CHAPTER I

INTRODUCTION

1.1. Background

Drought is one of the main natural hazards affecting the economy and the environment of large areas (Obasi, 1994; Bruce, 1994; Wilhite, 2000). It is a complex phenomenon which involves different human and natural factors that determine the risk and vulnerability to drought. Although the definition of drought is very complex (Wilhite and Glantz, 1985), it is usually related to a long and sustained period in which water availability becomes scarce (Havens, 1954; Dracup et al., 1980; Redmond, 2002). The glossary of Meteorology defines drought as a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrological imbalance in the affected area, on the degree of dryness and the duration of dry spell. But simply, drought is a lack of rainfall for a longer period of time in a particular geographic area. Similarly drought is a costly natural hazard affecting socio-economic activity and agricultural livelihoods as well as adversely impacting public health, and threatening the sustainability of many natural environments (Calow et al., 1999; Wilhite, 2000; Fink et al., 2004; Sheffield and Wood, 2008; Mishra and Singh, 2010) It develop slowly and can last from months to a few years.

Development of droughts is a slow and very complex process. Thus, the causes and mechanisms involved are still not fully understood. Among the contributing factors of drought development are precipitation, evapotranspiration and soil conditions where the primary factor controlling the formation and persistence of drought conditions is the precipitation. In recent years, due to effect of climate change drought studies are getting special attention (Byun and Wilhite, 1999). In context of Nepal, the study of drought is very important since it is most vulnerable country by different natural disasters like drought, flood and other.

1.2. Rationale of the Study

The study has been carried out in and around the Karnali basin which lies in the mid western development region of Nepal. The main goal of the thesis is doing research on different types of droughts and finding its type occurred on different years and months and their impact on the basin. And to compare the drought events with summer crops yield is another goal of the thesis. This thesis focus on meteorological droughts, defined as a lack of rainfall or precipitation and agricultural drought which is closely linked with agricultural production since both are driven by a lack of precipitation.

The Karnali region is bordered by Tibet (China), and defined by its mountainous terrain, highly variable precipitation. This region is mainly drained by Karnali river system.The region has the third largest river of Nepal i.e. Karnali river. It originates from the south of Mansarovar and Rakas lakes in China (Tibet) and enters Nepal near Khojarnath flowing in southern direction. The terrain in Karnali varies from high Himalaya to river valleys dissecting lower hills. Due to steep terrain, there is very little cultivable land, soils are poor and eroded. The majority of households rely on subsistence farming as their primary source of livelihood.

Farmers in Karnali commonly sow rice, maize and millet as summer crops, and wheat and barley as popular winter crops. Karnali districts have low population density and are remote and unconnected by infrastructure (roads and bridges). Some higher elevations are habitable only during the summer months. A vulnerability analysis conducted as part of the NAPA formulation in 2010 shows that the region is highly exposed to changing temperature and precipitation and all districts face the risk of drought. The Karnali region suffers chronic food deficits and exhibits alarming rates of hunger. The food security situation in the region deteriorated as a result of civil conflict and has been difficult to address because of weather and disasters like drought. (WFP)

So the region is one of the most vulnerable region of Nepal regarding drought. Therefore the study of drought in the particular region is very essential. Hence is one of the factor for selecting Karnali basin for the study.

1.3. Limitations of the Study

Since SPI Index is used for analyzing the precipitation for the drought identification in and around Karnali basin, the basic limitations of the study are the limitation of the SPI Index itself as generalized below.

- The SPI is based only on one parameter: precpitation
- The requirement for a long precipitation time series
- The need for time series of consistent length where multiple sites are being evaluated and compared.
- In regional analysis where the aim is to identify areas that may be more drought, extreme drought measured by SPI will tend to occur with the same frequency at all location as the timescale of analyses increases.
- Limited stations are selected for the data analysis for several reasons. This study tends to cover overall Karnali river basin however 13 stations of the basin are included in this study.
- The data of rainfall for about minimum of 30 years or more would give better result but it is not possible to obtain the rainfall data for 30 years in all the areas because the stations were not fixed in those periods and for some fixed stations the data are1 missing.
- The data of crops yield for only thirteen years i.e. from 1999-2013 for comparison were used**.**

1.4. Objectives of the Study

The Specific objectives of this study are:

1. To analyze the temporal drought intensity on each stations in and around Karnali basin using Standardized Precipitation Index (SPI)
2. To analyze the seasonality and frequency of drought and
3. To compare the drought events (moderate, severe and extreme) with different Cereals crops yield.

CHAPTER II

LITERATURE REVIEW

2.1. GENERAL

Droughts are recognized as an environmental disaster and have attracted the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists and agricultural scientists. Droughts occur in virtually all climatic zones, such as high as well as low rain- fall areas and are mostly related to the reduction in the amount of precipitation received over an extended period of time, such as a season or a year. Temperatures; high winds; low relative humidity; timing and characteristics of rains, including distribution of rainy days during crop growing seasons, intensity and duration of rain, and onset and termination, play a significant role in the occurrence of droughts. In contrast to aridity, which is a permanent feature of climate and is restricted to low rainfall areas (Wilhite, 1992), a drought is a temporary aberration. Approximately 85% of natural disasters are related to extreme meteorological events (Obasi,1994). Drought is one of the most complicated and least understood natural hazards, affecting more people than any other hazards (Wilhite, 2000). It is a slowly developing phenomenon, only indirectly affecting our life. Although drought first appears as below-average rainfall within a normal part of climate, it can develop as an extreme climatic event and turn into a hazardous phenomenon which can have a severe impact on communities and water dependent sectors (McKee et al., 1993).

Four interrelated categories of drought are usually distinguished: hydrological drought, socioeconomic drought, meteorological drought and agricultural drought. In this study only the meteorological drought will be considered. It is expressed solely on the basis of the degree of dryness (usually related to the departure of rainfall from average) and duration of the dry period. Two different indexes named The Standardized Precipitation Index (SPI) and The Palmer Drought Severity Index (PDSI) are frequently used for short term precipitation and long term precipitation respectively for drought study.

2.2. Standardized precipitation index

Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) as an alternative to the Palmer Index in Colorado (Heim, 2002). Although SPI is a comparatively new index, it has been used in Turkey, Argentina, Canada, Spain, Korea, Hungary, China and India for real time monitoring or retrospective analyses of droughts (Patel et al., 2007). The Standardized Precipitation Index (SPI) was developed in the USA 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 rainfall anomalies.

The SPI calculation for any location is based on the long-term precipitation record for a desired period, eg. SPI(24) for 24-months, SPI(18) for 18-months etc. The China Meteorological Service uses SPI and publishes daily maps of this index for the whole country on their web site.

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a de- sired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero **(**McKee et al., 1993; Edwards and McKee, 1997). The fundamental strength of SPI is that it can be calculated for a variety of time scales. This versatility allows SPI to monitor short-term water supplies, such as soil moisture which is important for agricultural production, and long-term water resources, such as groundwater supplies, stream flow, and lake and reservoir levels. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, stream flow, and reservoir storage reflect the long- term precipitation anomalies. For example, Szalai et al. (2000) examined how strong the connection of SPI is with hydrological features, such as stream flow and groundwater level at stations in moisture status of a region.

2.3. Interpretation of SPI

A 1-month SPI map is very similar to a map displaying the percentage of normal precipitation for a 30-day period. In fact, the derived SPI is a more accurate representation of monthly precipitation because the distribution has been normalized. For example, a 1-month SPI at the end of November compares the 1-month precipitation total for November in that particular year with the November precipitation totals of all the years on record. Because the 1-month SPI reflects short-term conditions, its application can be related closely to meteorological types of drought along with short-term soil moisture and crop stress, especially during the growing season. The 1-month SPI may approximate conditions represented by the Crop Moisture Index, which is part of the Palmer Drought Severity Index suite of indices.

A 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. In primary agricultural regions, a 3-month SPI might be more effective in highlighting available moisture conditions than the slow-responding Palmer Index or other currently available hydrological indices. A 3-month SPI at the end of August in the United States Corn Belt would capture precipitation trends during the important reproductive and early grain- filling stages for both corn and soybeans. Meanwhile, the 3-month SPI at the end of May gives an indication of soil moisture conditions as the growing season begins. It is important to compare the 3-month SPI with longer timescales.

The 6-month SPI compares the precipitation for that period with the same 6-month period over the historical record. The 6-month SPI indicates medium-term trends in precipitation and can be very effective showing the precipitation over distinct seasons. Information from a 6-month SPI may also begin to be associated with anomalous stream flows and reservoir levels.

12-month up to 24-month SPI

The SPI at these timescales reflects long-term precipitation patterns. A 12-month SPI is a comparison of the precipitation for 12 consecutive months with that recorded in the same 12 consecutive months in all previous years of available data. Because these timescales are the cumulative result of shorter periods that may be above or below normal, the longer SPIs tend to gravitate toward zero unless a distinctive wet or dry trend is taking place. SPIs of these timescales are usually tied to stream flows, reservoir levels, and even groundwater levels at longer timescales.

2.4. Advantages of SPI:

SPI is simply the result of the normal quantile transformation applied to a fitted parametric distribution of the original value. The main advantage of SPI exists in a quantitative analysis of shortage of precipitation with reference to a climatic mean state: e.g.: annual precipitation itself is dominated by summer precipitation, whereas small precipitation variability in the other seasons may be crucial to drought but plays negligible contribution to annual one. Since it is based only on precipitation, the important advantage is its simplicity. Another advantage is that SPI with different time scales (McKee et al., 1993; Komuscu, 1999) can identify various drought types. The SPI is comparable in both time and space, but it is not affected by geographical and topographical differences (Lana et al., 2001). This versatility allows the SPI to monitor short term water supplies, such as soil moisture, important for agricultural production and longer term water resources such as ground water supplies, stream flow and lake reservoir levels (Hayes et al., 1999). The other advantage of the SPI is that because of its normal distribution, the frequencies of the extreme and severe drought classifications for any location and any timescale are consistent. McKee et al. (1993) suggest an SPI classification scale and according to this scale (SPI -2.0) an extreme drought occurs approximately two to three times in 100 yr, an acceptable frequency for water management planning. Finally, because it is based only on precipitation and not on soil moisture conditions as is the PDSI, the SPI is just as effective during winter months and is also not adversely affected by topography.

Although developed for use in Colorado, the SPI can be applied to any location with a dataset of 30yr or longer. Montana, Wyoming, New Mexico, South Carolina, and Nebraska have investigated or are using the SPI as part of their State wide efforts to monitor drought. Meanwhile, researchers in Mexico, Costa Rico, Argentina, Brazil, Turkey, Hungary, South Africa, and Kenya have either considered or are using the SPI for projects in their respective countries. However in Nepal, the use of SPI and its extensive use have not been found yet.

2.5. Limitations of SPI

Since it is based only on precipitation, the length of precipitation record and nature of probability distribution play an important role for calculating SPI and the following section discusses the limitations of SPI.

i. Length of precipitation record

The length of a precipitation record has a significant impact on the SPI values. Similar and consistent results are observed when the SPI values, computed from different lengths of record, have similar gamma distributions over different time periods. However, the SPI values are significantly discrepant when the distributions are different. It is recommended that the SPI user should be aware of the numerical differences in the SPI values if different lengths of record are used in interpreting and making decisions based on the SPI values. For example, Wu et al. (2005) investigated the effect of the length of record on the SPI calculation by examining correlation coefficients, the index of agreement, and the consistency of dry/wet event categories between the SPI values derived from different precipitation record lengths. The reason for discrepancy in the SPI value is due to changes in the shape and scale parameters of the gamma distribution when different lengths of record are involved.

ii. Probability distributions

The use of different probability distributions affect the SPI values as the SPI is based on the fitting of a distribution to precipitation series. Some of the commonly applied distributions include: gamma distribution (McKee et al., 1993; Edwards and McKee, 1997; Mishra and Singh, 2009); and Pearson Type III distribution (Guttman, 1999); and lognormal, extreme value, and exponential distributions have been widely applied to simulations of precipitation distributions (Lloyd-Hughes and Saunders, 2002; Madsen et al., 1998; Todorovic and Woolhiser, 1976; Wu et al., 2007). Two types of problems arise:

(i) When SPIs are calculated for long time scales (longer than 24 months) fitting a distribution might be biased due to the limitation in data length and it is true that when finer resolutions of spatial analysis need to be investigated, long data sets are not available in many catchments around the world. Lloyd-Hughes and Saunders (2002) and Sonmez et al. (2005) reported biased SPI values.

(ii) For dry climates where precipitation is seasonal in nature and zero values are common, there will be too many zero precipitation values in a particular season. In these climatic zones, the calculated SPI values at short time scales may not be normally distributed because of the highly skewed underlying precipitation distribution and because of the limitation of the fitted gamma distribution. This may be prone to large errors while simulating precipitation distributions in dry climates from small data samples.

