CHAPTER ONE

1. INTRODUCTION

1.1. Drought

Drought is a normal, recurring feature of climate; it occurs virtually in all climatic regions (Wilhite 1993). It occurs in high as well as low rainfall areas. It is a temporary aberration, in contrast to aridity, which is a permanent feature of the climate and is restricted to low rainfall areas. Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length, although other climatic factors (such as high temperatures, 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. Drought is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity, number of rainfall events). Thus, each drought year is unique in its climatic characteristics and impacts. Drought differs from other natural hazards in several ways.

1. First, since the effects of drought often accumulate slowly over a considerable period of time and may linger for years after the termination of the event, the onset and end of drought is difficult to determine. Because of this, drought is often referred to as a creeping phenomenon (Tannehill 1947). Although Tannehill first used this terminology more than fifty years ago, climatologists continue to struggle with recognizing the onset of drought and scientists and policy makers continue to debate the basis (i.e., criteria) for declaring an end to a drought.

2. Second, the absence of a precise and universally accepted definition of drought adds to the confusion about whether or not a drought exists and, if it does, its degree of severity.

Realistically, definitions of drought must be region and application (or impact) specific. This is one explanation for the scores of definitions that have been developed. Wilhite and Glantz (1985) analyzed more than 150 definitions in their classification study, and many more exist. Although the definitions are numerous, many do not adequately define drought in meaningful terms for scientists and policy makers. The thresholds for declaring drought are arbitrary in most cases (i.e., they are not linked to specific impacts in key economic sectors). These types of problems are the result of a misunderstanding of the concept by those formulating definitions and the lack of consideration given to how other scientists or disciplines will eventually need to apply the definition in actual drought situations (e.g., assessments of impact in multiple economic sectors, drought declarations or revocations for eligibility to relief programs). Third, drought impacts are nonstructural, in contrast to, the impacts of floods, hurricanes, and most other natural hazards. Its impacts are spread over a larger geographical area than are damages that result from other natural hazards. For these reasons, the quantification of impacts and the provision of disaster relief are far more difficult tasks for drought than they are for other natural hazards. Emergency managers, for example, are more accustomed to dealing with impacts that are structural and localized, responding to these events by restoring communication and transportation channels, providing emergency medical supplies, ensuring safe drinking water, and so forth. These characteristics of drought have hindered the development of accurate, reliable, and timely estimates of severity and impacts and, ultimately, the formulation of drought contingency plans by most governments.

Drought severity is dependent not only on the duration, intensity, and spatial extent of a specific drought episode, but also on the demands made by human activities and vegetation on a region's water supplies. The characteristics of drought, along with its far- reaching impacts, make its effects on society, economy, and environment difficult to identify and quantify. This continues to represent a formidable challenge to those scientists involved in operational climate assessments.

Many persons consider drought to be largely a natural event. In reality, the risk associated with drought for any region is a product of both the region's exposure to the event (i.e., probability of occurrence at various severity levels) and the vulnerability of society to the event. The natural event (i.e., meteorological drought) is a result of the occurrence of persistent large-scale disruptions or anomalies in the global circulation pattern of the atmosphere. Exposure to drought varies spatially and there is little, if anything, that we can do to alter drought occurrence.

Vulnerability, on the other hand, is determined by social factors such as population, demographic characteristics, technology, policy, social behavior, land use patterns, water use, economic development, diversity of economic base, and cultural composition. These factors change over time, so vulnerability will change in response to these changes. Subsequent droughts in the same region will have different effects, even if they are identical in intensity, duration, and spatial characteristics, because societal characteristics will have changed. However, much can be done to lessen societal vulnerability to drought. Improved understanding of a region's drought climatology will provide critical information on the frequency and intensity of historical events. Identifying the factors that explain who and what is at risk and why (i.e., the underlying factors behind the vulnerability) can lead to the development and implementation of a wide variety of mitigation actions and programs to reduce impacts from future drought events.

1.2. Problem Statement

The Horn of Africa is known for frequent and severe droughts. On average, a severe drought may be anticipated once every couple of years during the months that comprise the season(s). Most recently, a two-year (2006 and 2007) drought occurred in an area that covered much of eastern Ethiopia, northeastern Kenya, and southern Somalia. These droughts affect hundreds of thousands of residents and are exacerbated by the extreme poverty and persistent conflict.

The impact of drought on society and agriculture is a real issue but it is not easily quantified. Reliable indices to detect the spatial and temporal dimensions of drought occurrences and its intensity are necessary to assess the impact and also for decision-making and crop research priorities for alleviation (Seiler et al., 1998). The development and advancements in space technology, to address issues like drought detection, monitoring and assessment have been dealt with very successfully and helped in formulation of plans to deal with this slow onset disaster. With the help of environmental satellite, drought can be detected 4-6 weeks earlier than before and delineated more accurately, and its impact on agriculture can be diagnosed far in advance of harvest, which is the most vital for global food security and trade (Kogan, 1990).

Drought is a complex event which may impair social, economic, agricultural and other activities of society. It is a prolonged, abnormally dry period when there is shortage of water for normal needs. It is temporary, recurring natural disaster, which originates from the lack of precipitation and brings significant economic losses. It is a slow poison, no one knows when it creeps in, it can last any number of days and its severity cannot be predicted. The non-structural characteristic of drought impacts has certainly hindered the development of accurate, reliable, and timely estimates of severity and ultimately, the formulation of drought preparedness plans by most governments. The impacts of drought, like those of other hazards, can be reduced through mitigation and preparedness.

Through their socio-economic impacts on affected areas, droughts are recognized as such when they become natural disasters. However, they differ from most other natural disasters because their recurrence in drought-prone areas every few years is practically certain. They also differ by lacking sudden and easily identified onsets and termination. Droughts vary widely in degree of severity, duration and aerial extent.

Drought preparedness planning has become a widely accepted tool for governments at all levels to apply to reduce the risks to future events. In Ethiopia, planning has been employed by local state, and regional governments. There fore it is essential to assess drought using different drought indices. Incorporating spatial-temporal aspect, this study aims at studying the spatio-temporal variation of drought patterns and drought severity using the Standardized Precipitation Index (SPI) to assess the occurrence of drought within the historical record of rainfall data.

1.3. Research objective

Droughts are extreme hydrological events that may adversely affect the social, economic, cultural, political and other functions of a region. Drought predictions may prevent these adverse consequences to a significant extent. In order to reach such a target, it is necessary to develop a method of prediction based on the available past experiences as well as on environmental conditions. Drought occurrences are rather complex, since they depend on various interactions of many hydrological phenomena such as precipitation, runoff, evaporation, infiltration, and surface and groundwater storages.

The SPI method was first developed by Mckee et . al. (1993) transforms the precipitation parameter to a single numerical value for defining the drought condition of areas with different climates. The SPI allows the determination of duration, magnitude and intensity of droughts (Hayes et al., 1999). Its main advantage is that it can be calculated for several time scales (McKee et al., 1995) and identifies various drought types: hydrological, agricultural or environmental. This index enjoys several advantages over the others. Calculation of the SPI is easier than on more complex indices such as the Palmer Drought Severity Index (PDSI ; Palmer, 1965) , because the SPI requires only precipitation data, whereas the PDSI uses several parameters (Soul´ e, 1992) . Moreover, the PDSI has some shortcomings in spatial and temporal comparability (Alley, 1984; Karl, 1986; Guttman, 1999).

The general objective of this research is to analyze the spatio-temporal pattern of drought employing the Standard Precipitation Index and to determine the occurrence of drought within the historical record of rain fall data.

The specific objectives of this research are

- Assessing and analyzing of drought occurrence by means of Standard Precipitation index (SPI)
- Assessment of occurrence of drought in SNNPR.
- Identifying and locating drought prone areas in SNNPR.
- Identifying occurrence of drought in relation to La Nina and El Nino events.

The outcome of this research provides for concerned bodies the meaningful and understandable information about the spatio- temporal aspect of the drought in SNNPR. This kind of information is essential for a broad group of users who are interested in monitoring, mitigation and management of drought.

1.4. Structure of the thesis

This thesis contains six chapters. The first chapter highlights the background and objectives the research. Chapter two Literature Review clarifies drought definition, types of index and covers previous research carried out in the field of drought as well as analysis and monitoring. Chapter three gives detailed description of the study area. Chapter four describes datasets used for the research and explains the method considered in order to achieve the research objective. Chapter five presents analysis of long-term SPI to arrive at pattern of drought by incorporating spatio-temporal information. Also this chapter describes about the results obtained after the analysis has been done. Chapter six provides conclusion of this study in accordance with the discussion made and gives recommendation for further research.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

Drought is a natural part of climate that affects nearly every region on earth (Wilhite, 2000). Although specific definitions of drought may vary by sector and region, drought generally originates from deficiency of precipitation over extended period of time, resulting in water shortage for some activity, group, or environmental sector. Throughout the world, drought ranks first among all natural hazards in terms of the number of people directly affected. However, some regions are more prone to drought disaster because of the frequency of the hazard itself and societal vulnerability. Each country also differs in its capacity to effectively prepare for respond to drought. Therefore, the number of people affected by drought and the types of impacts experienced will vary by region.

Drought is an extended period where water availability falls below the statistical requirements for a region. It is not a purely physical phenomenon, but rather interplays between natural water availability and human demands for water supply.

There are two main kinds of drought definitions: conceptual and operational. Conceptually, it can be defined as “a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield.”(National Drought Mitigation Center, 2006, USA). Conceptual definitions may also be important in establishing drought policy. Operational definitions identify the beginning, end, spatial extent and severity of a drought. They are often region-specific and are based on scientific reasoning, which follows the analysis of certain amounts of hydro meteorological information. They are beneficial in developing drought policies, monitoring systems, mitigation strategies and preparedness plans. Operational definitions are formulated in terms of drought indices. It is not possible to avoid droughts. The success of drought preparedness and its impact, amongst the others, on how well the droughts are defined and drought characteristics quantified (Smakhtin and Hughes, 2004).

Several indices have been developed for the quantification of drought based on the type of drought. With the advancements in remote sensing technology, the historical drought indices were over powered by the newly developed indices from remote sensing data that are considered to be real time. Also, the remote sensing has provided a complete coverage of extended regions with a spatial resolution of a few hundred meters to few kilometers. Thus, for an accurate assessment of the occurrence, extent and severity of drought, it is necessary to get a correct picture of the spatial and temporal distribution of a number of meteorological, hydrological and surface variables. Space observation having this potential has made a significant contribution in this field. The satellite sensors that have the capability to retrieve surface parameters with high spatial and temporal resolutions over large areas have provided a comprehensive view of the situation. Many drought studies have made an extensive use of the AVHRR derived data, as it monitors earth surface changes continuously, freely accessible and moreover it's widely recognized around the world.

Droughts differ from one another in three essential characteristics: intensity, duration, and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic index from normal and is closely linked to duration in the determination of impact. Many indices of drought are in widespread use today, such as the deciles approach (Gibbs and Maher 1967; Lee 1979; Coughlan 1987) used in Australia, the Palmer Drought Severity Index and Crop Moisture Index (Palmer 1965, 1968; Alley 1984) in the United States. A relatively new index that is gaining increasing popularity in the United States and world wide is the Standardized Precipitation Index (SPI), developed by McKee et al. (1993, 1995).

Another distinguishing feature of drought is its duration. Droughts usually require a minimum of two to three months to become established but then can continue for months or years. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event. Droughts also differ in terms of their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity shift from season to season..

2.2. Types of drought

Droughts can be classified in four major categories:

Meteorological drought: It simply implies rainfall deficiency where the precipitation is reduced by more than 25% from normal in any given area. These are region specific, since deficiency of precipitation is highly variable from region to region.

Hydrological drought: These are associated with the deficiency of water on surface or subsurface due to shortfall in precipitation. Although all droughts have their origination from deficiency in precipitation, hydrological drought is mainly concerned about how this deficiency affects components of the hydrological system such as soil moisture, stream flow, ground water and reservoir levels etc.

Agricultural drought: This links various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual potential evapo-transpiration, soil, soil water deficits, and reduced ground water or reservoir levels. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, and its stage of growth and the physical and biological properties of the soil.

Socio-economic drought: It is associated with the demand and supply aspect of economic goods together with elements of meteorological, hydrological and agricultural drought. This type of drought mainly occurs when the demand for an economic good exceeds its supply due to weather related shortfall in water supply.

Figure 2-1 shows the relation among different kinds of drought and their duration of time:- meteorological drought, hydrological drought, agricultural drought and socio-economic drought.

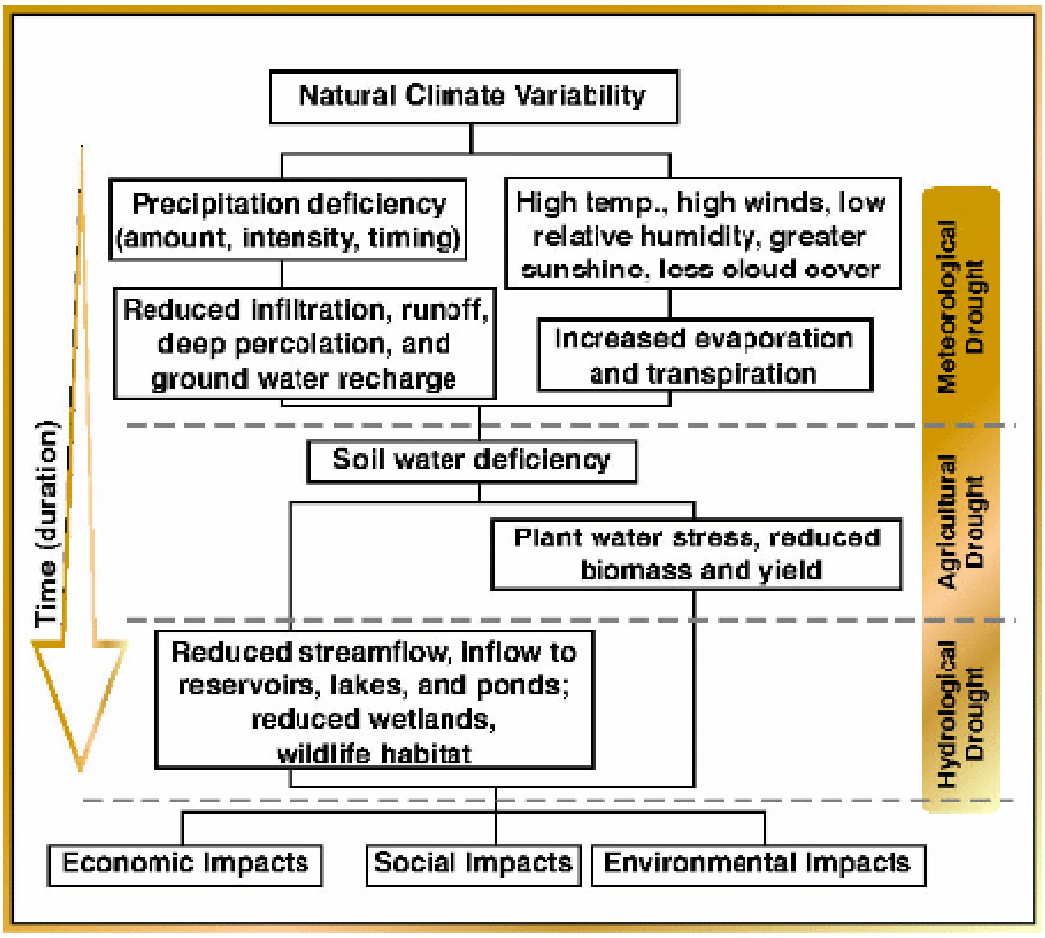

Figure 2-1: Relationship between meteorological, hydrological and agricultural drought

(Source: National Drought Mitigation Centre, http://drought.unl.edu/whatis/concept.htm)

2.3. Drought indices

Drought indices have been developed as a means to measure drought. Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), Surface Water Supply Index (SWSI) and Standardized Vegetation Index (SVI). (Hayes et al., 1999), used the Standardized Precipitation Index (SPI) to monitor the 1996 drought in the United States of America and shown that the onset of the drought in the USA in 1996 could have been detected one month in advance of the Palmer Drought Severity Index (PSDI). Using SPI index one can develop climatology of the spatial extension and intensity of droughts which provides additional understanding of its characteristics and an indication of the probability of recurrence of drought at various levels of severity. Ji and Peters (2003) undertook a study relating to assessing vegetation response in the northern Great Plains using vegetation and drought indices. The study focused on three major areas namely relationship between NDVI and SPI at different time scales, response of NDVI to SPI during different time periods within a growing season and regional characteristics of the NDVI-SPI relationship. It was found that the 3-month SPI has the highest correlation to the NDVI, because the 3- month SPI is best for determining drought severity and duration. Also it was found that seasonality has a very significant effect on the relationship between the NDVI and SPI.

Drought indices assimilate thousands of bits of data on rainfall, snow pack, stream flow, and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, far more useful than raw data for decision making.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. For example, the Palmer Drought Severity Index has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance, but the Palmer Index is better when working with large areas of uniform topography. Western states, with mountainous terrain and the resulting complex regional microclimates, find it useful to supplement Palmer values with other indices such as the Surface Water Supply Index, which takes snow pack and other unique conditions into account.

The National Drought Mitigation Center is using a newer index, the Standardized Precipitation Index, to monitor moisture supply conditions. Distinguishing traits of this index are that it identifies emerging droughts months sooner than the Palmer Index and that it is computed on various time scales.

Most water supply planners find it useful to consult one or more indices before making a decision. What follows is an introduction to each of the major drought indices in use in the United States and in Australia.

2.3.1. Percent of Normal

The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using the percent of normal are very effective when used for a single region or a single season. Percent of normal is also easily misunderstood and gives different indications of conditions, depending on the location and season. It is calculated by dividing actual precipitation by normal precipitation—typically considered to be a 30-year mean—and multiplying by 100%. This can be calculated for a variety of time scales. Usually these time scales range from a single month to a group of months representing a particular season, to an annual or water year. Normal precipitation for a specific location is considered to be 100%.

One of the disadvantages of using the percent of normal precipitation is that the mean, or average, precipitation is often not the same as the median precipitation, which is the value exceeded by 50% of the precipitation occurrences in a long-term climate record. The reason for this is that precipitation on monthly or seasonal scales does not have a normal distribution. Use of the percent of normal comparison implies a normal distribution where the mean and median are considered to be the same. An example of the confusion this could create can be illustrated by the long-term precipitation record in Melbourne, Australia, for the month of January. The median January precipitation is 36.0 mm (1.4 in.), meaning that in half the years less than 36.0 mm is recorded, and in half the years more than 36.0 mm is recorded. However, a monthly January total of 36.0 mm would be only 75% of normal when compared to the mean, which is often considered to be quite dry. Because of the variety in the precipitation records over time and location, there is no way to determine the frequency of the departures from normal or compare different locations. This makes it difficult to link a value of a departure with a specific impact occurring as a result of the departure, inhibiting attempts to mitigate the risks of drought based on the departures from normal and form a plan of response (Willeke et al., 1994).

2.4.2. Standardized Precipitation Index (SPI)

The understanding that a deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snow pack, and stream flow led McKee, Doesken, and Kleist (1993) to develop the Standardized Precipitation Index (SPI). The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee et al. (1993) originally calculated the SPI for 3–, 6–,12–, 24–, and 48–month time scales.

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean 3-months SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the 3-months SPI is normalized, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using the 3-months SPI.

McKee et al. (1993) used the classification system shown in the SPI values table to define drought intensities resulting from the SPI. McKee et al. (1993) also defined the criteria for a drought event for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude".

Based on an analysis of stations across Colorado, McKee determined that the SPI is in mild drought 24% of the time, in moderate drought 9.2% of the time, in severe drought 4.4% of the time, and in extreme drought 2.3% of the time (McKee et al., 1993). Because the SPI is standardized, these percentages are expected from a normal distribution of the SPI. The 2.3% of SPI values within the "Extreme Drought" category is a percentage that is typically expected for an "extreme" event (Wilhite 1995). In contrast, the Palmer Index reaches its "extreme" category more than 10% of the time across portions of the central Great Plains. This standardization allows the SPI to determine the rarity of a current drought, as well as the probability of the precipitation necessary to end the current drought (McKee et al., 1993).

The SPI has been used operationally to monitor conditions across Colorado since 1994 (McKee et al., 1995). It is also being monitored at the climate division level for the contiguous United States by the National Drought Mitigation Center and the Western Regional Climate Center (WRCC).

2.3.3. Palmer Drought Severity Index (The Palmer; PDSI)

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply (Palmer, 1965). Palmer based his index on the supply-and-demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific locations. The objective of the Palmer Drought Severity Index (PDSI), as this index is now called, was to provide measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between months (Palmer, 1965).

The PDSI is a meteorological drought index, and it responds to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking into account stream flow, lake and reservoir levels, and other longer-term hydrologic impacts (Karl and Knight, 1985). The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapo-transpiration, soil recharge, runoff, and moisture loss from the surface layer. Human impacts on the water balance, such as irrigation, are not considered. Complete descriptions of the equations can be found in the original study by Palmer (1965) and in the more recent analysis by Alley (1984).

Palmer developed the PDSI to include the duration of a drought (or wet spell). His motivation was as follows: an abnormally wet month in the middle of a long-term drought should not have a major impact on the index, or a series of months with near-normal precipitation following a serious drought does not mean that the drought is over. Therefore, Palmer developed criteria for determining when a drought or a wet spell begins and ends, which adjust the PDSI accordingly. Palmer (1965) described this effort and gave examples, and it is also described in detail by Alley (1984). In near-real time, Palmer’s index is no longer a meteorological index but becomes a hydrological index referred to as the Palmer Hydrological Drought Index (PHDI) because it is based on moisture inflow (precipitation), outflow, and storage, and does not take into account the long-term trend (Karl and Knight, 1985).

In 1989, a modified method to compute the PDSI was begun operationally (Heddinghaus and Sabol, 1991). This modified PDSI differs from the PDSI during transition periods between dry and wet spells. Because of the similarities between these Palmer indices, the terms *Palmer Index* and *Palmer Drought Index* have been used to describe general characteristics of the indices.

The Palmer Index varies roughly between -6.0 and +6.0. Palmer arbitrarily selected the classification scale of moisture conditions based on his original study areas in central Iowa and western Kansas (Palmer, 1965). Ideally, the Palmer Index is designed so that a -4.0 in South Carolina has the same meaning in terms of the moisture departure from a climatologically normal as a -4.0 in Idaho (Alley, 1984). The Palmer Index has typically been calculated on a monthly basis, and a long-term archive of the monthly PDSI values for every climate division in the United States exists with the National Climatic Data Center from 1895 through the present. In addition, weekly Palmer Index values (actually modified PDSI values) are calculated for the climate divisions during every growing season and are available in the *Weekly Weather and Crop Bulletin*.

