# Project Report

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# Agricultural Drought Assessment Using Remote Sensing and GIS in Gandaki Province, Nepal

by

## Master of Science (Geographical Information Science & Systems)

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A project report submitted in partial fulfilment of the requirements of
the degree of
Master of Science (Geographical Information Science & Systems) – MSc (GISc)

Advisor:

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Kathmandu, 3.27.2021

## Science Pledge

By my signature below, I certify that my project report is entirely the result of my own work. I have cited all sources of information and data I have used in my project report and indicated their origin.

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| Kathmandu, 27th March, 2021 | |
| Place and Date | Signature |

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# ABSTRACT

Drought is one of the major natural hazards. It is a deficient of significant rainfall/precipitation over a long period. It is silent and has an extensive spatial dimension. It has a serious and devastating impact on agriculture, water supply, eco-system socio-economic stability of an entire region. It is not possible to avoid drought but can be monitored and drought preparedness can be developed for the management of its impact. Remote Sensing is one of the tools for monitoring drought over a large area. There are different types of drought: Meteorological, Agricultural, Hydrological and Socioeconomic drought. Drought occurs whenever the links in the hydrological cycle got broken. There are different working methods for monitoring drought. We can analyze precipitation, NDVI, soil moisture, evapotranspiration, and groundwater anomalies for drought monitoring. We used TRMM Multi-Satellite Precipitation Analysis (TMPA) for the monthly precipitation data and MODIS NDVI data for the Vegetation Index. The precipitation data from the years 2005-2015 were downloaded and precipitation anomaly was obtained for all year. Similarly, MODIS NDVI images from 2005-2015 were downloaded, averaged, and NDVI anomaly was obtained with the help of average NDVI. Anomaly was obtained by the departure of NDVI from the long-term average, normalized by long-term variability. It was generated by subtracting the long-term mean from the current value for that month of the year for each grid cell. Finally, we compared the precipitation anomaly images to the vegetation anomaly images. We concluded that most of the negative precipitation anomalies were occurring where the negative vegetation anomalies had occurred. It suggests that the TMPA SPI data and MODIS NDVI data can be used for monitoring the occurrence of drought in Gandaki Province.

# Table of Contents

## List of Figures



## List of Maps

## List of Tables

# ABBREVIATION

| | |
|---|---|
| AOI | Area of Interest |
| AVHRR | Advanced Very High Resolution Radiometer |
| CBS | Central Bureau of Statistics |
| CMG | Climate Modeling Grid |
| CMI | Crop Moisture Index |
| DHM | Department of Hydrology and Meteorology |
| DTW | Deep Tube Well |
| ENVI | Environment for Visualizing Images |
| EOS | Earth observing system |
| ERDAS | Earth Resource Development Assessment System |
| EVI | Enhanced Vegetation Index |
| FAO | Food and Agricultural Organization |
| GDP | Gross Domestic Product |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| HDF | Hierarchical Data Format |
| IDW | Inverse Distance Weighted |
| LAI | Leaf Area Index |
| LANDSAT | Land Satellite |
| LST | Land Surface Temperature |
| LULC | Land Use Land Cover |
| MoALD | Ministry of Agriculture and Livestock Development |
| MODIS | Moderate Resolution Imaging Spectrometer |
| MoF | Ministry of Finance |
| MRT | MODIS Reprojection Tool |
| MSS | Multi Spectral Satellite |
| MUTM | Modified Universal Transverse Mercator |
| NASA | National Aeronautics and Space Administration |
| NDVI | Normalized Difference Vegetation Index |
| PDSI | Palmer Drought Severity Index |
| QGIS | Quantum GIS |
| RDI | Reconnaissance Drought Index |
| RS | Remote Sensing |
| SPEI | Standardized Precipitation Evapotranspiration Index |
| SPI | Standardized Precipitation Index |
| SR | Surface Reflectance |
| SWIR | Short Wave Infrared |

| | |
|---|---|
| TCI | Temperature condition index |
| VCI | Vegetation condition index |
| WDI | Water deficit index |
| WGS | World Geodetic System |
| WSVI | Water Supply Vegetation Index |

# CHAPTER 1: BACKGROUND

## 1.1 Introduction

Drought is an insidious natural hazard that originates from deficiency of precipitation over certain period of time, resulting in a shortage of water for some activity, group, or environmental sector etc. It is a common climatic phenomenon in most climatic regimes (Ryu et al., 2019). The water scarcity is being further compounded by droughts which affect both surface water and groundwater resources and can lead to reduced water supply, deteriorated water quality, crop failure, and disturbed riparian habitats (Belal et al., 2014). Therefore, understanding drought and modeling its components have drawn attention of ecologists, hydrologists, meteorologists, and agricultural scientists. Droughts are of great importance in water resources planning and management (Mishra & Singh, 2011). According to Saji & Yamagata, (2003) Indian Ocean Dipole mode index (DMI) is a recently noticed player for precipitation variability along peninsular and western Indian subcontinent. Therefore, hydroclimatic variability around Nepal cannot be distant from the influence of these indices like ENSO and DMI (Sigdel & Ikeda, 2010).

Wilhite & Glantz, (1985) classified the drought in four major categories. They are: (i) Meteorological drought, (ii) Hydrological drought (iii) Agricultural Drought, and (iv) Socio-economic Drought. Meteorological drought simply implies rainfall deficiency where the precipitation is reduced by more than 25% from normal in any given area. Meteorological drought basis on the degree of dryness and dry period. The American Meteorological Society defines it as a period of abnormal dry weather sufficiently prolonged to cause serious hydrologic imbalances. Agriculture drought connects various characteristics of metrological and hydrological droughts like as: precipitation shortages, soil, soil water deficits, and reduced ground water or reservoir levels and evapotranspiration.