2.6. Drought definitions

There has been difficult to find a precise definition of drought around the world due to differences in hydrometeorlogical variables and socioeconomic factors in different regions. Yevjevich (1967) stated that widely diverse views of drought definitions are one of the principal obstacles to investigations of droughts. When defining a drought it is important to distinguish between conceptual and operational definitions (Wilhite and Glantz, 1987).

Conceptual definitions – those stated in relative terms (e.g., a drought is a long, dry period), where as Operational definitions, on the other hand, attempt to identify the onset, severity, and termination of drought periods. Some of the commonly used definitions are:

(i) The World Meteorological Organization (WMO, 1986) defines ‘drought means a sustained, extended deficiency in precipitation.’

(ii) The UN Convention to Combat Drought and Desertification (UN Secretariat General, 1994) defines ‘drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.’

(iii) The Food and Agriculture Organization (FAO, 1983) of the United Nations defines a drought hazard as ‘the percentage of years when crops fail from the lack of moisture.’

(iv) The encyclopedia of climate and weather (Schneider, 1996) defines a drought as ‘an extended period – a season, a year, or several years of deficient rainfall relative to the statistical multi year mean for a region.’

(v) Gumbel (1963) defined a ‘drought as the smallest annual value of daily streamflow.’

(vi) Palmer (1965) described a ‘drought as a significant deviation from the normal hydrologic conditions of an area.’

(vii) Linseley et al. (1959) defined ‘drought as a sustained period of time without significant rainfall.’ However, drought definitions vary, depending on the variable used to describe the drought. Hence, drought definitions can be classified into different categories which are discussed below.

2.7. Classification of droughts

The droughts are generally classified into four categories (Wilhite and Glantz, 1985; American Meteorological Society, 2004), which include: meteorological, hydrological, agricultural and socioeconomic. The first three deals with ways to measure drought as a physical phenomenon while the last deals with drought in terms of supply and demand tracking the effects of water shortfall as it ripples through socioeconomic systems.

(i) Meteorological drought is defined as a lack of precipitation over a region for a period of time. Precipitation has been commonly used for meteorological drought analysis (Pinkeye, 1966; Santos, 1983; Chang, 1991; Eltahir, 1992). Considering drought as precipitation deficit with respect to average values (Gibbs, 1975), several studies have analyzed droughts using monthly precipitation data. Other approaches analyze drought duration and intensity in relation to cumulative precipitation shortages (Chang and Kleopa, 1991; Estrela et al., 2000).

(**ii) Hydrological drought** is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system. Streamflow data have been widely applied for hydrologic drought analysis (Dracup et al., 1980; Sen, 1980; Zelenhasic and Salvai, 1987; Chang and Stenson, 1990; Frick et al., 1990; Mohan and Rangacharya, 1991; Clausen and Pearson, 1995). From regression analyzes relating droughts in streamflow to catchment properties, it is found that geology is one of the main factors influencing hydrological droughts (Zecharias and Brutsaert, 1988; Vogel and Kroll, 1992)

(**iii) Agricultural drought** is usually refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources. A decline of soil moisture depends on several factors which affect meteorological and hydrological droughts along with differences between actual evapotranspiration and potential evapotranspiration. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant and stage of growth, and the physical and biological properties of soil. Several drought indices, based on a combination of precipitation, temperature and soil moisture, have been derived to study agricultural droughts.

(iv) Socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an eco- nomic good (water) (AMS, 2004). Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

Time scale	SPI	Drought type
1-month	SPI-1	Meteorological
3-months	SPI-3	Agricultural
6-months	SPI-6	Hydrological
12-months	SPI-12	Extreme hydrological

Table No 2-1: SPI time scale for different drought

2.8. Impact of droughts around the globe during recent decades

Droughts produce a complex web of impacts that span many sectors of the society, including economy and may reach well beyond the area experiencing a drought. They are a widespread phenomenon (Kogan, 1997), since about half of the earth's terrestrial surfaces are susceptible to them. More importantly, almost all of the major agricultural lands are located there (USDA, 1994). Of all the 20th century natural hazards, droughts have had the greatest detrimental impact (Bruce, 1994; Obasi, 1994). In recent years, large scale intensive droughts have been observed on all continents, affecting large areas in Europe, Africa, Asia, Australia, South America, Central America, and North America (Le Comte, 1995; Le Comte, 1994) and high economic and social costs have led to increasing attention to droughts (Downing and Bakker, 2000). The impacts of drought on Asia and other continent are discussed below:

Asia

According to a recent IPCC study, production of rice, maize and wheat in the past few decades has declined in many parts of Asia due to increasing water stress, arising partly from increasing temperature, increasing frequency of El Nino events and reduction in the number of rainy days (Bates et al., 2008). For examples, during 1999–2000, up to 60 million people in Central and Southwest Asia were affected by a persistent multi-year drought, one of the largest from a global perspective IRI, 2001), with Iran, Afghanistan, Western Pakistan, Tajikistan, Uzbekistan and Turkmenistan experiencing the most severe impacts.

In another example, frequent severe droughts in 1997, 1999 to 2002 in many areas of northern China caused large economic and societal losses (Zhang, 2003). In 2000, agricultural areas affected by droughts were estimated to exceed 40 million hectares. Because of droughts, water shortage, desertification, and dust storms accompanied the drying climate in both rural and urban areas. It is also observed that there has been an increased risk of droughts since the late 1970s, as global warming progresses and produces both higher temperatures and increased drying (Zou et al., 2005; Dai et al., 2004).

India is amongst the most vulnerable drought-prone countries in the world; a drought has been reported at least once in every three years in the last five decades. What is of concern is its increasing frequency. Since the mid-nineties, prolonged and wide- spread droughts have occurred in consecutive years, while the frequency of droughts has also increased in recent times (FAO, 2002; World Bank, 2003).

Europe

The drought situation in many European regions has already become more severe (Demuth and Stahl, 2001). For example, Lehner et al. (2006) presented a continental, integrated analysis of possible impacts of global change (here defined as climate and water use change) on future flood and drought frequencies for the selected study area of Europe. The global integrated water model Water GAP was evaluated regarding its capability to simulate high and low flow regimes, which was then applied to calculate relative changes in flood and drought frequencies. The results indicated large ‘critical regions’ for which significant changes in flood or drought risks might be expected under proposed global change scenarios. It is observed that during the past 30 years, Europe has been affected by a number of major drought events, most notably in 1976 (Northern and Western Europe), 1989 (most of Europe), 1991 (most of Europe), and more recently, the prolonged drought over large parts of Europe associated with the summer heat wave in 2003 (Feyen and Dankers, 2009). The most serious drought in the Iberian Peninsula in 60 years occurred in 2005, reducing overall EU cereal yields by an estimated ten per cent (United Nations Environment Programme, 2006). Since 1991, the yearly average economic impact of droughts in Europe has been €5.3 billion, with the economic damage of the 2003 drought in Europe amounting to at least €8.7 billion (European Communities, 2007).

North America

During the last two decades, the impacts of droughts in the United States have increased significantly with an increased number of droughts or an increase in their severity (Wilhite and Hayes, 1998; Changnon et al., 2000). For example, the impact of the 1988 large- area drought on the US economy has been estimated at $40 billion, which is 2–3 times the estimated loss caused by the 1989 San Francisco earthquake (Riebsame et al., 1990). Based on the data available from the National Climatic Data Center, USA (2002), nearly 10% of the total land area of the United States experienced either severe or extreme droughts at any given time during the last century.

Although most regions of Canada have experienced droughts, the Canadian Prairies (and to a lesser extent, interior British Columbia) are more susceptible mainly due to their high variability of precipitation in both time and space (Environment Canada, 2004).

Australia

Drought is a recurring theme in Australia, with the most recent, the so called 'millennium' drought, now having lasted for almost a decade (Bond et al., 2008). This severe drought has affected most of Southern and Eastern Australia and is regarded as one of the worst in the region since European settlement (Murphy and Timbal, 2007), with many rivers experiencing record low flows over this period—in some cases almost 40% below previous records (Murray Darling Basin Commission, 2007).

Africa

Since the late 1960s, the Sahel—a semiarid region in West Africa between the Sahara desert and the Guinea coast rainforest—has experienced a drought of unprecedented severity in recorded history. The drought has had a devastating impact on this ecologically vulnerable region and was a major impetus for the establishment of the United Nations Convention on Combating Desertification and Drought (Zeng, 2003). While the frequency of droughts in the region is thought to have increased from the end of the 19th century, three long droughts have dramatic environmental and societal effects upon the Sahel nations.
(Source: A.K. Mishra, V.P. Singh / Journal of Hydrology 391 (2010))

2.9. Drought in Nepal

Nepal being underdeveloped country, the impacts of drought is much severe and due to its fragile geology and steep topography makes it one of the most disaster prone countries in world.. Nepal is one of the most food insecure countries in Asia. The country is susceptible to disasters, including flash flood, GLOF and melting snow in the mountains and droughts and inundation in the terai. Estimates suggest that approximately 38 percent of the country's population does not consume enough food and is undernourished. In recent years, the combination of climate-related disasters, high food prices, and low economic growth has resulted in higher food insecurity in the most vulnerable communities, particularly in Western Nepal. The current food security situation in many part of the country is worrisome and comparatively every year has deteriorated sharply. World Food Programme estimates that the winter drought has added approximately 700,000 to the 2.7 million people who were already identified as needing immediate assistance due to the impact of high food prices and previous natural disasters. This brings the total number of food insecure people to 3.4 million people. The region most vulnerable is the Far and Mid West Hills and Mountains. WFP warns that Nepal's food security situation has suffered considerably due to the collision of crises over the past many years.

The increase in the variability of rainfall regimes, suggest that agriculture in Nepal will face immense challenges as seasonal drought increases. The impact of the 2008-2009 winter droughts on farming and on local food security was severe. In that period, most monitoring stations received less than 50% of normal rainfall, 30% recorded no precipitation at all and temperatures were 1-20C above average. At the national level, wheat and barley production decreased by 14.5% and 17.3% respectively and the 2009 maize production was also seriously affected communities which supplement their food supply from agriculture with forest products also found that the drought had severely reduced what they could harvest. At present, 40 districts, mostly in the West, face major food deficits and the World Food Programme (WFP) anticipates having to provide Nepal with almost four times the food aid it did in the past.

(Source:Climate change in Nepal:Impacts and Adaptive Strategies, Ajaya dixit)

Drought has not only led to food insecurity, but to deterioration of water sources especially in Jajarkot, Dailekh and Rukum districts of Nepal. Poor water resources, lack of hygiene practices and underlying levels of poor nutrition led to a diarrhea outbreak in this area.

Similarly data from the Central Bureau of Statistics (CBS) show that over the last decade around 31,000 ha of land owned by some 5% of all households, have become uncultivable due to climate related hazards, mostly drought, landslide and flood. In the eastern terai unusually low rains in 2005/2006 associated with an early monsoon resulted in crop losses of almost 30%.The cold wave of 1997/1998 also had negative impacts on agricultural productivity resulting in losses of up to 38% in chickpeas and lentils and 28% in potato.

A decline in rainfall from November to April has affected winter and spring crops. Wheat and barley are particularly susceptible to variability in winter precipitation. Furthermore many people are migrating from their actual places due to shortage of food and lack of cultivable land mostly in the western part of Nepal as consequences of drought. (WFP)

The study also show that although Nepal is known as a water-rich country, holding second position after Brazil, the people of western terai in the plain belt have been suffering from insufficient and unhygienic drinking water. Drought has reduced the water level in the well to the extent that residents are forced to drink poor quality water from a surface well sometimes one hour away from the village. This makes life particularly difficult for those who have to collect the water.
(Source: Drought Diagnosis and Monitoring over Bangladesh and Nepal, 2009)
Some of the major drought episodes over the Kathmandu city and other parts of the country are discussed below.

Drought of 1979

In 1979, there was a remarkable change in monsoon circulation in the abnormal order and the onset of 1979 monsoon for Kathmandu was delayed by two weeks. As a result at Kathmandu during June to September was 1124mm. The withdrawal date of monsoon in 1979 over Kathmandu was earlier about three weeks than normal. During this period, northwest, central and northeast India experienced heavy drought.

Drought of 1982

In 1982, the onset of monsoon over Kathmandu is delayed by two weeks and as a result mainly some parts of eastern Nepal experienced drought during June-September. The total monsoon rainfall recorded during June- September was 978mm at Kathmandu airport station. The withdrawal date of monsoon over Kathmandu was 20th September just before the normal date. Bangladesh, Burma, Sri-Lanka, northwest, central and South India also experienced drought during 1982 monsoon period. The year of 1982 was the El-Nino active year and other parts of the world also experienced during this year.