The Palmer Index is popular and has been widely used for a variety of applications across the United States. It is most effective measuring impacts sensitive to soil moisture conditions, such as agriculture (Willeke et al., 1994). It has also been useful as a drought monitoring tool and has been used to trigger actions associated with drought contingency plans. Alley (1984) identified three positive characteristics of the Palmer Index that contribute to its popularity: (1) it provides decision makers with a measurement of the abnormality of recent weather for a region; (2) it provides an opportunity to place current conditions in historical perspective; and (3) it provides spatial and temporal representations of historical droughts. Several states, including New York, Colorado, Idaho, and Utah, use the Palmer Index as one part of their drought monitoring systems.

2.3.4. Crop Moisture Index (CMI)

The Crop Moisture Index (CMI) uses a meteorological approach to monitor week-to-week crop conditions. It was developed by Palmer (1968) from procedures within the calculation of the PDSI. Whereas the PDSI monitors long-term meteorological wet and dry spells, the CMI was designed to evaluate short-term moisture conditions across major crop-producing regions. It is based on the mean temperature and total precipitation for each week within a climate division, as well as the CMI value from the previous week. The CMI responds rapidly to changing conditions, and it is weighted by location and time so that maps, which commonly display the weekly CMI across the United States, can be used to compare moisture conditions at different locations.

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

2.3.5. Surface Water Supply Index (SWSI)

The Surface Water Supply Index (SWSI) was developed by Shafer and Dezman (1982) to complement the Palmer Index for moisture conditions across the state of Colorado. The Palmer Index is basically a soil moisture algorithm calibrated for relatively homogeneous regions, but it is not designed for large topographic variations across a region and it does not account for snow accumulation and subsequent runoff. Shafer and Dezman designed the SWSI to be an indicator of surface water conditions and described the index as "mountain water dependent", in which mountain snow pack is a major component.

The objective of the SWSI was to incorporate both hydrological and climatological features into a single index value resembling the Palmer Index for each major river basin in the state of Colorado (Shafer and Dezman 1982). These values would be standardized to allow comparisons between basins. Four inputs are required within the SWSI: snow pack, stream flow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI is computed with only snow pack, precipitation, and reservoir storage in the winter. During the summer months, stream flow replaces snow pack as a component within the SWSI equation.

The procedure to determine the SWSI for a particular basin is as follows: monthly data are collected and summed for all the precipitation stations, reservoirs, and snow pack/stream flow measuring stations over the basin. Each summed component is normalized using a frequency analysis gathered from a long-term data set. The probability of non-exceedence—the probability that subsequent sums of that component will not be greater than the current sum—is determined for each component based on the frequency analysis. This allows comparisons of the probabilities to be made between the components. Each component has a weight assigned to it depending on its typical contribution to the surface water within that basin, and these weighted components are summed to determine a SWSI value representing the entire basin. Like the Palmer Index, the SWSI is centered on zero and has a range between -4.2 and +4.2.

The SWSI has been used, along with the Palmer Index, to trigger the activation and deactivation of the Colorado Drought Plan. One of its advantages is that it is simple to calculate and gives a representative measurement of surface water supplies across the state. It has been modified and applied in other western states as well. These states include Oregon, Montana, Idaho, and Utah.

Several characteristics of the SWSI limit its application. Because the SWSI calculation is unique to each basin or region, it is difficult to compare SWSI values between basins or regions (Doesken et al., 1991). Within a particular basin or region, discontinuing any station means that new stations need to be added to the system and new frequency distributions need to be determined for that component. Additional changes in the water management within a basin, such as flow diversions or new reservoirs, mean that the entire SWSI algorithm for that basin needs to be redeveloped to account for changes in the weight of each component. Thus, it is difficult to maintain a homogeneous time series of the index (Heddinghaus and Sabol, 1991). Extreme events also cause a problem if the events are beyond the historical time series, and the index will need to be reevaluated to include these events within the frequency distribution of a basin component.

2.3.6. Reclamation Drought Index

The Reclamation Drought Index (RDI) was recently developed as a tool for defining drought severity and duration, and for predicting the onset and end of periods of drought. The impetus to devise the RDI came from the Reclamation States Drought Assistance Act of 1988, which allows states to seek assistance from the Bureau of Reclamation to mitigate the effects of drought.

Like the SWSI, the RDI is calculated at a river basin level, and it incorporates the supply components of precipitation, snow pack, stream flow, and reservoir levels. The RDI differs from the SWSI in that it builds a temperature-based demand component and duration into the index. The RDI is adaptable to each particular region and its main strength is its ability to account for both climate and water supply factors.

Oklahoma has developed its own version of the RDI and plans to use the index as one tool within the monitoring system designated in the state's drought plan. The RDI values and severity designations are similar to the SPI, PDSI, and SWSI.

2.3.7. Deciles

Arranging monthly precipitation data into deciles is another drought-monitoring technique. It was developed by Gibbs and Maher (1967) to avoid some of the weaknesses within the "percent of normal" approach. The technique they developed divided the distribution of occurrences over a long-term precipitation record into tenths of the distribution. They called each of these categories deciles. The first deciles are the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth deciles is the largest precipitation amount within the long-term record. By definition, the fifth deciles are the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications.

The decile method was selected as the meteorological measurement of drought within the Australian Drought Watch System because it is relatively simple to calculate and requires less data and fewer assumptions than the Palmer Drought Severity Index (Smith et al., 1993). In this system, farmers and ranchers can only request government assistance if the drought is shown to be an event that occurs only once in 20–25 years (deciles 1 and 2 over a 100-year record) and has lasted longer than 12 months (White and O'Meagher, 1995). This uniformity in drought classifications, unlike a system based on the percent of normal precipitation, has assisted Australian authorities in determining appropriate drought responses. One disadvantage of the decile system is that a long climatological record is needed to calculate the deciles.

2.4. ENSO and Ethiopian Droughts

ENSO was found to be one of the main factors that lead to drought in Ethiopia. Research at the NMSA began to focus on the links between the distribution of rainfall, Sea Surface Temperatures (SST) (including the Pacific, Indian and Atlantic Oceans), and Ethiopian weather (Kassahun 1999).

El Niño (EN) is the increase in the surface temperatures (SST) in the central and eastern equatorial Pacific Ocean. EN results from changes in the pattern and direction of winds and ocean currents in the region, which have potentially catastrophic effects. There are also changes in atmospheric pressure across the Pacific Basin between Darwin, Australia, and Tahiti called the Southern Oscillation (SO). The SO is the seesaw "in atmospheric mass involving exchanges of air between eastern and western hemispheres . . . with centers of action located over Indonesia and the tropical Southern Pacific Ocean" (Trenberth 1991). Thus, El Niño-Southern Oscillation (ENSO) is a coupled air and ocean phenomenon with global weather implications. It is believed that ENSO is often associated with devastating droughts in Northeast Brazil, Australia, parts of Africa, the failure of the Indian monsoons, hurricanes along the east coast of North America, and so forth (Glantz 1993).

Many researchers now believe that the occurrence of various droughts in Africa, especially in Southern Africa and the Horn, are caused by physical processes related to the occurrence of ENSO events thousands of miles away. If valid and reliable information about the linkages between these occurrences becomes available, it could help to forecast Sub-Saharan African droughts.

There have been notable droughts in Ethiopia throughout human history (Haile 1988; Degefu 1987; Pankhurst 1966; Nicholls 1993; Webb and Braun 1994). Previous droughts and the frequency of rainfall deviation from the average suggest that droughts occur every 3-5 and 6-8 years in northern Ethiopia and every 8-10 years for the whole country (Haile 1988).

Haile (1988) believes that Ethiopian drought is caused by ENSO, along with sea surface temperature (SST) anomalies in the Southern Atlantic and Indian Oceans combined with anthropogenic activities. ENSO events and SST anomalies affect rainfall distribution in Ethiopia by displacing and weakening the rain-producing air masses (1988).

There is a remarkable correspondence between annual rainfall in Ethiopia and ENSO events (Haile 1988). A statistical analysis by Attia and Abulhoda (1992) shows that "ENSO episodes are negatively tele-connected with the floods of the Blue Nile and Atbara" rivers that originate in Ethiopia. Eltahir (1996) also concluded that ENSO events affect flows of the Nile River (indicating drought in highland Ethiopia, which is a source of 85 percent of Nile water) and that knowledge of these events could be used to improve the predictability of its annual flow. Empirical data indicate an association between ENSO events and droughts in Ethiopia. Thus, an ENSO-based early warning system, used effectively by policymakers, could help to reduce the societal impacts of drought in Ethiopia.

According to Nicholls (1993), 1888 was a major ENSO year that damaged the economies of Brazil and Australia, as well as Ethiopia. Drought struck Ethiopia in 1888, leading to the historic deadly famine of 1888/89. About one-third of the population died because of famine, and ninety percent of the animals perished due to render pest infestation and the drought (Webb and Braun 1994). In 1957/58 drought and locust invasion led to famine in Tigray. The 1972/73 drought led to the Wollo famine, during which about 200,000 people died. In all these cases, there was little early warning. When past ENSO events are compared with drought and famine periods in Ethiopia, they show a remarkable association. Some drought years have coincided with EN events, while others have followed it.

Table 2-5: Chronology of El Niño and Drought/Famine in Ethiopia till 1993.

El Niño Years	**Drought/Famine**	**Regions**
1539-41	1543-1562	Hararghe
1618-19	1618	Northern Ethiopia
1828	1828-29	Shewa
1864	1864-66	Tigray and Gondar
1874	1876-78	Tigray and Afar
1880	1880	Tigray and Gondar
1887-89	1888-1892	Ethiopia
1899-1900	1899-1900	Ethiopia
1911-1912	1913-1914	Northern Ethiopia
1918-19	1920-22	Ethiopia
1930-32	1932-1934	Ethiopia
1953	1953	Tigray and Wollo
1957-1958	1957-1958	Tigray and Wollo
1965	1964-66	Tigray and Wollo
1972-1973	1973-1974	Tigray and Wollo
1982-1983	1983-1984	Ethiopia
1986-87	1987-1988	Ethiopia
1991-92	1990-92	Ethiopia
1993	1993-94	Tigray, Wollo, Addis

Sources: Quinn and Neal (1987, 14451); Degefu (1987, 30-31); Nicholls 1993; Webb and Braun; Ayalew 1996.

The 1982-83 ENSO "was the most extreme event in at least a century," with equatorial SSTs in the Pacific Ocean increased by an average of 2 degrees Celsius and exceeding 6 degrees *Celsius* on the coast of Peru (Cane 1993). In Ethiopia, the 1983-84 droughts took the lives of an estimated one million people, destroyed crops, contributed to the death of animals, and threatened the lives of millions of people with starvation.

The association between ENSO and droughts in Ethiopia is due to an atmospheric teleconnection or "the linkages over great distance of seemingly disconnected weather anomalies" (Glantz el. al., 1991). This means that the oceanic and atmospheric processes in another part of the world, such as the equatorial Pacific, could affect Ethiopian climate. Reliable ENSO information could be useful to forecast drought with longer lead time, enabling policy-makers to introduce early mitigating policies.

A study by Cane et al. (1994) found a correlation between Zimbabwean maize yield and ENSO that, according to the authors, enables prediction of maize production with a lead time of up to a year. These findings show that in the 1970s and 1980s, droughts and low maize yields vacillated nearly in step with El Niño. Thus, a warming of the central and eastern equatorial Pacific surface waters appears to provide a warning for policymakers to take actions in preparation for future drought in their region. Such findings could be used for drought early warning in Ethiopia as well.

Nicholls (1993) believes that ENSO information could have provided an early warning to decision makers about Ethiopia's severe 1888 drought, had such information existed then. The other Ethiopian droughts and famines in the 20th century appear to have followed ENSO events as well. I do not think that the correlation between droughts in the Horn of Africa and El Niño events is coincidental. The current state of knowledge also suggests that monitoring the Southern Oscillation Index (SOI) could predict drought with a longer lead time (*ibid*.).

2.5. Impact of ENSO on the *Belg* rains

The *Belg* rainfall is generally considered variable in quantity and distribution. However, southwestern Ethiopia and some areas in the central highlands receive between 500-700 mm of rainfall during this season. The rest of the country gets a low amount of rainfall. The relation between Pacific SST and *belg* rainfall show a negative association with SOI (Babu 1999). The *belg* rainfall between 1970 and 1988 and its comparison with February to May SOI show that normal to above normal *belg* rainfall exists during negative SOI (*ibid.*). During ENSO years (e.g. 1982, 1987, 1992), the *belg* rains were above normal, while during La Niña years, the *belg producing* regions of Ethiopia received below normal rainfall, as shown in 1991, 1994, 1999 and 2000 (Kassahun 1999).The relationship is created because “high negative or positive index” makes the weather system deviate from the norm by pushing or bringing that precipitation.

The El Niño led to climate anomalies on the *Kiremt*, *Bega*, and *belg* seasons of 1997-98 in Ethiopia. The 1997-98 Ethiopian rainfall was characterized as deficient and erratic (Babu 1999). This led to a decline in food production, the outbreak of disease, such as cholera and cerebral malaria, which killed hundreds of people, and displacement of people due to flooding (Babu 1999).

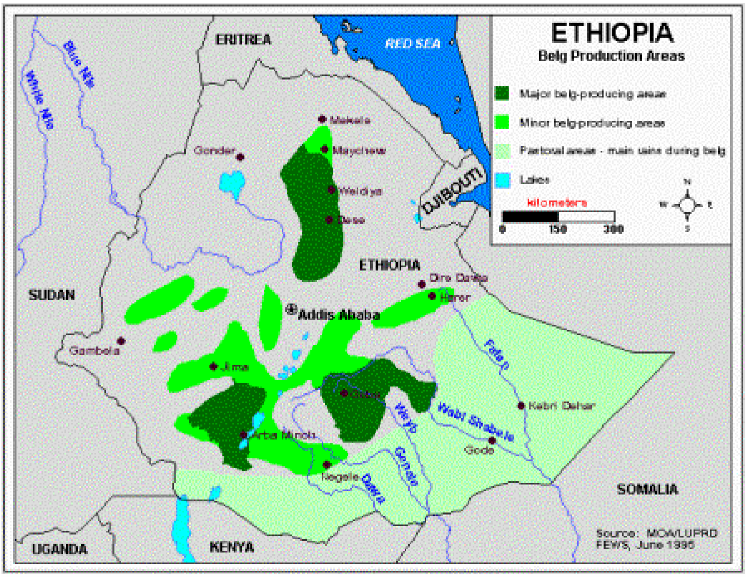

Figure 2-2. Belg grain producing area

The belg season accounts for around 8 to 10 percent of annual grain production, but in some areas like SNNPRS it is the main harvest season and account about 70 percent of the annual grain production. Figure 3- shows Belg grain production areas of Ethiopia.

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3.1. Location and Extent of study area

The Southern Nations Nationalities and Peoples’ Regional State is one of the regional states of the Federal Democratic Republic of Ethiopia. It is located in the south and south western part of the country and has a population of about 15 million. It is the fourth largest region in terms of geographical outreach with an estimated area of 118,000 square kilometer and third largest region in terms of population making it the most densely populated i.e., it accounts for 20% of the national population and 10% of the total area of the country. Administratively, the region is divided in to 13 zones with 104 woredas of which 8 are special woredas without link to zonal administration. It is the most diverse region in the nation and inhabited by 56 different ethnic groups.

SNNPR extends west from the Rift Valley as it runs through southern Ethiopia. The Rift Valley lakes, in a line from north-east to southwest, roughly mark the eastern borders of the territory: Lakes Ziway, Awassa, Abiyata, Shala, Abaya, Chamo, Chew Bahir and finally on the border with Kenya, the northern tip of Lake Turkana into which flows the Omo River. That river is served by the biggest drainage pattern in the Region, entering from the north along the boundary between Wolayita and Dawro Administrative Zones and defining the northern-western boundary of Gamo Gofa Administrative Zone before the river enters the main valley in South Omo, with some drainage from Bench Maji. There are other more localized drainage areas, notably those serving the Bilate River which runs into Lake Abaya and the Weito River which runs into Chew Bahir.

Drought and famine have a history of repeated occurrence in the SNNPR. With the exception of western zones in the region, all zones and special woreda are registered as drought prone areas with reduced crop production being unable to feed their population. Out of the total 104 woredas (in 13 zones and 8 special woredas) 63 woredas are affected by drought and malaria epidemics, and has fallen under a serious need of food and medical support.

Such meteorological drought resulting from lack of rainfall for a long period of time has peculiar characteristics; it has been described as a “a green drought and green famine” where there is nothing to eat and nothing in the backyard whereas greenery and abundant growth in the field is evident across the area. Absolute dependency on rainfall, increased deforestation, poor natural resource management, unchecked population growth, lack of knowledge on water resource, conservation strategies etc exacerbate the effect of drought in the region.

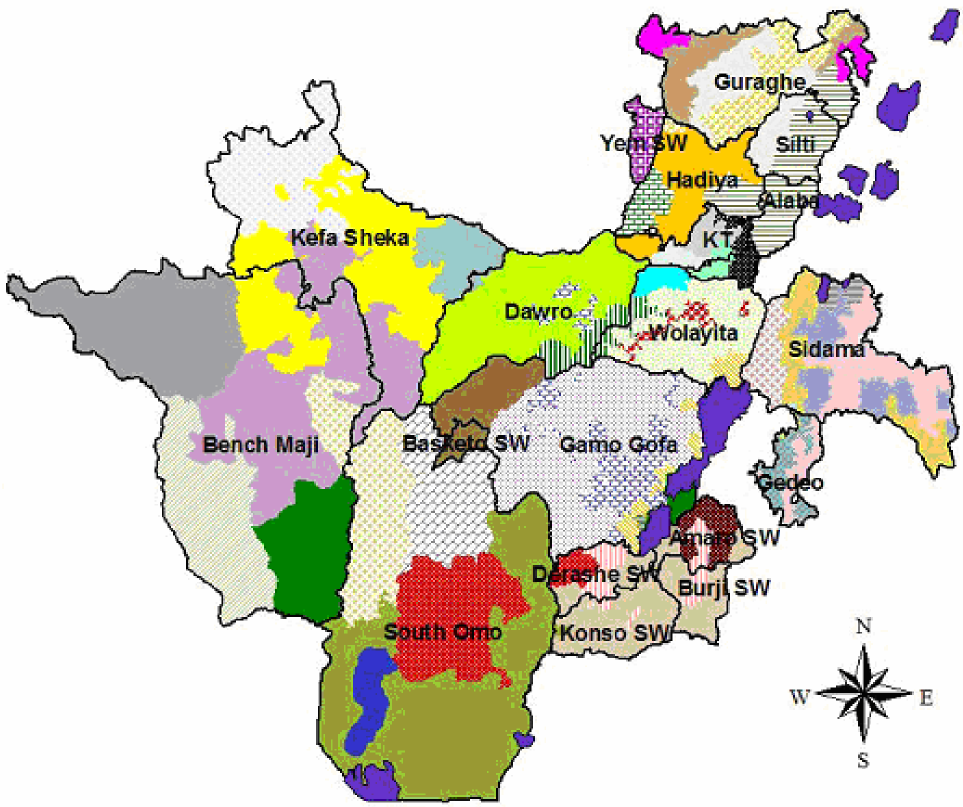

Figure 3-1. Map of the Southern Nations, Nationalities and Peoples Regional State

Table 3-1: Stations used in this study

No	Station	Longitude	Latitude	Altitude
1	Awassa	38.483	7.064	1694m
2	W/sodo	37.749	6.821	1854m
3	M/abaya	37.771	6.29	1221 m
4	Billate	38.088	6.822	1361m
5	Billate Tena	38.126	6.932	1496m
6	Dilla	38.307	6.38	1519m
7	A/minch	37.561	6.061	1220 m
8	Hossina	37.856	7.568	2306 m
9	Sawla	36.841	6.305	1348 m
10	Emdibir	37.936	8.118	2082 m
11	Buie	38.554	8.330	2054 m
12	Jinka	36.559	5.779	1373 m
13	Wolkite	37.774	8.281	1884 m
14	Wush wush	35.15	6.59	2050m
15	Tepi	36	7.2	2011m
16	Masha	35.48	7.33	2180m

3.2. Climate and Topography

The climate of SNNPRS is also varied and can be divided into five agroecological zones. (1) Haroor (Hottest), Kolla (hot), Woinadega (warm), Dega (cool) and worch (coldest). These zones support different crops and vegetable types. It is also worth to mention that these variations largely attributed to relief effect. The regions rainfall intensity, duration and amount increases from North to South West. The mean annual temperature of the region varies from less than 10°C in the extreme highlands to the east /parts of Sidama highlands/ to over 27 °C in the lowlands to the south in the omo rate plain /Debub Omo zone/.

Characterized by a varied topography, SNNPRS has a land of outstanding natural beauty with high mountains, steep valleys and rolling plains. The most remarkable land feature of the region is the great rift valley that runs along the eastern edge of the region and the Omo valley which is the major feature of the region that roughly cuts in to two halves. Along the Omo river valley, a series of high lands complexes are found such as Keffa high lands, Kulo Kunta highlands, Gofa High lands etc... are the prominent examples. The altitudinal variation of the region extends from the lowest point at-lake Roudolf (Torkana) 376m above sea level to mount Guge of Gamo highlands which is 4200m above sea level.

The Region's cool highland terrains are not extensive, but they are densely populated. Notable highland areas are in Gurage and Hadiya Administrative Zones in the north-east, in Sidama and Gedeo Administrative Zones where they form a south-western leg of the Arsi-Bale massif, and in the Gamo and Gofa highlands of the center/south-west. The dominant, temperate midlands are relatively 'wet' or 'dry' mainly depending on their altitude within the range of roughly 2500 to 1500 meters above sea level, and this has an effect on the relative success of enset or coffee production, to name two key products. The main lowland areas stretch to the south-west and west, mainly in South Omo and Bench Maji Administrative Zones, and with their relatively high temperatures and low rainfall they are particularly the scene of agro-pastoralism. Elsewhere there are smaller areas of more arable lowland, for instance surrounding Lakes Abaya and Chamo in the Humbo, Arba Minch Zuria and Amaro Special woredas and further south in Dirashe and Konso Special Woredas. But the relatively narrow Bilate river valley is more or less agro-pastoral lowland.

SNNPR is a region of relatively high rainfall by Ethiopia standards. Few woreda reporting stations show less than 1000mm of annual precipitation in the 30-year mean 1971-2000. Those that do are lowland areas such as the Hamer rangeland (601mm) and the lowlands around Lake Abaya mentioned above (around 900mm), whilst Konso (609mm) has the lowest rainfall for an arable area – and this is where a traditional technique of land terracing helps to conserve soil moisture. By contrast the highest rainfall is found in the north-western areas of Masha Anderacha (2180mm) Gesha (2004mm), Yeki (1776) and Bench (1735mm) which are mainly in the Sheka and Kaffa Cereals and Enset and the Western Coffee and Spices Livelihood Zones. Elsewhere the Limu area scores high (1811mm, in the Hadiya-Kembata Cereal and Enset Livelihood Zone), as does the Gamo highland at Chencha (1704mm, in the Gamo Gofa Enset and Barley Livelihood Zone). The range for most of the midland of the center, north-east and east of the Region, where the majority of the Region's population live, is between 1100mm and 1500mm.

