed by healthy green leaves. On the contrary, the reverse action takes place in the case of unhealthy leaves. Thus, NDVI is defined as the difference between the maximum absorption of radiation in red due to chlorophyll pigment and the maximum reflectance in NIR spectral region as a result of leaf cellular structure (Tucker, 1979). Mathematically, it is expressed as:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

Where NIR and red are the reflectance values in the near infrared and red bands of the electromagnetic energy respectively. Though the values of NDVI range from negative one to positive one, values less than zero do not have ecological meaning. With this modification, photosynthetically active vegetations are associated with higher values of NDVI and the reverse works for stressed vegetation.

To derive the seasonal pattern of NDVI for specified years, average NDVI of each year was defined using:

$$Averege\ NDVI_Y = \frac{(NDVI_6 + NDVI_7 + NDVI_8 + NDVI_9)}{4} \quad (2)$$

where $NDVI_Y$ is the value of NDVI for Y year and $NDVI_6 + NDVI_7 + NDVI_8 + NDVI_9$ stands for the value of NDVI of particular months in that year. In the same way, mean of NDVI for 10 years were computed using the following expression

$$Mean\ NDVI = \frac{(Averege\ NDVI_{Y_1} + Averege\ NDVI_{Y_2} + \ldots + Averege\ NDVI_{Y_{10}})}{10} \quad (3)$$

$Averege\ NDVI_{Y1} + \ldots + Averege\ NDVI_{Y10}$ stands for yearly average of NDVI value for 10 years.

3.5.3 Drought Severity Index (DSI)

The occurrence of drought is mainly indicated by the continuous existence of negative deviation of NDVI value. These are explained interims of monthly and seasonal deviation of NDVI that developed from time series of long term mean of respective deviations. Specifically, monthly deviation of NDVI was computed by finding the difference between the NDVI for the current month and time series of a long term mean for this month. In the same context, Drought Severity Index (DSI) of NDVI was calculated by making the difference between mean NDVI of current season and times series of long term mean of seasonal NDVI value using Arc tool box (spatial analyst tools-local-cell statistics).

In this process based on the computation of NDVI average over the last ten years and its long term mean, drought severity index was computed using

$$Drought\ Severity\ Index\ (DSI) = NDVI_i - NDVI_{mean}\ n \quad (4)$$

where $NDVI_i$ is the NDVI value for i^{th} year and $NDVI_{mean}\ n$ is the long term mean of NDVI for the year n. In this case, where the value of DSI is below zero it indicates that prevailing of drought situation whereas positive values indicates there is relatively wet condition. In line with this Thenkabail et al. (2004) the deviation from long term mean can be used efficiently as one of the drought indicators as it would reflect the conditions of healthy vegetation in normal and wet years.

Accordingly deviations were generated and interpreted. In using NDVI as means of agricultural drought assessment, scientific communities identified two limitations. Firstly, different vegetations have different relationship between chlorophyll content and vegetation water condition (Thomas *et al*., 2004). Secondly, when there are extensive periods of cloud coverage, the NDVI values tend to be depressed giving a wrong conclusion about drought condition (Tsegaye, 1998). In order to address limitations associated with NDVI, Kogan (1995) suggested Vegetation Condition Index for identifying drought related vegetation stress and impacts of drought on overall vegetation condition.

3.5.4 Vegetation Condition Index (VCI)

Vegetation Condition Index (VCI) is the normalization of NDVI between the maximum and minimum values, which was proposed for the monitoring of drought in vegetation (Kogan 1995).

$$NDVI\ max = NDVI_1 + NDVI_1 + \ldots + NDVI_n \quad (5)$$

Where $NDVI\ max$ is maximum NDVI in j^{th} month in j^{th} year and

$NDVI_1 + NDVI_1 + \ldots + NDVI_n$ is NDVI from 1 to NDVI in n year in j^{th} month.

$$NDVI\ min = NDVI_1 + NDVI_1 + \ldots + NDVI_n \quad (6)$$

Where $NDVI\ min$ is minimum NDVI in jth month in jth year and $NDVI_1 + NDVI_1 + \ldots + NDVI_n$ is NDVI from 1 to NDVI in n year in jth month

Using the computed NDVI maximum and minimum, VCI is calculated as

$$VCI = 100 * \frac{NDVIj - NDVImin}{NDVImax - NDVImin} \quad (7)$$

where $NDVI_{max}$ and $NDVI_{min}$ are maximum and minimum values of NDVI for the considered month or year during the study period, respectively. The current month or year is indicated by j. VCI value is being measured in percentage ranging from 1 to 100. The value between 50 and 100% show that condition of vegetation is above normal whereas the values ranging from 35 to 50% indicate the drought condition and below 35% indicates severe drought condition (Kogan, 1995).

3.5.5 Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) was calculated to examine the spatio-temporal extent and intensity of meteorological drought event. The SPI was developed by McKee *et al.* (1993) to quantify the precipitation deficit for multiple time scales like 3, 6, 12, 24 and 48 months. They defined SPI as the number of deviation that the observed value would deviate from the long term mean, for a normally distributed random variable. Since the precipitation is not normally distributed, a transformation is first applied so that the transformed precipitation values follows normal distribution. In this case, the positive value of SPI indicates wet conditions while the negative signifies drought condition.

Table 3.1: Standardized Precipitation Index

SPI	Drought Conditions
2.00 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 and less	Extremely dry

McKee *et al.* (1993)

In this case seasonal rainfall data were used as an input to compute the SPI for the periods 2005 – 2014. The method of Inverse Distance Weighted (IDW) has been used to interpolate the SPI values. IDW interpolation explicitly implements the assumption that things that area close to one other are more like than those that are further apart (ArcGIS 10.2). The interpolation has been performed in ArcGIS 10.2. The interpolated maps are then been reclassified into different drought severity classes. The methodological flow chart of SPI is indicated in fig. 3.1

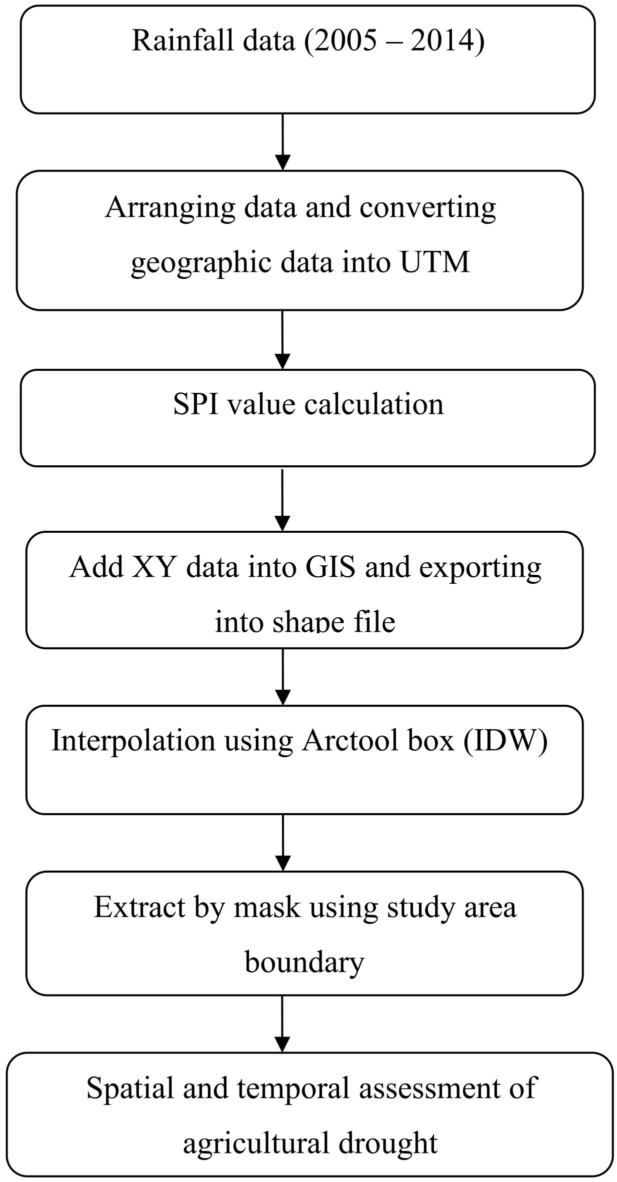

Figure 3.1: SPI Estimation and Spatial Representation Methodology

3.5.6 Drought Coping Strategies Analysis

Data related to drought coping strategies, the fourth specific objective, was mainly analyzed qualitatively. In this view, data collected through qualitative methods were summarized and analyzed in a thematic approach. Similar themes were grouped together and then discussed. Where appropriate, a qualitative ethnographic summary that involved quotations from the group and individual interviews were made to illustrate and support points of view expressed by the informants. Some analysis was also carried out by using quantitative descriptions. Descriptive statistical tools such as percentages, tables, graphs and diagrams were utilized to analyze data. Details of the flow chart is indicated in the figure 3.2