Drought of 1987

In 1987, drought occurred due to failure of monsoon however the onset of monsoon over Kathmandu is delayed by few days only. The advancement of monsoon, after crossing the Kathmandu is so delayed that it took two weeks to reach in western parts of Nepal. As a result, moderate and severe drought occurred in central and western Nepal in June. But western Nepal continuously experienced drought in some parts during remaining monsoon period. The total monsoon rainfall recorded during June-September was 1043mm. The withdrawal date of monsoon over Kathmandu was 26th September just after the normal date. (Source:Dawadi-2001)

Drought in Karnali

Karnali which lies in Mid Western region of Nepal is one of the most affected region from drought and other natural disasters. Karnali rates 48.1 on the Human Poverty Index (HPI-1) and is the most impoverished region in Nepal. The Karnali region suffers chronic food deficits and exhibits alarming rates of hunger. An assessment of data generated by NekSAP Food Security Monitoring System shows that Karnali communities are more susceptible to drought. Despite significant food assistance to the Karnali region, most of the districts in the Karnali and Far West are currently classified as highly food insecure. In Dailekh, wheat and barley production decreased by more than 70% due to drought and there is limited agricultural land available, no facility for irrigation. Similarly in Jumla, barley and wheat production decreased by 50-70% due to the drought and other many districts are severly affected by drought. Many people are migrating from the region to another or even in India.
(Source: United Nations World Food Programme (WFP), Food Security Monitoring System (NekSAP))

CHAPTER III

STUDY AREA

3.1. Karnali Basin

Nepal is situated in the lap of Himalayas which is located in between latitude 26° 22' N to 30° 27' N and longitude 80° 4'E to 88° 12'E. It is surrounded by People's Republic Of China (Tibet from the north and India on the three remaining sides). The total area of the country is 1,47,181 sq. km and extended approximately 885km in east-west direction and 193 km in north south direction. Though small in size, it has a complex and fragile topography with altitude ranging from almost sea level i.e. 90m in the south to the highest place on earth (Mount Everest) i.e.8848m in the north within a span of 200 km. This large north-south variation of topography gives rise to different climatic regions.

Geographically Nepal is divided into three regions: the Mountain, Hill and Terai. The northern mountain range (Himalayas) is covered with snow all over the year where the highest peak of the world, the Mount Everest stands. The middle range (Hill) is captured by gorgeous mountains, high peaks, valleys and lakes. The Southern range (Terai) is the Gangatic plain of alluvial soil and consists of dense forest area, national parks, wild life reserves and conservation areas. Owing to its unique geographical position, the Himalayan mountain range influences the weather and climate in various ways. It acts as a strong barrier for the circulation pattern, as a heat source in summer and heat sink in winter. The surface boundary conditions of the Himalayas determine the performance of the monsoon rainfall that has immense impact on water resources and agriculture. Nepal is the second richest in water resources possessing 2.3% of the world's water resource with its 6000 rivers of 45000 km in length. The main rivers are Koshi, Gandaki (Narayani), Karnali, Mechi, Mahakali, Bagmati and Rapti.

The Karnali (Nepali) or Ghaghara (hindi) is the third largest river which lies in the mid western and far western development region of Nepal. It originates from the south of mansarover and rakes lakes in China (Tibet) and enters Nepal near khojarnath flowing in southern direction. The total drainage area of karnali river in china is 2500 sq.Km approx and that in Nepal approximately 41500 sq.Km. The total drainage area of the river is approximately 44000 sq.Km.Lake Mansoravar rises in the Southern slopes of the Himalayas

in the glaciers of Mapchachungo, at an elevation of about 3,962 metres (12,999ft)above sea level. The river flow south through one of the most remote and least explored areas of Nepal as the karnali river 202- km. Seti River drains the Western part of the catchement, meeting the karnali near in Doti District north of dundras hill. Another Tributary, the 264-km long bheri, rises in the west part of Dhaulagiri Himalaya and drains the eastern part of the catchement, meeting the karnali near Kuineghat in Surkhet. Cutting southward across the Siwalik Hills, it Splits into two branches, the geruwa on the left and Kauriala on the right near chispani to refoin the indian border and from the proper Ghaghara tributaries originating in Nepal are the west Rapti,the kali(or Mahakali) and the little Gandak.
(Source: Wikipedia)

3.2. Selected stations for the study

Thirteen stations are choosen for this study which lie in different geographical regions of the Karnali basin. The Stations are chosen on the basis of the availability of the long term precipitation data, Station index name, longitude, latitude and elevation of the selected stations are given below:

Table No 3-1: Selected stations for the study

S.N.	Index no	Station name	District	Degree Latitude	Degree Longitude	Elevation (in meter)
1	201	Pipalkot	Bajhang	80°52’	29°37’	1456
2	202	Chainpur	Bajhang	81°13’	29°33’	1304
3	203	Silgadhi Doti	Doti	81°19’	29°23’	1400
4	206	Asara Ghat	Achham	81°27’	28°58’	1388
5	0302	Thirpu	Kalikot	81°46’	29°19’	1006
6	0303	Jumla	Jumla	82°10’	29°17´	2300
7	0305	Serighat	Kalikot	81°36’	29°08’	1210
8	0308	Nagma	Kalikot	81°54’	29°12’	1905

9	0401	Puspa camp	Surkhet	81°15’	28°53’	0950
10	0402	Dailekh	Dailekh	81°43’	28°51’	1402
11	0403	Jamu(Tikuwa kuna)	Surkhet	81°20’	28°42’	2060
12	0405	Chisapani(karnali)	Bardiya	81°16’	28°39’	0225
13	0406	Surkhet(Birendranagar)	Surkhet	81°37’	28°36’	0720

3.3. Topography

Karnali is a perennial trans-boundary river originating on the Tibetan Plateau near Lake Mansarovar. It cuts through the Himalayas in Nepal and joins the Sarda River at Brahmaghat in India. Together they form the Ghaghra River, a major left bank tributary of the Ganges.The Karnali River is about 507 km in length and is formed by the joining of Mugu Karnali and Humla Karnali at Galwa. Karnali River is one of the longest river and it exposes the oldest part of the Sivalik Hills of Nepal. The bottom of the Karnali River is mostly boulder-strewn at its upper reaches and sandy at its lower reaches and the river water is clean except in rainy season. Its depth ranges from 3-10 m but in deep gorges varies from 50 m-100m. Karnali fans divides into two main channels, first Geruwa on the left and Kauralia on the right near downstream Chisapani.

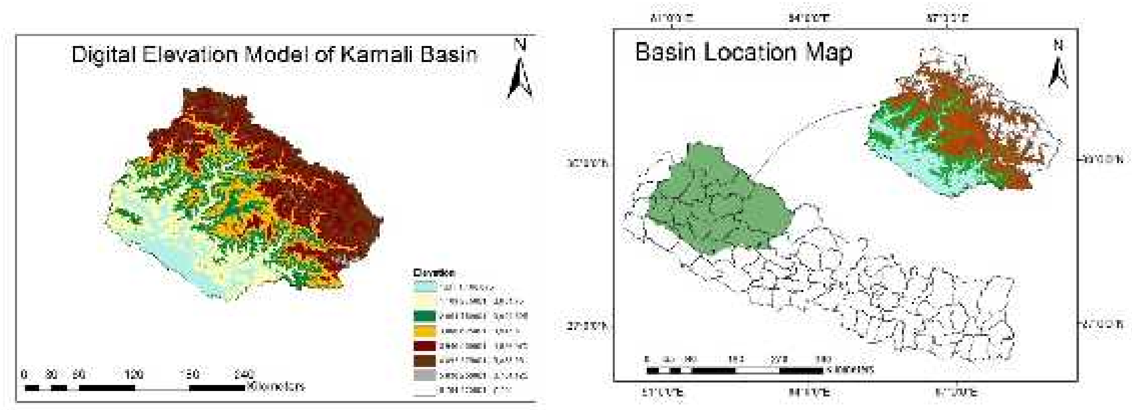


Figure No 3: Study area

The Karnali River Basin lies between the mountain ranges of Dhaulagiri in Nepal and Nanda Devi in Uttarakhand. Dhaulagiri II, elevation 7,751 metres (25,430 ft), is the highest point of the entire basin. In the north, it lies in the rain shadow of the Himalayas. The basin formed by the river has a total catchment area of 127,950 square kilometres (49,400 sq mi), of which 45 percent is in India.The Karnali drains western Nepal, with the Bheri and Seti as major tributaries. The upper Bheri drains Dolpo, a remote valley beyond the Dhaulagiri Himalaya with traditional Tibetan cultural affinities. The upper Karnali rises inside Tibet near sacred Lake Manasarovar and Mount Kailash. The area around these features is the hydrographic nexus of South Asia since it holds the sources of the Indus and its major tributary the Sutlej, the Karnali—a Ganges tributary—and the Yarlung Tsangpo/Brahmaputra. It is the center of the universe according to traditional cosmography The population of the Basin districts in Nepal increased from 1.9 million in 1971 to 4.7 million people in 2001, almost a 250% increase over three decades. The Karnali zone has the lowest population density in Nepal. There are no large settlements on the banks of the river, which is only crossed near Chisapani (outlet of Karnali river) by the Mahendra Highway .The average population density of the Basin area increased from 53 persons/km^2 in 1981 to 87 persons/km^2 in 2001. There is a steady growth in the economically active population in the basin districts. The average literacy rate has increased from a mere 7.5% in 1971 to 45% in 2001. The social status of the permanent households increased from 24% in 1991 to 31% in 2001.

(Source: Wikipedia)

3.4. General Season and Climatic Feature

Nepal's climate is a result of the Asian monsoon and the interaction with the extreme topography of the country including an enormous range of altitude within such a short north-south distance. Nepal is characterized by monsoon circulation, principally easterly winds during the summer, and westerlies from October to May. The seasons of Nepal are categorized by four groups such as Pre-monsoon or Spring season (MAM), Summer monsoon or Rainy season (JJAS), Post monsoon (ON) and Winter season (DJF). The onset of monsoon begins around June 10 in eastern part so monsoon strikes in the Karnali region only after twenty four hour from the east and sometimes two or three days later due to the strong westerlies. The onset and retreat of the southeasterly summer monsoon is associated with the movement northwards and southwards of the ITCZ. The summer monsoon, which lasts from June to September, involves a large amount of precipitation. However, the monsoon does not begin abruptly. There is a gradual transition from the dry winter season to the summer monsoon as a result of the pre-monsoon convective rains, which are frequently accompanied by thunderstorms (Kraus 1988).

Karnali basin is divided by five climatic zones.

- Hot monsoon climate in the Terai, Inner Terai, and Siwalik regions with a hot and wet summer, and mild and dry winter
- Warm temperate monsoon climate in the Middle Mountains up to a height of about 2,100 masl
- Cool temperate monsoon climate in the Middle Mountains and the High Mountains between 2,100 and 3,300 masl
- Alpine climate in the High Mountain region up to a height of about 4,800 masl
- Tundra type of clomate abopve the snow line where there is perpetual frost and cold desert conditions (Shankar and Shrestha, 1985).

Indian Summer Monsoon contributes most of the annual precipitation (80%) in Nepal during the rainy months June - September. The remaining amount of precipitation comes from the western disturbances during October - May, especially in the western parts of the country. The average annual precipitation in Nepal is about 1600 mm, with large variations between eco-climatic zones. Domroes (1979) reported the east-west variations in mean annual as well as monthly precipitation at some stations in Nepal.

3.5. Precipitation

Being located in the northern limit of the tropics, Nepal gets both summer precipitation and winter precipitation (Singh 1985). The thermal regime in the vast Eurasian region, the location of the Inter-Tropical Convergence Zone (ITCZ), and the resulting general atmospheric circulation dominates the precipitation regime of Nepal. During the monsoon, depressions form in the Bay of Bengal and move northwest causing heavy rain in their path. Nepal receives the first monsoon showers in the southeastern part of the country and they spread slowly towards the northwestern part of the country with diminishing intensity. The retreat of the summer monsoon begins from the northwestern part of the country. The amount of summer monsoon precipitation, therefore, shows marked variation from south to north and east to west. Further the contribution of the summer monsoon precipitation to the annual total is substantially greater in the southeastern part of the country compared to the northwestern end. In addition, there is also the altitudinal dependence of monsoon precipitation. Maximum precipitation occurs around 1,000 masl in the Narayani Basin and around 1,500 masl in the Sapta Koshi Basin, whereas for the Karnali Basin, the maximum precipitation altitude is not unambiguous (Alford 1992).