On the rangeland of Kuraz only two months on average show above 100mm (April and October) whilst Bench and Limu show virtually continuous high precipitation between February or March and October, with most months above 200mm and no month below 100mm. However, there are 'good' rainfall years and 'bad' rainfall years which are defined not only by variations in overall precipitation but by irregularities such as a late start to the spring rains which seriously delays maize and sorghum seeding, or dry spells at critical periods of growth which much reduce the grain or tuber formation in plants that otherwise look quite healthy. As a rule of thumb, irregularities in rainfall increase as altitude decreases; but in the lowlands it is not always clear what is real rainfall 'irregularity' and what is within a locally quite normal range of inter-annual variation. People have their own judgment when they are trying to make a living from cereal crops in areas traditionally considered suitable only for livestock grazing. In other words, it is not always clear what is a temporary climatic aberration and what is a result of chronic population pressure pushing people down the hill, so to speak.

CHAPTER FOUR

DATA AND METHODOLOGY

First, an appropriate drought monitoring (historical) index must be selected. Many drought indices have been proposed to date, for instance, Palmer Drought Severity Index (PDSI), Deciles Index, China-Z Index (CZI), and the well-known Standardized Precipitation Index (SPI) (McKee eta!., 1993). The SPI was chosen for this study because of its simplicity and being based solely on the accessible precipitation data. The SPI is calculated from monthly precipitation record by first fitting the gamma probability distribution function and then transforming into a normal distribution so that the mean SPI is set to zero (McKee et a!., 1993; Edwards and McKee, 1997). Positive and negative SPI values indicate wet and dry conditions, respectively.

4.1. Data

Monthly rainfall datasets were acquired for the period of 18 to 31 years ranging from 1973-2007 for the SNNPRS. Monthly rainfall for 16 rain stations has been used to derive Standardized Precipitation Index (SPI). The data has been collected from the National Meteorological Agency (NMA).

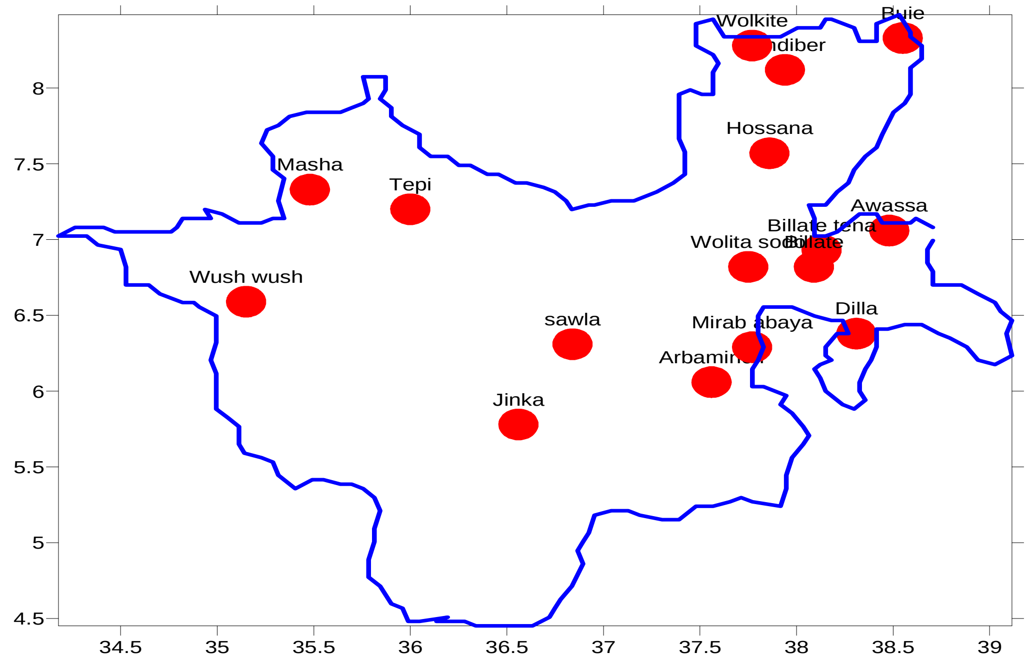

Figure 4-1: SNNPR Map Showing Weather Monitoring Stations taken for this study

4.2. Methodology

4.2.1. Homogeneity Test

In the paper the software tool RAINBOW is used which is designed to study meteorological or hydrologic records by means of a frequency analysis and to test the homogeneity of the record. Frequency analysis of rainfall data requires that the data be homogeneous and independent. The restriction of homogeneity assures that the observations are from the same population. One of the tests of homogeneity is based on the cumulative deviations from the mean:

$$S_k = \sum_{i=1}^{K} (X_i - \overline{X}) \qquad k=1\ldots\ldots\ldots\ldots n \qquad 4.1$$

Where Xi are the records from the series X1, X2, …, X_n and the mean. The initial value of S(k=0) and last value S(k=n) are equal to zero. When plotting the S_k's (sometimes called a residual mass curve) changes in the mean are easily detected. For a record Xi above normal the S_k increases, while for a record below normal S_k decreases. For a homogenous record one may expect that the S_k's fluctuate around zero since there is no systematic pattern in the deviations of the Xi's from their average value.

To test the homogeneity of the data set, the cumulative deviation is plotted in the Homogeneity plot menu. The cumulative deviation is rescaled by dividing the S_k's by the sample standard deviation value (s). By evaluating the maximum (Q) or the range (R) of the rescaled cumulative deviations from the mean, the homogeneity of the data of a time series is tested:

$$Q = \max\left[\frac{S_k}{s}\right] \qquad 4.2$$

$$R = \max\left[\frac{S_k}{s}\right] - \min\left[\frac{S_k}{s}\right] \qquad 4.3$$

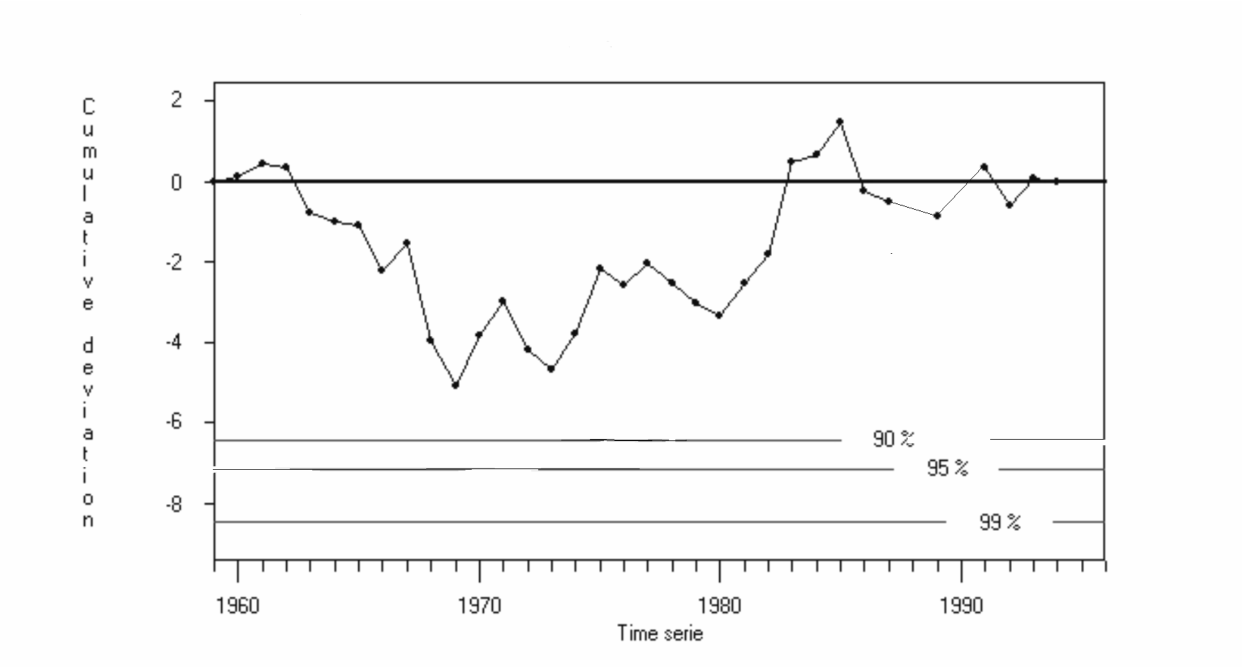

Figure 4.2: Homogeneity plot in the RAINBOW soft ware

High values of Q or R are an indication that the data of the time series is not from the same population and that the fluctuations are not purely random. Critical values for the test-statistic which test the significance of the departures from homogeneity are plotted in the Homogeneity plot menu as well (3 horizontal lines). If the cumulative deviation crosses one of the horizontal lines the homogeneity of the data set is rejected with respectively 90, 95 and 99% probability. The probability of rejecting the homogeneity of the data set is reported in the Homogeneity statistics menu. The menu is displayed by clicking on the ‘Statistics’ button in the Homogeneity plot menu.

4.2.2. Standard Precipitation Index.

McKee *et al.* (1993) developed the Standardized Precipitation Index (SPI) for the purpose of defining and monitoring drought. Among others, the Colorado Climate Center, the Western Regional Climate Center, and the National Drought Mitigation Center use the SPI to monitor current states of drought in the United States. The nature of the SPI allows an analyst to determine the rarity of a drought or an anomalously wet event at a particular time scale for any location in the world that has a precipitation record.

Computation of the SPI involves fitting a Gamma probability density function to a given frequency distribution of precipitation totals for a station. The alpha and beta parameters of the Gamma probability density function are estimated for each station, for each time scale of interest (1, 3, 6, 9, 12 months, etc.), and for each month of the year. The Gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \qquad 4.4$$

Where are α and β are the shape and scale parameters respectively, x is the precipitation amount and $\Gamma(\alpha)$ is the gamma function. Maximum likelihood solutions are used to optimally estimate α and β:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad 4.5$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}}$$

Where:

$$A = In(\hat{x}) - \frac{\sum In(x)}{n} \qquad 4.6$$

Where n = number of precipitation observations

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. Since g(x) is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x)=q+(1-q)G(x) \qquad 4.7$$

Where q is the probability of a zero and G(x) is the cumulative probability of the incomplete gamma function. If m is the number of zeros in a precipitation time series, then q can be estimated by m/n. By applying Eq. (4.7), errors are eventually introduced to parameters α and β of Gamma distribution. These errors depend on the number of months with null precipitation (x=0) and they are evident only for the 1-month precipitation. For larger time scales (e.g. 3-month, 6-month, etc) the probability of null precipitation was zero.

The cumulative probability, H(x), after its computation, is transformed to the standard normal random variable z with mean equal to zero and variance of one, which is the value of the SPI. SPI value is more easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z:

$$Z = SPI = -\left(t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \qquad \text{for } 0<H(x)<=0.5 \qquad 4.8$$

$$Z = SPI = \left(t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \qquad \text{for } 0.5<H(x)<1.0 \qquad 4.9$$

Where:

$$t = \sqrt{In\left(\frac{1}{(H(x))^2} \right)} \qquad \text{for } 0<H(x)<=0.5 \qquad 4.10$$

$$t = \sqrt{In\left(\frac{1}{(1.0 - H(x))^2} \right)} \qquad \text{for } 0.5<H(x)<1.0 \qquad 4.11$$

C_o= 2 515517

$C_{1=}$ 0 802853

$C_{2=}$ 0 010328

D1= 1.432788

$D_{2=}$ 0 189269

D_3= 0 001308

Once standardized the strength of the anomaly is classified as set out in Table 4.1. This table also contains the corresponding probabilities of occurrence of each severity arising naturally from the Normal probability density function. Thus, at a given location for an individual month, moderate dry periods (SPI <=-1) have an occurrence probability of 15.9%, whereas extreme dry periods (SPI<=-2) have an event probability of 2.3%. Extreme values in the SPI will, by definition, occur with the same frequency at all locations.

An analyst with a time series of monthly precipitation data for a location can calculate the SPI for any month in the record for the previous *i* months where *i*=1, 2, 3,..., 12, ..., 24, ..., 48, ... depending upon the time scale of interest. Hence, the SPI can be computed for an observation of a 3 month total of precipitation as well as a 48 month total of precipitation. For this study, a 3 month and 6 month SPI is used for a short-term or seasonal drought index, a 12 month SPI is used for an intermediate-term drought index. Therefore, the SPI for a month/year in the period of record is dependent upon the time scale. For example, the 3 month SPI calculated for January, 1943 would have utilized the precipitation total of November, 1942 through January, 1943 in order to calculate the index. Likewise, the 12 month SPI for January, 1943 would have utilized the precipitation total for February, 1942 through January, 1943 while the 48 month SPI would have utilized the precipitation total for February, 1939 through January, 1943. The computer program used to compute SPI is described below.

Table 4.1. Weather classification by SPI values and corresponding event probabilities.

SPI values	Category	Probability (%)
2.00 or more	Extremely wet	2.3
1.5 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2
-0.99 to 0.99	Near normal	68.2
-1.49 to -1.00	moderately dry	9.2
-1.99 to -1.50	Severely dry	4.4
-2 to less	Extetremely dry	2.3

The situation end of March-beginning of April is critical for Short Cycle crops planted in *Belg season* (crops planted around February and harvested before August). The poor rains in February-March could lead to a complete failure of the crops of the Belg season, with a critical situation end of June when the harvest is expected to join with the kiremet harvest of November-December. Belg season contributes to around 10 % of the total annual production of Ethiopia but it can represent up to 70 % of the local production and is thus quite essential in SNNPR. Thus in this study we are going to analyze only droughts that occur during the agriculturally important rainy seasons Belg and kiremet.

4.2.3. SPI Program files

The program to compute SPI for different time scales (e.g. 1,3, 6, ….) is already compiled and all libraries are included (it is compiled in C^{++} for PC). The SPI program is relatively easy to operate. The input files should be prepared for each station in the format.

Header

yyyy mm pppp

yyyy mm pppp

yyyy mm pppp

yyyy mm pppp

yyyy mm pppp

yyyy mm pppp

yyyy mm pppp

yyyy mm pppp

where Header = a string which describes the file, or something about the station, etc, yyyy = year, mm = month (in digit format 1,2,3 etc), pppp = precipitation multiplied by 100. The yyyy mm and pppp may either be separated by space or commas. Missing values are denoted by -9900

The output of the program is in the following format

Header

yyyy mm spi3 spi6 spi12 spi24

yyyy mm spi3 spi6 spi12 spi24

yyyy mm spi3 spi6 spi12 spi24

yyyy mm spi3 spi6 spi12 spi24

yyyy mm spi3 spi6 spi12 spi24

Where, spi3 = SPI for a 3 month rainfall total, spi6 = SPI for a 6 month rainfall total, spi12 = SPI for a 12 month rainfall total, spi24 = SPI for a 24 month rainfall totalspi24 = SPI for a 24 month rainfall total.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1. Results of homogeneity Test

The results of homogeneity test process are given in Table 5-1 in which the years that contain inhomogeneous data are tabulated. Missing values are obtained and filled by computing long year means. This table shows probability of rejecting homogeneity for observed data for 16 stations.

Table 5-1. The list of precipitation stations and propbability of rejecting Homogeneity for each station.

Stations	No.of observation with propbability of Rejecting Homogienity			
	90%	95%	99%	Years
Arbaminch	No	No	No	-
Awassa	No	No	No	-
Billate	No	No	No	-
Billate Tena	No	No	No	-
Buie	No	No	No	-
Dilla	No	No	No	-
Emdibir	No	No	No	-
Hossana	No	No	No	-
Jinka	No	No	No	-
Masha	No	No	No	-
Mirab Abaya	Yes	Yes	N0	1992
Sawla	No	No	No	-
Wolita Sodo	No	No	No	-
Wolkite	Yes	Yes	Yes	1996, 1997, 1998, 1999
Wush Wush	No	No	No	-
Tepi	No	No	No	-

The results of homogeneity test using RAINBOW software showed that 2 out of 16 stations have an in homogeneity. For instance, the station Mirab abaya (Fig.5-1) shows inhomoginity in 1992 with the probability of rejectance 90%. Wolkite (Fig.5-2) station also shows inhomoginity of data in the years 1996, 1997, 1998 and 1999 with probability of rejectance 95%, 99%, 99% and 95% respectively. These data were rejected and homogenization were made by regretting them with the neighboring stations and replaced by the values computed by regression.

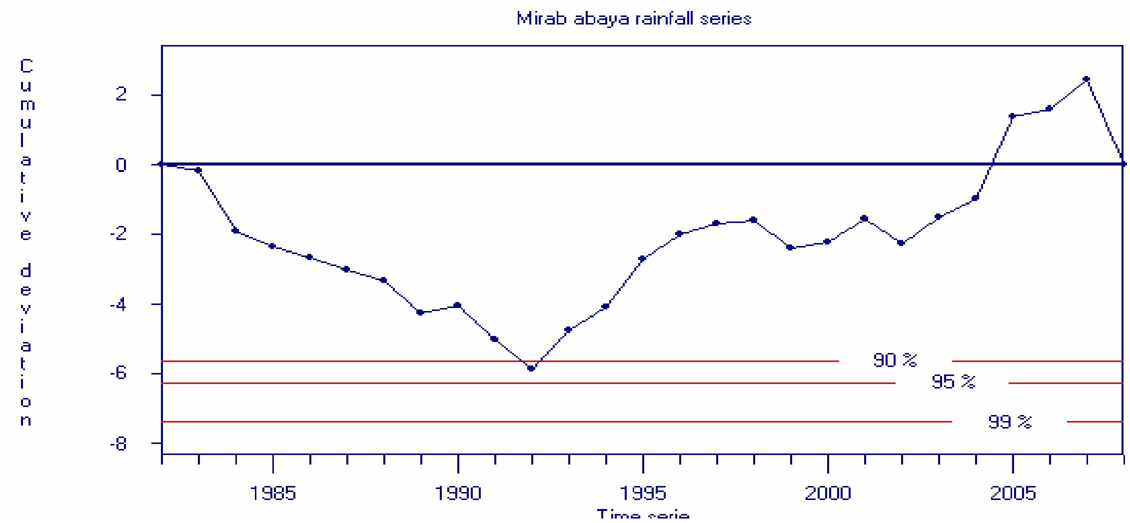

Figure 5-1. Homogeniety test for mirab abaya

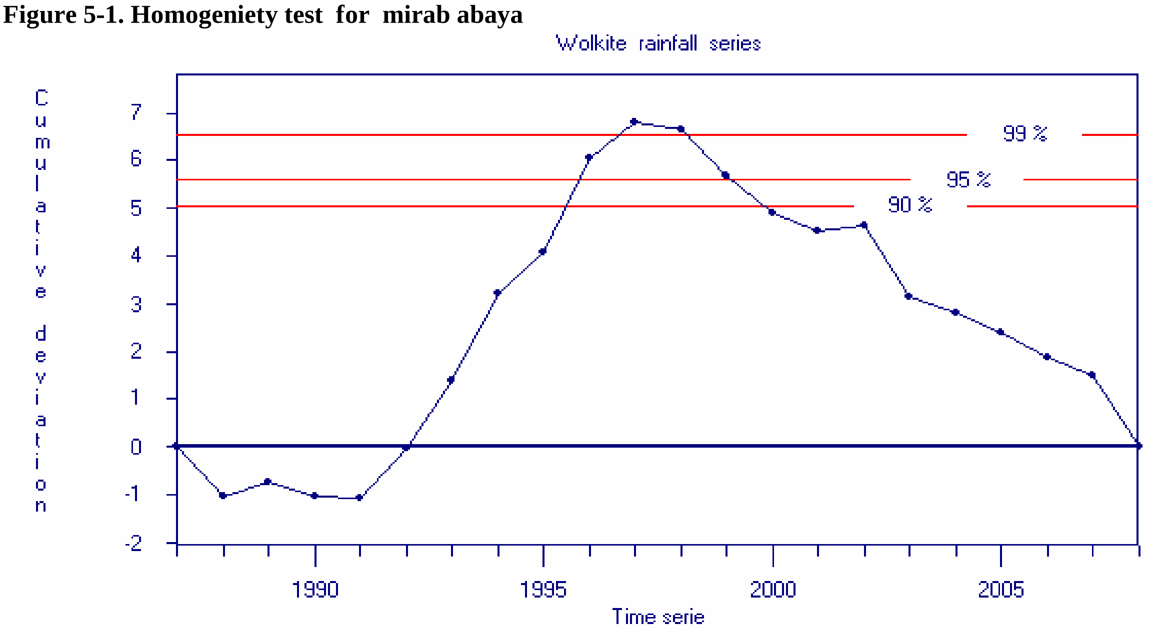

Figure 5-2. Homogeniety test for W olkite

5.2. Temporal And Spatial analysis of Drought in SNNPR

The temporal and spatial characteristics of droughts in SNNPR region were assessed by analyzing the SPI values of each station. The computed 3-month SPI values of different stations for the period of analysis that ranges from 1973 to 2007 were entered into surfer 8 data base. Firstly, the temporal variation of SPI calculated from average monthly precipitation for each station was assessed. Analysis of the computed 3- month SPI time series revealed the most severe and moderate droughts occurred in the region. Then, the spatial characteristics of droughts during these severe and moderate dry periods were analyzed and visualized within the surfer 8. The spatial characteristics of droughts were further analyzed and the areas affected by a specified drought severity were estimated within surfer 8.

SPI is used for quantification of precipitation deficit at different time scales, since SPI gives the indication of drought characteristics like onset, severity and spatial extent. Therefore it can be used as drought monitoring tool. For the identification of the drought sensitive stations, SPI data for the Belg and Kiremet season was used. The SPI values for 16 meteorological stations were analyzed in order to identify drought sensitive stations. For the selection of the drought year, SPI was used. The year corresponding to lowest SPI within the time series was taken and considered as drought year.

We used data series of monthly mean precipitation for calculation of Standard Precipitation Index (SPI). We calculated 3-months–SPI3 for Kiremet and Belg seasons. The 3- month SPI uses the precipitation total of March, April and May while for Belg. Time series of SPI for selected stations are presented here. Similar time series have been derived for other stations. Time series of SPI for various time scales were computed using the average monthly precipitation of the 16 station which have relatively longer years of rainfall data in the range of 1973 - 2007. A 3- month SPI can be used to monitor soil moisture conditions at the start of the growing season or precipitation during the different stages of plant development or reproduction. The temporal evolution of 3-month SPI time series showed that the region experienced extreme to moderate droughts for both seasons.

5.3. Temporal Characteristics of Drought for Belg

BELG season contributes to around 10 % of the total annual production of Ethiopia but it can represent up to 70 % of the local production and is thus quite essential in SNNPRS. Analysis of the 3-month SPI time series indicated that the record minimum SPI observed at Blate 1984 for Belg season. Figures 5-1 to 5-16 shows time series of 3-month SPI for 16 stations.