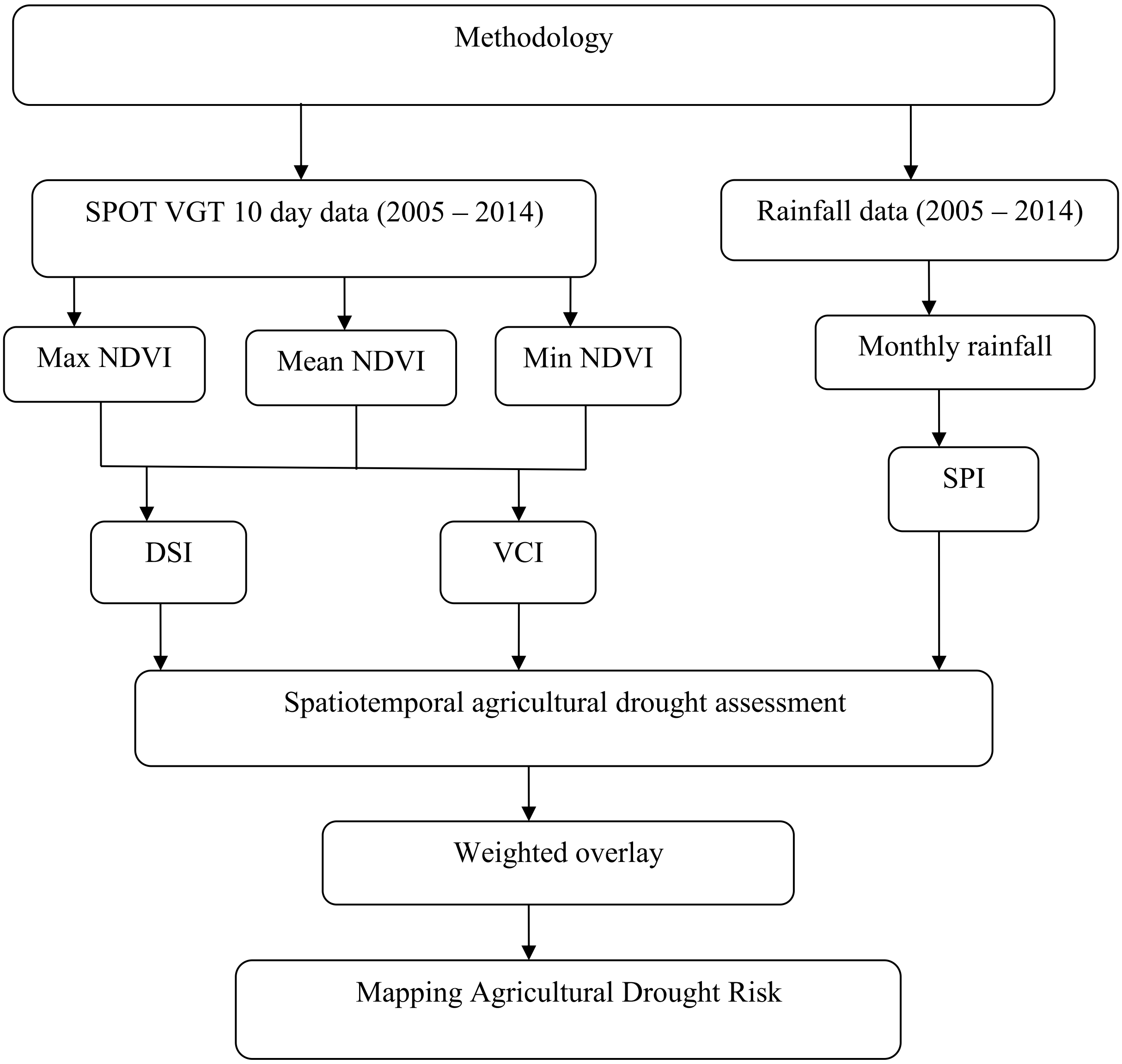

Figure 3.2: Methodological flow chart

CHAPTER 4: RESULTS AND DISCUSSION

This chapter deals with results and discussions of the remote sensing indices for mapping agricultural drought, relationship between seasonal rainfall and NDVI, temporal pattern of drought severity index, Standaredized Precipitation Index (SPI) and drought severity, temporal aspects of Standardized Precipitation Index (SPI), identification of drought severity and analysis of drought coping strategies.

4.1 Remote Sensing Indices for Mapping Agricultural Drought

4.1.1 Monthly Deviation of NDVI

Under this sub section some monthly deviation of NDVI is discussed. July 2005 and June 2012 were identified from all months over the past ten years representing drought and wet months respectively. Their detailed analysis using figure 4.1 was indicated.

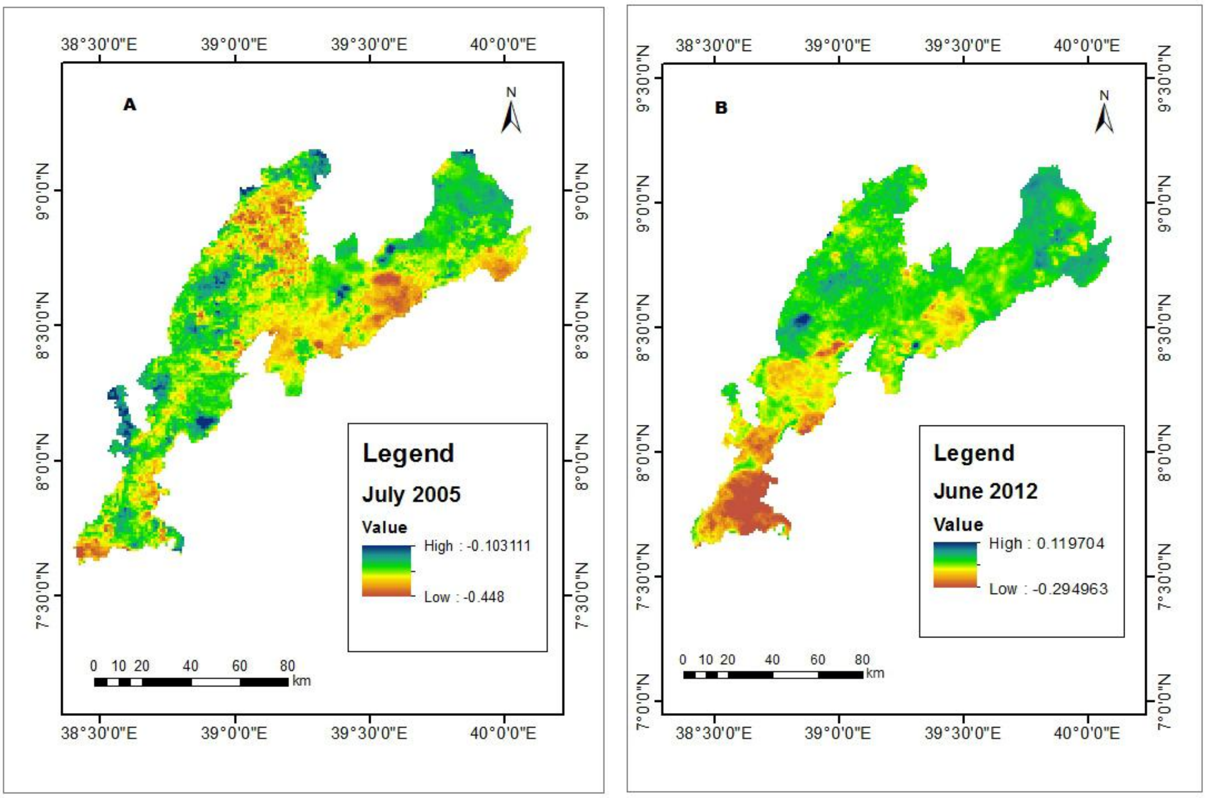

Figure 4.1: Agricultural drought of July 2005 (A) and June 2012 (B) of NDVI

With regard to monthly deviation of NDVI, in comparing with the considered months of the years, the month with low NDVI value (higher magnitude of drought) was analyzed. Accordingly, figure 4.1 (A) shows 2005 July monthly deviation of NDVI value. As it can be seen from the figure, in relation to the remaining considered months of the years, the severity of drought was higher in July 2005. During this time, the districts affected by drought were Adami Tulu Jido Kombolcha, Adama, Bosat, Southern part of Fantale, Dugda, Bora and some parts of Ada`a. This does not mean that there was no drought in other parts of the study area. However, it was higher in spatial coverage during month of July 2005.

In the same way, figure 4.1(B) shows the June monthly deviation of 2012. Thus, in comparing with the years of considered months, the magnitude of drought in June 2012 was lower. Except some parts of Adama, Dugda and Adami Tulu Jido Kombolcha districts, almost all the remaining districts were characterized by higher NDVI value indicating that lower severity of drought. The value of NDVI in the majority of the study area is positive indicating that there was vegetation cover during specified time. This implies that the majority of the study areas were not under the impact of drought and thus, as it can be seen from the map, it was identified as wet month among the considered months in study area.

4.1.2 Drought Severity Index (DSI)

As it is explained in the first part of chapter four of this thesis, drought severity index was computed by finding the deviation of current NDVI values from their long term means of considered years. When there is below zero deviation, it is possible to conclude that there is drought situation though their extent and magnitudes differs. In this study, the result of drought severity index indicated that most of the considered years were characterized by having negative NDVI value showing that there was drought in study area. However, their level of drought is different from year to year.

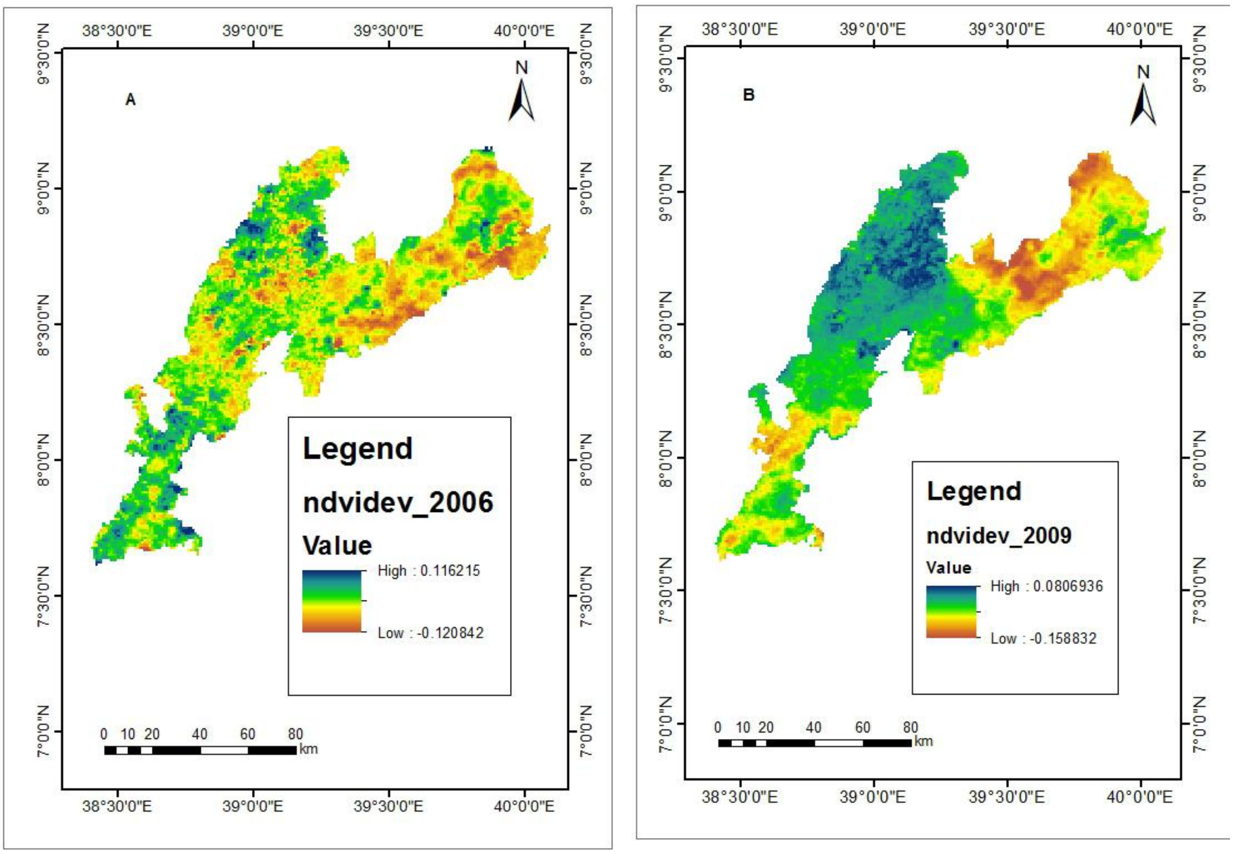

Figure 4.2: Spatial pattern of agricultural drought years of 2006 (A) and 2009 (B) expressed by drought severity index

In comparing with the remaining years, 2006 and 2009 were characterized by having lower NDVI value thereby identified as drought years. As it can be seen from the figure 4.2 (A) drought was occurred during summer season of 2006. Specifically, the districts affected were Fantale, Adama, Adami Tulu Jido Kombolcha, some parts of Dugda, Liban and Bora. In the same way, the data obtained from the zone indicated that during 2006 for the mentioned districts food aid was distributed indicating that there was drought in the study area. Accordingly, Available document showed that Adama district received about 80 quintals of grains and 439 kilo grams of pulses. Whereas Adami Tulu Jido Kombolcha district provided about 2096 quintals of grains. In addition, about 3298 and 241 quintals of grains and supplementary foods respectively were distributed for Bosat district. This district again was given about 11069 liters of edible oil and 135 kilo grams of pulses during the same period. On the other hand, Fantale district received about 3067 quintals of grains and 9.75 quintals of supplementary foods. In the same way, the district also received relief distribution of 307 kilo grams of pulses. About 196.46 and 3.5 quintals of grains and supplementary foods were provided indicating that there was moderate drought that affects very few segments of the communities.