The average precipitation of the basin is 1409 mm which is taken from thirteen stations of thirty four years. Among the thirteen stations, Chisapani has the highest rainfall amount i.e. 2255 mm whereas Thirpu occupy the lowest amount of rainfall i.e.569 mm.

Summer monsoon precipitation occurs in solid form at high altitude and plays an important role in the nourishment of numerous glaciers of the Himalayas. While general circulation models predict a significant increase in monsoon precipitation with the increase of atmospheric greenhouse gases, amounting to a 15% increase with double carbon dioxide concentration, no long-term trend in precipitation is yet apparent in Nepal. Similarly monsoon precipitation in Karnali is found to be related to El Nino and other large-scale climatological parameters.

Winter precipitation is caused by westerly disturbances having their origin in the Mediterranean. The lows formed here are steered and swept eastwards by the westerly aloft. Westerly disturbances affect northern and western parts of Nepal (Singh 1985). Winter precipitation contributes significantly to the annual total precipitation in the northwestern part of the country .It plays a major role in the mass balance of glaciers in western Nepal.

CHAPTER IV

METHODOLOGY

4.1. Data Collection

This dissertation paper is based on secondary source of data and information.The data and information are collected from various agencies like Department of Hydrology and Meteorology (DHM), Central Library of Tribhuvan University (T.U.), Ministry of Agricultural Development (MoAD), different official annual reports bulletins, journals, different books and dissertation (all of the data source has been mentioned in the reference of this dissertation paper) written by various authors. Similarly more informations were obtained from the websites of different countries related to Meteorology. Different maps, diagrams, tables and appendices are presented for the illustration of discussions and findings. Finally, a dissertation paper has been prepared to fulfill the objectives. The precipitation data from 1970 to 2013 of thirty five stations was taken in the beginning but due to the data unavailability and quality, twenty two stations had to reduced and thirteen stations was made final with thirty four years (from 1980 to 2013) for the output of the study. The missing data were in filled using the Average method and then the data was tested for consistency by Mann-Kendall test. Similarly different crops yield data of mid western region from 1999 to 2011 of was used for comparison with drought events.

4.2. SPI Methodology

The Standardized Precipitation Index (SPI) was developed by McKee et al (1993). It was designed to quantify the precipitation deficit for multiple timescales. SPI is a probability index, considered only precipitation for any given time scales, which was developed for monitoring and assessing drought for any rainfall station with historic data. In order to calculate the SPI, a probability density function that adequately describes the precipitation data must be determined. The gamma distribution function was selected to fit the precipitation data from each station. The gamma distribution is defined by its frequency or probability density function,

$$g(x) = \frac{1}{\tilde{}\,\Gamma(\sim)} x^{\sim -1} e^{-x/} \qquad \text{for } x > 0 \qquad \text{(i)}$$

Where,

$\alpha > 0$	α is a shape parameter	(ii)
$\beta > 0$	β is a scale parameter	(iii)
$x > 0$	x is the precipitation amount	(iv)
$\Gamma(\alpha) = \int^{\infty} y^{\alpha-1} e^{-y} dy$	$\Gamma(\alpha)$ is the gamma function	(vi)

For example, equation i shows the gamma distribution with parameters $\alpha = 2$ and $\beta = 1$. This distribution is skewed to the right with a lower bound zero much like a precipitation frequency distribution.

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 (3 months, 12 months, 48 months, etc.) and for each month of the year.

Thus, the probability of rainfall being less than or equal to the average rainfall for that area will be about 0.5, while the probability of rainfall being less than or equal to an amount much smaller than the average will be also be lower (0.2, 0.1, 0.01etc, depending on the amount). Therefore if a particular rainfall event gives a low probability on the cumulative probability function, then this is indicative of a likely drought event depending on the time scale. Alternatively, a high rainfall event with a high probability on the cumulative probability function is an anomalously wet event. Therefore, the SPI can effectively represent the amount of rainfall over a given time scale, with the advantage that it provides not only information on the amount of rainfall, but that it also gives an indication of what this amount is in relation to the normal. Such information helps define whether a station is experiencing drought or not. Its output is in units of standard deviation from the median based on the record length. The longer the period used to calculate the distribution parameters, the more likely you are to get better results (e.g., 50 years better than 20 years).

From Thom (1996), the maximum likelihood solutions are used to optimally estimate

α and β:

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

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad \text{(vii)}$$

Where,

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \qquad \text{(viii)}$$

n= number of precipitation observations (ix)

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. The cumulative probability is given by

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{B}^{\hat{\alpha}}\,\Gamma(\hat{\alpha})}\int_0^x x^{\hat{\alpha}-1} e^{-x/\hat{\beta}} dx \qquad \text{(x)}$$

Letting $t = x/\hat{\beta}$, this equation becomes the incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}} e^{-t} dt \qquad \text{(xi)}$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)\,G(x) \qquad \text{(xii)}$$

Where, q is the probability of a zero. If m is the number of zeros in a precipitation time series, Thom (1966) states that q can be estimated by m/n. Thom (1966) uses tables of the incomplete gamma function to determine the cumulative probability G(x). McKee et al.

(1993) use an analytic method along with suggested software code from Press et al. (1988) to determine the cumulative probability.

The cumulative probability, H(x), is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. This is an equiprobability transformation which Panofsky and Brier (1958) state has the essential feature of transforming a variate from one distribution (i.e. gamma) to a variate with a distribution of prescribed form (i.e. standard normal) such that the probability of being less than a given value of the variate shall be the same as the probability of being less than the corresponding value of the transformed variate. This method is illustrated in figure 4.2 In this figure, a 3 month precipitation amount (January through March) is converted to a SPI value with mean of zero and variance of one. The left side of figure 4.2 contains a broken line with horizontal hash marks that designate actual values of 3 month precipitation amounts (x-axis) for Fort Collins, Colorado for the months of January through March for the period 1911 through 1995. The broken line also denotes the empirical cumulative probability distribution (y-axis) for the period of record. The empirical cumulative probabilities were found optimally as suggested by Panofsky and Brier (1958) where the precipitation data is sorted in increasing order of magnitude so that the k^{th} value is k-1 values from the lowest and where n is the sample size:

Empirical cumulative probability =k/ (n+1) (xiii)

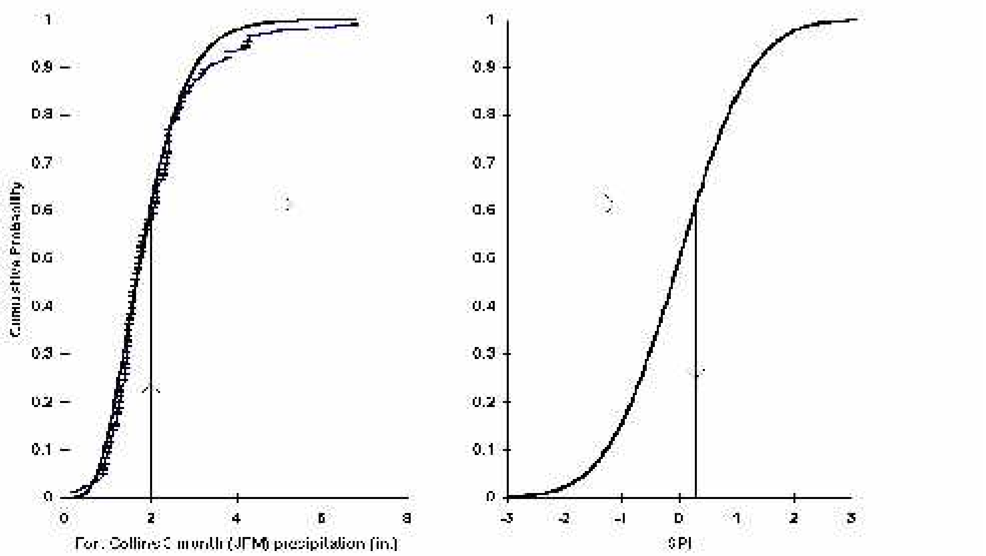


Fig.4-1: Example of equiprobability transformation from fitted gamma distribution to the standard normal distribution.

The smooth curve on the left hand side of figure 4.2 denotes the cumulative probability distribution of the fitted gamma distribution to the precipitation data. The smooth curve on the right hand side of figure 4.2 denotes the cumulative probability distribution of the standard normal random variable Z using the same cumulative probability scale of the empirical distribution and the fitted gamma distribution on the left hand side of the figure. The standard normal variable Z (or the SPI value) is denoted on the x-axis on the right hand side of the figure. Hence, this figure can be used to transform a given 3 month (January through March) precipitation observation to a SPI value. For example, to find the SPI value for a 2 inch precipitation observation, simply go vertically upwards from the 2 inch mark on the x-axis on the left hand side of figure 4.2 until the fitted gamma cumulative probability distribution curve is intersected. Then go horizontally (maintaining equal cumulative probability) to the right until the curve of the standard normal cumulative probability distribution is intersected. Then proceed vertically downward to the x-axis on the right hand side of figure 4.2 in order to determine the SPI value. In this case, the SPI value is approximately +0.3.

Since it would be cumbersome to produce these types of figures for all stations at all time scales and for each month of the year, the Z or 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:

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

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad \text{for } 0.5 < H(x) < 1.0 \qquad \text{(xv)}$$

Where,

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

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

$$c_0 = 2.515517$$

$$c_1 = 0.802853$$

$$c_2 = 0.010328$$

$$d_1 = 1.432788 \qquad \text{(xviii)}$$

$$d_2 = 0.189269$$

$$d_3 = 0.001308$$

Conceptually, the SPI represents a z-score or the number of standard deviations above or below that an event is from the mean. However, this is not exactly true for short time scales since the original precipitation distribution is skewed. Nevertheless, figure 4.3 show that during the base period for which the gamma parameters are estimated, the SPI will have a standard normal distribution with an expected value of zero and a variance of one. Katz and Glantz (1986) state that requiring an index to have a fixed expected value and variance is desirable in order to make comparisons of index values among different stations and regions meaningful.

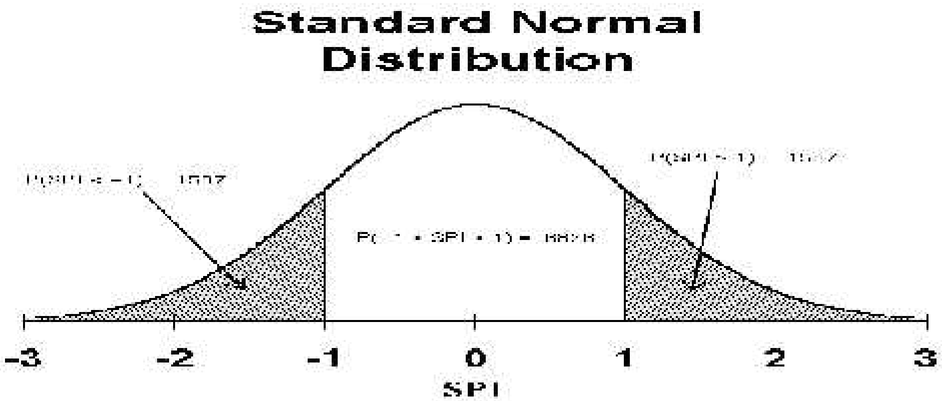


Figure. 4-2: Standard normal distribution with the SPI having a mean of zero and variance of one.

Akinremi et al. (1996) states that the spatial and temporal dimensions of drought create problems in generating a drought index because not only must an anomaly be normalized with respect to location, but the anomaly must also be normalized in time if it is to produce a meaningful estimate of drought. The SPI accomplishes both. The SPI is normalized to a station location because it accounts for the frequency distribution of precipitation as well as the accompanying variation at the station. Additionally, the SPI is normalized in time because it can be computed at any number of time scales, depending upon the impacts of interest to the analyst.

Additionally, no matter the location or time scale, the SPI represents a cumulative probability in relation to the base period for which the gamma parameters were estimated. Following is a table of SPI and its corresponding cumulative probability.

Table No 4-3: SPI and Corresponding Cumulative Probability in Relation to the Base Period

SPI	Cumulative Probability
-3.0	0.0014
-2.5	0.0062
-2.0	0.0228
-1.5	0.0668
-1.0	0.1587
-0.5	0.3085
0.0	0.5000
+0.5	0.6915
+1.0	0.8413
+1.5	0.9332
+2.0	0.9772
+2.5	0.9938
+3	0.9986

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 3 months total of precipitation as well as a 48 months total of precipitation. 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.