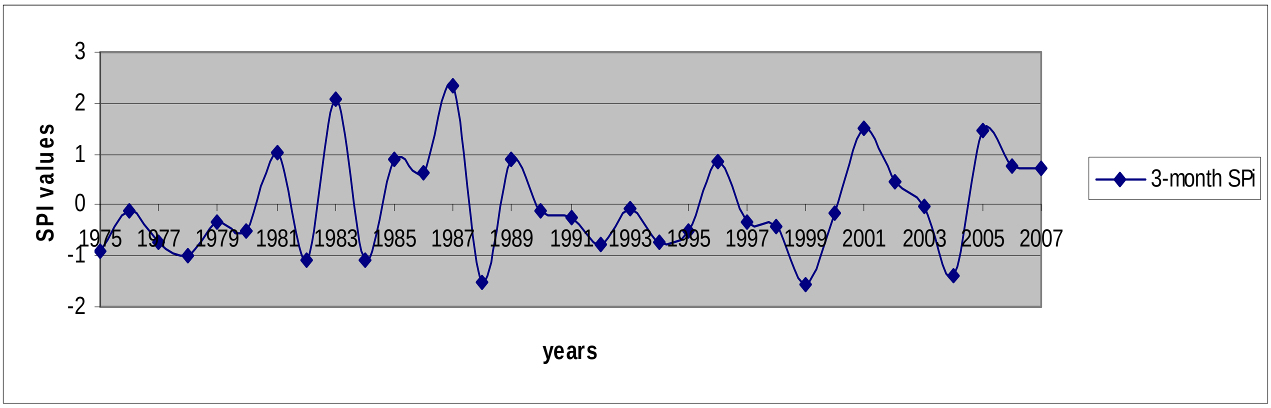

Figure 5-3. 3- Month SPI time series of Awassa for belg season.

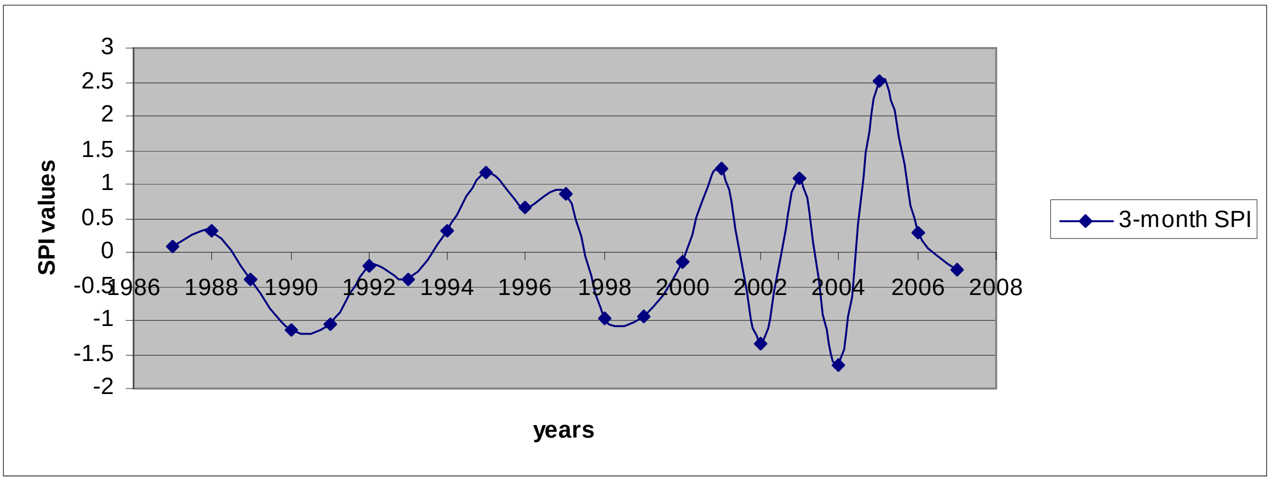

Figure 5-4. 3- Month SPI time series for Arbaminch belg season.

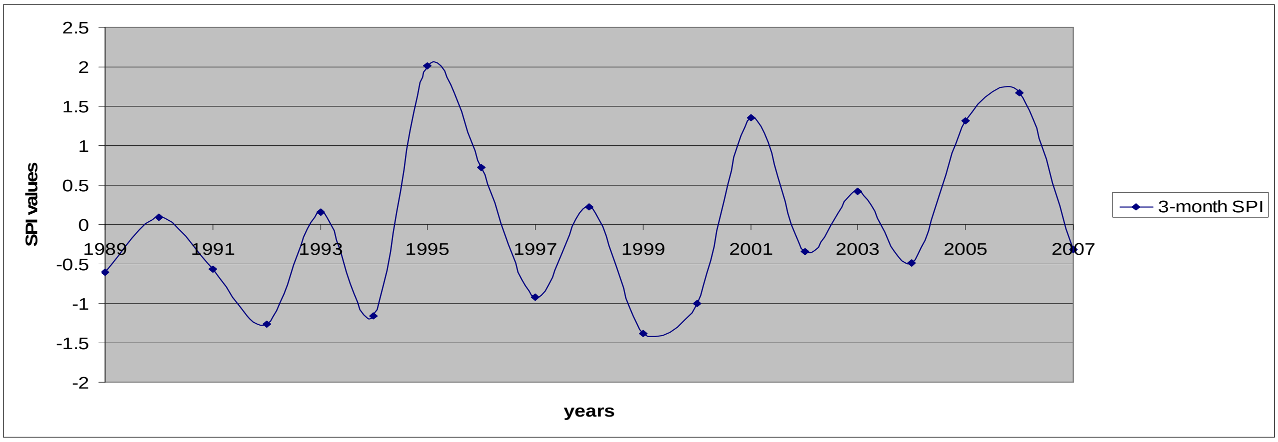

Figure 5-5. 3- Month SPI time series of Buie for belg season

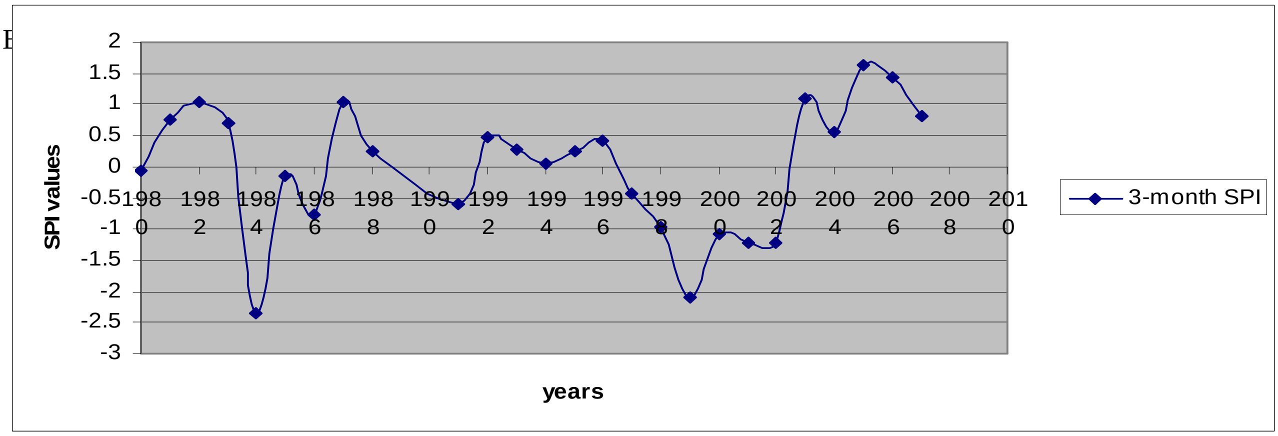

Figure 5-6. 3- Month SPI time series of Billate for belg season.

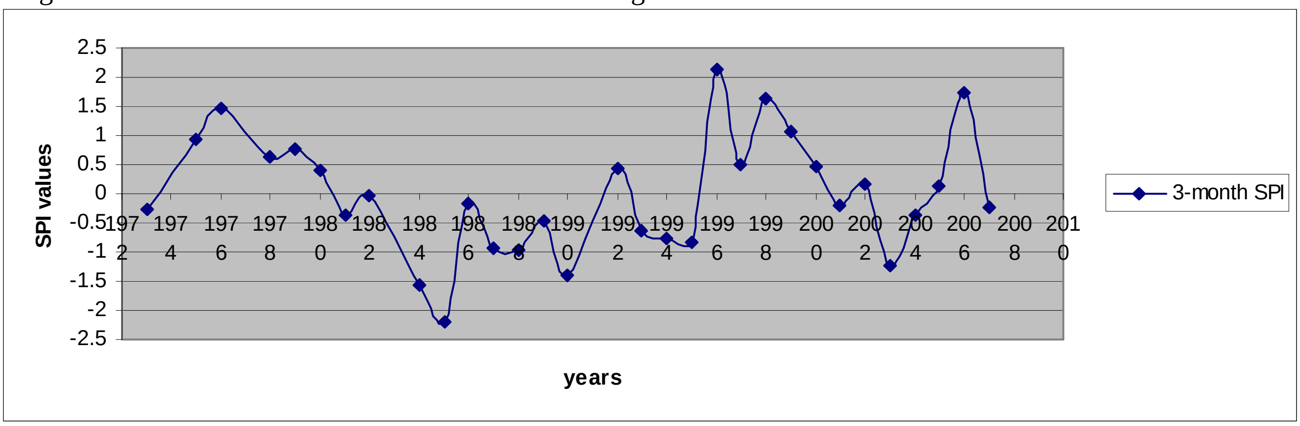

Figure 5-7. 3- Month SPI time series of Billate tena for belg season.

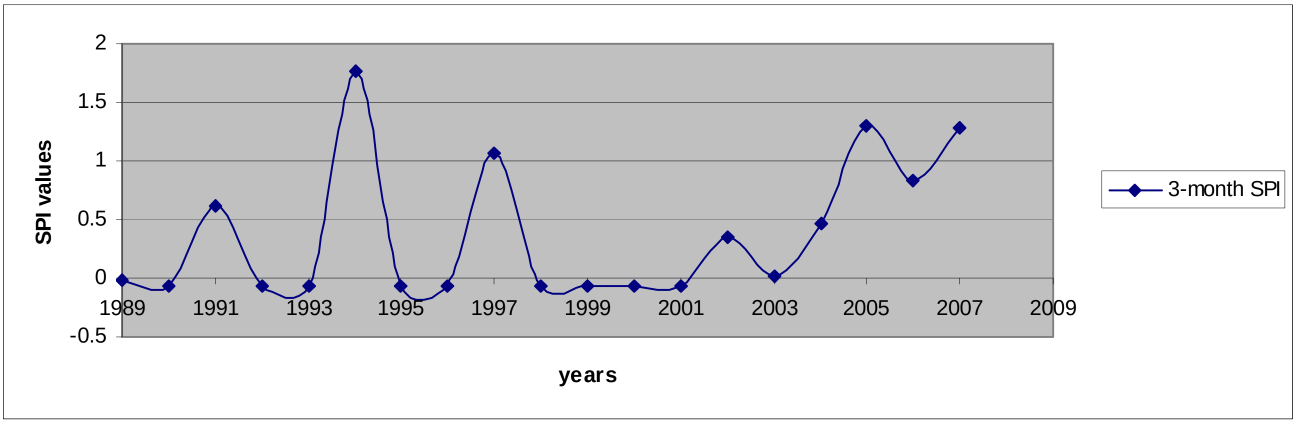

Figure 5-8. 3- Month SPI time series of Dilla for belg season

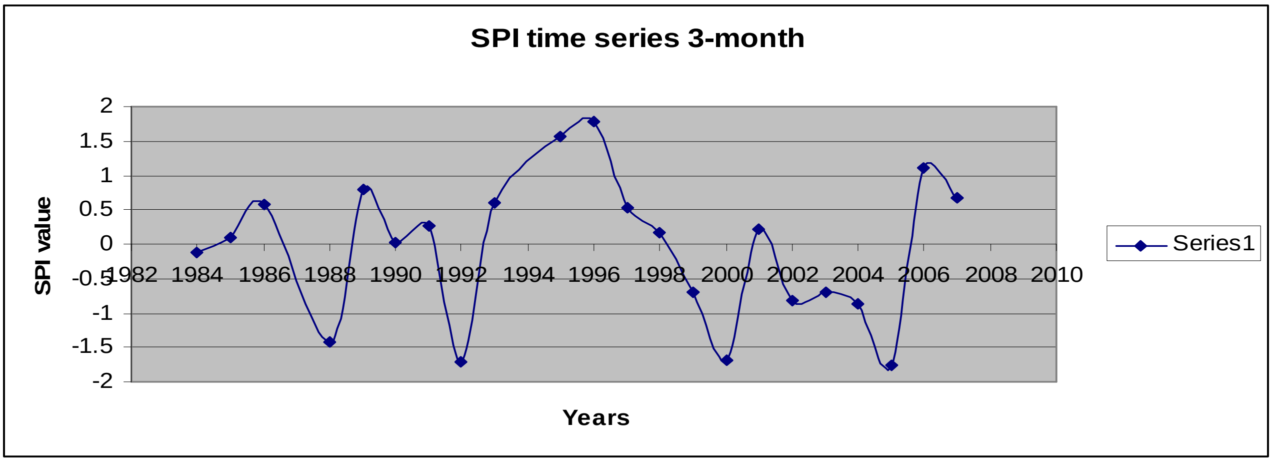

Figure 5-9. 3-Month SPI time series of Emdibir for belg season

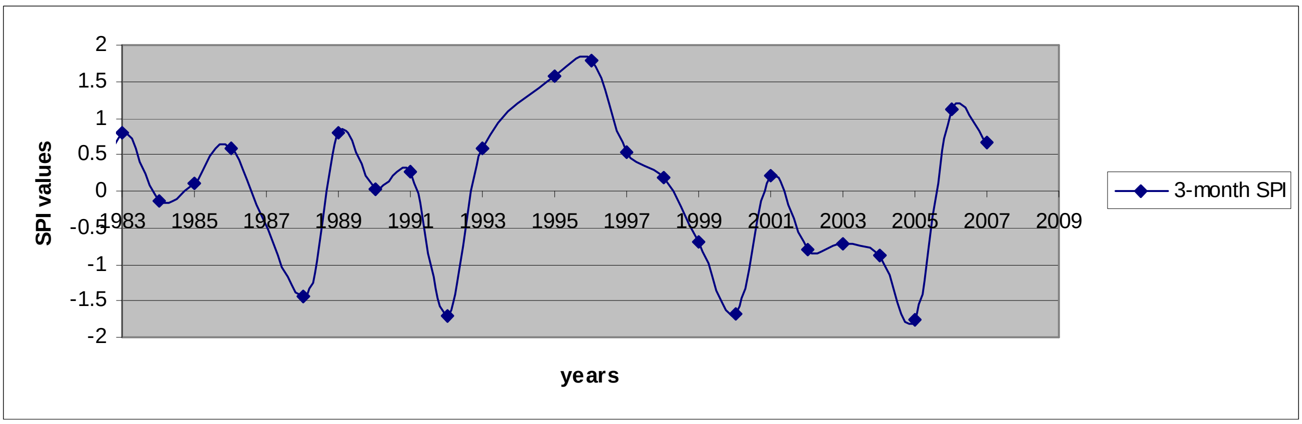

Figure 5-10. 3- Month SPI time series of Hossana for BELG season

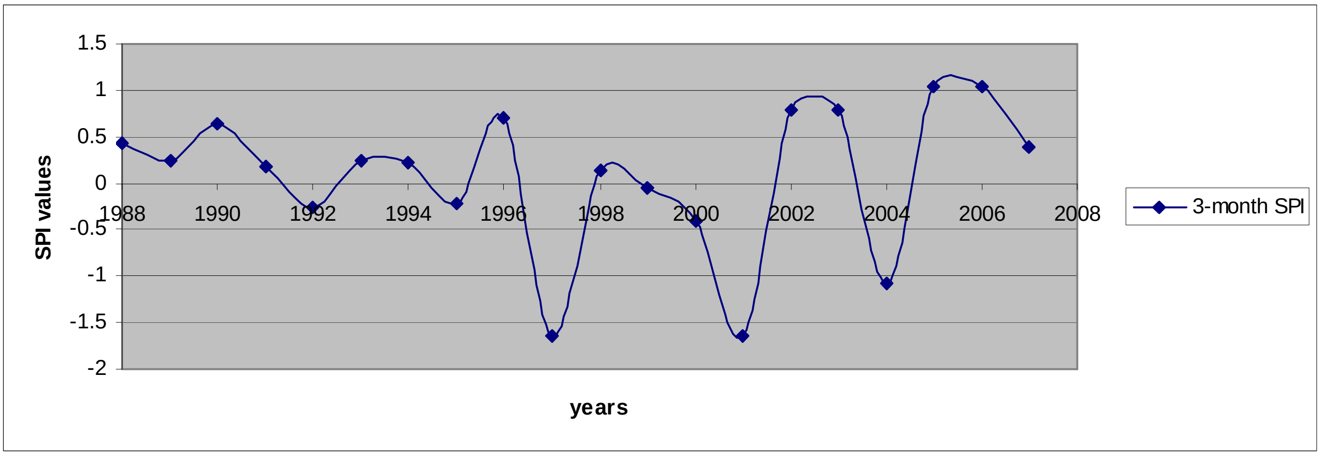

Figure 5-11. 3- Month SPI time series of Jinka for belg season.

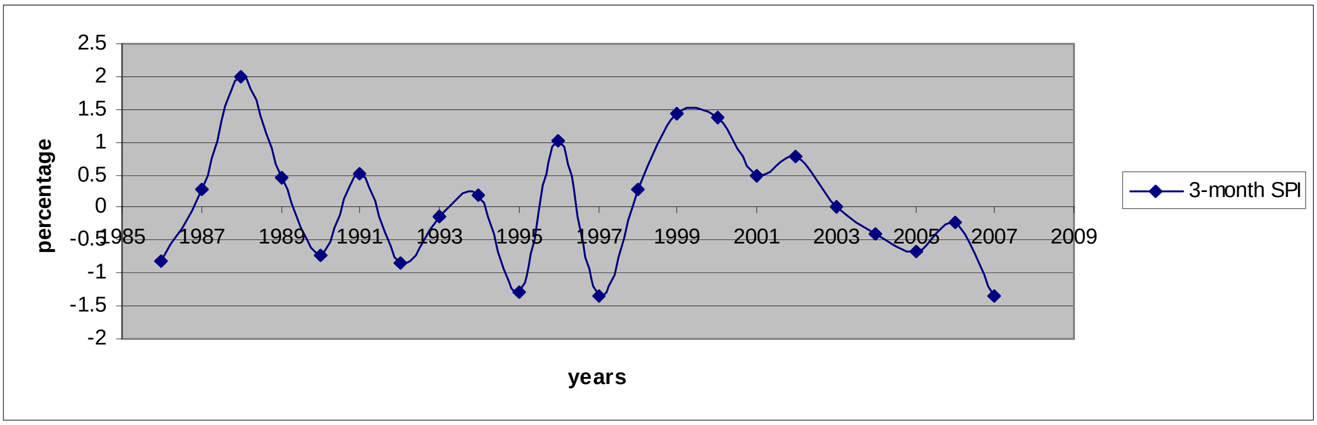

Figure 5-12. 3- Month and 6-month SPI time series of Masha for belg season.

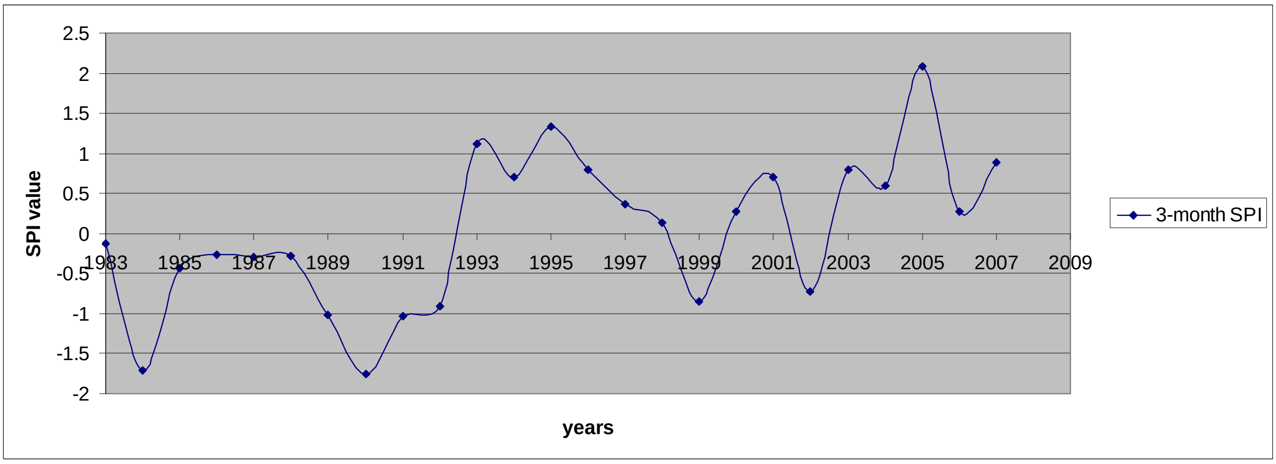

Figure5-13. 3- Month SPI time series of Mirab abaya for belg season.

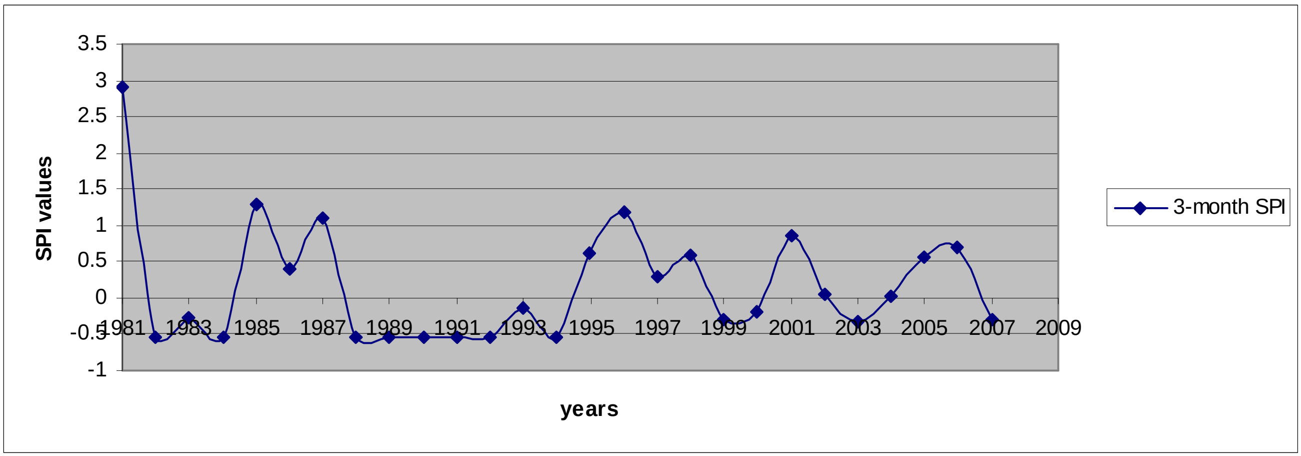

Figure 5-14. 3- Month SPI time series of Sawla for belg season.