The drought severity index of NDVI 2009 is shown in figure 4.2 (B). As it can be observed from the map, large part of the study areas were affected by drought in specified year. The districts affected by drought in that year were Adami Tulu Jido Kombolcha, Bosat, Fantale and some parts of Adama. In this case it is possible to conclude that majorities of the study areas were affected by drought even though the magnitude differs.

According to the document from East Shewa Zone during 2009, the above mentioned districts were provided with various food aids as the techniques of drought coping. Thus, Adama received 1336 quintals of gains and 60 quintals of supplementary foods. About 3441 and 180 quintals of grains and supplementary foods were distributed for affected communities in the Adama Tulu Jido Kombolcha. Moreover, Bosat district has received 1572 quintals of grains and 164 quintals of supplementary foods during 2009. Finally Fantale district being the acted district has received about 1658 quintals of grains as drought coping strategies.

Similarly, according to the research carried out by Mohammed (2014) the year 2006 and 2009 were identified as drought years in which SPOT NDVI data were utilized to identify drought years. Large volume of relief distributions that aimed at supporting the affected societies was also another manifestation of the drought magnitude. More over according to the key informant with expert at zone level and focus group discussants, the two years were mentioned as drought years of the zone. The focus group discussants particularly added that as a result of the droughts, they lost most of their agricultural output.

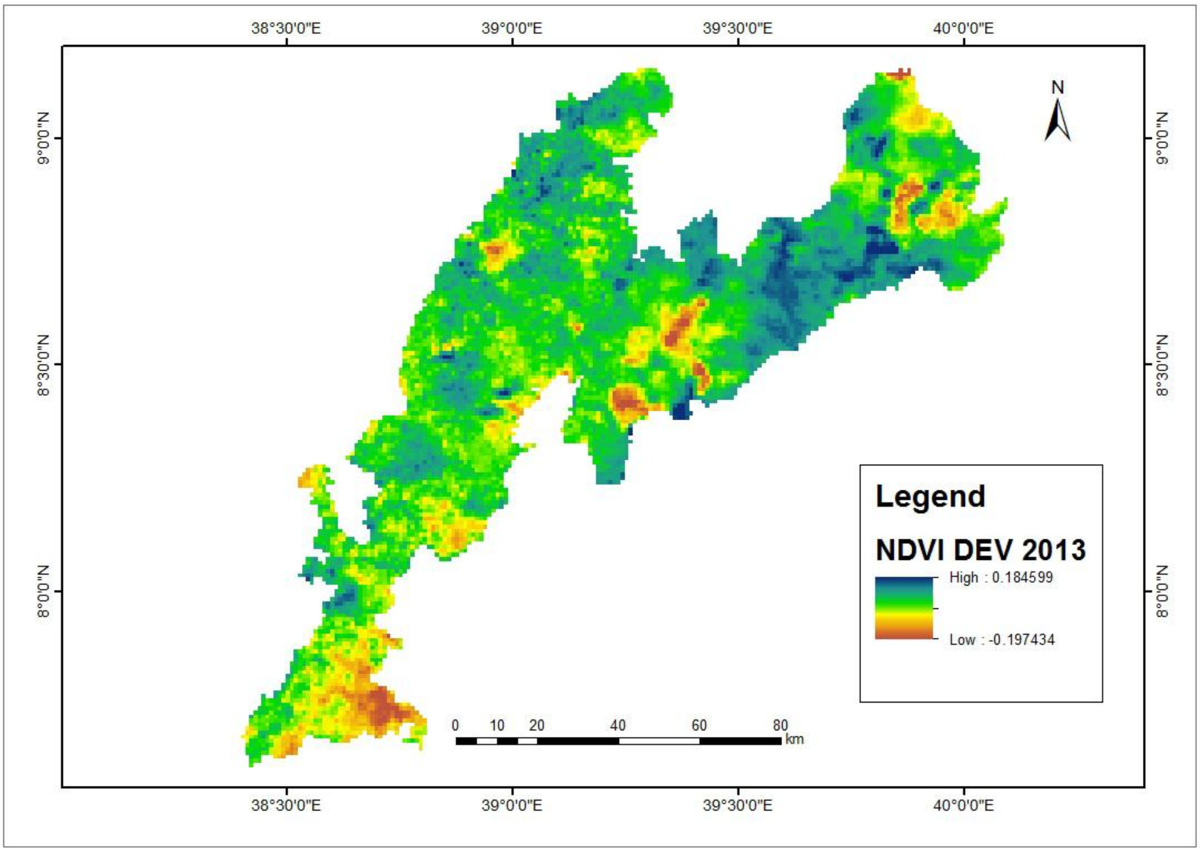

Figure 4.3: Spatial pattern of agricultural drought severity for wet year (2013) expressed by drought severity index

As it is explained at the beginning of this section, the drought severity index of NDVI identified relatively one wet year (2013). This does not mean that totally there were no droughts in 2013 in study area. However, in comparing with the remaining years, the identified year can be considered as wet year. Thus, as it has been indicated in figure 4.3 except some parts of Bosat, Adami Tulu Jido Kombalcha and very few parts of Fantale, almost all districts of study area were wet during 2013 year. Of course, during this year there were relief distributions to the above mentioned districts even though it was limited to provision of grains only. In addition, the amount was also small in comparing the remaining years. This is in agreement with the research conducted by Mohammed (2014) in Sire district which is located near by the study area. Study conducted by Gizachew (2010) using NOAA (8 km by 8 km spatial resolution) NDVI data however identified 2007 and 2008 as wet years of the study area. In fact he only studied time series data of 1996 – 2008. Of course, 2008 year can also be considered as wet year but it spatial coverage was a bit larger than 2013.

4.1.3 Vegetation Condition Index (VCI)

In this paper, VCI were computed and compared to identify maximum vegetation growth during 2005 – 2014 taking into consideration June to September months. The time series data of the VCI is mainly used to analyze the trends of drought happenings. As it is explained in the literature review part f this paper, drought condition is noticeable when the value of VCI is below 50 and the severity of drought declines when the value of VCI is above the threshold.

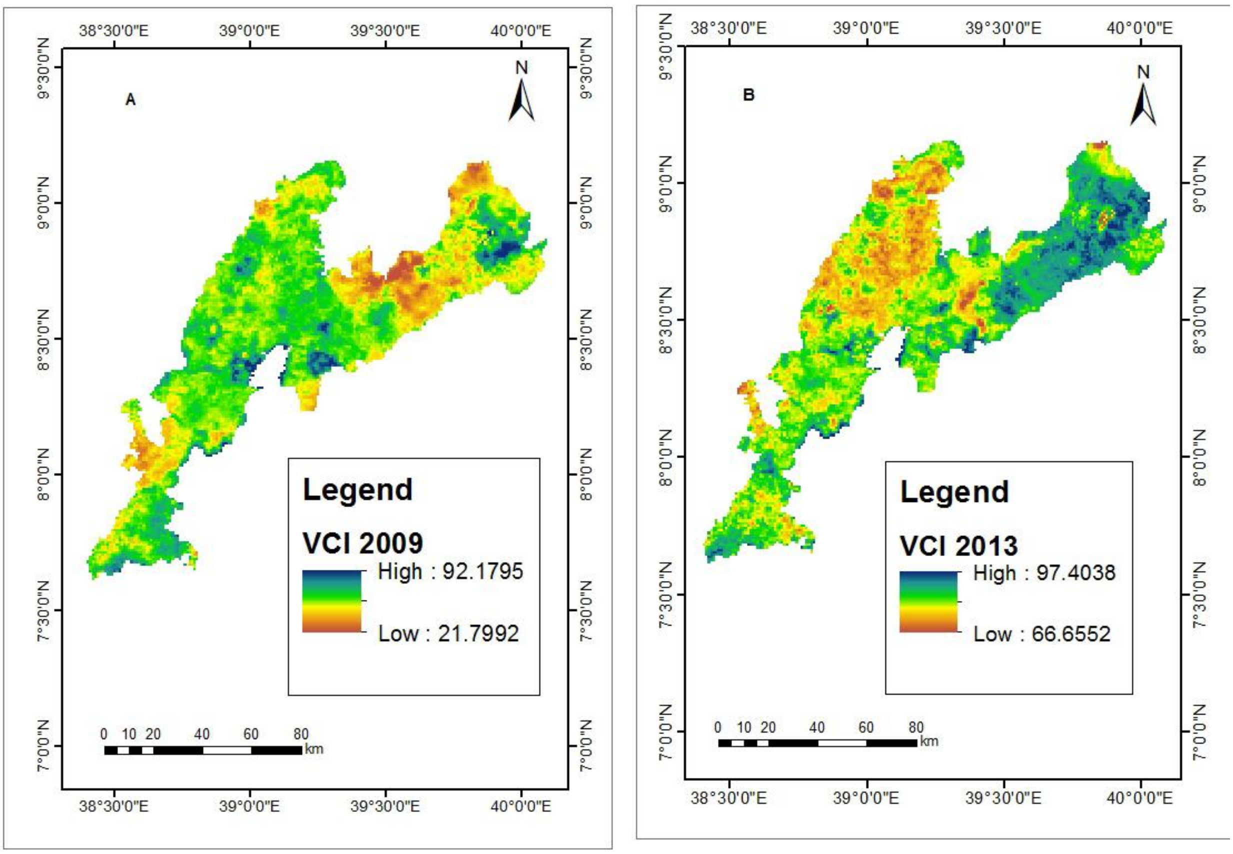

Figure 4.4: Spatial pattern of agricultural drought severity for drought year 2009 (A) and 2013 (B) expressed in Vegetation Condition Index

Based on the result of this study, the minimum value of VCI was observed during 2009 indicating that the condition of vegetation was not good. This implies that there was the influence of drought that affects the vegetation conditions. This is due to the fact that unfavorable weather conditions resulted into unhealthy vegetation condition. As it is shown in the figure 4.4 (A) almost all regions of the study area were under the influence of drought during 2009 of June to September. This does not mean that all regions were equally exposed to the stress. Specifically, northeastern and southwestern parts of the study area were seriously affected by drought. In this year, in almost all months of the growing seasons the values of VCI were below the average indicating the existence of drought. In this case, it can be summarized that 2006, 2009 and 2011 were the years characterized by having large portions of area affected by drought though the 2009 was identified as relatively severe drought.