The calculation of the SPI is rather straight forward. In summary therefore, the SPI can effectively represent the amount of rainfall over a given time scale, with the advantage that it provides not only information on the amount of rainfall, but that it also gives an indication of what this amount is in relation to the normal, thus leading to the definition of whether a

Station is experiencing drought or not. It gives output in units of standard deviation from the average based on as-long-a- rainfall-distribution-as-there-is-data-for. The longer the period used to calculate the distribution parameters, the more chances of getting a better results .Therefore, you can use a longer period (i.e. 1970-2013) to calculate the parameters of the distribution and then extract the SPI values for only a given time period (could be one year, or a number of years to give a time series). The SPI can be calculated from 1 month up to 72 months. Statistically, 1–24 months is the best practical range of application (Guttman, 1994, 1999). This 24-month cutoff is based on Guttman's recommendation of having around 50–60 years of data available. Unless one has 80–100 years of data, the sample size is too small and the statistical confidence of the probability estimates on the tails (both wet and dry extremes) becomes weak beyond 24 months. In addition, having only the minimum 30 years of data (or less) shortens the sample size and weakens the confidence. Technically, one could run the SPI on less than 30 years of data bearing in mind, however, the statistical limitations and weaker confidence pointed out above.

Drought categories may be differently defined in terms of SPI as shown in the following table.

Table No 4-4: SPI value for chosen period

SPI Values	Drought Category
2.00 and above	extremely wet
1.50 to 1.99	very wet
1.00 to 1.49	moderately wet
0.99 to -0.99	near normal
-1.00 to -1.49	moderately dry
-1.50 to -1.99	severely dry
-2.00 and below	extremely dry

4.3. Program Operation and Input Structure

The program is available in a Windows/PC version and can be downloaded for free. The latest SPI program (SPI_SL_6.exe), sample files such as those described below and instructions for Windows/PC use can be found at http://drought.unl.edu/MonitoringTools/ DownloadableSPIProgram.aspx.

The program can calculate up to 6 SPI time windows at one time for any given location. It was compiled in C++ for PC and all libraries are included. The SPI program is relatively easy to operate. Prepare an input file with all your data for one particular station. All input files must follow this format, which features three columns indicating respectively the year, month and monthly precipitation value. A header, usually the name of the station, must be included at the top of the input file otherwise the program will produce an empty output file. The precipitation total must NOT include decimals and can be in inches or millimetres. For example:

Header
yyyy mm pppp
yyyy mm pppp
yyyy mm pppp
yyyy mm pppp
etc

where, Header=a string which describes the file, or name of the station,etc yyy= year

mm = month (in digit format 1,2,3 etc)

pppp = precipitation multiplied by 100

Attention must be paid to column spacing and missing data in the input file. If the monthly precipitation value is missing for a particular month or months, one must use -99 for the missing data value. Do not use a blank in the precipitation column. Zero is a valid value for typically dry months in arid regions or for those locations having distinct wet or dry seasons. Ideally, one would want at least 30 years of monthly/weekly data in order to have some confidence in the statistics, but that would be the case with most indices when assessing any drought climatology for a given location or region.

4.4. Running SPI Program

The spi program is implemented as a unix-style filter; i.e. it reads from standard input (stdin) and writes to standard output (stdout). Thus it is easy to use with a variety of input data and output processing without rewriting the SPI generating program. All that needs to be done is to write apropriate 'frontend' and 'backend' filter. For example, if several data streams are to be analyzed and each has a different format, we need only to write a filter that reads each format and outputs the format spi expects. Similarly, we may have several filters that plot time series or perform statistical analysis on the resulting index values. SPI also requires specifying one or more time scale parameters. Simply add these to the command line. For example:

spi 3 6 12 <infile.dat >outfile.dat

The requirements to run spi are:

An operating system that supports unix-like I/O redirection. Other operating system may be used, but will require some code modifications. Sufficient memory to support the program and data arrays. A math library that provides l gamma(), the log gamma function. (On some systems lgamma may be named gamma.)

Unix systems:

1) Edit Makefile to suit our system.

2) Type 'make'.

If there is any trouble running spi because of not having enough memory in our system, one may want to edit spi.h and change the lines:

#define BEGYR 1850

#define ENDYR 2000

to specify a shorter period of record.

In general, the input data file name must have four characters as “.cor” or “.txt” since the SPI program will not recognize any other file extension. The length of file name is not restricted but the name must not contain any spaces. The data files should be edited using either Notepad or WordPad. The easiest way to set up a new data file is usually to select an existing data file, edit it, and then save under a new name. Set up a directory with the SPI executable program file and at least one “.COR” file in it: From Windows Explorer select the SPI_SL_6.exe file and click OPEN to start the program running. The program runs in a separate window. Firstly, the program prompts the user for the number of n-month calculations wanted. If the answer is ‘2’ the program will request the period ‘n’ of the first n month period e.g. 3 for a SPI (3) analysis, and then the second ‘n’. The program then prompts the user for the name of the input data file. Type in the name and press Enter. The program then prompts the user for the output file name to be used. In case of output file, the same name can be given as it to input file but with a different 4 character extension such as “.OUT”. (The extension must not exceed 4 characters including the full stop or period symbol). It is recommended to adopt a naming system that reflects the SPI analyses to be carried out in order to keep the results of each analysis separate Once the user has given the output file name the program automatically opens an output file with this name. The screen will clear almost instantly as the program takes only seconds to run.

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

etc

where, yyyy= year, mm=month

spi-3 = SPI for a 3 month rainfall total

spi-6 = SPI for a 6 month rainfall total

spi1-2 = SPI for a 12 month rainfall total

spi-24 = SPI for a 24 month rainfall total

To obtain a graph of the variability of SPI values over time, or to use the SPI values in a further calculation – for example to create a composite index based on more than on SPI series, the user may wish to transfer the results into Excel. For this, just open the Excel and using the File Open command select the “.OUT” files (remember to look for “All file types”). Excel will then open the file import wizard.

CHAPTER V

RESULTS

5.1. Station-wise Temporal Analysis of Drought

The output data of 3 month SPI of each stations of the study area from 1980 to 2013 is plotted along with time series. The magnitude and duration of each type of drought such as normal, moderate, severe and extreme over the study area is noticed and after the thorough study of 3 month time scale which is prepared in excel format given in appendix, each of normal, moderate, severe and extreme droughts of thirteen different stations, their corresponding SPI values and the months and years suffered by either of the droughts on different years are described on the following table.

Table No 5-1: Drought Episode for Pipalkot Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1984,1986-1988,1990,1991, 1993-2009,2011-2013 July 1980-1991,1993-2008,2010-2013 August 1980-2008,2010-2013
	Moderate	-1.00 to -1.49	June 1985,1992 & 2010
	Severe	-1.50 to -1.99	Not found
	Extreme	-2.00 and below	June 1989 & 2010 July 1992 & 2009 August 2009

Table No 5-2: Drought Episode for Chainpur Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980,1984,1986,1987, 1989-2006,2008,2009, 2012 & 2013 July 1980-1991 & 1994-2013 August 1980-1986,1988-1992 & 1994-2013
	Moderate	-1.00 to -1.49	June 1985 & 2007 July 1992 &1993 August 1987
	Severe	-1.50 to -1.99	June 1988,2010 & 2011
	Extreme	-2.00 and below	August 1993

Table 5-3: Drought Episode for Silgadhi Doti Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1988,1990-2002,2004,2006,2007,2009 & 2011-2013 July 1980-1995,1998-2004, 2006,2007 & 2010-2013 August 1980-1991,1993-1996, 1998-2004,2006,2007, 2009 & 2011-2013
	Moderate	-1.00 to -1.49	June 1989,2005 & 2008 July 1996,1997 & 2009 August 1992 & 1997
	Severe	-1.50 to -1.99	June 2010 July 2005 & 2008 August 2005 & 2008
	Extreme	-2.00 and below	Not found

Table 5-4: Drought Episode for Asaraghat Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1981-1988,1990-2009 2011- 2013 July 1980-1991,1993,1994 1997-2002,2004,2006- 2013 August 1980-1991,1995-2002, 2004 & 2007-2013
	Moderate	-1.00 to -1.49	June 1980,1989 & 2010 July 1992,1995 & 1996 August 1992,1994,2003 & 2006
	Severe	-1.50 to -1.99	July 2003 & 2005, August 2005
	Extreme	-2.00 and below	Not found

Table 5-5: Drought Episode of Thirpu Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1983,1985-1987, 1989-1991,1993-2010, 2012 & 2013 July 1980-1993,1995,1998- 2001,2003,2005-2010, 2012 & 2013 August 1980-1983,1985,1987, 1989-1993,1995,1996, 1998-2003,2005-2010 2012 & 2013
	Moderate	-1.00 to -1.49	June 1984,1992 & 2011 July 1994,1996,1997,2002,2004 & 2011 August 1984,1988,1994 & 1997
	Severe	-1.50 to -1.99	June 1988 August 2011
	Extreme	-2.00 and below	August 2004

Table 5-6: Drought Episode for Jumla Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1988,1990,1991, 1997-2004,2006-2008, 2010-2013 July 1980-1995,1997, 1999-2001,2003-2011 & 2013 August 1980,1981,1983,1984,1986, 1988-1997,1999-2008, 2010-2013
	Moderate	-1.00 to -1.49	June 1992,1996 & 2009 July 1998 August 1982,1985,1987 & 1998
	Severe	-1.50 to -1.99	June 1989 July 1996 & 2012
	Extreme	-2.00 and below	June 2005 July 2002 August 2009

Table 5-7: Drought Episode for Serighat Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1982,1984-1993,1995-2004, & 2006-2013 July 1980-1982,1984-2005 & 2008-2013 August 1980,1981,1983-2001 & 2005-2013
	Moderate	-1.00 to -1.49	June 1994 July 2006 August 1982,2002 & 2004
	Severe	-1.50 to -1.99	July 1983
	Extreme	-2.00 and below	June 1983 & 2005 July 2007 August 1983

Table 5-8: Drought Episode for Nagma Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1987,1990-1992,1994-1995,1997-2006,2008-2013 July 1980-1988,1990-1995,1997, 1999-2001,2003-2013 August 1980-1983,1985-1995,1997, 1999-2013
	Moderate	-1.00 to -1.49	June 1988,1993 & 1996 July 1989,1998 & 2002 August 1984,1997 & 1998
	Severe	-1.50 to -1.99	June 1989 & 2007 July 1996
	Extreme	-2.00 and below	Not found

Table 5-9: Drought Episode for Puspa Camp Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1981-1984,1986-2004, 2006-2011 & 2013 July 1980-1991,1993-2011 & 2013 August 1980-1985,1987-1991, 1993-2003,2005, 2007-2011 & 2013
	Moderate	-1.00 to -1.49	June 1980 & 1985 July 1992 August 1986,1987,1992,2004,2006 & 2012
	Severe	-1.50 to -1.99	July 2012
	Extreme	-2.00 and below	June 2005 & 2012

Table 5-10: Drought Episode for Dailekh Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1981-1984,1986-2013 July 1980-1988,1990, 1991,1993-1997, 1999,2000,2001, 2003-2011 & 2013 August 1980-1986,1988- 1991,1993-2011 & 2013
	Moderate	-1.00 to -1.49	July 1989,1992,1999 & 2012 August 1982,1987 & 1992
	Severe	-1.50 to -1.99	June 1985 July 2002 August 2012
	Extreme	-2.00 and below	June 1980

Table 5-11: Drought Episode for Jamu Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1984,1986,2002,2003,2004,2005,2008-2011& 2013 July 1980-1988,1990,1992-1997 1999-2001,2003-2011& 2013 August 1980-1988,1990,1991,1993,1994,1996-2001& 2007-2013
	Moderate	-1.00 to -1.49	June 1985,2003,2006 & 2012 July 1989,1991,1998 & 2012 August 1989,1992,1995,2002,2004 & 2006
	Severe	-1.50 to -1.99s	July 2002 August 2003 & 2005
	Extreme	-2.00 and below	June 2007

Table 5-12: Drought Episode for Chisapani Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1980-1982,1984, 1986,1988-1991, 1993-2004,2006- 2009,2011& 2013 July 1980,1981,1984- 1986,1988-1991, 1993-2004 & 2006-2013 August 1980-1982,1984- 1991,1993-2004 & 2006-2013
	Moderate	-1.00 to -1.49	June 1983,1985,1992 &2010 July 1982 & 1987 August 1983
	Severe	-1.50 to -1.99	June 1987 & 2012 July 1983 & 1992
	Extreme	-2.00 and below	June 2005 July 2005 August 1992 & 2005

Table 5-13: Drought Episode for Surkhet Station

SPI Type	Drought Type	SPI Value	Months/Years
3 Month SPI	Normal	0.99 to 2 & above	June 1981,1982,1984,1985-2009, 2011 & 2013 July 1980,1981,1984-2009,2011 & 2013 August 1980-1982,1984-2009, 2011 & 2013
	Moderate	-1.00 to -1.49	June 1983 & 1985 July 1982,2002 & 2012 August 1983,1987 & 2010
	Severe	-1.50 to -1.99	July 2010 August 2012
	Extreme	-2.00 and below	June 2010 & 2012 July 1983

Since SPI 3 take only three months of a year so June, July and August was taken for the study which is named as a summer season. Based on this season, the above table shows that the most of the years and months of all stations are in a normal drought category. After normal drought, moderate type has been found most in each of the station. Similarly severe drought was recorded not more than four year in each of the drought episodes table from all the stations throughout the period of thirty four year (1980 to 2013). Among the thirteen stations, Pipalkot was not suffered from severe type of drought.