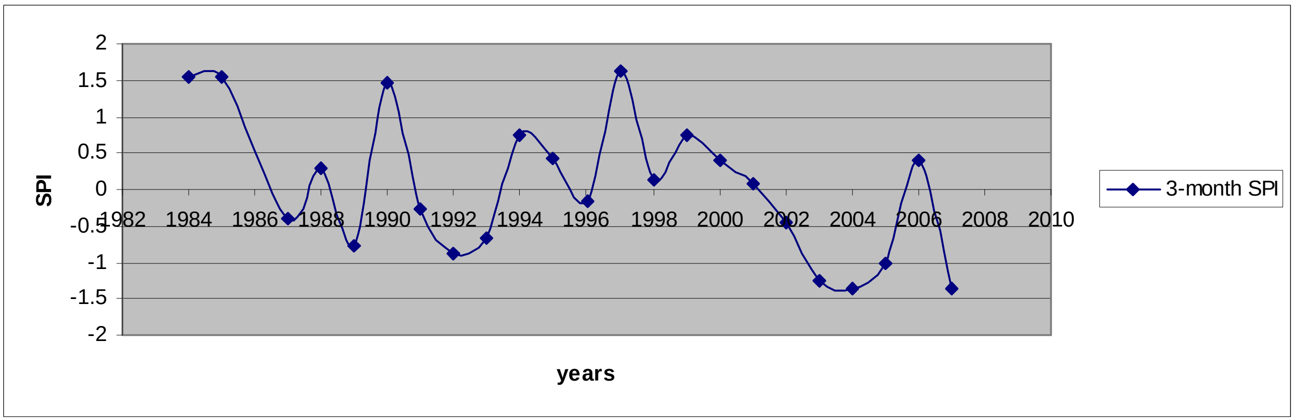

Figure 5-15. 3-Month SPI time series of Tepi for belg season.

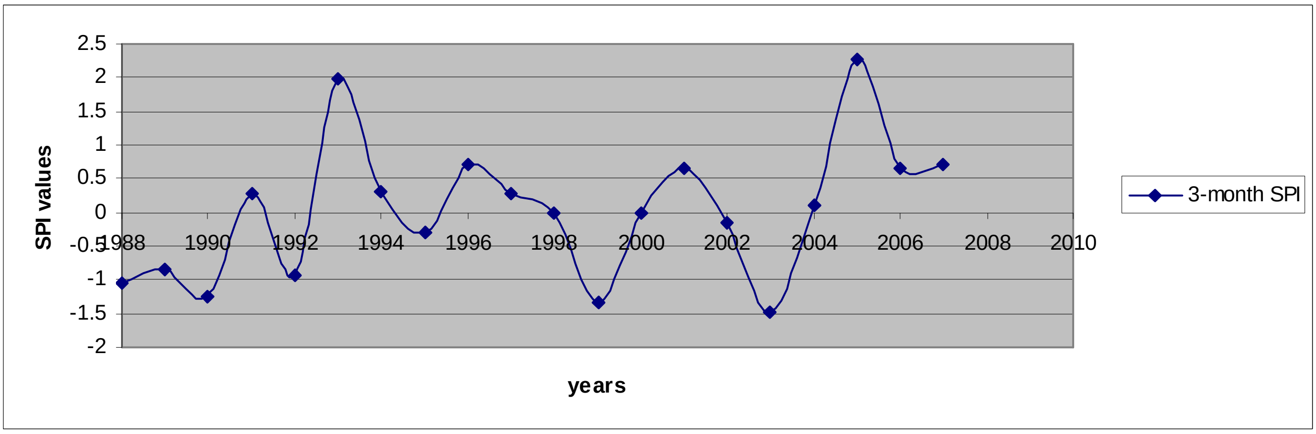

Figure 5-16. 3- Month SPI time series of Wolita Sodo for belg season.

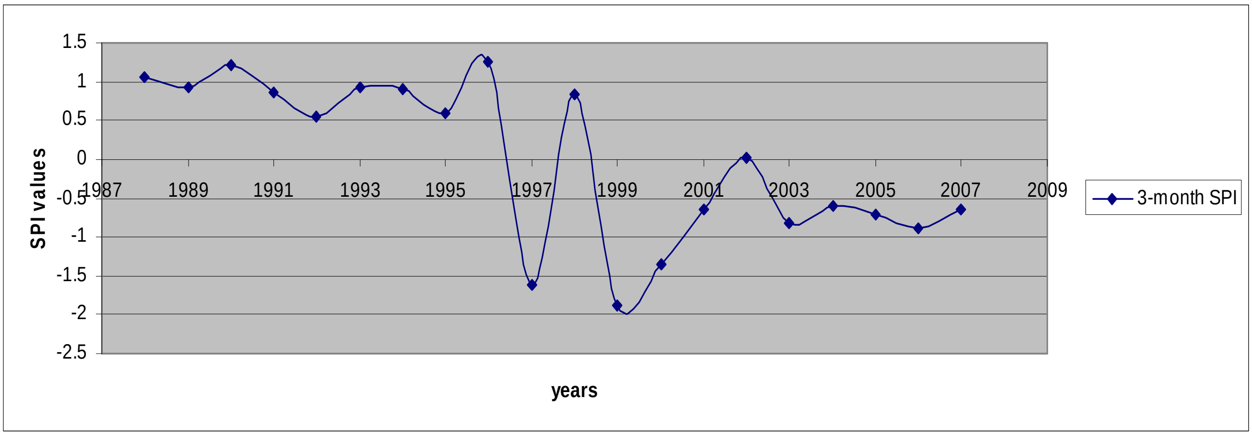

Figure 5-17. 3-Month SPI time series of Wolkite for belg season.

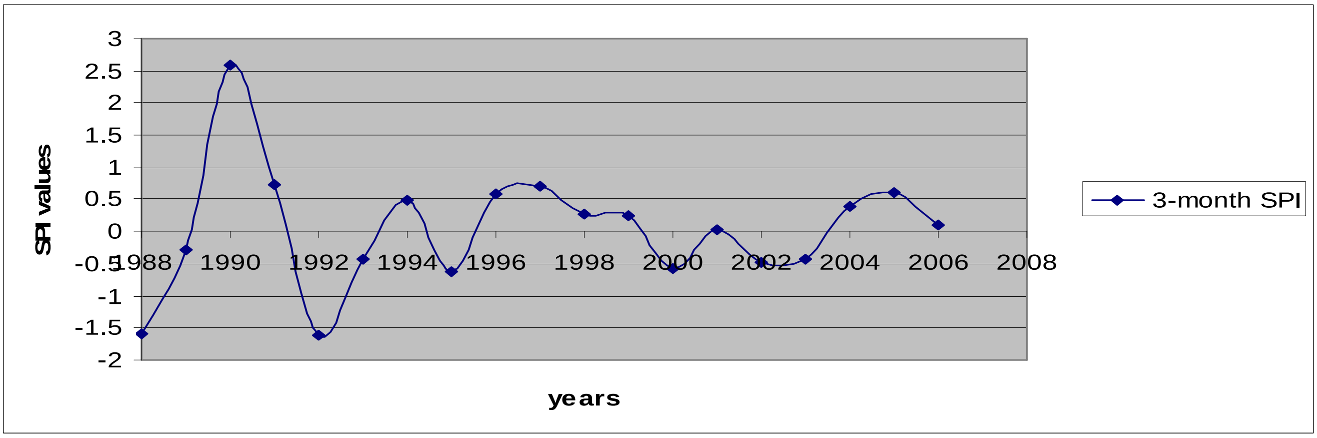

Figure 5-18. 3- Month and 6- month SPI time series of Wush wush for belg season.

The analysis of the 3-month SPI time series indicated that the record minimum SPI observed in 1984 and 1999 at Billate station. The drought severity in this time scale was evaluated as extreme (SPI= −2.35 in 1984 and SPI= −2.11 in 1999). The year 1984 was the El Nino that resulted in great drought over Ethiopia and 1999 was La Nina year. Table 5-2. Shows lists of stations and years of extreme, severe and moderate droughts and their occurrence in relation to El Nino and La Nina. El Nino years are highlighted with green color and La Nina years with red color.

Table 5-2: list of stations and years each station experiences extreme, severe and moderate drought for Belg Season.

Sl.no.	Station Name	Years of extereme drought	SPI	Years of severe drought	SPI	Years of moderate drought	SPI
1	Arbaminch	No		2004	-1.66	1990 1991 2002	-1.13 -1.06 -1.33
2	Awassa	No		1988 1999	-1.53 -1.56	1982 1984 2004	-1.07 -1.1 -1.39
4	Billate tena	No		1973 1988 1992	-1.82 -1.83 -1.88	1984 1986	-1.48 -1.32
5	Buie	No		No		1992 1994 1999	-1.26 -1.16 -1.38
5	Mirab abaya	No		1984 1990	-1.71 -1.75	1989 1991 2003	-1.02 -1.03 -1.26
6	Tepi	No		No		2005 2007	-1.01 -1.36
7	Wolita sodo	No		No		1990 1999 2003	-1.26 -1.35 -1.47
8	Emdiber	No		1992 2000 2005	-1.71 -1.68 -1.75	1988	-1.43
9	Hossana	No		1988 1989	-1.58 -1.67	1991 1999	-1.23 -1.22
10	Dilla	No		No		No	
11	Sawla	No		No		No	
12	Billate	1984 1999	-2.35 -2.11	No		2000 2001 2002	-1.09 -1.22 -1.21
13	Wush wush	No		1988 1992	-1.59 -1.62	No	
14	Jinka	No		1997 2001	-1.64 -1.65	2004	-1.08
15	Masha	No		No		1995 1997 2007	-1.29 -1.34 -1.34
16	Wolkite	No		1997 1999	-1.62 -1.89	2000	-1.34

According to the NMSA, a cool event (La Niña) leads to decreased rainfall in the *belg* season and heavy rainfall during the main (*kiremt*) rainy season (Bekele 1993). A warm event is associated with an above-normal rainfall during the *belg* season. According to previous droughts, a positive SST anomaly that lasts at least a year is always associated with severe *kiremt* drought in Ethiopia (*ibid*.). Thus, during ENSO years, *belg* rains are heavy and the main summer (*kiremt*) rains are reduced. In normal seasons, *belg* rains are variable and the main rains are stable (Glantz 1996). The abnormally heavy rainfall in the 1996 summer (*meher*) season in Ethiopia (when NMSA had issued an early warning) might have been linked to a La Niña (eg, cold event).

When the 3-month SPI is analyzed it was seen that, severe droughts recorded in the year 2004 and moderate droughts have been observed in the years 1990, 1991 and 2002, the remaining years have been recored normal rain fall. It has been seen that moderate droughts occur more frequently than severe drought and no extreme drought have been recorded.

Awassa have been experienced two severe drought in the historical data records, in the years 1988 and 1999 (Fig. 5-3) with SPI -1.53 and -1.56 respectively. Moderate droughts have been observed in the years, 1982, 1984 and 2004 with SPI values -1.07, -1.1 and -1.39 respectively. Billate tenna is one of the stations that expreinced frequent Severe drought. It has been observed that severe droughts were recorded in years 1973, 1988 and 1992 with SPI values -1.82, -1.83 and -1.88 respectively. Moderate droughts were observed in 1984 and 1986 with SPI of -1.48 and -1.32.

Moderate to severe drought have been observed at Emdiber. Severe droughts occurred in the years, 1992, 2000 and 2005 with SPI value -1.71, -1.68 and -1.75 respectively. Moderate droughts have been occurred in 1988 with SPI value of -1.43. Billate (Fig. 5-6) is the only station which has been recorded an extreme drought in 1984 and 1999 with SPI -2.35 and -2.11. Also it has been observed that more frequent drought have been occurred in Billate in 2000, 2001 and 2002.

In general severer to moderate drought has been observed in many of the stations considered in different years. Severe drought occurred in Arbaminch (Fig. 5-4), in the year 2004(SPI = -1.66), at Mirab abaya (Fig.5-13) in the years of 1984 and 1990, at Hossana (Fig.5-10), in the years, 1988 and in 1989, at Wush wush (Fig. 5-18) in 1988 and 1992, at Jinka (Fig. 5-11) in 1997 and 2001, at Wolkite (Fig. 5-17), in 1997 and in 1999 during Belg season. Moderate droughts have been observed almost in all of the stations at different years. More frequent moderate droughts have been observed at Arbaminch in the years, 1990, 1991 and 2002, at Tepi (Fig.5-14) in the years 2003, 2004, 2005 and 2007, at Buie (Fig. 5-5) in the years 1992, 1994 and 1999, at Wolaita Sodo (Fig. 5-15) in the years 1990, 1999 and 2003, at Billate from 2000–2002 and at Masha (Fig. 5.11) in the years 1995, 1997 and 2007. Dilla (Fig.5-8) and Sawla (Fig. 5-14) stations haven't experienced any drought phenomenon in the whole years analyzed.

Many of the drought years for Belg season occurred in the El Nino years that result major drought in the country while the precipitation is expected to be normal and above normal for belg producing regions in Ethiopia. Some drought also occurred during La Nina years at which the amount of pricipitation is expected to be below normal. As a result some station in SNNPR is sensitive to El Nino years and other are sensitive to La Nina years.

5.4. Temporal Characteristics of drought for Kiremet

Kiremet season contributes to around 10 % of the total annual production of SNNPR. It is there fore essential to make analysis of the 3-month SPI time series for this season. Figures 5-19 to 5- 34 present time series of 3-month SPI for 16 stations.