In contrast to the 2009 VCI, the 2013 VCI was characterized by having low effect of drought over the majorities of the study area (Fig 4.4). It has been found that large portions of study area were not under the influence of drought conditions. From the final output of VCI maps, it can be generalized that low impact of drought was indentified in 2008, 2012 and 2013. However, in comparing with the remaining years the 2013 year was considered as wet year. This is because in all most all the growing months of the year, the value of VCI was above the average indicating that good condition of vegetations in the area.

4.2 Relationship between Seasonal Rainfall and NDVI

As it is explained in the review literature part of this paper, seasonal analysis of historical rainfall and the response of vegetation interims of NDVI are very important. Figure 4.5 shows the relationship between long term NDVI and seasonal pattern of rainfall for the whole study area during the period of 2005 – 2014. As it can be observed in the figure, there is an increasing correlation between long term NDVI and seasonal rainfalls. Thus it has been shown that there is good correlation (r=0.7) between them. This does not mean that they are exactly increasing in similar pattern. However, there were slight year to year variations in both long term NDVI and rainfall. This is mainly due to the fact that NDVI has some lag time response to the existing rainfall conditions of the area. According to the study carried out by Chopra (2006) in Gujrat, India the coefficient of determination between long term NDVI and seasonal rainfall was 0.4. In the same way it is also possible to generalize that from all 10 years of data about 71% of NDVI variability can be explained as a result of seasonal rainfall. On the other hand study conducted in this study area by Gizachew (2010) for the period between1996 – 2008 has revealed that 42% of NDVI variability was explained by seasonal rainfall. Whereas the study carried out by Mohammed (2014) in Sire district showed that 59% of NDVI variability was attributed to the seasonal rainfall.

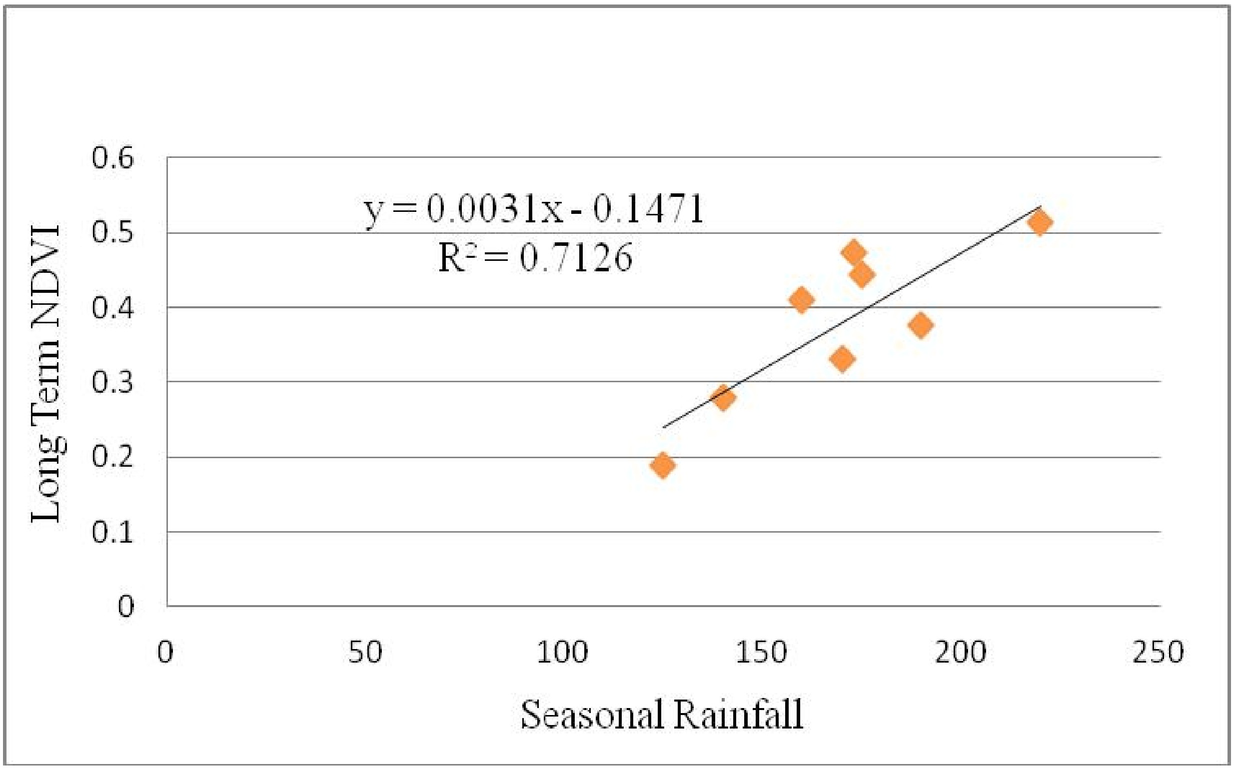

Figure 4.5: Relationship between long term NDVI and seasonal rainfall (2005 – 2014)

4.3 Temporal Pattern of Drought Severity Index

As it can be understood from the figure 4.6 agricultural seasons of 2012 and 2013 years have DSI above zero indicating that they were relatively wet years. However, that of 2012 year was taken as the wettest year as its DSI is about 0.02. Even thought the severity varies from year to year, in all the remaining years the value of DSI was below zero indicating some level of drought condition. As it can be observed from the tempral profile of the area 2005 and 2009 years were conssidered as the drought periods. This findings are inline with the findings obtained by Mohammed (2014) in Sire district.However, Gizachew (2010) in study on agricultural drought using NOAA NDVI data in East Shewa zone identifed 2000 and 2002 as drought years. Of course, his study inluded the time between 1996 to 2008. In fact, this study has got similar result with Gizachew regarding wet season as he identified 2008 as wet year. It is also possible to conclude that the level of vegitation was sparse. The peak of DSI was seen in 2005 follwed by 2009.

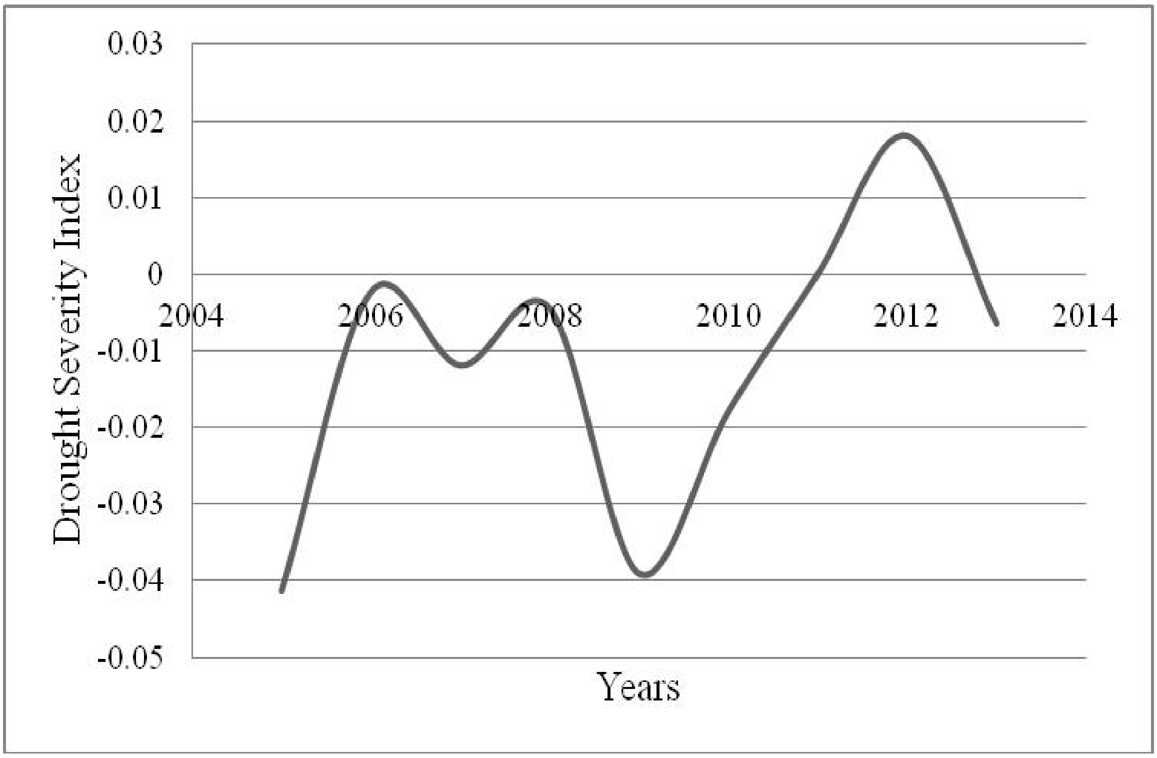

Figure 4.6: Temporal pattern of Drought Severity Index of 2005 – 2014.

4.4 Standaredized Precipitation Index (SPI) and Drought Severity

As it is brifly explined in 3.6.5 section of this thesis, negtive SPI values indicate that the rainfall of the area is less than median rainfall and the posetive indicate the rainfall is greater than median rainfall. Drought risk was carried out using SPI in East Shewa Zone by interpolating SPI values over the past 10 years. SPI during slected drought years of 2005 and 2009 and wet years of 2012 and 2013 have been presented in order to show the spatial pattern of SPI during these years.