The extreme drought is found less recorded among the other three categories in which Pipalkot, Jumla, Serighat and Surkhet stations were found more suffered and Silghadi Doti, Asaraghat and Nagma stations were not suffered from this type of drought in any year.

5.2. Frequency Analysis

The frequency of drought occurring in thirteen stations taken from 1980 to 2013 years have shown in the given table. From the table, almost all of the years were recorded by normal type of drought in all the stations which is the predominant among the categories as we can say, so normal drought is given empty in the table. After that most of the years were recorded as moderate drought in all of the stations. It was found that 37, 33 and 44 moderate drought were recorded during the month of June, July and August respectively. Then most of the years in most of the stations apart from one station in which altogether 16 in June, 14 in July and 8 in August were recorded as a severe drought. And finally extreme drought type were recorded in ten stations where 11, 6 and 5 in total found in the month of June, July and August respectively.

We can see from the table that the number of drought events is highest during the 7 years of time interval i.e. from 1987-2013 with 22 droughts in the month of June whereas highest with total of 13 droughts from 1994-2000 and 2001-2007 in July and similarly from 2000-2007 is the highest drought events with 16 droughts in the month of August.

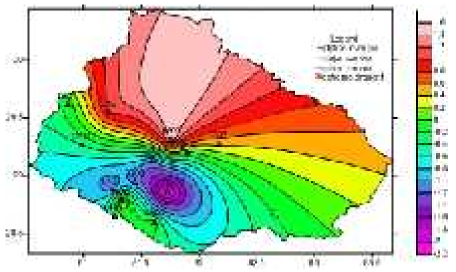
Drought Categories/Period	1980-1986	1987-1993	1994-2000	2001-2007	2008-2013	Total (1980-2013)
			June			
Normal						
Moderate	11	10	4	4	8	37
Severe	1	11	0	0	4	16
Extreme	1	1	0	5	4	11
Total	13	22	4	9	16	64
			July			
Normal						
Moderate	2	10	11	5	5	33
Severe	2	1	2	5	4	14
Extreme	1	1	0	3	1	6
Total	5	12	13	13	10	53
			August			
Normal						
Moderate	9	11	9	10	5	44
Severe	0	0	0	4	4	8
Extreme	0	1	0	2	2	5
Total	9	12	9	16	11	57

Table 5-14: Drought occurrences at Karnali basin

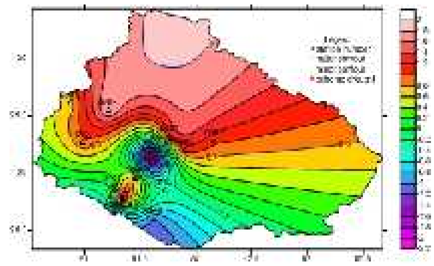
5.3. Analysis of extreme drought

From different drought events i.e. moderate, severe and extreme which were recorded in thirteen stations, the contour map marked by different symbols and colors in the study area was made for extreme drought occurred in different months and years of different stations by using software named Surfer 11. In all the maps, the small triangle symbol indicate the different stations number, the small line with blue and red colors indicate major contour line ,small line with black color indicate minor contour line and red cross line indicate the extreme drought. The side bar with multiple colors indicate the color scale of the study area map.

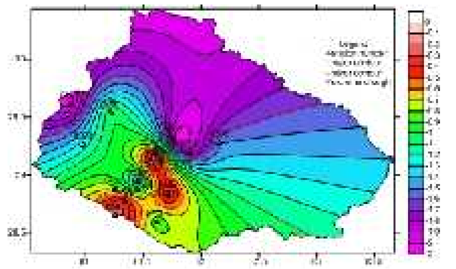
Figure 5-1-A of Map (a), map (b), map (c), map (d), map (e), map (f) and map (g) shows that the extreme drought occurred in seven stations in the month of June in the years 1980,1983,1989,2005,2007 & 2012. Similarly figure 5-2-B of maps (a), (b), (c), (d), (e) and (f) shows the extreme drought occurred in six stations in the month of July in the year 1983,1992,2002,2005,2007 & 2009. And fig 5-3-C of maps (a), (b), (c), (d) & (e) shows the extreme drought recorded in the years in five stations in the years 1983,1993,2004,2005 and 2009 during the month of August.



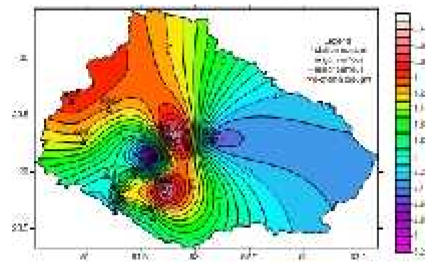
(a)



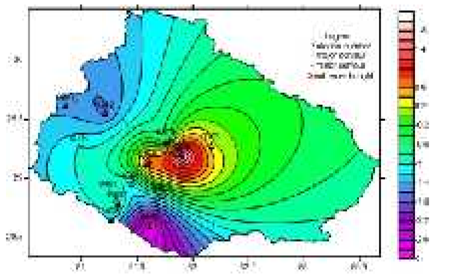
(b)



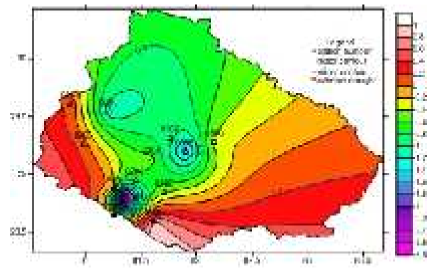
(c)



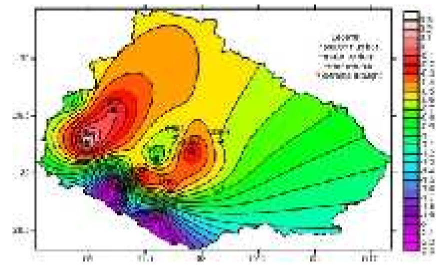
(d)



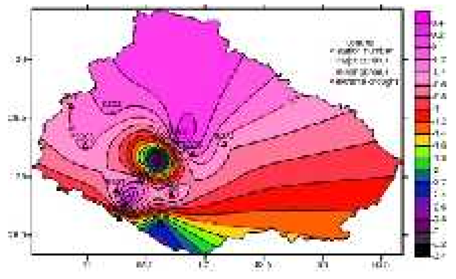
(e)



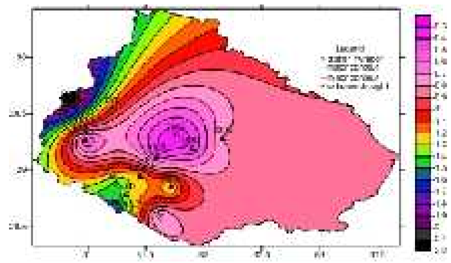
(f)



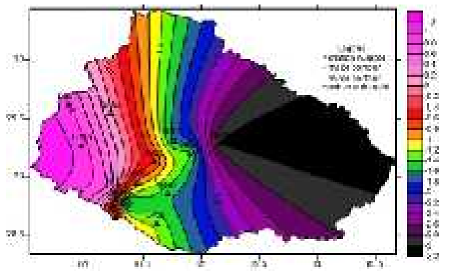
(g)**Figure 5-1-A: (a),(b),(c),(d),(e),f) &(g): extreme droughts for June**



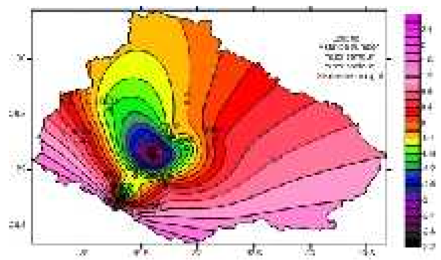
(a)



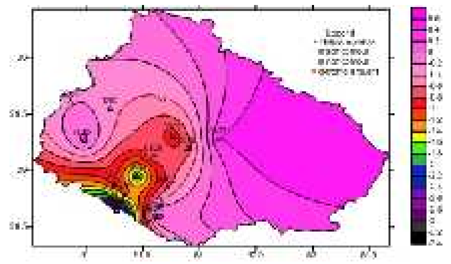
(b)



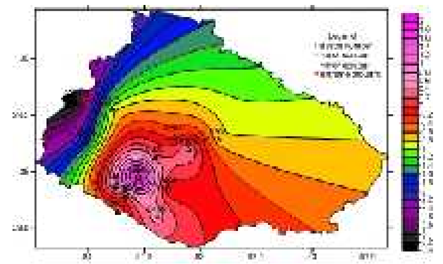
(c)



(d)

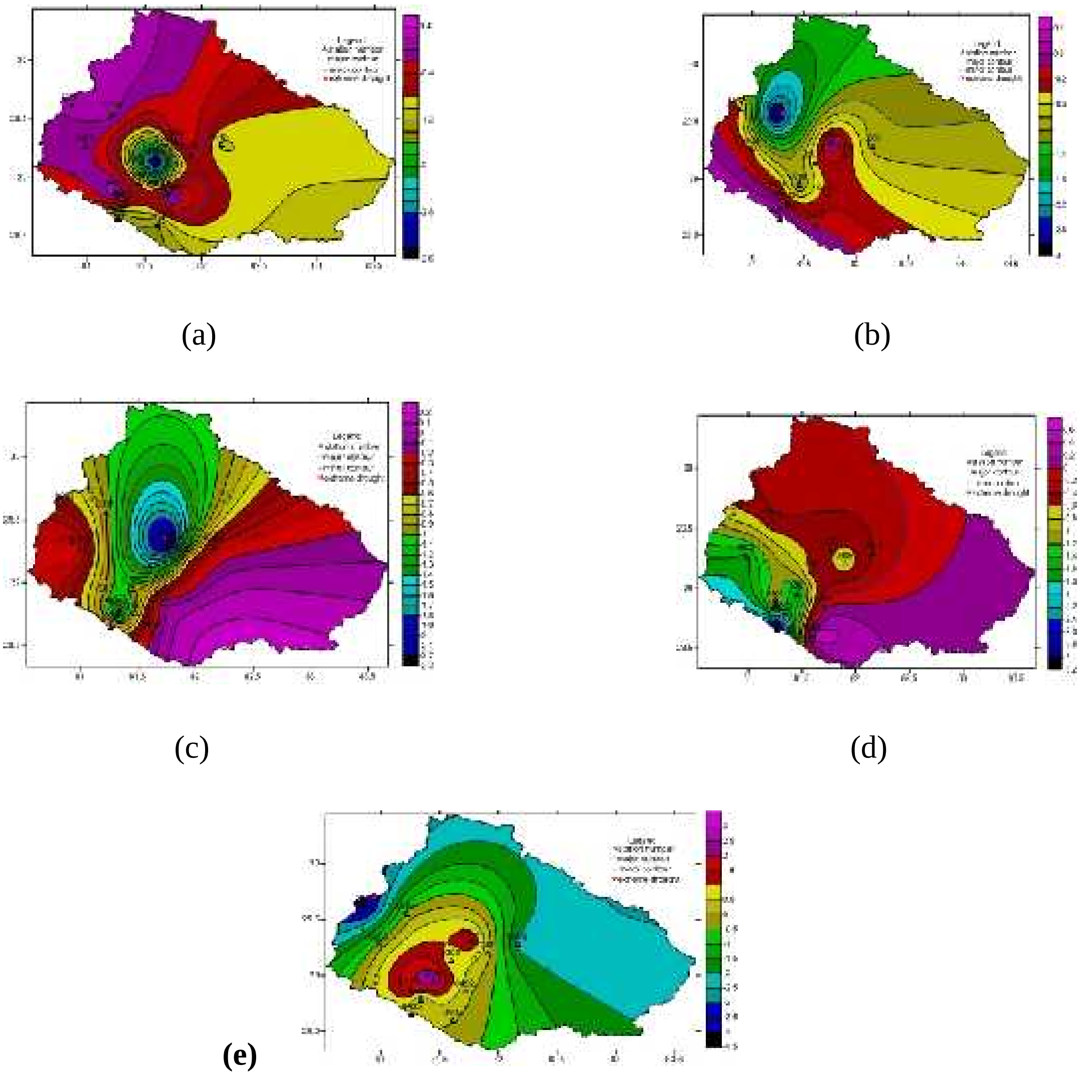


(e)



(f)

Figure 5-2-B: (a), (b), (c), (d),(e) & (f): Extreme droughts for July



(a) (b) (c) (d) (e)

Figure 5-3-C: (a),(b),(c),(d) &(e):Extreme droughts for August

CHAPTER VI

DISCUSSIONS

6.1. Comparison of drought events and cereal crops

The graph was plotted between the number of drought events (moderate, severe and extreme) for the months of June, July, August and the crop yields of paddy, maize and millet from the year 1999 to 2011 shown in the figure below. The graph (a) shows that the yield of paddy has increased at the rate of 0.1484, 0.1374 and 0.1209 as shown in the equations of moderate, severe and extreme respectively except in the year 2001, 2004 and 2006 .In those three years of decrement, moderate drought was found but we are not sure that the yield was affected by this drought event because as we see in other years, the yield was found increased though severe and extreme drought events were recorded in those increasing years. The reason behind the increment of yield may be due to the construction of different irrigational canal around the study area since the system of building canals for agricultural purposes are developing more often particularly in the western regions of Nepal. And other reason may be uses of different organic fertilizers and various newly developed chemicals for quick production by the farmers.