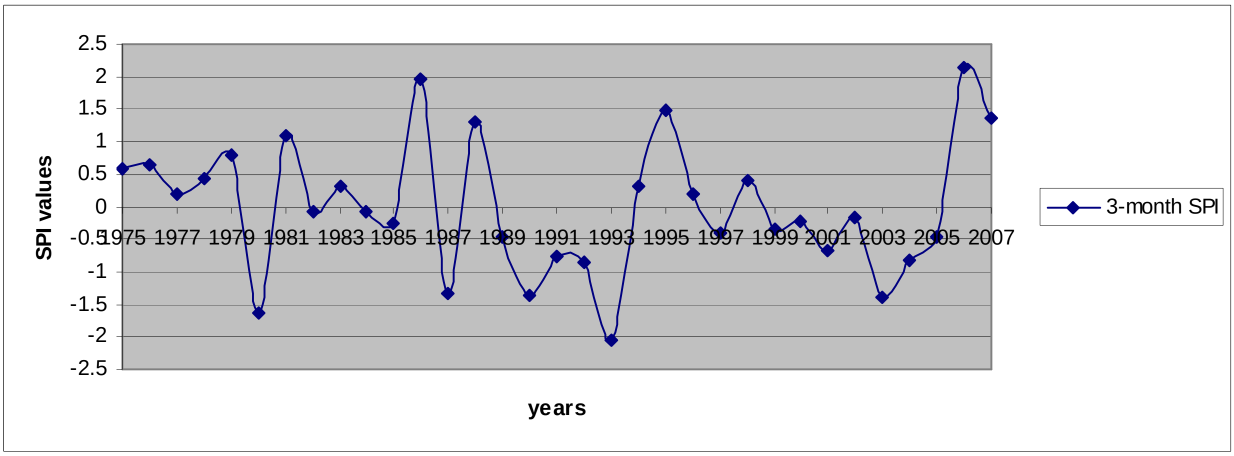

Figure 5-19. 3- Month SPI time series of Awassa for kiremet season

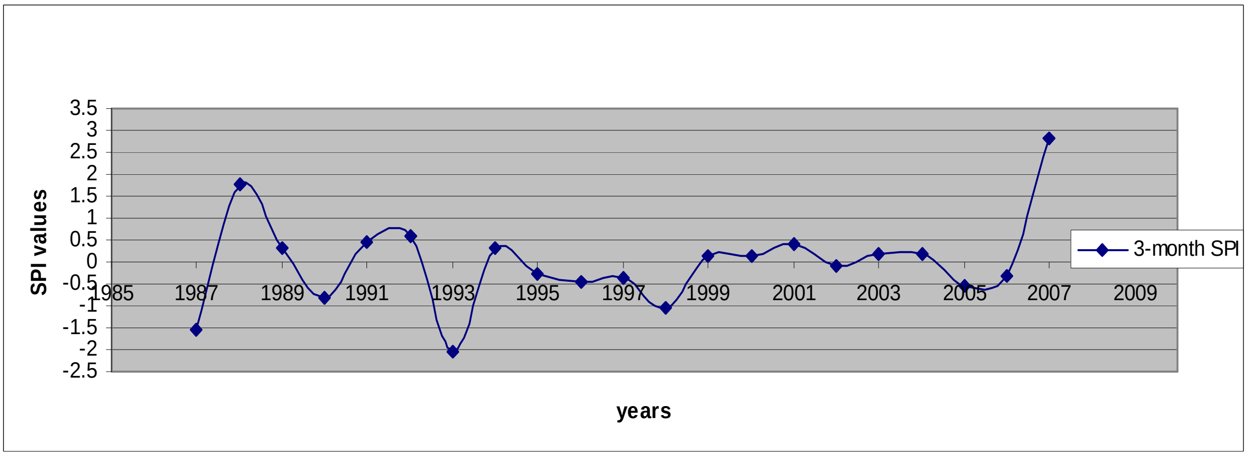

Figure 5-20. 3- Month SPI time series of Arbaminch or kiremet season

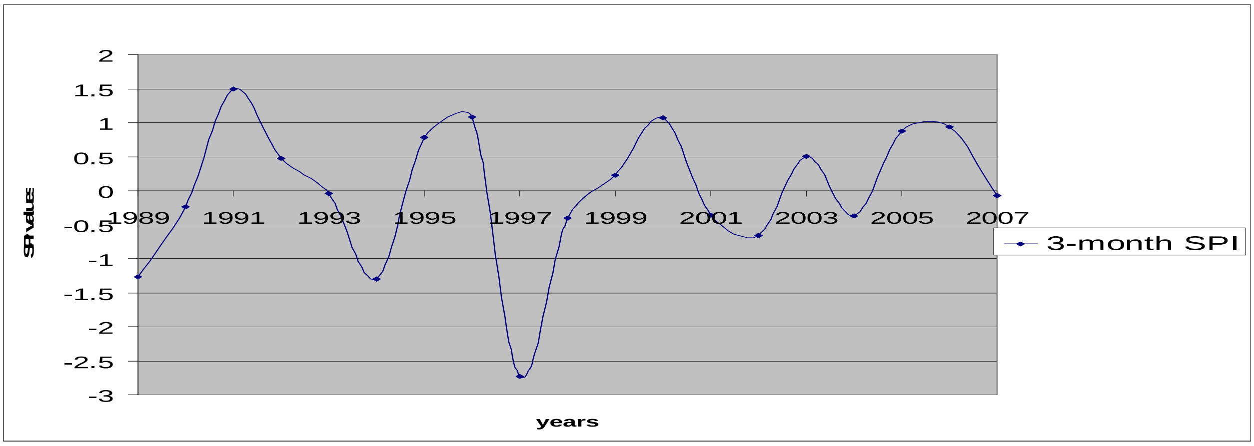

Figure 5-21.3- Month SPI time series of Buie or kiremet season

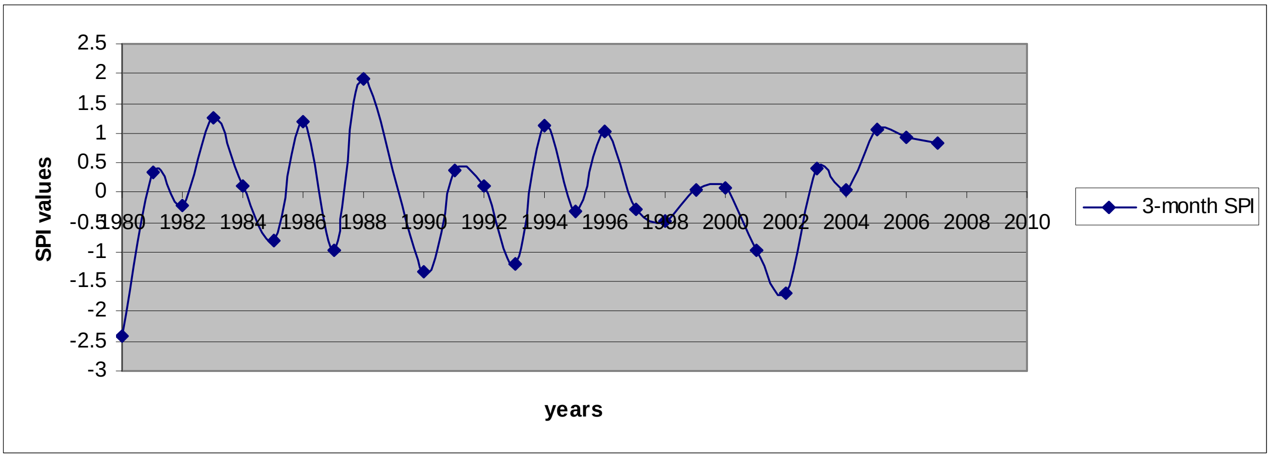

Figure 5-22.3-Month SPI time series of Bellate for kiremet season

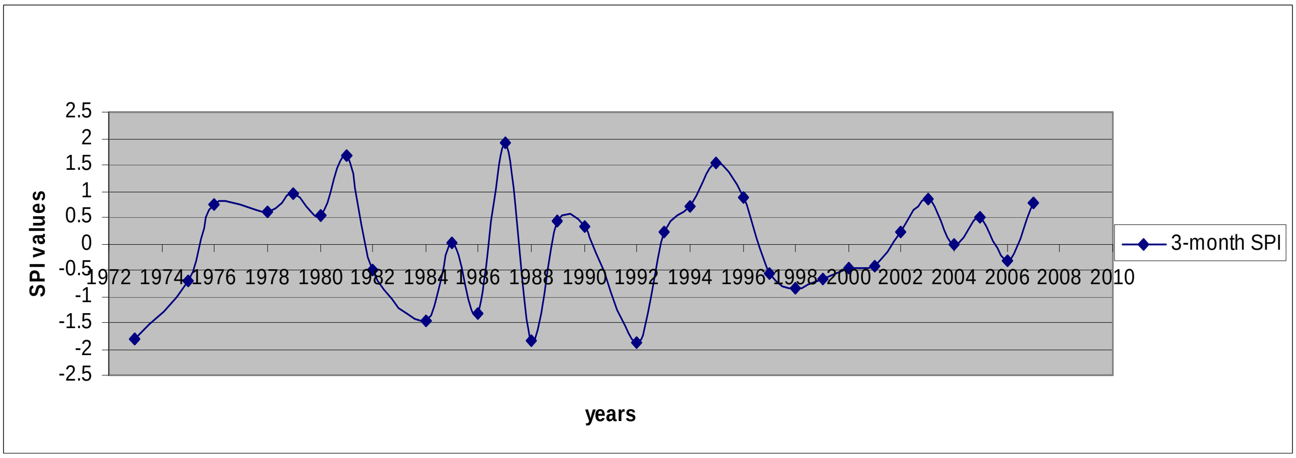

Figure 5-23. 3 –Month SPI time series of Billate tena for kiremet season

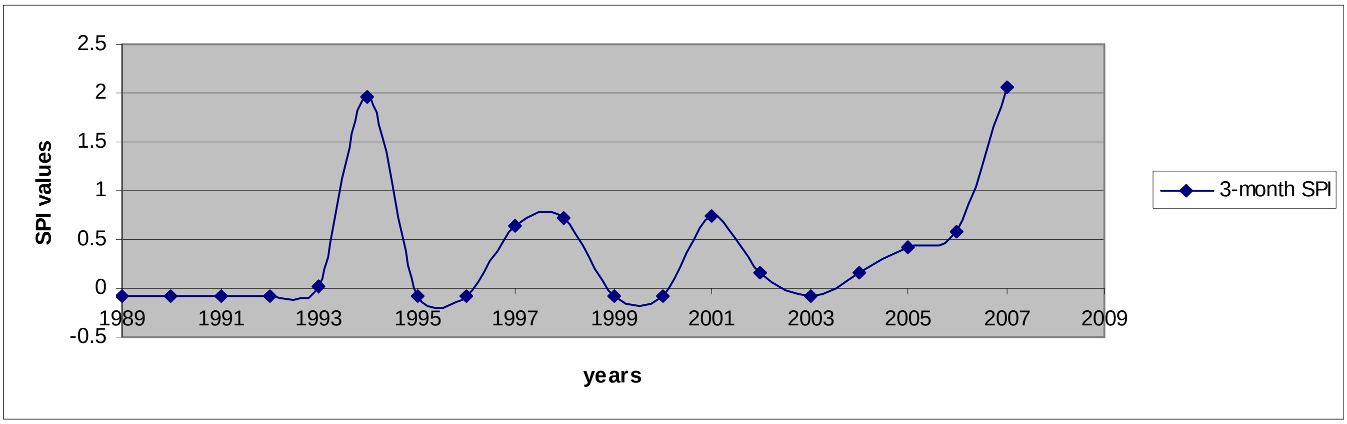

Figure 5-24. 3- Month SPI time series of Dilla for kiremet season

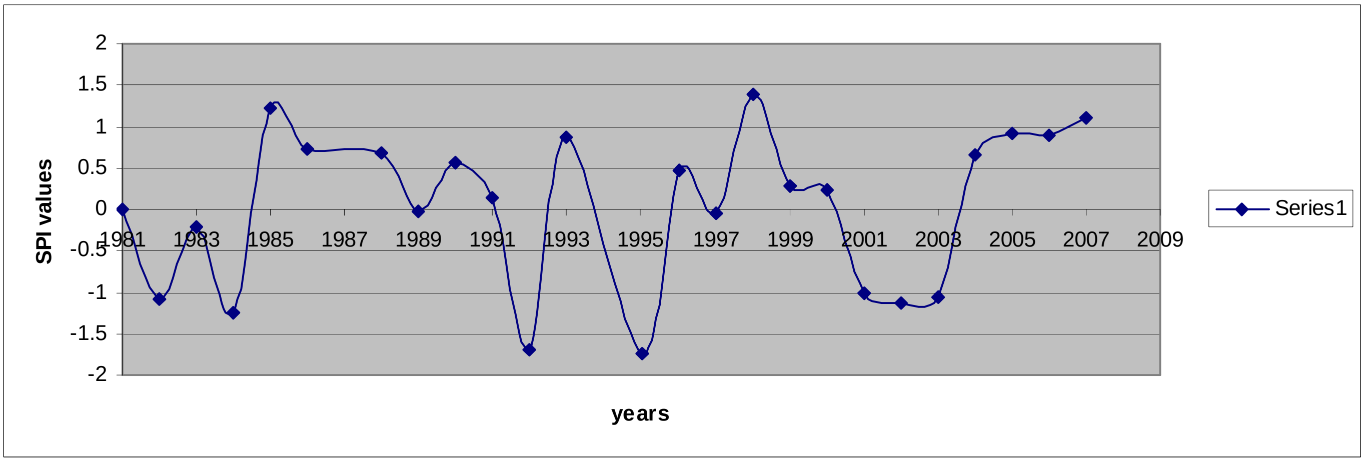

Figure 5-25. 3- Month SPI time series of Emdibir for kiremet season

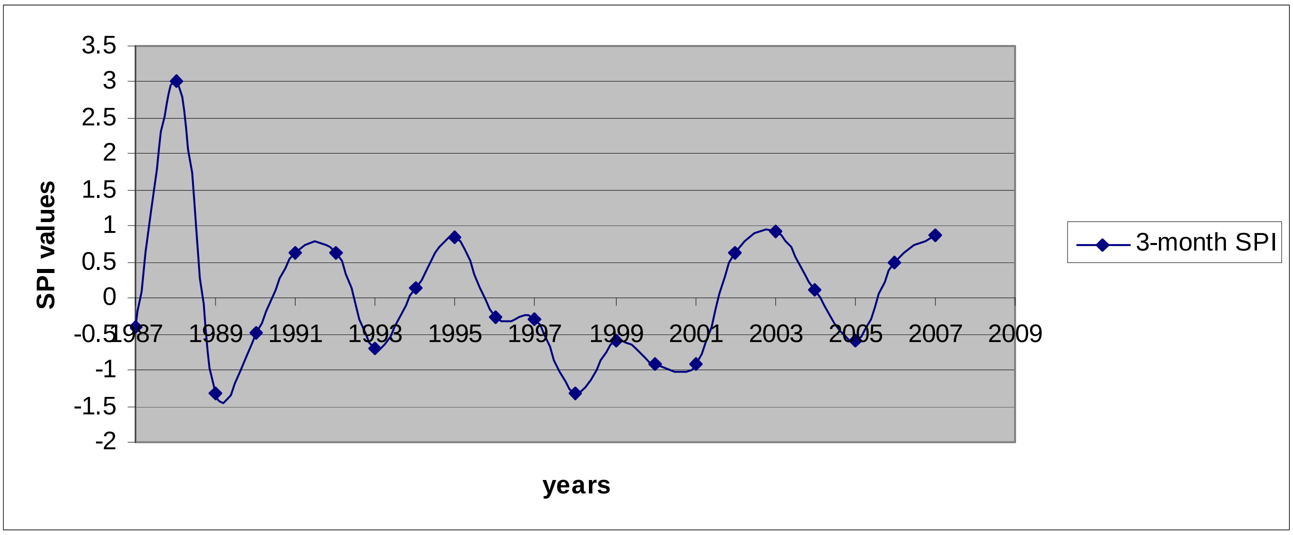

Figure 5-26. 3- Month SPI time series of Hossana for kiremet season

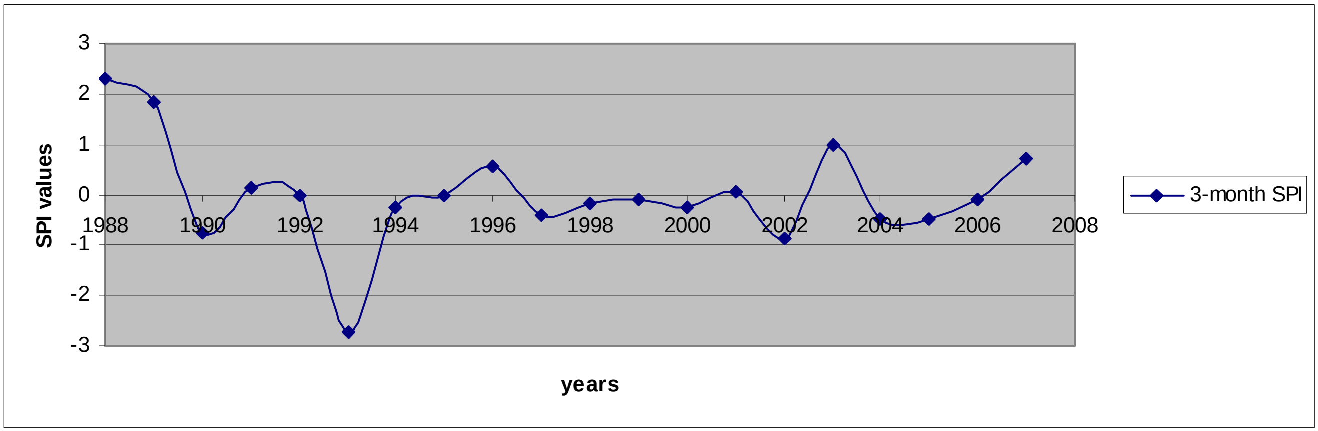

Figure 5-27. 3- Month SPI time series of Jinka for kiremet season

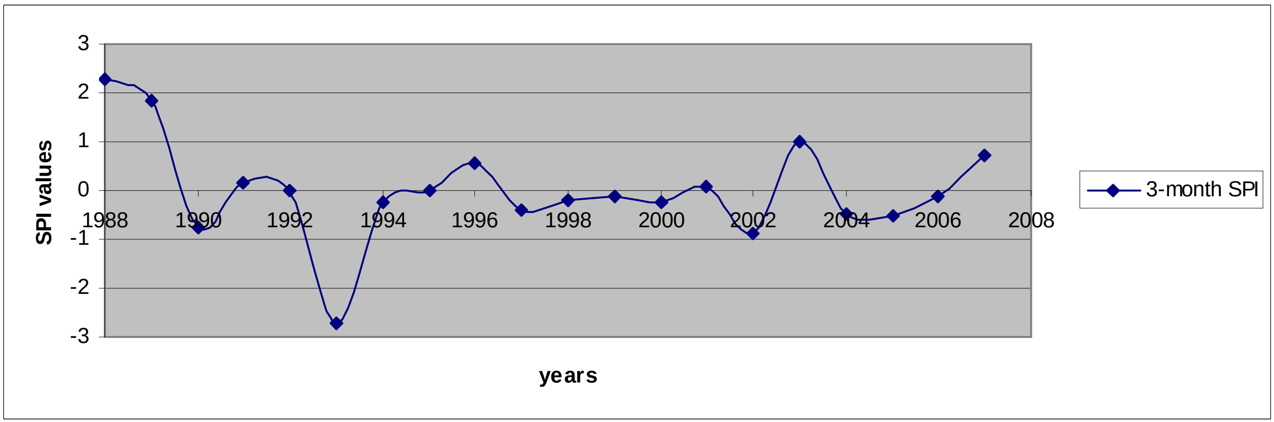

Figure 5-28. 3- Month SPI time series of Masha for kiremet season.

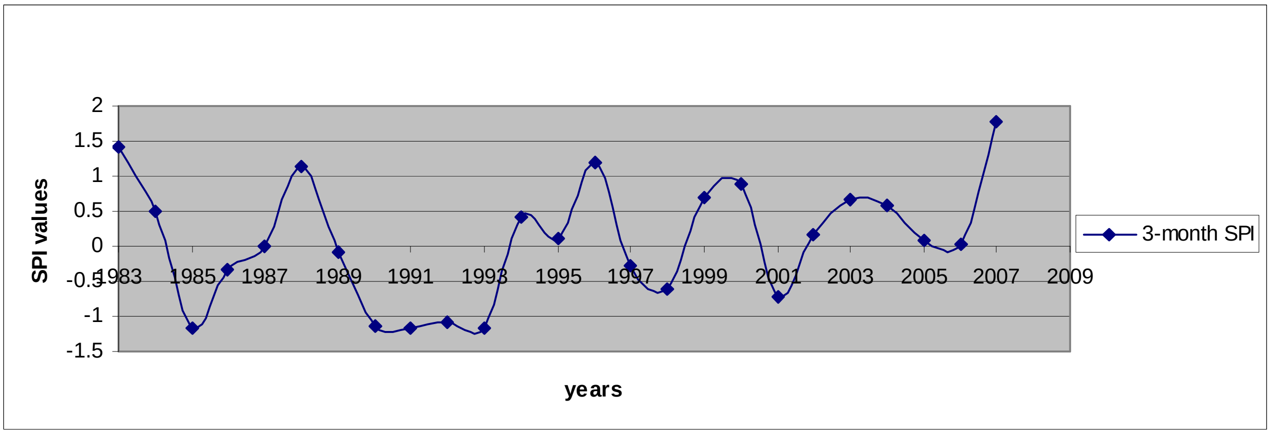

Figure 5-29. 3- Month SPI time series of Mirab abaya for kiremet season

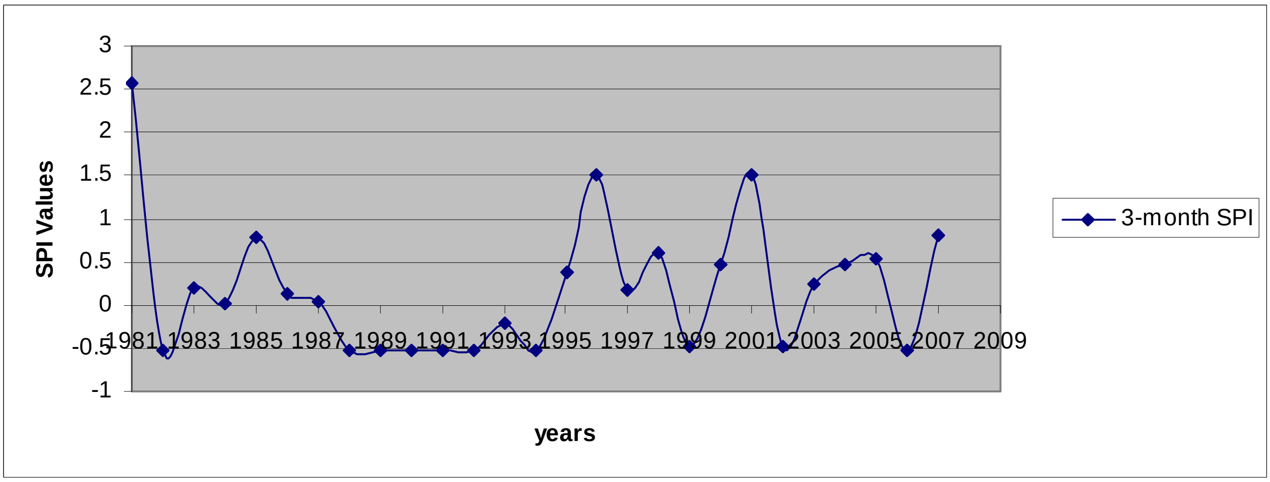

Figure 5-30. 3- Month SPI time series of Sawla for kiremet season

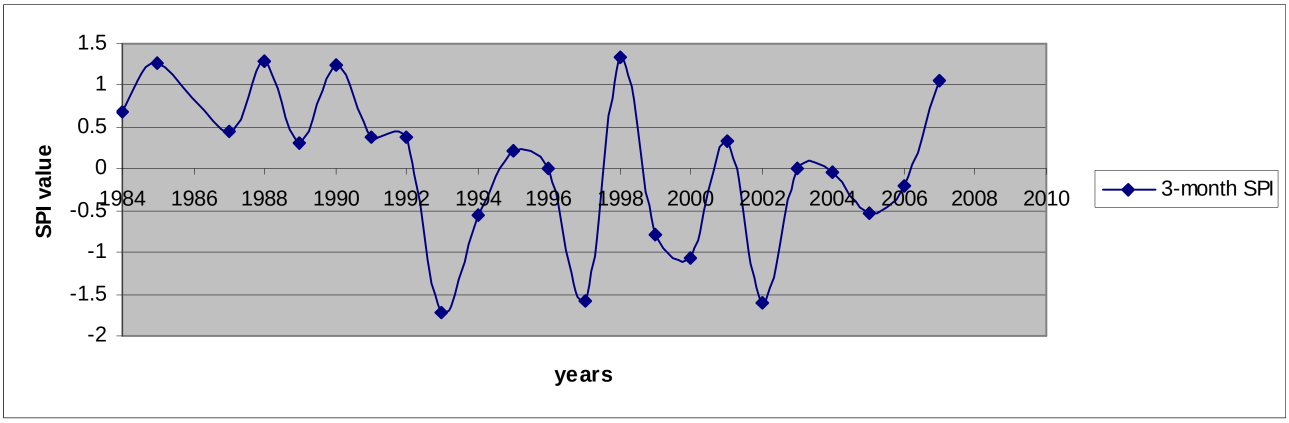

Figure 5-31. 3- Month SPI time series of Tepi for kiremet season

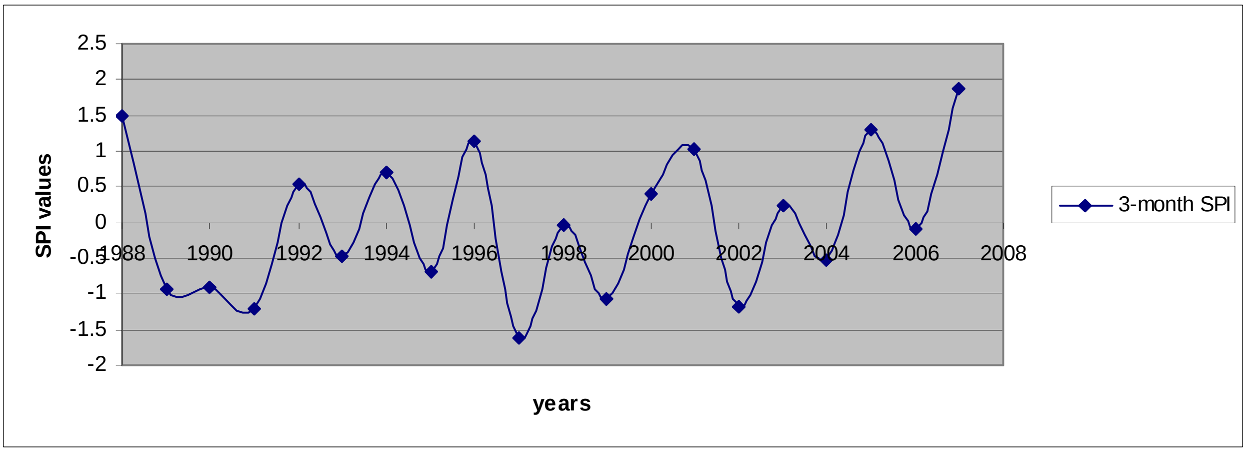

Figure 5-32. 3-Month SPI time series of Wolita Sodo for kiremet season.

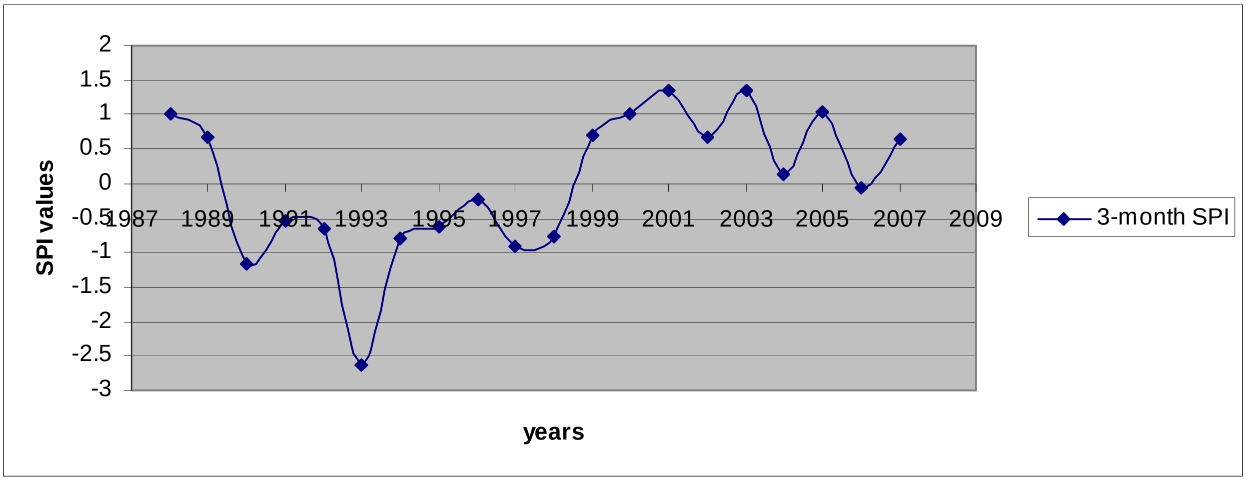

Figure 5-33. 3- Month SPI time series of Wolikite for kiremet season

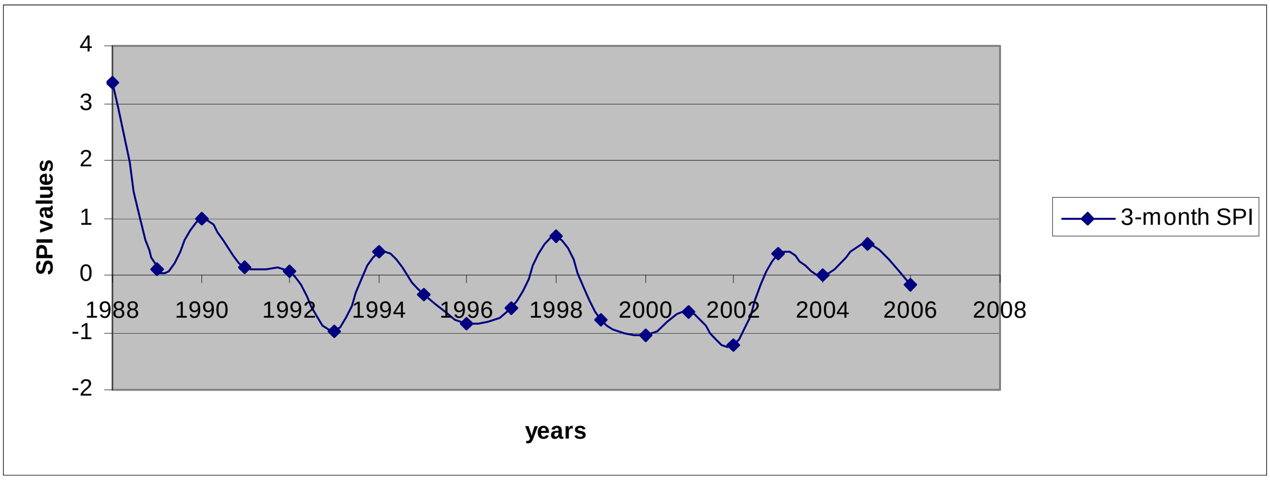

Figure 5-34. 3- Month SPI time series of Wushwush for kiremet season

El Niño affects the *Kiremt* seasonal weather in Ethiopia by weakening the rain-producing systems in the region and by distorting the amount and distribution of rainfall in Ethiopia (Kassahun 1999). La Niña has the opposite effect on the *Kiremt* rainfall, as was seen in 1970, 1971, 1988 and 1996, when there was above-normal *Kiremt* rainfall in Ethiopia (Kassahun 1999). Regions that are usually affected by El Niño are northern, northeastern and eastern parts of Ethiopia. Table 5-2 presents list of stations and years each station experiences extreme, severe and moderate drought for Meher season. El Nino events are highlighted as green color and La Nina years are highlighted as red.