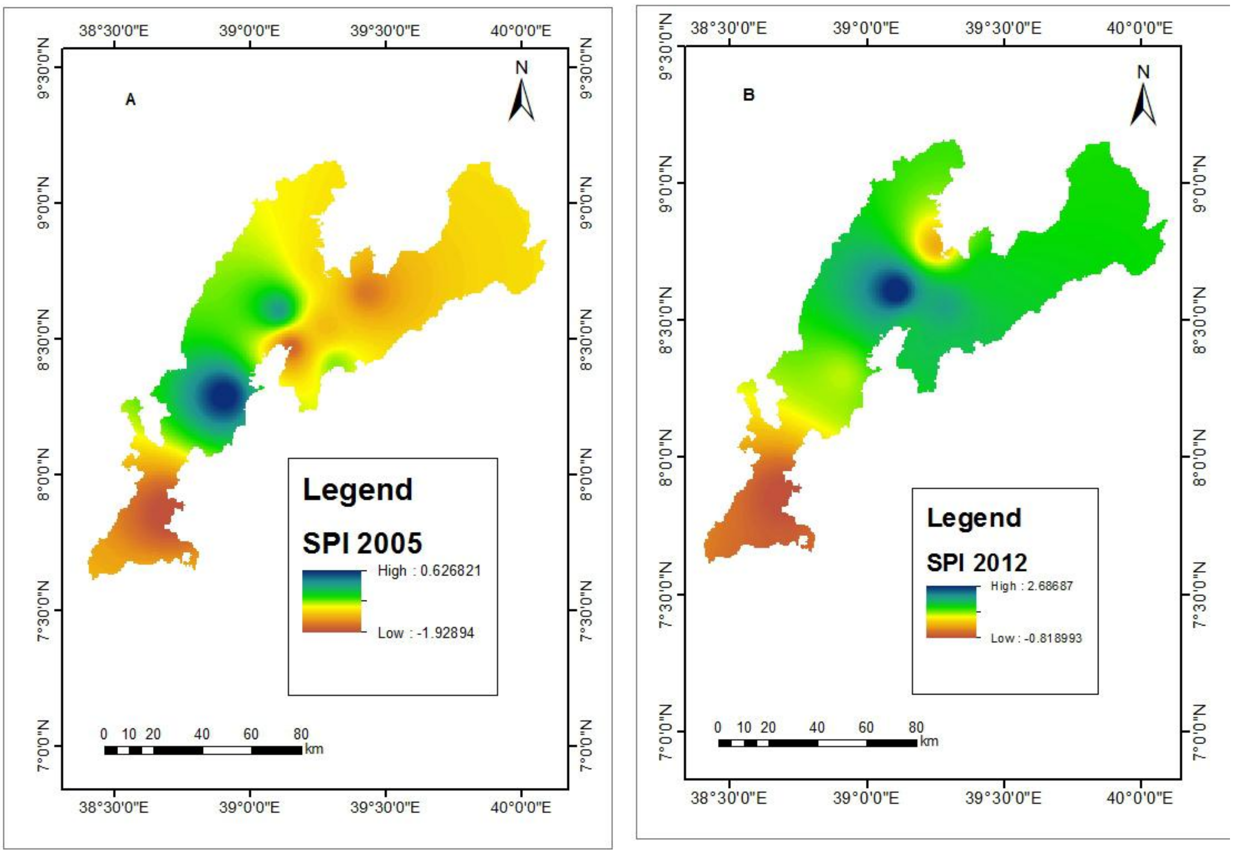

Figure 4.7: Spatial pattern of agricultural drought severity for drought year 2005 (A) and wet year 2012 (B) expressed in Standardized Precipitation Index

As it has been shown in figure 4.7, except the central part of East Shewa Zone scuch as Bora, Dugda and Lume all areas of the study area were under the impact of drought in 2005. Of course, the severity was relatively higher in Adami Tulu Jido Kombolcha, Bosat and some parts of Adama. It can be also said that this pattern wass happened due to the impact of low amnount rainfall distribution. This does not mean that there was no drought in the remaining years. For instance, in 2009 there were the occurances of drought in some parts of the study area like in Adaama, Fantale and Bosat. As it has been said earlier the spatial coverge of drought occurred in 2005 was greater than that of 2009. Hence, accordiing to the SPI result 2005 and 2009 were identified as drought years in East Shewa Zone. As a rsult of these, there were relief distributions carriedd out by the governmnet in order to help the victmed societies. This was confirmed by the information collected from officials of Agricultural and Rural Developmet and Disaster Prepardness and Preventation of the zone. This finding is again in agreement with Gizachew and Suryabhagavan (2014).

In the same way, 2012 and 2008 were identified as relatively wet years using SPI result.The Figure 4.7 (B) depicts that the spatial pattern of drought in specified years. In 2012, except few areas East Shewa Zone, the majorties of the zone were not under the influence of drought. This also implies growing season of 2012 can be considred as good agricultural time as it was not characterized by water deficit. Though 2008 was also under the influnce of drought, its spatial coverege is relatively higher that 2012.

4.5 Temporal Aspects of Standardized Precipitation Index (SPI)

Figure 4.8 shows the tempral profile of SPI of 2004 – 2014. As it is indicated in the figure the SPI value is above zero for the years 2007, 2008, 2010, 2011 and 2012. Though in these years the value of SPI is above zero, the level of drought was not exactly equal in all years. For instance, the highest value of SPI was recorded in 2012 and followed by 2008 year. This implies that the wettest year over the past ten years was 2012 and follwed by 2008. The growing season of both years were characterized by having excess moinsture. Moreover, the result of the focus group discussions and key informant interviews also identified the year 2012 as the wettest year. This is in agreement with the information obtained through anaylysis of satellite data and rainfall data obtained from the meteorological stations of the zone.

Simalrly, in 2005, 2006 and 2009 the value of SPI is below zero indicating some level of drought inthese years. As it is explained in wet years, there was variations in the level of drought. For example as it can be concluded from the figure 4.8 the level of drought was the highest in 2005 followed by 2009. According to the information obtained from two offices of East Shewa Zone: Agricultural and Rural Development and Disaster Preparedness and Prevention, during the years of 2005 and 2009 there was severe agricultural drought in the zone. According to them that draught resulted into crop failures in North Eastern part of the zone such as Fentale, Bosat and some parts of Adama. The influence also seriously affected the Southern part of the zone particularly Adami Tulu Jido Kombolcha.

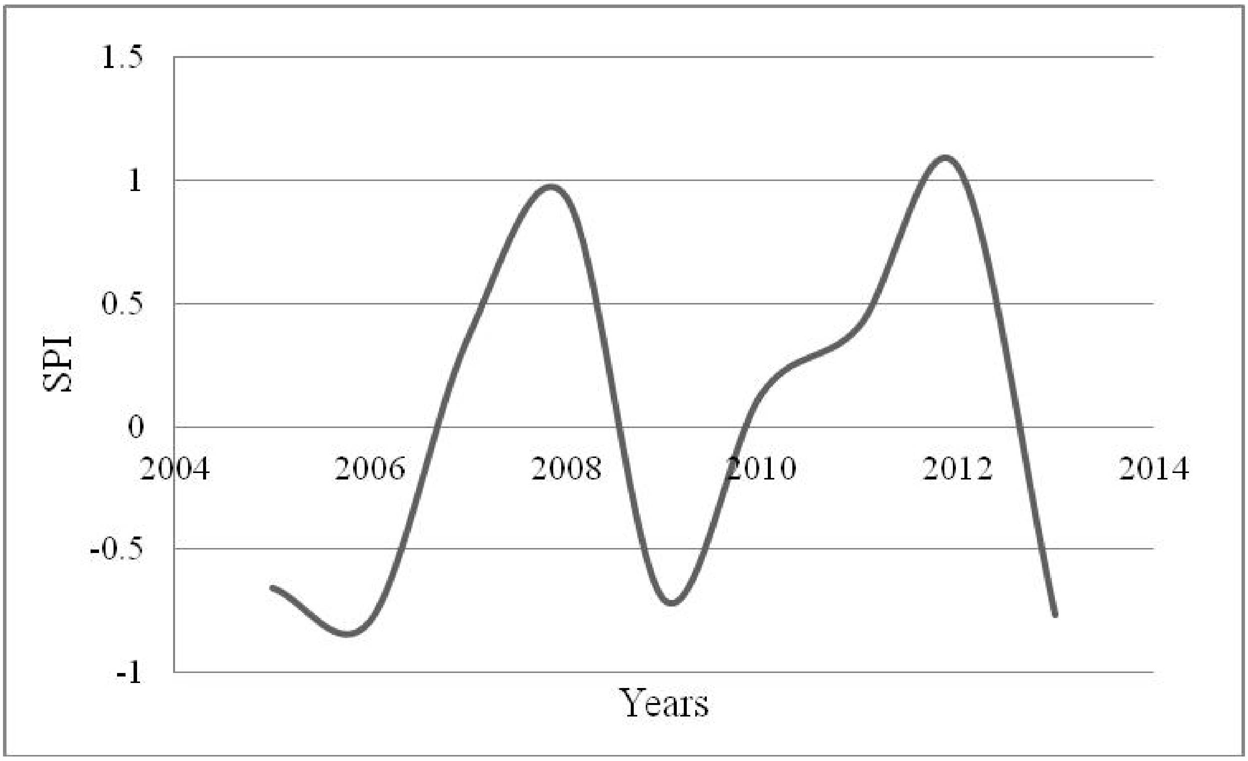

Figure 4.8: Temporal pattern of SPI f or growing season of 2004 – 2014

4.6 Identification of Drought Severity

According to Song and Saito (2004) drought severity class is done based on the value of its NDVI like extreme drought with NDVI less than -0.25, severe drought between -0.1 to -0.25, moderate drought 0.1 to -0.1, mild drought 0.1 to 0.25 and no drought with NDVI greater than 0.25. Accordingly, agricultural drought severity map has been developed by integrating drought severity index, vegetation condition index and standardized precipitation index.