Besides, using water efficiently that includes proper domestic water use practice, good irrigation practice, changing crops and cropping practice, rainwater harvesting and other different water conservation practices makes the impact of drought reduce which ultimately helps in the agricultural production. Hence in concerned with these instances, we can analyze that there was no effect of drought to the yield of paddy during the period of 1999 to 2011.

Similarly the graph (b) also indicates that the yield of maize has been in increasing trend at the same rates as that of paddy apart from 2008 and 2009. During these two years, moderate and extreme droughts were found but again we cannot say those events has influenced the yield because as we see in 2005, maximum number of drought events occurred but the yield was not affected rather it was found in increasing phase. And finally the graph (c) shows that the yield of millet also found increased for almost all of the years at the same rates as that of paddy and maize. In the year 2004, moderate and extreme drought events were recorded and was found in decreasing phase and like maize though the highest number of drought events were recorded in the year 2005 but the yield was not affected again. Therefore similar analysis can be made for the yields of maize and millet as was done for paddy.

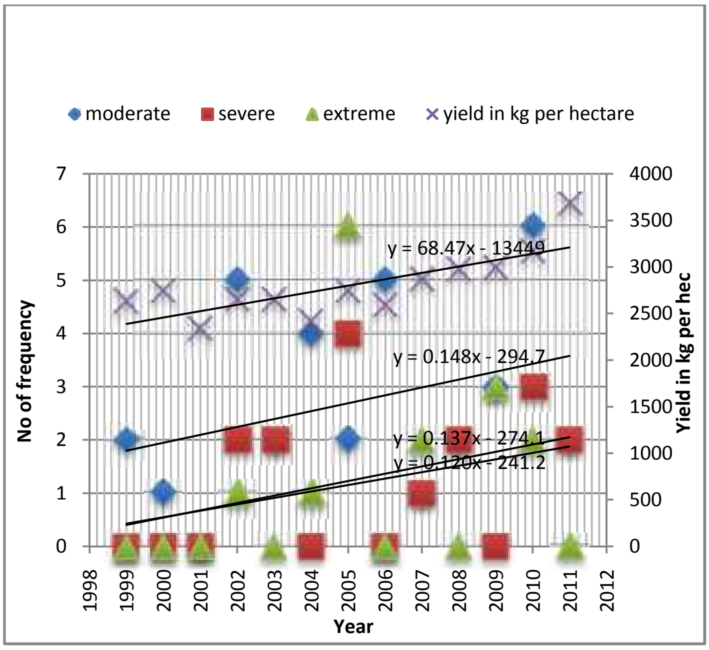


Figure 5-4(a): yield of paddy and drought events

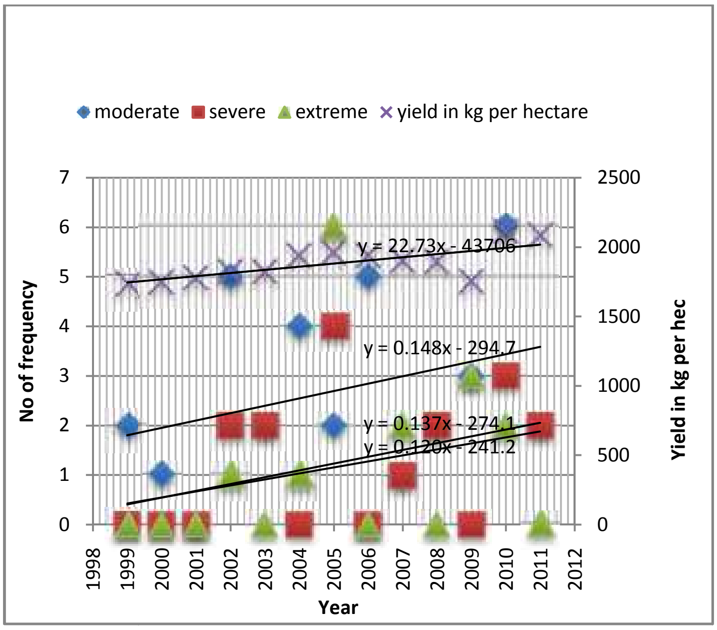


Figure 5-5 (b): yield of maize and drought events

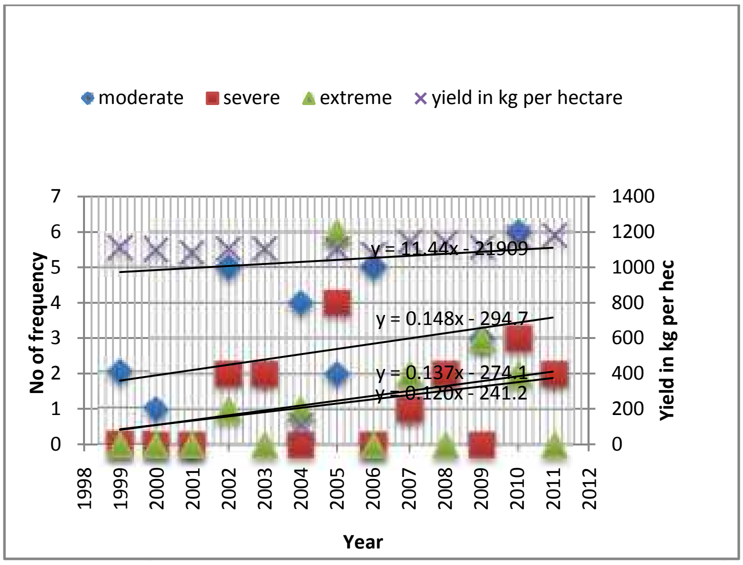


Figure 5-6(c): yield of millet and drought events

CHAPTER VII

CONCLUSION AND RECOMMENDATIONS

7.1. Conclusion

From this study of drought using SPI tool, the following conclusions can be made.

- Due to the simplicity of SPI that can run only with precipitation data, it is found very easy tool to analyze the drought.
- From the station wise analysis, almost all the stations are suffered from normal drought for the same year or different years. Similarly after normal drought, moderate type has been found most in all the stations and then severe and extreme drought were next suffering drought events.
- It is observed that 4 stations were more suffered from extreme drought i.e. Pipalkot, Jumla, Serighat and Surkhet and 3 stations i.e. Silghadi, Doti, Asaraghat and Nagma were not suffered from this type. The most suffered extreme drought year was 2005 among all the stations of the basin.
- From the frequency analysis, it is observed that most of the years were recorded by moderate type of drought than severe and extreme in all the stations thus indicating that the moderate drought spreading in almost all parts of the study area.
- It is also observed that June was the highest recorded drought events in number from 1987 to 2013.
- Finally the study shows that the yield of cereal crops (paddy, maize & millet) were in increasing trend though some years were found decreased and not confirmed whether the decrement was by the drought events (moderate, severe, extreme) or not because while looking at increment years of the yield, different drought events were found occurring but was not affected to the yield of all three crops that was used for the study. The reasons for not affecting yield although the occurrences of drought are may be constructing of irrigational canals, more use of chemical fertilizers by the surrounding people and farmers and applying water efficiently like proper use of domestic water, cropping practice and rain water harvesting around the study area. Because of the limitation in the study, it

difficult to find all the answers related to drought. The study finding can be more utilized particularly in the agricultural sectors.

7.2. Recommendations

Based on the results and discussions made in the previous chapters, the following recommendations are given.

- The study of drought in Nepal is limited so more study should be done for monitoring and detecting drought in prone area particularly.
- Drought monitoring practice for the country is needed in a regular basis.
- The effective data should be available and also the quality of data must be given prioritized by different concerns authorities since the use of available data is not only in need for the drought study but for other research field too.
- Different tools should be used more and more for the study of drought in Nepal and the study based on satellite or remote sensing data also should be developed.
- The long term data of different crops should be used and study on wet and dry spells of a week or more would be effective for monitoring agricultural drought.
- Survey of irrigational canal and more study on quick agricultural production using different chemicals should be done.
- More use of different practices for agricultural purpose like water use practice, cropping practice, irrigation practice particularly by the farmers and understanding of changing crop pattern like selecting weather resistant crops are needed.

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Wikipedia: A free Enclyopedia
www.fao.com
www.google.com
www.ncdc.noaa.gov
(nepaldetail.blogspot.com/.../mid-western-development-regionmwdr-mid..)

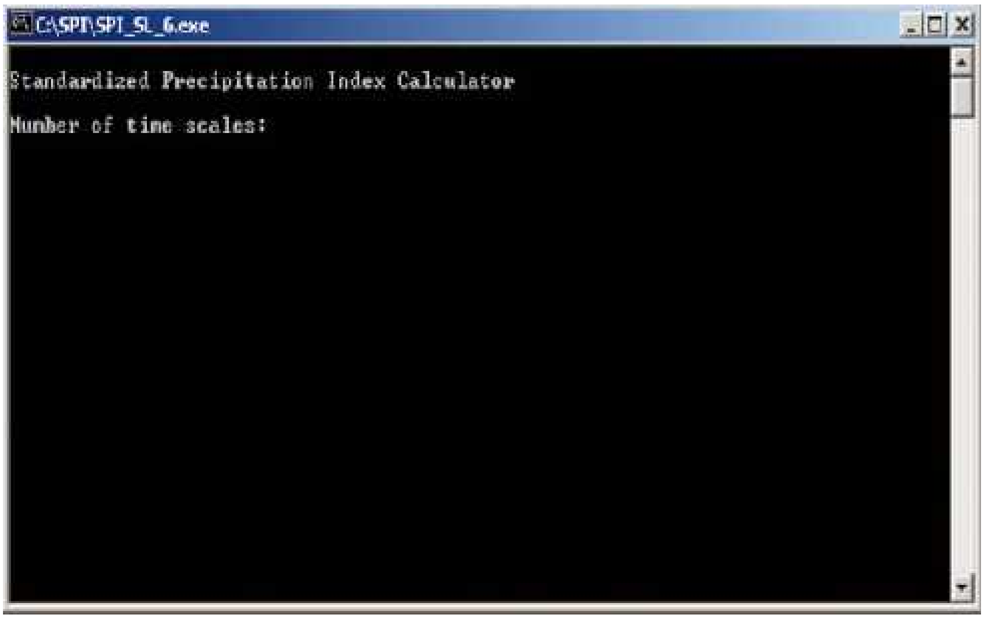
APPENDICES

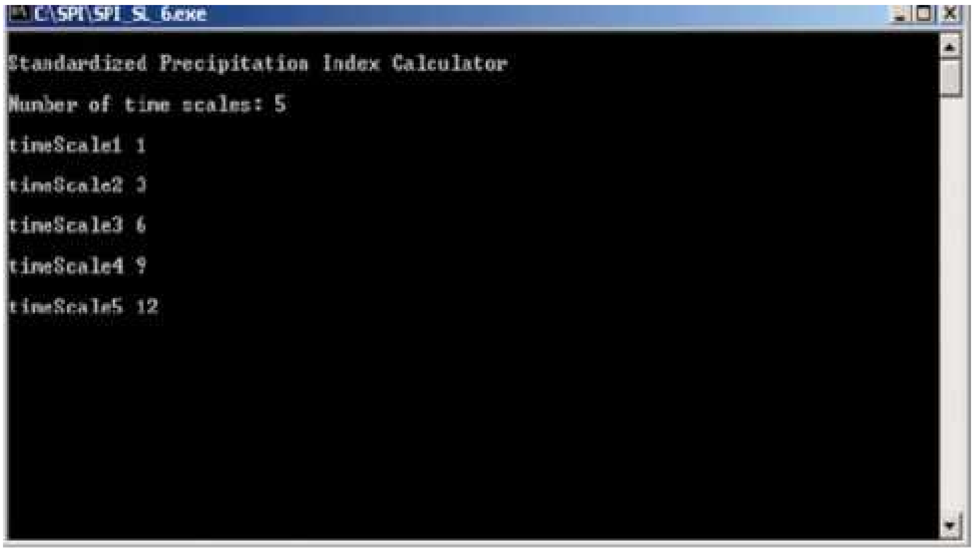
Appendix-1: Input file for SPI program-the file has been truncated

station206

1970	1	76
1970	2	9
1970	3	23
1970	4	3
1970	5	57
1970	6	396
1970	7	551
1970	8	287
1970	9	71
1970	10	14
1970	11	0
1970	12	0
1971	1	42
1971	2	71
1971	3	39
1971	4	165
1971	5	121
1971	6	226
1971	7	190
1971	8	109
1971	9	256
1971	10	125
1971	11	1
1971	12	0
1972	1	4
1972	2	96
1972	3	22
1972	4	14
1972	5	16
1972	6	88
1972	7	387
1972	8	140
1972	9	238
1972	10	44
1972	11	10
1972	12	2
1973	1	101
1973	2	53
1973	3	20
1973	4	2
1973	5	90
1973	6	326
1973	7	208
1973	8	194