Table 5-3: list of stations and years each station experiences extreme, severe and moderate drought for Kiremet season.

Sl.no.	Station Name	Years of extereme drought	SPI	Years of severe drought	SPI	Years of moderate drought	SPI
1	Arba Minch	1993	-2.04	1987	-1.53	1998	-1.05
2	Awassa	1993	-2.04	1980	-1.64	1987 1990 2003	-1.33 -1.35 -1.4
3	Billate tena	1985	-2.2	1984	-1.56	1990 2003	-1.41 -1.22
4	Buie	1997	-2.17	1989	-1.95	No	
5	Mirab abaya	No		no		1985 1990 1991 1992 1993	-1.18 -1.14 -1.18 -1.09 -1.18
6	Tepi	No		1993 1997 2002	-1.71 -1.59 -1.61	2000	-1.06
7	Wolita sodo	No		1997	-1.61	1991 1999 2002	-1.21 -1.08 -1.17
8	Emdiber	No		1992	-1.7	1982 1984 2001 2002 2003	-1.09 -1.24 -1.01 -1.14 -1.06
9	Hossana	No		No		1989 1998	-1.31 -1.31
10	Dilla	No		No		No	
11	Sawla	No		No		No	
12	Billate	1980	-2.42	2002	-1.7	1990 1993 2000 2002	-1.33 -1.19 -1.05 -1.23
13	Wush wush			No			
14	Jinka	1993	-2.72	No		No	
15	Masha			No		1992 1996 2006 2007	-1.04 -1.1 -1.1 -1.1
16	Molkite	1993	-2.64	No		1990	-1.17

Many stations have been experienced extreme droughts (SPI<-2) compared to Belg season. Arbaminch (Fig. 5-20), Awassa (Fig. 5-19), Jinka (Fig. (5-27) and Wolkite (Fig. 5-33) experienced extreme drought in 1993. Billate tena (Fig. 5-20), Billate (Fig. 5-4), Buie (Fig. 5-21) experienced extreme drought in the years 1985, 1980 and 1997 respectively. Severe droughts (-2<SPI<-1.5) have been observed in many of the stations considered in different years. Severe drought occurred in Arbaminch, in the year 1987, in Awassa in1980, in Blate tena in 1984, at Billate in 1980, at Tepi in the years 1993, 1997 and 2002, at Emidiber in the years 1992, and 1995, at Wolita sodo in 1997 and Billate in 2002. Moderate drought has been observed many of the stations at different years. More frequent moderate droughts have been observed at Mirab abaya in the years, 1985, 1990, 1991, 1992 and 1993 and at Emdibir in the years 1982, 1984, 2001, 2002 and 2003.

5.5. Drought occurrence frequency

5.5.1. Belg Season

Figure 5- 35, shows the number of years each station experienced severe drought relative to the number of years analyzed. Among the number of years analyzed more frequent (three) severe drought have been occurred at Billate tena and Emdiber and less frequent (one) severe drought at Arbaminch. No severe drought have been recorded at the following stations:- Buie, Tepi, Dilla, Sawla, Wush wush, Jinka, Masha and Wolkite.

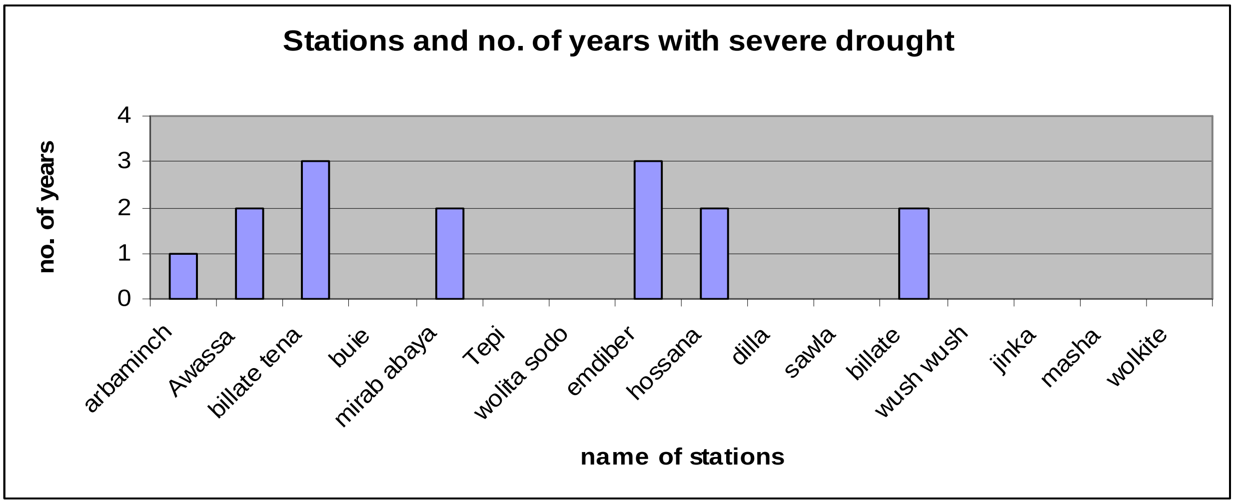

Figure 5–35. Stations and no. of years with severe droughts for each station for BELG.

Figure 5-36 shows the number of years each stations experienced moderate drought relative to the number of years analyzed. Except Dilla and Sawla stations all the stations considered in this study experience moderate droughts frequently. Among the number of years analyzed more frequent moderate drought have been occurred at Tepi, and less frequent moderate drought at Emdibir, Jinka and Wolkite.

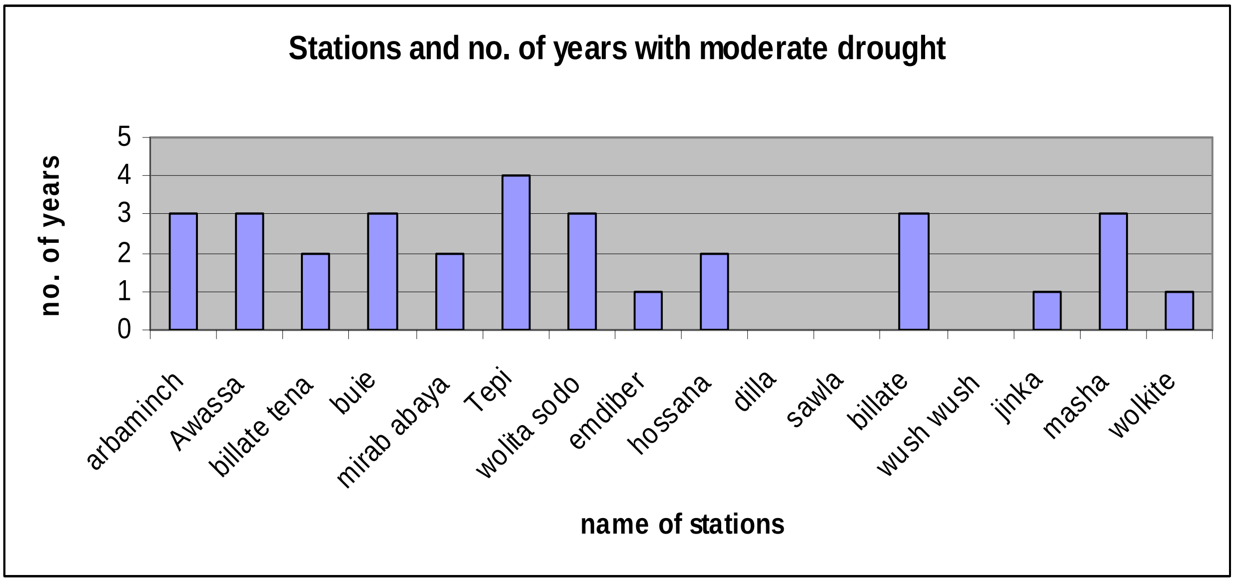

Figure 5-36. Stations and no. of years with moderate drought for each station BELG.

5.5. 2. Kiremet Season

For Kiremet season more number of stations have experienced extreme drought compared to Belg season. Figure 5-37 shows the frequency of severe droughts occurrence with respect to each station. Severe droughts have been observed more frequently at Tepi (three) and Emdiber (two) stations. Arbaminch, Awassa, Billate tena, Buie and Wolita sodo experienced less frequent severe drought (one) and other stations didn't experience severe srought in their historical data.

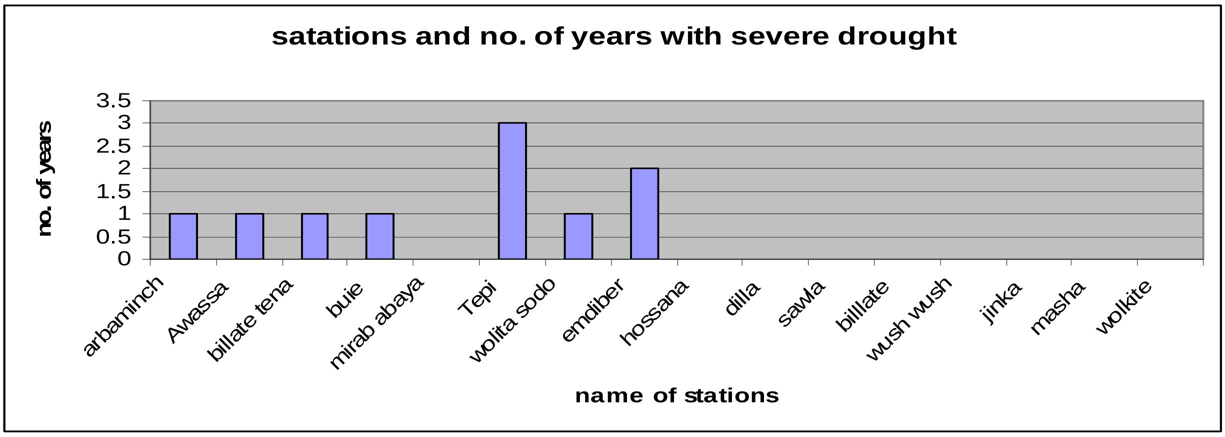

Figure 5-37. Stations and no. of years with severe drought for each station for Kiremet

Figure 5-38 shows all stations have experienced more frequent moderate droughts except Dilla and Sawla. More frequent moderate droughts have been observed at Mirab Abaya (five), Emdiber (five) and Masha (four) stations and less frequent drought (one) at Arbaminch, Tepi and Wolkite for Meher season.

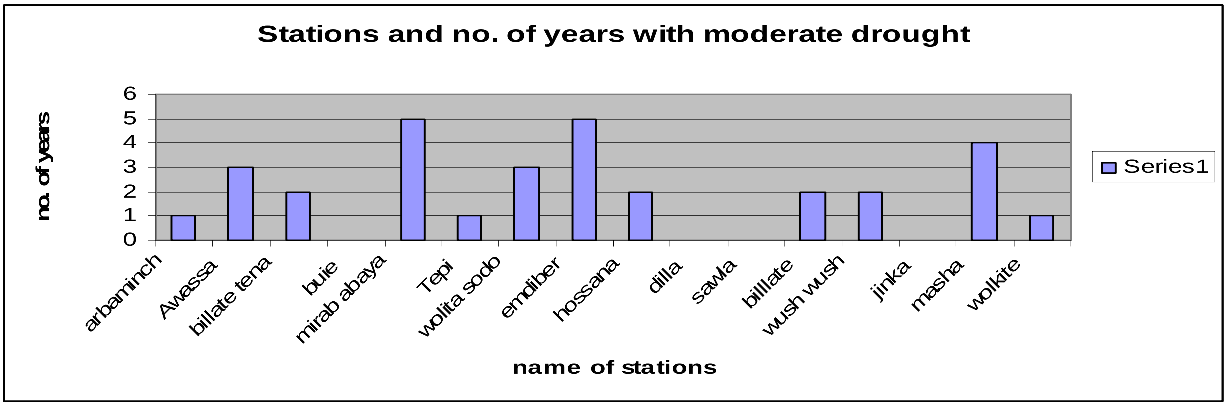

Figure 5-38. Stations and no. of years with sever drought for each station for MEHER.

5.6. Sspatial Characteristics of Drought in SNNPR

Although the estimation of drought severity at a point or as regional representative gives useful information for drought management, it is interesting and important to assess the drought over a specified region. The regional drought analysis is useful for determining the spatial distribution and characteristics of drought, and evaluating the most affected areas for a specific drought event. In this study, the spatial analysis was performed by plotting 3-month SPI value using surfer 8 soft ware. Fig. 5-39 to 5-41 presents the spatial characteristics of drought in SNNPR from 1989 to 2007

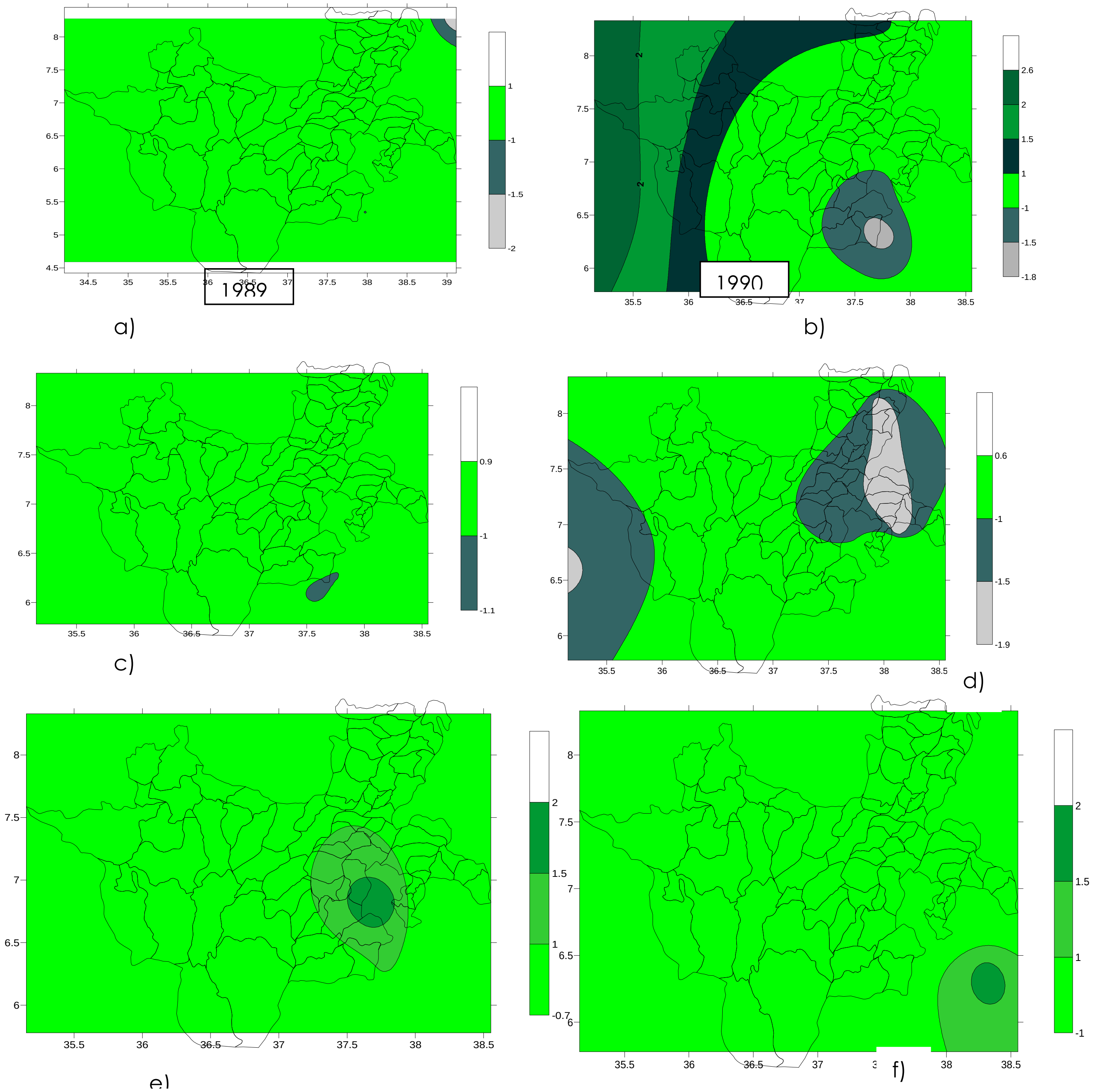

Figure 5-39(a)–(f). Spatial Characteristics of Drought in SNNPR, 1989-1994)

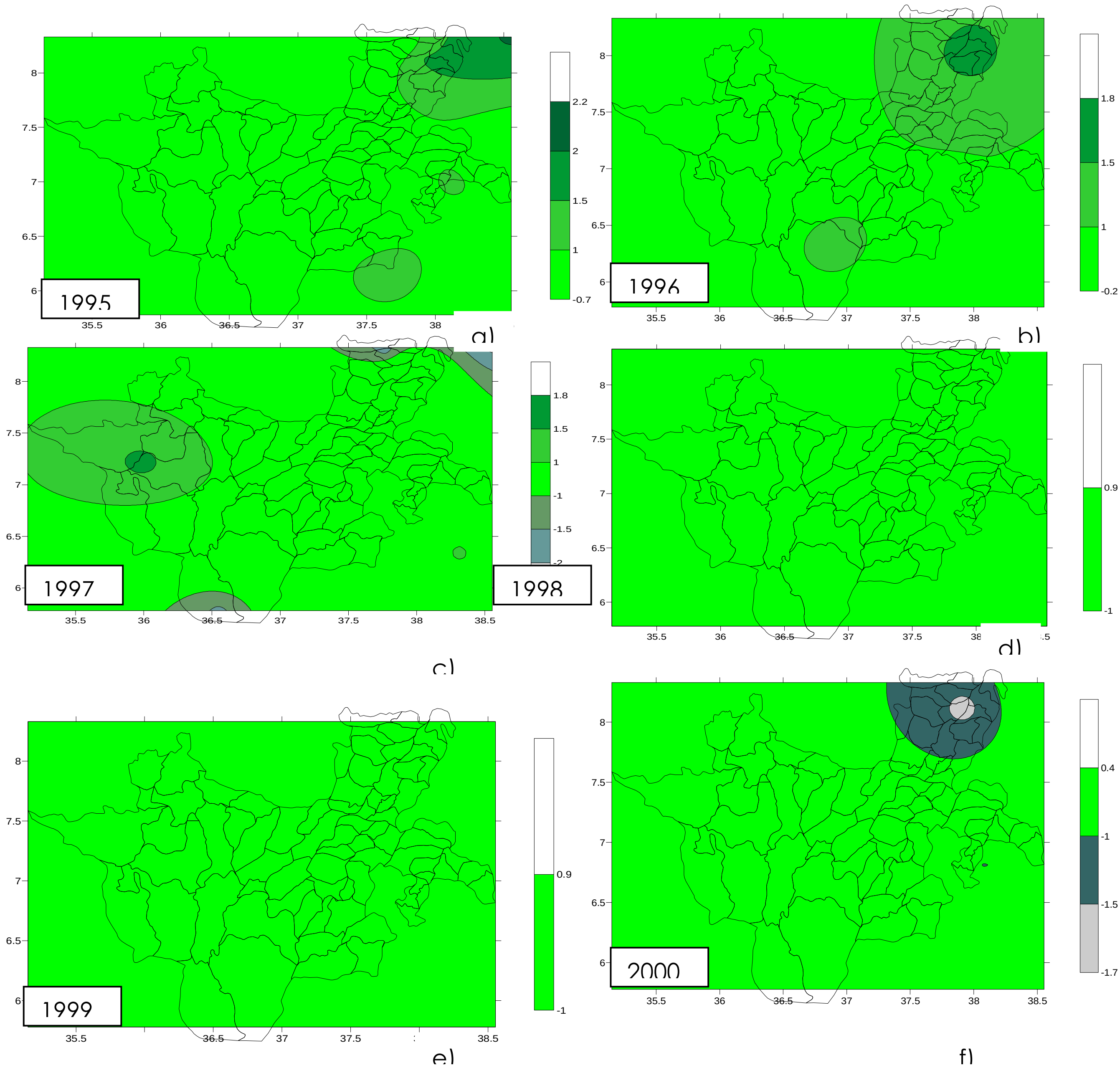

Figure 5-40 (a)–(f). Spatial Characteristics of Drought in SNNPR (1995-2000)

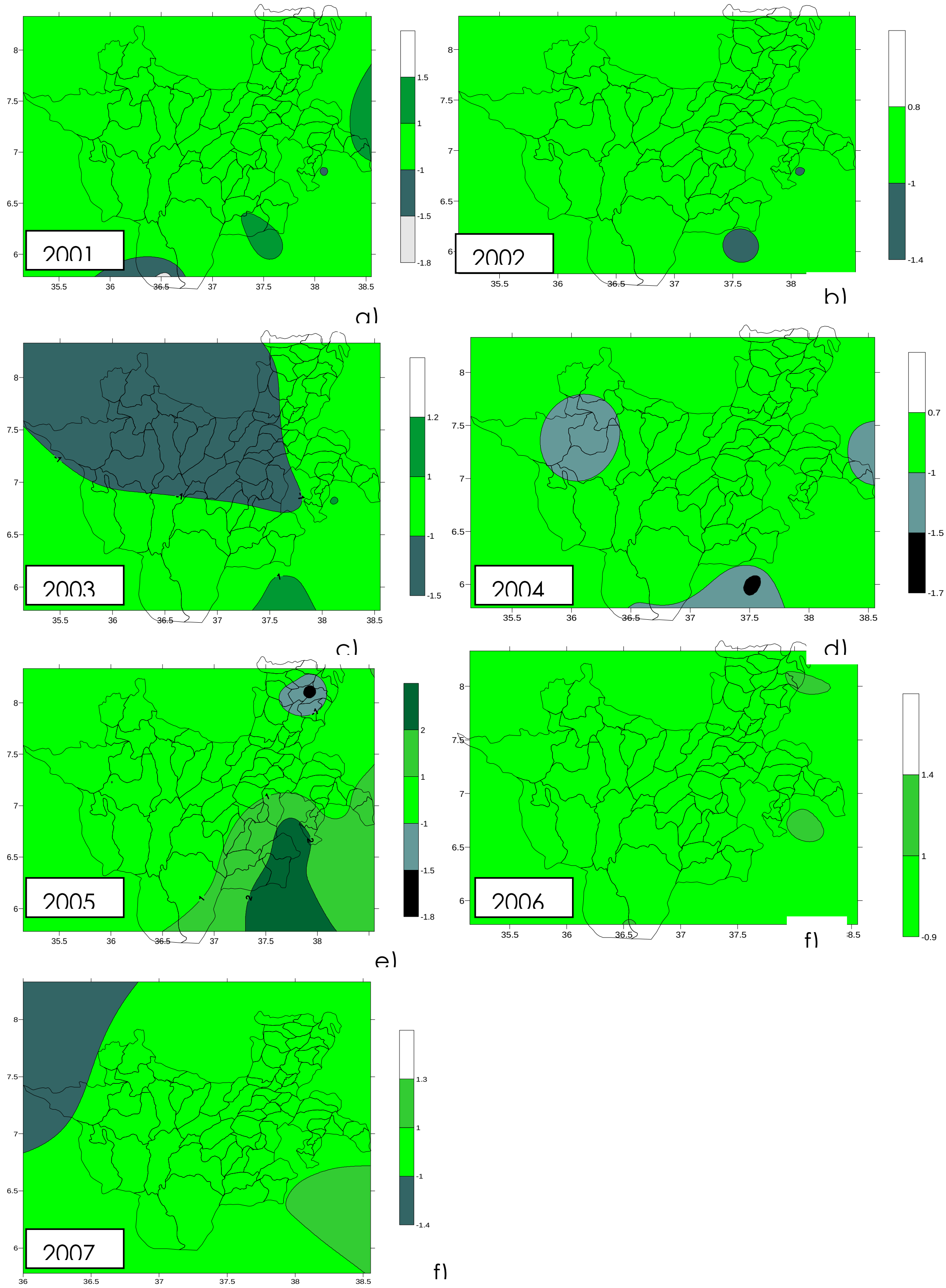

Figure 5-41 (a)–(g). Spatial Characteristics of Drought in SNNPR (2001-2007)57

Using the developed SPI database and the abilities of Surfer 8, one can visualize the distribution of SPI values across the area of interest for various time scales. As an example, Fig.5-39 shows the variation of SPI across SNNPRS from 1989 to 2007 for time scales of 3-month for Belg season as most of the areas in this region receives the majority of their annual rainfall in this season and about 70 percent of the grain is produced also in this season. It should be noted that year 2003 is the driest year in record for that covers wide area of the region. The spatial distribution of drought for this particular year is quite different when the 3-month SPI was assessed (Fig. 5-39). Using the 3-month SPI, it seems that an area in the north of the region, North West and with direction north to southeast was the area affected the most by the drought.