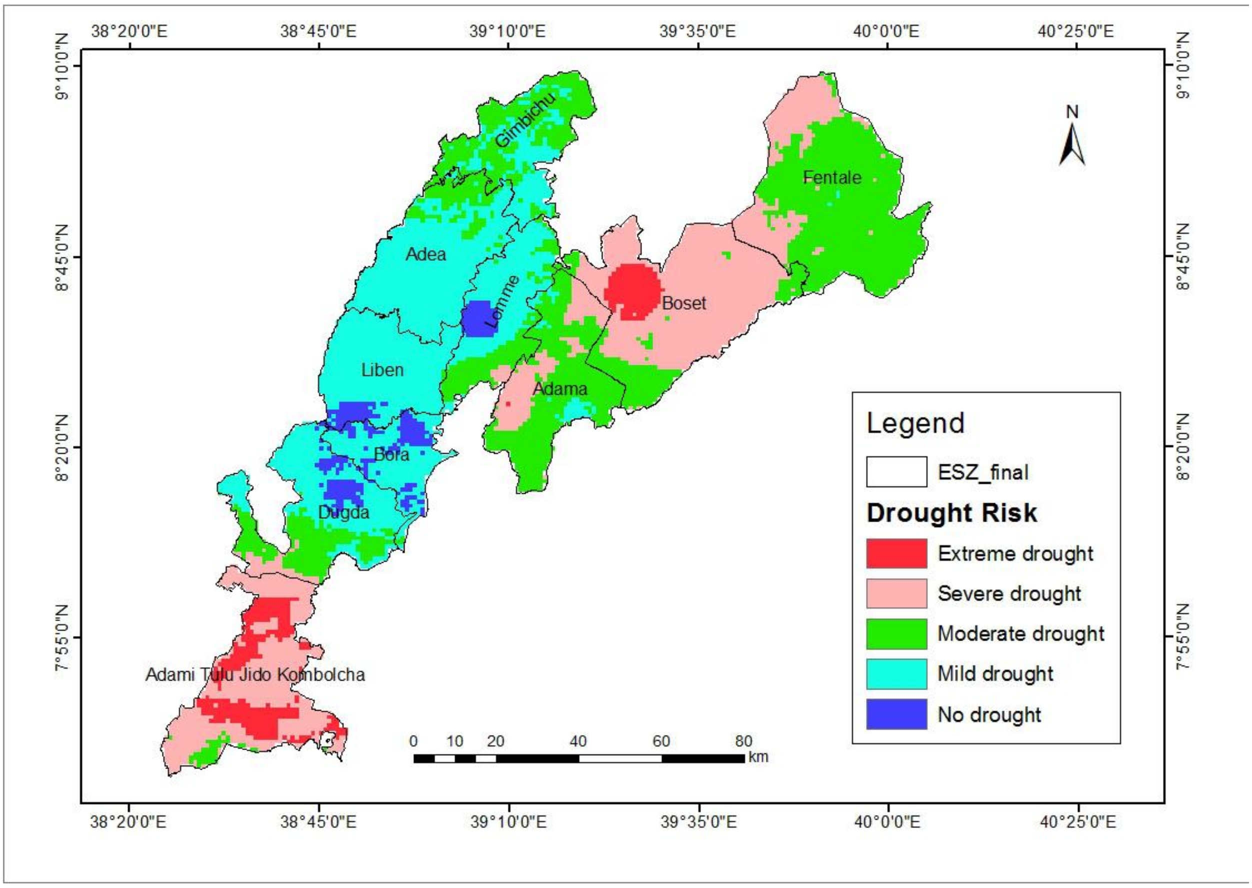

Figure 4.9: Agricultural drought risk map

Table 4.1: Drought severity level

Drought severity level	Area (sq.km)	Area (percent)
Extreme drought	466.7	5.1
Severe drought	2923.8	31.9
Moderate drought	2484.4	27.1
Mild drought	2988.6	32.5
No drought	314.5	3.4

The layers representing drought indices according to their degree of influence using weighted overlay. Hence, according to the result obtained from the integrattion of indices, the East Shewa Zone is cclassified into fives classes extending from extremly drought to no drought. Based on the result indicated in the (Fig 4.9) the percentges of the area affected by different level of drought is about 97%. As it can be seen from the (Table 2) among these, 5.1% of the zone are under extreme drought risk, 31.9% severe drought, 27.1% moderate drought and

32.5% are under mild drought. Thus, In this case it is only the remaining 3% of the East Shewa Zone that are not vulnerable to drought (Table 2). As it can be seen from the figure 4.9 most of central and western part of east shewa zone is categrized into mild drought while north eastern and southern part of the study area is catagorized into severe and moderate drought.

4.7 Analysis of Drought Coping Strategies

Among drought coping strategies identified by the respondents, the major ones were sale of assets, provision of food rations by the government and support offered by informal networks, borrowing, pretty trading. The coping strategies adopted by both households and external organizations like institutional support were mostly ex-post measures. The drought coping strategies identified in this study are classified into two classes based the sources of strategies. The first class is these strategies by external bodies including government and the second class is the strategies directly implemented by the affected communities.

4.7.1 Coping Strategies Practiced by Communities

Most of the focus group discussants in Adami Tulu Jido Kombolca Adama district reported that even though it is characterized by very low income return, they engaged on informal trades as means of withstanding drought crisis. In this case women take the lion share in generating income for their family member using local drinks like Areke and Tella. It has been also reported that there were family members who engaged in daily labor including the head of the house as the drought coping strategy. In order to earn income, these groups of people took part in farming, small scale businesses, construction activities and others. Moreover, the result of the interviews conducted with Adama district expert are almost similar with what have been identified by the discussants. Furthermore, the discussants in Adama district also pointed out that some of the people living nearby the main road were participating in hoarse cart as strategy for minimizing drought crisis. The observations made by the discussants in this study contradicts with the findings in Northern part of Kenya by Opiyo et al. (2015) that sated harvesting of wild fruits for food, honey production, basket making, and handicraft products crafted from the palm tree as drought coping strategies.

The result of the interview held with expert of Disaster Prevention and Preparedness of Adami Tullu Jido Kombolcha district showed that it was a common practice to observe while most communities were selling their output right after harvest season. As a result they could not withstand shocks and this is the manifestation of weak saving culture. On the other hand, the discussants of the same district were also confirmed that they took some of agricultural output right after harvest time.

Moreover, the focus group discussants of Bosat also identified some of the coping strategies being utilized by the societies such as borrowing money and/or fodder from friends, relatives or neighbors, sending their children to other relatives. Another strategy identified as an immediate response to drought was reduction in meals consumed per day with most discussants indicated eating at least once in a day during drought periods. In line with coping strategies, Makoti and Waswa (2015) pointed out that this leads to health problems particularly malnutrition among children and pregnant women. The recently conducted research by Diriba and Jema (2015) in Yabello District, Borana Zone of Ethiopia, identified similar drought coping strategies. However, according to research conducted in rural areas of Swaziland on drought coping strategies by Vilane et al. (2015), pointed out strategies like vegetables marketing and selling, dress making, carpentry, labor for food and money, free primary education and feeding schemes as major drought coping strategies practiced by the communities and institutions of the area which are not consistent with the findings of this study. There were also some discussants who indicated temporary migration of some family members in search of employment opportunities in response to drought events. In the same vein, the identified drought coping strategies in Feddis District, East Harargehe Zone of Ethiopia were borrowing, migration to surrounding urban areas, selling fuel wood and charcoal, pulling children out of school and participating in petty trading (Anteneh, 2013) which has similarity with the current study. Other drought coping strategies practiced in the study area were selling dried cow dung, participating in daily laborer in irrigation project taking place in zone, selling charcoal and firewood.

4.7.2 Coping Strategies Provided by the Institution

According to Disaster Prevention and Preparedness expert of East Shewe Zone, once the occurrences of drought is observed and agreed on, beneficiary screenings are carried out in places where drought take place. He also mentioned major drought coping strategies provided so far in the study area like provisions of drinking water, fodder for animals, grains, pulses, food oil and supplementary food. These ideas were also pointed out by almost all the focus group discussants of the selected districts. In addition, the experts reported that supplementary food is provided only for 35% of the beneficiaries. These groups of beneficiaries include pregnant women, children, lactating women and other malnourished societies.

According to the result of key informant interviews and focus group discussants, in order to avoid culture of dependency, the provision of drought coping strategies were connected with development activities like soil and water conservation works. In this way beneficiaries think that they are provided with food rations because of the work they accomplished. In this processes however, about 20% of the beneficiaries are expected to receive the drought coping methods without participating in any developmental activities. These groups of the societies are children, pregnant women, old aged individuals and physically disabled individuals. The underlying concept is that these groups of communities cannot fully take part in the physical development activities.

Regarding the challenges observed while providing drought coping strategies to the beneficiary, the summary of the result obtained from focus group discussion and interview were weak implementation of policies and strategies designed for this purpose, including the government employees in the provisions of food rations, nepotism and cheating, helping each other based on their relationship, excluding some individuals entitled to receive food rations and considering children as household and provision food rations accordingly. In the same vein, they were asked to identify the possible ways to minimize the challenges observed so far. Accordingly, effective implementation of policies and strategies, giving awareness creation regarding the policies and strategies and developing the habit of receiving immediate feedbacks from the beneficiaries were the major ones.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The occurrence of drought is mainly indicated by the continuous existence of negative deviation of NDVI value. In identifications of wet and drought years of the study period, some level disagreement between the result of NDVI and the interview and focus group discussions have been observed. In addition, in some cases the identification of drought and wet years identified by SPI and drought severity index showed some level of variations. Moreover, the magnitude of drought indicated by NDVI and SPI results were not consistently related to the relief distribution made in response to the occurrence of drought. During considered years in almost all parts of study area, the value of drought severity index was very low suggesting that there is low ground vegetation cover.

Using the drought severity index, 2006 and 2009 were identified as drought years as their larger areas are under the influence of drought. However, according to the result of SPI, 2005 and 2009 were identified as drought years. The variations may be associated to lag time of NDVI response. In addition during these years large volume of relief distributions were carried out for the communities of the zone. On the other hand 2008 and 2012 were identified as wet years. The relationship between long term NDVI and seasonal pattern of rainfall for the whole study area during the period of 2005 – 2014 shows good correlation (r=0.7) between them. Using the weighted overlay analysis, the drought risk map of the study area was constructed. Accordingly only 3% of the study areas are not vulnerable to drought while the remaining 97% were under different level of drought risk. Hence, during the specified years it can be concluded that with exception some small parts of study area, the majority of the study area were hit by drought. This was also supported by the result obtained from focus group discussions and key informant interviews. In addition, even though many differences were not observed in crop yield, production was relatively low in these years.

Considering that all individuals in the communities of affected areas are not equally exposed to the drought impact, beneficiary screening is the first task in provision of drought coping menses. Once this task completed and agreed on, various drought coping strategies were employed by communities and the government in response to happening of drought. Some of the drought coping methods were petty trading, cart, daily labor, saving, borrowing, reducing food intake, provision of grains, supplementary foods, pulses, food oils, drinking water, selling dried cow dung, charcoal and firewood and fodder for animals by government and different private institutions. Even though all these methods were being practiced in affected communities, the focus group discussants were not satisfied with the provision of food rations. This is mainly because of insufficient food rations, water and fodder distributed at the time of drought occurrences.

5.2 Recommendations

Based on the findings indicated in this research, the following recommendations are formulated.