Appendix 2-: Calculation of SPI using SPI_SL_6.exe under progress





Appendix 3: Output file of SPI program-the file has been truncated.

station206

1970	1	0.9	-99	-99	-99	-99
1970	2	-1.4	-99	-99	-99	-99
1970	3	-0.09	-0.17	-99	-99	-99
1970	4	-1.14	-1.68	-99	-99	-99
1970	5	-0.73	-1.28	-99	-99	-99
1970	6	1.73	1.08	0.83	-99	-99
1970	7	2.19	2.87	2.25	-99	-99
1970	8	0.28	2.37	1.88	-99	-99
1970	9	-0.55	1.07	1.45	-99	-99
1970	10	0.03	-0.34	1.42	-99	-99
1970	11	0.11	-0.78	1.57	-99	-99
1970	12	-0.11	-0.58	0.78	1.09	-99
1971	1	0.26	-0.41	-0.54	0.98	-99
1971	2	0.77	0.21	-0.69	1.19	-99
1971	3	0.36	0.47	-0.18	1.26	-99
1971	4	2.43	1.92	1.36	1.87	-99
1971	5	0.66	1.87	1.86	2.1	-99
1971	6	0.38	1.47	1.47	1.41	-99
1971	7	-1.27	-0.5	0.73	0.03	-99
1971	8	-1.91	-1.63	-0.47	-1.01	-99
1971	9	1.2	-0.82	0.18	0.06	-99
1971	10	1.41	0.39	-0.02	0.55	-99
1971	11	0.19	1.48	-0.18	0.54	-99
1971	12	-0.11	1	-0.4	0.52	1.26
1972	1	-1.08	-1.86	-0.02	0.38	1
1972	2	1.25	-0.01	1.37	0.47	1.21
1972	3	-0.12	0.05	0.66	0.41	1.22
1972	4	-0.4	0.35	-0.57	-0.26	1.26
1972	5	-2.49	-2.09	-1.91	-0.75	1.19
1972	6	-1.39	-2.44	-2.03	-1.38	0.2
1972	7	0.9	-0.92	-0.76	-0.56	-0.39
1972	8	-1.4	-0.97	-1.63	-0.41	-1.02
1972	9	1.08	0.37	-0.72	-0.42	-0.29
1972	10	0.54	-0.01	-0.56	-0.79	-0.18
1972	11	0.63	0.99	-0.18	-0.73	-0.14
1972	12	-0.07	0.2	0.31	-0.75	-0.16

Appendix 4: SPI of different months at different time scales

Year	Month	SPI1	SPI3	SPI6	SPI12	SPI24
1970	1	0.9	-99	-99	-99	-99
1970	2	-1.4	-99	-99	-99	-99
1970	3	-0.09	-0.17	-99	-99	-99
1970	4	-1.14	-1.68	-99	-99	-99
1970	5	-0.73	-1.28	-99	-99	-99
1970	6	1.73	1.08	0.83	-99	-99
1970	7	2.19	2.87	2.25	-99	-99
1970	8	0.28	2.37	1.88	-99	-99
1970	9	-0.55	1.07	1.45	-99	-99
1970	10	0.03	-0.34	1.42	-99	-99
1970	11	0.11	-0.78	1.57	-99	-99
1970	12	-0.11	-0.58	0.78	1.09	-99
1971	1	0.26	-0.41	-0.54	0.98	-99
1971	2	0.77	0.21	-0.69	1.19	-99
1971	3	0.36	0.47	-0.18	1.26	-99
1971	4	2.43	1.92	1.36	1.87	-99
1971	5	0.66	1.87	1.86	2.1	-99
1971	6	0.38	1.47	1.47	1.41	-99
1971	7	-1.27	-0.5	0.73	0.03	-99
1971	8	-1.91	-1.63	-0.47	-1.01	-99
1971	9	1.2	-0.82	0.18	0.06	-99
1971	10	1.41	0.39	-0.02	0.55	-99
1971	11	0.19	1.48	-0.18	0.54	-99
1971	12	-0.11	1	-0.4	0.52	1.26
1972	1	-1.08	-1.86	-0.02	0.38	1
1972	2	1.25	-0.01	1.37	0.47	1.21
1972	3	-0.12	0.05	0.66	0.41	1.22
1972	4	-0.4	0.35	-0.57	-0.26	1.26
1972	5	-2.49	-2.09	-1.91	-0.75	1.19
1972	6	-1.39	-2.44	-2.03	-1.38	0.2
1972	7	0.9	-0.92	-0.76	-0.56	-0.39
1972	8	-1.4	-0.97	-1.63	-0.41	-1.02
1972	9	1.08	0.37	-0.72	-0.42	-0.29
1972	10	0.54	-0.01	-0.56	-0.79	-0.18
1972	11	0.63	0.99	-0.18	-0.73	-0.14
1972	12	-0.07	0.2	0.31	-0.75	-0.16

Appendix 5: Average rainfall for different stations

Year	201	202	203	206	302	303	305	308	401	402	403	405	406
1980	2102.8	1595.5	1250.2	1068.6	894.6	1045.9	982.9	911.7	1466.7	1434.5	2122	1917.9	1418.2
1981	2298.9	1645.1	1342.4	1161.1	732.7	1003.7	1588.7	869.8	1487.8	1477.4	2233.9	2541.7	1995.7
1982	2159.6	1661.5	1352.9	1445	664.6	1051.1	1254	949.6	1306	1317.2	1696.8	1877.9	1496
1983	2708.5	2005	1949.1	1529.6	961.7	895.3	906.2	1008.9	2273.5	2289.9	1709.2	2023.7	1754.8
1984	2563.9	1495.7	1262.8	1160	376.6	628.2	668.3	540.3	1295	1277.7	1418.5	2482.7	1614.4
1985	2430.1	1675	1445.3	1497.4	650.7	876.6	1511.7	905	1663	1684.8	2355.1	2863	2045.7
1986	2280.1	1662.1	1609.9	1125	661.8	856.2	1286.5	752.4	1483	1482.6	1585.4	2055.1	1930.4
1987	2205	1349.3	1182.1	1144.6	486.9	696.6	1389.1	763.7	1128.5	1096.8	1108.3	1918.9	1247.6
1988	2359.8	1609.5	1253.6	1279.7	453.5	885	1506	741.1	1567.1	1629.9	1939.6	2366.1	1914.3
1989	2477.5	1547.1	1525	1255.6	506.5	703.8	1441	501.3	1729.7	1432.5	849.3	2543.5	1539.4
1990	2451.2	1803.9	1582.5	1536	756.1	829.3	1623.8	862.7	1758.7	2435.8	2038.6	2797.6	1929.2
1991	1949.5	1657.8	1516.6	1175.9	638.1	892.9	1425.2	794.4	1663.2	1509.3	969.8	1978.5	1350.6
1992	1617.9	1455	990.2	884.3	541	757.6	1138.4	705.5	1254	1222.3	715.7	1592.2	1485
1993	2262.7	1302.1	1394.3	1426.1	852.4	821.3	1461.6	768.1	1787.1	1597.9	1039.8	2301.9	1452.1
1994	1908.2	1298.8	1086.8	861	394.4	813.6	1072.5	561.4	1372.3	2138.4	875.6	1604.1	1272.1
1995	2076.5	1676.9	1286.6	1236.8	715.8	829	1696.2	808.2	1756.8	1895.7	676.4	2150.6	1514.2
1996	2076.5	1649.9	1199.1	1118.3	592.1	832.8	1304.8	666.5	1683.8	3097.8	1088.4	2069.7	1431.2
1997	2321	1768.1	1317	1231.1	447.6	773.6	1359.8	716.6	1600.3	1808	1242.5	2649.3	1709.6
1998	2600.2	1665.8	1436.7	1154.4	426	833.7	1279.2	689.7	1885.3	1948.1	1229.2	2731.1	1753.8
1999	2009.2	1437.6	1624.7	1100.4	509	675.7	1498.1	606.4	1560.6	1711.5	1014.2	2353.3	1708.1
2000	3112.6	1809.8	1224.95	1356.8	562.6	886.6	1392.5	767	2011.6	1289.9	1109.3	2105.3	1899.5
2001	2121.6	1321.8	1113	1056.1	354.2	728.1	1194.5	569.2	1259.9	1819.6	1012.1	2342.4	1722.1
2002	2517.2	1853	1553.1	1396.1	754.2	842.2	1049.6	796.6	1259.9	1327.3	899.5	2178.1	1537.7
2003	2338.1	1747.3	1270.9	1192.4	541.7	842.9	1103.8	968.7	1633.3	1979.4	737.3	2271.5	1849.1
2004	1847.4	1316.7	1284.8	1148.8	305.2	685.4	1305.6	667.5	1363.4	1280.9	520.5	2096.3	1425.3
2005	2015	1444.9	1220.5	902.4	344	669.5	1517.2	667.5	1354.3	1907.4	573.6	1868.4	1809.8
2006	2255	1467.1	1454	1017.3	442.7	747.7	1515.7	773.6	1420.6	1784.2	940.9	2075	1484.9
2007	2353.3	1619.6	1277.45	1279.9	576.2	831.8	1226.2	863.6	1650	1697	759	3293.2	1864.2
2008	1888.6	1653.9	849.6	1182.5	750.7	966.7	2099	1042.1	1461.3	1985.7	788.7	2735.7	1507.6
2009	1340.7	1672.9	1647.6	2107.1	510.5	696.3	1799	814.86	2193.2	1686.3	1099.7	2228.5	1726.4
2010	2069.7	1381.5	1061.55	1240.5	715.7	795.3	1806.3	1172.2	1516	1162.8	1256.7	1886.1	974.5
2011	2682.4	1381.5	1647.17	1289.7	273.3	944.7	1771.6	817.5	1536.5	1784.5	1004.1	2341.6	1659
2012	2293.3	1230.9	1711.5	1040.6	358.9	785.2	1114.9	865.7	1054.5	1490.5	1036.3	2192.4	1173.2
2013	2639.7	1454.8	1578.8	1468.3	580.7	989.3	1337.1	839.3	1814.4	1446.4	1798.9	2224.6	2113.5
Average rain	2245.11	1568.2	1367.73	1237.3	568.6	826.87	1371.4	786.73	1566.21	1680.29	1219	2254.6	1626.7

Appendix 5: Production and yield of cereal crops in MW. region

Area,Production And Yield of Cereal Crops in MW.Region
(Area in Hectare,Production in Metric Ton and Yield in kg)

Year	Paddy			Maize			Millet		
	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield
1999/00	157662	414080	2626	51015	260957	1728	21084	22331	1107
2000/01	159896	438037	2740	149925	262226	1749	21127	23242	1100
2001/02	154086	360968	2343	150596	267571	1777	20460	22186	1084
2002/03	158007	418562	2649	149603	272588	1822	20622	22826	1107
2003/04	158007	418562	2649	149603	272588	1822	20622	22826	1107
2004/05	151524	366439	2418	148506	287248	1934	20918	23297	114
2005/06	156094	427912	2741	148678	290684	1955	20931	23174	1107
2006/07	152342	394718	2591	157526	304737	1935	20871	22426	1075
2007/08	160662	460116	2864	154322	293185	1900	21014	24974	1146
2008/09	165939	492267	2967	153538	290280	1891	20818	23768	1142
2009/10	165080	492825	2985	159147	278832	1752	21457	23914	1115
2010/11	173720	549294	3162	153490	323040	2105	21737	25471	1172
2011/12	171647	628995	3664	140431	291726	2077	16161	19117	1182.9