Figure 5-39 also shows there is less probability of drought occurrence in many of the areas in the region as most of the areas is this region receive normal rain fall in many of the years analyzed in this study. However severe and moderate drought has been observed occasionally. For instance drought occurs in 1990, at the South Eastern portion of the region. In 1992, the East, North East and Western areas of the region have experienced moderate and severe drought. A major drought that's covered most of the areas of the region is experienced in 2003. Other droughts have occurred in at the North East portion of the region in 2000 and 2005 and South and North west portion in 2004.

UNIT SIX

CONCLUSIONS AND RECOMENDATIONS

6.1. Conclusion.

This study was focused on presenting analysis of the temporal and spatial characteristics and frequency of droughts in SNNPRS, Ethiopia. The 3-month SPI computed was used as an indicator of drought severity. The SPI was computed for 16 stations representing the different parts of the region. Using this database an analysis of the temporal variation and frequency of droughts using 3-month SPI was made and analysis of the spatial variation of droughts with the help sulfur 8 software was also discussed.

The temporal and spatial drought analyses indicated that SNNPRS experience quite frequent moderate and severe droughts on seasonal basis. Severe and extreme droughts have been experienced intensely at Billate tena and Emdiber and less frequent severe drought at Arbaminch during belg season and severe droughts have been observed more frequently at Tepi and Emdiber stations. Arbaminch, Awassa, Billate tena, Buie and Wolita sodo experienced less frequent severe drought and other stations didn't experience severe drought in their historical data.

The spatial analysis of droughts also illustrates that severe and moderate drought has been experienced in different years. For instance drought occurs in 1990, at the South Eastern portion of the region. In 1992, the East, North East and Western areas of the region have experienced moderate and severe drought. A major drought that's covered large portion of the region is experienced in 2003. Other droughts have occurred in at the North East portion of the region in 2000 and 2005 and South and North West portion in 2004. The identification of the temporal and spatial characteristics of droughts in the region will be useful for the development of a drought preparedness plan in the region.

6.2. Recommendations.

Drought is the most complex of all natural hazards. The lack of progress in drought preparedness planning and the development of national drought policies is a reflection of this complexity. As countries move towards a higher level of preparedness, drought monitoring and early warning systems become paramount because these systems provide the information necessary to make timely decision regarding the management of water and other natural resources.

Just as critically important is the development of delivery systems that provide decision makers at all levels and for all primary sectors with data and information that will assist them in making timely decisions. These decision support tools provide end users with information they need to reduce the most serious consequences of drought and reduce the need for government and donor intervention in the form of drought assistance and relief.
The Standard Precipitation Index is one of the tools used to monitor the areal extent and frequency of drought in a certain region. In this study data obtained from limited stations that have a relatively long year record of rain fall have been used for the computation of the Standard Precipitation Index (SPI). A better result would have been obtained if there is more number of stations with longer years of record.

To compensate the scarcity and un availability of long year rainfall data, remote sensing data obtained from satellite such as NDVI, can be used to compute Standard vegetation index (SVI) or Vegetation Condition Index (VCI), as remote sensing data have better spatial and temporal coverage compared to ground data.

The future research steps will be to investigate the interconnectivity of meteorological drought with hydrological and water resources drought, to evaluate the forecasting potential of droughts using remote sensing indices (e.g. NDVI) and meteorological data, and to predict the spatiotemporal distribution pattern of SPI with a generalized global interpolation model.

REFERENCES

Alley, W.M., 1984, The Palmer Drought Severity I ndex: Limitat ions and Assumpt ions, Journal of Climate and Applied Meteorology (23) , p. 1100-1109.

Attia, B.B., and A.B. Abulhoda, 1992: The ENSO Phenomenon and Its Impact on the Nile's Hydrology. In M.A. Abu-Zeid and A.K. Biswas (Eds.), *Climate Fluctuations and Water Management*. Butterworth Heinemann. 71-79.

Ayalew, M. (Former Head of The Early Warning and Planning Department, The Relief and Rehabilitation Commission), 1996: Addis Ababa, Ethiopia. *Letter,* August 26.

Babu, A., 1999: The Influence of El Niño/ Southern Oscillation (ENSO) on the Ethiopian Seasonal Rainfall. *Paper presented at ICTP/WMO International Technical conferenceon long-range Weather Forecasting Research (Trieste, Italy, 8-12 April 1991*).

Banik, P., Mandal, A. and Rahman, M.S., 2002. Markov chain analysis of weekly rainfall data in determining drought-proneness. Discrete Dynamics in Nature and Society, 7(4): 231-239.

Bavadam, L., 2001. Dealing with drought frontline, pp. 09-22.

Bekele, F., 1993: Ethiopian Use of ENSO Information in Its Seasonal Forecasts. In M. H. Glantz (Ed.), *Workshop on Usable Science: Food Security, Early Warning and El Niño*. 25-28 October, 1993. Budapest, Hungary, Boulder: National Center for Atmospheric Research, 117-121.

Brown, F.J., Reed, C.B., Hayes, J.M., Wilhite, A.D. and Hubbard, K., 2002. A Prototype Drought monitoring system integration climate and satellite data Pecora 15/Land Satellite Information IV/ISPRS Commission I/FIEOS 2002 Conference Proceedings

Bruzzone, L. and Prieto, D., 2000 Automatic analysis of the difference image for unsupervised change detection Ieee Transactions on Geoscience and Remote Sensing 38(3): 1171-1182

Bruzzone, L. and Prieto, D., 2002. An adaptive semiparametric and context-based approach to unsupervised change detection in multitemporal remote-sensing images IEEE Transactions on

Image Processing 11(4): 452-466

Cane, M.A., 1993: ENSO and Its Prediction: How Well Can We Forecast It? *Usable Science: Food Security, Early Warning and El Niño.* 25-28 October 1993, Budapest, Hungary, Boulder: National Center for Atmospheric Research.

Cane, M.A., E. Gideon, and R.W. Buckland, 1994: Forecasting Zimbabwean maize yield using eastern equatorial Pacific seas surface temperature. *Nature*, **370**:21, July, 204-5.

Cazacioc, L. and Cipu, E.C., 2004. Evaluation of the transition probabilities for daily precipitation time series using a Markov chain model, 3-rd International Colloquium ”Mathematics in Engineering and Numerical Physics”. Balkan Society of Geometers, Geometry
Balkan Press 2005, Bucharest, Romania.

Coughlan, M.J. 1987. Monitoring drought in Australia. Pages 131-144 *in* Planning for Drought: Toward a Reduction of Societal Vulnerability (D. A. Wilhite and W. E. Easterling, ed.). Westview Press, Boulder, Colorado.

Degefu, W., 1987: Some aspects of meteorological drought in Ethiopia. In M. H. Glantz (Ed.), *Drought and Hunger in Africa*. Cambridge: Cambridge University Press.

DPPC (Disaster Preparedness and Prevention Commission), 1996: *DPPC News.* **6**:3, April.

Doesken, N.J.; T.B. McKee; and J. Kleist. 1991. Development of a surface water supply index for the western United States. Climatology Report Number 91–3, Colorado State University, Fort Collins, Colorado.

Eltahir, E.A., 1966: El Niño and the natural variability in the flow of the Nile River. *Water Resources Research.* **32**:1, 131-137.

Edwards, Daniel, C., McKee and Thomas, B., 1997. Characteristics of 20th Century Drought in the United States at Multiple Time Scales. Climatology Report No. 97-2, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523-1371.

Farmer, G., 1993: What does the famine early warning community need from the ENSO research community? *Workshop on Usable Science: Food Security, Early Warning and El Niño.* 25-28 October, Budapest, Hungary, Boulder: National Center for Atmospheric Research, 163-168.

Gibbs, W.J., Maher, J.V., 1967**:** Rainfall Deciles as Drought Indicators. Australian Bureau of Meteorology, Bull. 48, 37 pp.

Glantz, M.H., 1996a: Are Famines so Difficult to Predict? *Internet Journal of African Studies.* http://www.brad.ac.uk/research/ijas/, **1**.

Glantz, M.H., 1996b: *Currents of Change: El Niño's Impact on Climate and Society.* Cambridge UK: Cambridge University Press.

Glantz, M.H., 1993: Introduction. Forecasting El Niño: Science's Gift to the 21st Century. In M.H. Glantz (Ed.), Workshop on *Usable Science: Food Security, Early Warning and El Niño.* 25-28 October, Budapest, Hungary, Boulder: National Center for Atmospheric Research, 3-11.

Glantz, M. H., R. W. Katz, and N. Nicholls, 1991: *Teleconnections Linking Worldwide Climate Anomalies.* Cambridge: Cambridge University Press.

Gommes, R.; and F. Petrassi. 1994. Rainfall variability and drought in Sub-Saharan Africa since 1960. Agrometeorology Series Working Paper No. 9, Food and Agriculture Organization, Rome, Italy.

Gonfa, L., 1996: *Climate Classifications of Ethiopia.* Meteorological Research Reports Series, No. 3, May. Addis Ababa, Ethiopia, National Meteorological Services Agency.

Gore, P.G. and Ponkshe, A.S., 2004. Drought in Gujarat Districts and State as key indicators to all India drought. Journal of Agrometerology, 6(1): 47-54.

Gupta, R., 2000. Water governance in Gujarat state, India International Journal of Water Resources Development, 20(2): 131-147.

Guttman, N.B., 1999. Accept ing the Standardized Precipitat ion Index: A Calculation Algoritm, Journal of the American Water Resources Association, Vol.35, No.2, pp.311-322.

Haile, T., 1988: Causes and Characters of Drought in Ethiopia. *Ethiopian Journal of Agricultural Sciences.* **10**:1-2, 85-97.

Hailu Kassaye, R., 2006. Suitability of Markov random field based method for super resolution land cover mapping, ITC, Enschede, 77 p. pp.

Hayes and Michael, J., 2006. Drought Indices National Drought Mitigation Center USA.

Hayes, M., Svoboda, M., Wilhite, D. and Vanyarkho, O., 1999 Monitoring the 1996 drought using the standardized precipitation index Bulletin of the American Meterological Society 80(3):429-438.

Heddinghaus, T.R.; and P. Sabol. 1991. A review of the Palmer Drought Severity Index and where do we go from here? In *Proc. 7th Conf. on Applied Climatology*, pp. 242–246. American Meteorological Society, Boston.

Ji, L. and Peters, A.J., 2003. Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices. Remote Sensing of Environment, 87(1): 85-98.

Jurgen, V.V., Alain, A.V., Isbelle, B., Stefan, N. and Francesca, S., 1998. Drought Monitoring from Space Using Empirical Indices and Physical Indicators, International Symposium on 'Satellite-Based Observation"-A Tool for study of the Mediterranean basin',Tunis,Tunisia. Joint Research Centre of European Commission.

Kaplan, R. D., 1988: *Surrender or Starve, the wars behind the famine.* Boulder and London: Westview Press.

Karl, T.R., 1986, The Sensit ivity of the Palmer Drought Severity I ndex and Palmer's Z- I ndex to their Calibrat ion Coefficients Including Potent ial Evapotranspiration, Journal of Climate and Applied

Meteorology, n.25.

Karl, T.R.; and R.W. Knight. 1985. Atlas of Monthly Palmer Hydrological Drought Indices (1931–1983) for the Contiguous United States. Historical Climatology Series 3–7, National Climatic Data Center, Asheville, North Carolina.

Kasetkasem, T., Arora, M. and Varshney, P., 2005 Super-resolution land cover mapping using a Markov random field based approach Remote Sensing of Environment 96(3-4): 302-314

Kasetkasem, T. and Varshney, P., 2002 An image change detection algorithm based on Markov random field models Ieee Transactions on Geoscience and Remote Sensing, 40(8): 1815-1823

Kassahun, A., 1999. Drought Risk Monitoring for the Sudan using NDVI 1982-1993, University College London, 39 pp.

Kogan, F.N. 1995. Droughts of the late 1980s in the United States as derived from NOAA polar-orbiting satellite data. *Bulletin of the American Meteorological Society* 76(5):655–668.

Kogan, F.N., 1990. Remote-Sensing of Weather Impacts on Vegetation in Nonhomogeneous Areas. International Journal of Remote Sensing, 11(8): 1405-1419.

Le Houérou, H.N.; G.F. Popov; and L. See. 1993. Agrobioclimatic classification of Africa. Agrometeorology Series Working Paper No. 6, Food and Agriculture Organization, Rome, Italy.

Lee, D. M. 1979. Australian drought watch system. Pages 173-187 *in* Botswana Drought Symposium (M. T. Hinchey, ed.). Bo tswana Society , Gaborone, Botswana.

Li, J., Lewis, J., Rowland, J., Tappan, G. and Tieszen, L.L., 2004. Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series. Journal of Arid Environments, 59(3): 463-480.

Li, S.Z., 2001. Markov Random Field Modeling in Image Analysis Springer-Verlag Telos, 323pp.

Liu, D.S., Kelly, M. and Gong, P., 2006. A spatial-temporal approach to monitoring forest disease spread using multi-temporal high spatial resolution imagery. Remote Sensing of Environment, 101(2): 167-180.

Lohani, V. and Loganathan, G., 1997 An early warning system for drought management using the Palmer drought index Journal of the American Water Resources Association 33(6): 1375-1386

Lohani, V.K., Loganathan, G.V. and Mostaghimi, S., 1998. Long-term analysis and short-term forecasting of dry spells by Palmer Drought Severity Index. Nordic Hydrology, 29(1): 21-40.

McKee, T.B.; N.J. Doesken; and J. Kleist. 1995. Drought monitoring with multiple time scales. Preprints, 9th Conference on Applied Climatology, pp. 233–236. January 15–20, Dallas, Texas.

McKee, T.B.; N.J. Doesken; and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. Preprints, 8th Conference on Applied Climatology, pp. 179–184. January 17–22, Anaheim, California.

McKee, T. B., N. J. Doesken, and J. Kleist. 1995. Drought monitoring with multiple time scales. Ninth Conference on Applied Climatology. American Meteorological Society, Boston.

Melgani, F. and Serpico, S.B., 2003. A Markov random field approach to spatio-temporal contextual image classification. Ieee Transactions on Geoscience and Remote Sensing, 41(11): 2478-2487.

Mengisteab, H., 1997: Disaster Preparedness and Prevention Commission. *Interview.* Addis Ababa, Ethiopia, January 23.

National Drought Mitigation Center, 2006. What is drought, SPI. National Drought Mitigation Center, USA.

National Drought Mitigation Center, 1996: *Understanding ENSO and Forecasting Drought*. March 1 enso.unl.edu/ndmc/enigma/elnino.htm.

NMSA (National Meorological Services Agency), 1996: *Climatic & Agroclimatic Resources of Ethiopia*. Meteorological Research Report Series, **1**:1, January. Addis Ababa, Ethiopia.

Nicholls, N., 1993: What are the potential contributions of El Niño - Southern Oscillation Research to Early Warning of Potential Acute Food-deficit Situations. in M. H. Glantz (Ed.), *Workshop on Usable Science: Food Security, Early Warning and El Niño,* 25-28 October, Budapest, Hungary, Boulder: National Center for Atmospheric Research, 169-177.

Palmer, W.C. 1968. Keeping track of crop moisture conditions, nationwide: The new Crop Moisture Index. *Weatherwise* 21:156–161.

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

Peters, A.J. et al., 2002. Drought monitoring with NDVI-based standardized vegetation index. Photogrammetric Engineering and Remote Sensing, 68(1): 71-75.

Pankhurst, R., 1966: The great Ethiopian famine of 1888-92. *Journal of History of Medicine and Allied Sciences*, **21**, 95-124 and 271-94.

Panofsky, H.A., Brier, G.W., 1958. Some Applicat ions of Stat ist ics to Meteorology, Pennslyvania State University Press, 244 pp.

Quinn, W. H. and V. T. Neal, 1987: El Niño Occurrences Over the Past Four and Half Centuries. *Journal of Physical Research,* **92**:C13, December 15, 14,449-14,461.

Rundquist, B., C. , Harrington, J.A. and Goodin, J.D.G., 2000. Mesoscale Satellite Bioclimatology. The Professional Geographer, 52(2).

Seiler, R., Kogan, F. and Sullivan, J., 1998. AVHRR-based vegetation and temperature condition indices for drought detection in Argentina Remote Sensing: Inversion Problems and Natural Hazards Advances in Space Research 21(3): 481-484.

Sen, Z., 1998 Probabilistic formulation of spatio-temporal drought pattern Theoretical and applied climatology, 61(3-4): 197-206.

Shafer, B.A.; and L.E. Dezman. 1982. Development of a Surface Water Supply Index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. In *Proceedings of the Western Snow Conference*, pp. 164–175. Colorado State University, Fort Collins, Colorado.

Singh, R.P., Roy, S. and Kogan, F., 2003. Vegetation and temperature condition indices from NOAA AVHRR data for drought monitoring over India. International Journal of Remote Sensing, 24(22): 4393-4402.

Sirdas and Sen, 2003. Spat io- temporal drought analysis in the Trakya region, Turkey. Hydrological Sciences–Journal–des Sciences Hydrologiques, 48(5) October 2003. p. 809-820.

Smakhtin, V.U. and Hughes, D.A., 2004. Review, Automated Estimation and Analyses of Drought Indices in South Asia. International Water Management Institute.

Smith, D.I.; M.F. Hutchinson; and R.J. McArthur. 1993. Australian climatic and agricultural drought: Payments and policy. *Drought Network News* 5(3):11–12.

Solberg, Schistad, H. and Anne., 2004. Flexible nonlinear contextual classification Pattern Recognition Letters 25(13): 1501-1508.

Solberg, A.H.S., Taxt, T. and Jain, A.K., 1996. A Markov random field model for classification of multisource satellite imagery. Ieee Transactions on Geoscience and Remote Sensing, 34(1): 100-113.

Soul'e, P.T., 1992. Spat ial pat terns of drought frequency and durat ion in the cont iguous usa based on multiple drought event definitions. Int J Climatol 12: 11-24.

Steinemann, A., 2003 Drought indicators and triggers: A stochastic approach to evaluation Journal of the American Water Resources Association 39(5): 1217-1233.

Thenkabail, P.S., Gamage, N., M.S.D. and Smakhtin, V.U., 2004. The Use of Remote Sensing Data for Drought Assessment and Monitoring in Southwest Asia. 85, International Water Management Institute, Colombo.

Tannehill, I. R. 1947. Drought: Its Causes and Effects. Princeton University Press, Princeton, New Jersey.

Thorn, H.C.S., 1966: Some Methods of Climatological Analysis. WMO Technics/Note Number No. 81, 81.16-22.

Trenberth, K. E., 1991: General Characteristics of El Niño-Southern Oscillation." In M. H. Glantz, R. Katz and N. Nicholls (Eds.), *Teleconnections linking worldwide climate anomalies.* Cambridge: Cambridge University Press, 13-42.

Tso, B. and Mather, P., 2001. Classification methods for remotely sensed data. Taylor and Francis.

Tso, B. and Olsen, R., 2005. A contextual classification scheme based on MRF model with improved parameter estimation and multiscale fuzzy line process Remote Sensing of Environment, 97(1): 127-136

Tucker, C., 1989 Comparing SMMR AND AVHRR data for Drought Monitoring International Journal of Remote Sensing 10(10): 1663-1672

Wan, Z., Wang, P. and Li, X., 2004. Using MODIS Land Surface Temperature and Normalized

Difference Vegetation Index products for monitoring drought in the southern Great Plains, USA. International Journal of Remote Sensing, 25(1): 61-72.

Webb, P. and J. von Braun, 1994: *Famine and Food Security in Ethiopia: Lessons for Africa.* Chichester: John Wiley & Sons.

Wilhite D.A., 2000 "Drought as a Natural Hazard: Concepts and Definitions", in Drought: A Global Assessment, Wilhite D.A., ed. Dordrecht, NL: Routledge.

White, D.H.; and B. O'Meagher. 1995. Coping with exceptional droughts in Australia. *Drought Network News* 7(2):13–17.

Wilhite, D.A. 1995. Developing a precipitation-based index to assess climatic conditions across Nebraska. Final report submitted to the Natural Resources Commission, Lincoln, Nebraska.

Wilhite, D. A. 1993. "Planning for drought: A methodology." *In* D. A. Wilhite, ed. *Drought Assessment, Management and Planning: Theory and Case Studies*, pp. 87–109. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Wilhite, D.A.; and M.H. Glantz, 1985. Understanding the drought phenomenon: The role of definitions. *Water International* 10(3):111–120.

Willeke, G.; J.R.M. Hosking; J.R. Wallis; and N.B. Guttman. 1994. *The National Drought Atlas*. Institute for Water Resources Report 94–NDS–4, U.S. Army Corps of Engineers.