- Satellite dataset employed in this study is SPOT NDVI having 1km spatial resolution at continental level. However, in order to effectively monitor and forecast the occurrences of drought in study area, satellite data products characterized by higher resolution is essential.
- Establishment of formal early warning information centers particularly for rainfall distributions 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.
- Training farmers regarding how to make use of weather forecast information on radio and television is vital for timely responding to drought periods.
- In order to increase the farmers' ability in drought coping, it is necessary to setup financial institutions in each Kebeles and encourage the culture of saving. This could help them to utilize that finance during drought events.
- Public and private partnership helps to address the need of drought coping strategies at the time of drought events.
- Rural areas need to get access regarding weather forecasting and expertise support for better utilization of the information.
- In order to investigate the role of different socioeconomic variables on agricultural drought in the study area, detailed study that incorporates both open and closed ended questionnaires is necessary.

References

Abbas, S., Nichol, J.E., Qamer, F. M. and Xu, J. (2014). Characterization of Drought Development through Remote Sensing: A Case Study in Central Yunnan, China. *Journal of Remote Sensing*. **6:** 4998-5018

Abbasi, S. (2014). Adaptation to Drought in Saskatchewan Rural Communities: A Case Study of Kindersley and Maidstone, Saskatchewan. Un published Msc thesis submitted to University of Saskatchewan, Saskatoon

Adama District Finance and development (2014). Adama district physical and socioeconomic profile. Unpublished materials

Adger, W.N., Hug, S., Brown, K., Conway, D. and Hume, M. (2003). Adaptation to Climate Change in Developing World. *Progress in Development Studies.* ***3*****(3):** 179-195.

Aghrab A., Bouabid R., Chafai Elalaoui A. (2008). *Drought characterization using drought indices in two areas of the Mediterranean basin: Meknes, Morocco, and Cordoba, Spain.* Drought management: scientific and technological innovations. Zaragoza: 193-198

American Meteorological Society (1997). Meteorological drought- Policy statement. Bull. *Amer. Meteor. Soc*. **78**: 847-849

Anteneh Derribew (2013). An Assessment of Coping Strategies for Drought Induced Food Shortages in Fedis District, East Hararghe Zone, Ethiopia. *International Journal of Science and Research*

APO (2004). *National Regional State of Oromia Adama Project Office. Adama Master Plan Revision Project; A Brief of Adama City*

Barring, L. and Hulme, M. (1991). Filters and approximate confidence intervals for interpreting rainfall anomaly indices. *J. Clim*. **4**: 837–847.

Birhanu Gedif, Legesse Hadish, Solomon Addisu and Suryabhagavan, K.V. (2014). Drought Risk Assessment using Remote Sensing and GIS: The Case of Southern Zone, Tigray Region, Ethiopia. *Journal of Natural Sciences Research.* Vol.**4 (23):** 87 – 94

Bramel, P.J., Nagado, S., Haugegen, J.M., Adugna, D., Dejene, T., Bekele,T. and Traedal, L.F. (2004). *Relief Seed Assistance in Ethiopia. Addressing Seed Security in Disaster Response*. International Center for Tropical Agriculture, Cali.

Brown, J., Wardlow, B., Tadesse Temesgen, Hayes, M. and Reed, B. (2008). The vegetation drought response index (VegDRI): a new integrated approach for monitoring drought stress in vegetation. *GIScience Remote Sens.* **45(1):**16–46

Camaro W. (2015). Vegetation dynamics and their relationships with precipitation in Africa for drought monitoring purposes. Unpublished PhD thesis

Cavatassi, R., Lipper, L. and Narloch, U. (2010). Modern variety adoption and risk management in drought prone areas: insights from the sorghum farmers of eastern Ethiopia. *Agricultural Economics.* 1–14

Chopra, P. (2006). Drought Risk Assessment Using Remote Sensing and GIS: a case study in Gujarat. Unpublished Msc thesis submitted to international institute for geo-information science and earth observation (ITC). Netherlands

Coulibaly, J., Gbetibouo, G. A., Kundhlande, G., Sileshi Gudeta and Beedy, T. L. (2015). Responding to Crop Failure: Understanding Farmers' Coping Strategies in Southern Malawi

CSA (2012). Population statistical abstract. Addis Ababa.

Dai, A. (2011). Drought under global warming: A review. *WIREs Clim. Change*. **2:** 45-65

Degefu Wegari (1987). Some aspects of meteorological drought in Ethiopia. Drought and Hunger in Africa. Cambridge: Cambridge University Press.

Demeke, A., Keil., A. and Zeller, M. (2012). 'Using Panel Data to Estimate the Effect of Rainfall Shocks on Smallholders Food Security and Vulnerability in Rural Ethiopia', *Climatic Change* **108(1):** 185–206

Dirriba Mengistu and Jema Haji (2015). Factors Affecting the Choices of Coping Strategies for Climate Extremes: The Case of Yabello District, Borana Zone, Oromia National Regional State, Ethiopi: *Science Research*. Vol. **3**, No. **4**, pp. 129-136

Domenikiotis, C., Spiliotopoulos, M., Tsiros, E. and Dalezios, N. (2004). Early Cotton Yield Assessment by the Use of the NOAA/AVHRR Derived Drought Vegetation Condition Index in Greece, *International Journal of Remote Sensing.* **25:** 2807–2819

Dracup, J. A., Lee, K. S., and Paulson, E. G. (1980). On the definition of droughts. *Water Resources Research.* **16(2):** 297-302.

Du, L., Tian, Q., Yu, T., Meng, Q., Jancso, T., Udvardy, P. and Huang, Y. (2013). A comprehensive drought monitoring method integrating MODIS and TRMM data. *Int. J. Appl. Earth Obs. Geoinf.* **23**: 245–253

ECA (2005). *GIS Implementation to Support Poverty Reduction Policy and Drought Management in Ethiopia*, Addis Ababa, Ethiopia

FAO (2011). *Fao-Adapt Framework Programme on Climate Change Adaptation*: Viale Delle Terme Di Caracalla: Rome, Italy

Ferrer, J., Perez, M. A., Perez, F. and Artes, J. B. (2007). Specific combined actions in Turia River during 2005-2007 drought, **80:** pp. 227–234.

Finance and Economic Development Bureau of Oromia (2007). Socioeconomic *profile of East Shewa Zone*. Addis Ababa

Franke, J. and Menz, G. (2007). Multi-temporal wheat disease detection by multi-spectral remote sensing. *Precision Agric.* **8(3):**161–172

Gao, B.C. (1996). Normalized dDfference Water Index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment*. **58:** 257- 266.

Gebrehiwot Tadesse, Van der veen, A. and Maathuis, B. (2011). Spatial and temporal assessment of drought in the northern highlands of Ethiopia. *International Journal of Applied Earth Observations and Geoinformation*. **13(3):** 309 – 321

Getachew Berhan, Hill, S., Tsegaye Tadesse and Solomon Atnafu (2011). Using Satellite Images for Drought Monitoring: A Knowledge Discovery Approach, *Journal of Strategic Innovation and Sustainability, vol*. **7(1):** 135 -153

Ghulam, A., Li, Z. L., Qin, Q. and Tong, Q. (2007). Exploration of the spectral space based on vegetation index and albedo for surface drought estimation, *Journal of Applied Remote Sensing*, Vol. **1**:1 – 12

Gizachew Legesse (2010). Agricultural drought assessment using remote sensing and GIS techniques. Unpublished thesis submitted to school of graduate studies of Addis Ababa University in partial fulfillment of the requirement for the degree maters of science in remote sensing and GIS

Gizachew Legesse and Suryabhagavan, K.V. (2014). Remote sensing and GIS based agricultural drought assessment in East Shewa Zone, Ethiopia, *Tropical Ecology,* **55(3)**

Goetz, S.J., Fiske, G.J., Bunn and A.G. (2006). Using satellite time-series data sets to analyze fire disturbance and forest recovery across Canada. *Remote Sens Environ* **101(3):**352–365

Golian, S., Mazdiyasni, O. and AghaKouchak, A.(2015). Trends in meteorological and agricultural droughts in Iran. *Theor Appl Climatol*, 119:679–688

Government of Ethiopia. (2009). Disaster Prevention and Preparedness Agency. Humanitarian Requirements-2009: Joint Government and Humanitarian Partners' Document. Addis Ababa, Ethiopia

Hammouri, N. and Naqa, A.E. (2007). Drought Assessment Using GIS and Remote Sensing in Amman-Zarqa Basin, Jordan. *Jordan Journal of Civil Engineering*. **1(2):** 142 – 152

Himanshu, S.K., Singh, G. and Kharola, N. (2015). Monitoring of Drought using Satellite Data. *International Research Journal of Earth Sciences. Vol.* ***3(1):*** *66-72*

Houghton, D.D., (2002). *Introduction to climate change*: Lecture notes for Meteorologists prepared by WMO-No. 926 secretariat of the World Meteorological Organization Geneva – Switzerland

Huailiang, C., Hongwei, Z., Ronghua, L. and Weidong, Y. (2009). Agricultural Drought Monitoring, Forecasting and Loss Assessment in China. *Remote Sensing for Agriculture, Ecosystems, and Hydrology* Proc. of SPIE Vol. **7472**·

Huang, Y., Tian, Q., Du, L. and Sun, S. (2013). Analysis of Spatial-Temporal Variation of Agricultural Drought and Its Response to ENSO over the Past 30 Years in the Huang-Huai-Hai Region, China. *Terr. Atmos. Ocean. Sci.*, Vol. 24, No. 4, Part II, 745-759.

IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

Kapoi, K. J. and Alabi, O. (2013). Agricultural Drought Severity Assessment Using Land Surface Temperature and NDVI in Nakuru region, Kenya. Proceedings of Global Geospatial Conference. Addis Ababa, Ethiopia, 4-8 November2013

Khalil, A.A., Abdel-Wahab, M.M., Hassanein, M. K., Ouldbdey, B., Katlan B. and Essa, Y.H. (2013). Drought Monitoring over Egypt by using MODIS Land Surface Temperature and Normalized Difference Vegetation Index. *Nature and Science*. **11(11):** 116 – 122

Khanna, M. (2009). Hydrological drought indices; Water technology centre, Indian Agricultural Research Institute, New Delhi, India

Kogan, F.N. (1995). Application of vegetation index and brightness temperature for drought detection. *Adv. Space Res.* **15:** 91–100.

Lemma Gonfa (1996). Climate Classification of Ethiopia. In: *Metrological Research Report Series*, No 3. Addis Ababa, pp 1 – 8.

Liang, L. Z., Tang, B. H., Wu, H., Ren, H., Yan, G., Wan, Z., Trigo, I. F. and Sobrino, J. A. (2013). Satellite-derived land surface temperature: Current status and perspectives. *Remote Sensing of Environment,* **131:** 14 – 37.

Makoti, A. and Waswa, F. (2015). Rural Community Coping Strategies with DroughtDriven Food Insecurity in Kwale County, Kenya. *Journal of Food Security,* Vol. **3**, No.**3**, 87-93

McKee, T.B., Doesken, N.J. and Kliest, J. (1993). The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, America. Meteorol. Soc. Boston, pp. 179–184.

Minamiguachi, D. (2005). The Application of Geospatial and Disaster Information for Food Insecurity and Agricultural Drought Monitoring and Assessment by the FAO GIEWS and Asia FIVIMS. Workshop on Reducing Food Insecurity Associated with Natural Disasters in Asia and the Pacific. Bangkok, Thailand.

Ministry of Finance and Economic Development (MoFED). (2007). Ethiopia: Building on Progress: A Plan for Accelerated and Sustained Development to End Poverty (PASDEP). Annual Progress Report: Addis Ababa, Ethiopia.

Mohammed Sultan (2014). Remote Sensing Based Agricultural Drought Assessment: A Case Study in Sire Woreda, Arsi, Ethiopia. Unpublished Msc Thesis Submitted to Addis Ababa University

Mokhtari, M. H., Adnan, R. and Busu, I. (2013)A new approach for developing comprehensive agricultural drought index using satellite- derived biophysical parameters and factor analysis method. *Nat Hazards*.**65**:1249–1274

Molua, L.E. (2002). Climate variability, vulnerability and effectiveness of farm-level adaptation options: The challenges and implications for food security in Southwestern Cameroon. *Environment and Development Economics*, **7(3):** 529–545.

Murad, H.and Islam, S. (2011). Drought assessment using remote sensing and GIS in North-West region of Bangladesh. 3rd International Conference on Water and Flood Management (ICWFM)

Muthumanickam, D., Kannan, P., Kumaraperumal, R., Natarajan, S., Sivasamy R. and Poongodi, C. (2011). Drought assessment and monitoring through remote sensing and GIS in western tracts of Tamil Nadu, *India International Journal of Remote Sensing*, Vol. 32, No. **18:** 5157–5176

Mutua, S.(2011). Strengthening Drought Early Warning at the Community and District Levels: Analysis of Traditional Community Warning Systems in Wajir & Turkana Counties. Oxfam GB, P O Box 40680, 00100 Nairobi, Kenya: Oxfam GB, Kenya.

National Meteorological Services (NMS) (2007). Climate Change National Adaptation Program of Action (NAPA) of Ethiopia. NMS, Addis Ababa, Ethiopia

National Drought Mitigation Center (2006) http://threeissues.sdsu.edu/three_issues_droughtfacts02.html accessed on 28 December 2015 at 3am

Opiyo, F., Wasonga, O., Nyangito, M., Schilling, J. and Munang, R. (2015). Drought Adaptation and Coping Strategies Among the Turkana Pastoralists of Northern Kenya. *International Journal of Disaster Risk Science*, **6**:295–309

Palmer, W. C. (1965). Meteorological drought. U.S. Department of Commerce, Weather Bureau, Research Paper No. 45.

Quin, Z., Tang, H., Li, W., Zhang, H., Zhao, S. and Wang, Q. (2014). Modelling impact of agro-drought on grain production in China. *International Journal of Disaster Risk Reduction,* **7:** 109 – 121

Ramos, J.G., Cratchley, C.R., Kay, J.A., Casterad, M.A., Martnez, A. and Domnguez, R. (2009) Evaluation of satellite evapotranspiration estimates using ground-meteorological data available for the Flumen District into the Ebro Valley of N.E. Spain. *Manage.* **96 (4)**

Renza, D., Martinez, E., Arquero, A. and Sanchez, J. (2010). Drought Estimation Maps by Means of Multidate Landsat Fused Images. *Remote Sensing for Science, Education, and Natural and Cultural Heritage*

Singh, R.P., Roy, S. and Kogan, F.N. (2003). Vegetation and temperature condition indices from NOAA AVHRR data for drought monitoring over India. *Int. J. Remote Sens*. **24**

Son, N.T., Chen, C.F., Chen, C.R., Chang, L.Y. and Minh, V.Q. (2012). Monitoring agricultural drought in the Lower Mekong Basin using MODIS NDVI and land surface temperature data. *Int. J. Appl.Earth Obs. Geoinf.* **18:** 417–427.

Song, X. and Saito, G. (2004). Early Detection System of Drought in East Asia using NDVI from NOAA/AVHRR data. *International Journal of Remote Sensing* **25**:3105-3111

Tadesse Temesgen, Wilhite, D., Harms, S., Hayes, M. and Goddard, S. (2004). Drought Monitoring Using Data Mining Techniques: A Case Study for Nebraska, USA. *Natural Hazards*, **33(1):** 137 – 159.

Temesgen Tadesse, Ringler, C. and Hassan, R. M. (2010). Factors affecting the choices of coping strategies for climate extremes: the case of farmers in the Nile Basin of Ethiopia. ACCFP Report

Thenkabail, P.S, Gamage, M.S.D.N., and Smakhtin, V.U. (2004). The use of remote sensing data for drought assessment and monitoring in Southwest Asia. *International Water Management Research Report* 85. Colombo, Sri Lanka

Thomas, J., Daoyi, C., Cosh, M., Li, F., Anderson, M., Walthall, C., Doriaswamy, P. and Hunt, R. (2004). Vegetation water content mapping using LANDSAT data derived normalized difference water index for corn and soya beans. *Remote Sensing of Environment* **92:** 475-482

Tsegaye Tadesse (1998).Improving drought management and planning through better monitoring in Africa. Drought Network News (1994 –2001) paper 81

Tucker, C.J. (1979). Red and photographic infrared linear combinations for monitoring vegetations. *Remote Sens.* **21:** 507 – 511

Vilane, B.R.T., Mnanyatsi, A.M. and Shabangu, K. (2015). Drought ccoping strategies at Lonhlupheko community. a semi-aride rural area in Swaziland. *African Journal of Agricultural Research,* vol ***10 (8),*** 783 - 788

Webb, P. and J. von Braun, (1992). Famine and Food Security in Ethiopia: Lessons for Africa.Chichester: John Wiley & Sons.

Wilhite, D.A. (1992). Preparing for Drought: A Guidebook for Developing Countries, Climate Unit, United Nations Environment Program, Nairobi, Kenya.

Wilhite, D.A. (2007). Drought: *International Perspectives on Natural Disasters: Occurrence, Mitigation and Consequences*, Volume **21:** 145 - 162

Wilhite, D., Svoboda, M. and Hayes, M. (2007). Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. *Water Resources Management Journal*, **21:** 763-774.

World Bank. (2003). Ethiopia: Risk and Vulnerability Assessment. Draft Report.

World Food Programme (2006). Millennium Development Goal 1: Eradicate Extreme Hunger and Poverty. Available http://www.unmillenniumproject.org/goals/index.htm . Retrieved June 20, 2015 at 2pm

World Meteorological Organization (WMO) (2006). Drought Monitoring and Early Warning: concepts, progress and future challenges. Weather and climate information for sustainable agricultural development, WMO-No 1006

Xu, D. and Guo, X. (2014). Compare NDVI extracted from Landsat 8 imagery with that from Landsat 7 imagery. *American Journal of Remote Sensing*. **2(2):** 10 – 14

Yaffa, S. (2013). Coping measures not enough to avoid loss and damage from drought in the North Bank Region of The Gambia. Int. J. Global Warming, Vol. **5**, No. **4**, 467 – 482.

Yang, W. (2010). Drought Analysis under Climate Change by Application of Drought Indices and Copulas. Msc Dissertation, Paper 716.

Yitayal Abebe and Adam Bekele (2014). The Impact of Soil and Water Conservation Program on the Income and Productivity of Farm Households in Adama District, Ethiopia. *Science, Technology and Arts Research Journal.* **3(3):** 198-203

Appendix A

Addis Ababa University

School of Earth Sciences

Stream of GIS and Remote Sensing

Guiding Questions for Focus Group Discussions

This guiding question is prepared to collect data pertinent agricultural drought coping strategies practiced by different parts of the communities and institutions in East Shewa Zone, Central Rift Valley Region of Ethiopia. The study will be conducted to full fill the requirements of a Msc degree in Remote Sensing and GIS at Addis Ababa University. As this research is entirely for academic purposes, you will not be asked for your names or any identifying information. All the information you provide is confidential and the researcher will guaranty your full anonymity. Most importantly open and honest answers are the most valuable as there are no wrong or right answers. If you have any queries about this research, please feel free to ask in any ways. I would like to thank you in advance for your voluntary participation in this study

1. Can you indentify the drought years and the wet years took place in your area based on your experience? Yes/no. When?
2. During drought events, how did you cope with the situation?
3. Is there any effort made by institutions (government, NGOs and civil societies) to you and your family to overcome the impacts of drought? Yes/No.
4. If yes, what are the drought coping strategies currently undertaken by the governmental bodies and NGOs?
5. What are the drought coping strategies currently undertaken by the communities of the area?
6. What are the major problems you faced related to drought coping strategies?
7. What are the major issues to be improved in dealing with drought?
8. How do you relate agricultural output of this area to wet and drought years?

Appendix B

Addis Ababa University

School of Earth Sciences

Stream of GIS and Remote Sensing

Guiding Questions for Key Informant Interviews

This guiding question is prepared to collect data pertinent agricultural drought coping strategies practiced by different parts of the communities and institutions in East Shewa Zone, Central Rift Valley Region of Ethiopia. The study will be conducted to full fill the requirements of a Msc degree in Remote Sensing and GIS at Addis Ababa University. As this research is entirely for academic purposes, you will not be asked for your names or any identifying information. All the information you provide is confidential and the researcher will guaranty your full anonymity. Most importantly open and honest answers are the most valuable as there are no wrong or right answers. If you have any queries about this research, please feel free to ask in any ways. I would like to thank you in advance for your voluntary participation in this study

1. Your service year______________________________
2. Your responsibility________________________________
3. Name of the office you are working in ___________________
4. What is your role and experience with regard to the occurrences of draught in this area?
5. How do you identify whether there is drought or not in your local area?
6. What are the major constraints you have faced drought coping mechanisms?
7. What could be done to strengthen the drought coping strategies during drought event in this area?
8. List the drought years you can recall over the last ten years in your zone.
9. Mention the wet years you experience in this zone over the past ten years.
10. Did you observe any kind relationship between crop yield and associated drought years and wet years? Explain in detail

CERTIFICATION

This is to certify that the thesis entitled as Mapping Agricultural Drought and its Coping Strategies Using Remote Sensing and GIS Techniques in East Shewa Zone, Central Rift Valley Region of Ethiopia is an authenticated work carried out by Hurgesa Hundera under our guidance and supervision. This is the actual work done for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University.

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