Statistical Information on Nepalese Agriculture 2075/76 reported that 21% of total land was cultivated agricultural land and 7% of total land was uncultivated agricultural land. By reviewing MoALD Statistical Information on Nepalese Agriculture report between 2070/71-2075/76 amount of production of cereal crops was increased by small percentages but total cultivated area was fluctuated. In 2014 cultivated area was decreased by 2.96% than 2013, but in 2015 total cultivated area was increased by 3.3% than 2014. This pattern goes to till 2019. So, fluctuation in cultivated area and production of crops due to population growth in arable zone and lack of rainfall.

There have been some studies on precipitation patterns over Nepal e.g. Shrestha et al., (2000), the study concerning on drought is very limited and new. Summer monsoon, June to September (JJAS) is associated with around 80 percent of total precipitation while winter season's western disturbance has relatively weak effects on precipitation which lies from December to February (Sigdel & Ikeda, 2010). In Nepal, drought disasters have been occurring frequently in recent years. It was not only experienced by the country in 2020, caused by climate change and global warming. It has occurred more frequently in duration from 2005 to 2015, every year. The average level of humidity is quite high making no difference between extreme minimum and maximum temperature levels. Winter season is basically dry, reduction in rain fall may have a serious impact on cultivation and crop production. Large number of farmers depends on precipitation so, dependency on precipitation may lead serious consequences on the national economy of Nepal due to long term drought situation. So, careful monitoring as well as early warning for dryness is a big challenge for drought management in Nepal. From the historical observations, this country has noticed that the serious droughts gave enormous nationwide impacts. With this condition, the high level of temperature does not determine the life and death of crops being cultivated, but it is more determined by water availability (Shofiyati et al., 2009).

In this research RS and GIS techniques will used for drought detection by using temporal images from MODIS terra surface reflectance (resolution 250m) based NDVI (2005-2015) and meteorological information based SPI. 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). It suggests that the TMPA SPI data and MODIS NDVI data can be used for monitoring the occurrence of drought in Nepal. In this regard, special attention to monitor the condition is encouraged to reduce the damage. An early warning of drought hazard would be very useful in the planning stage of agricultural development settings (Shofiyati et al., 2009). The present study aims at focusing on the drought index (SPI) over the country, Nepal, and focuses on the analysis of spatial pattern and temporal progression of the drought events. A relationship between the meteorological, agricultural and hydrological droughts can be analyzed from the figure below:

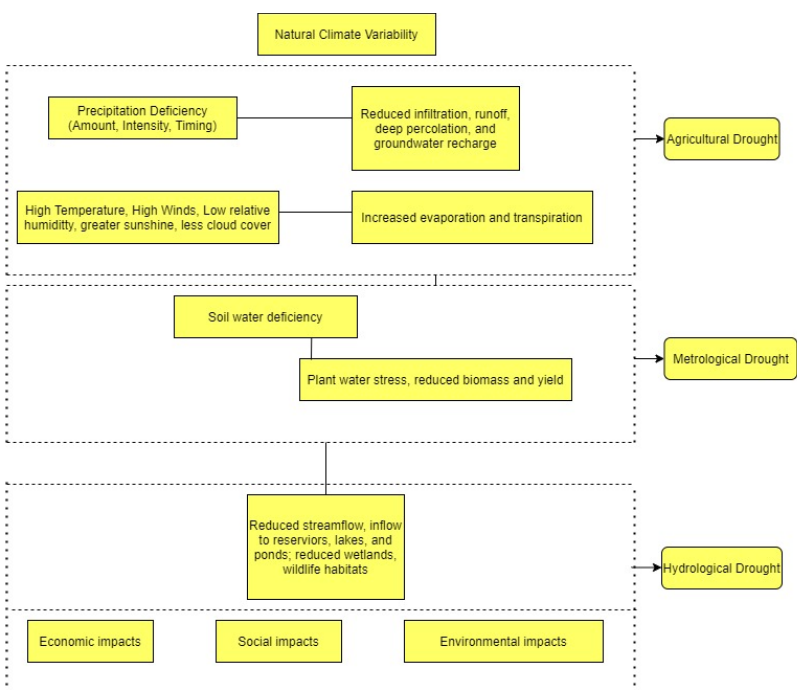



*Figure 1: Sequence of drought occurrence*

## 1.2 Background

The uncertainty in climatic environment is one of the serious threats in WRM and economy of the country.  Drought is one of the major aspect of climatic variability. Droughts are governed by regional climatic parameters like precipitation, transpiration, temperature, vegetation indices etc. So, the characteristics and consequences of drought vary with respect to climatic regimes around the world. In the winter season, the westerly jet stream develops over the southern Himalayas and directs the passage of extratropical storms (known as western disturbances) through Nepal. Pronounced interannual variability of winter storm occurrences is correlated with polar/Eurasia teleconnection pattern (Lang & Barros, 2003). Nepal is one of the most vulnerable countries with respect to climate change, due to greater warming in recent years than that of the global average (Adhikari, 2018a). Moreover, the mean annual temperature is predicted to be increased between 1.3 ◦C to 3.8 ◦C by the 2060s, and 1.8 ◦C to 5.8 ◦C by the 2090s while annual precipitation reduction could be within the range of 10% to 20%, across the country (MoE, 2010). In western Nepal, winter monthly precipitation amounts are on the order of 50 mm or less. The region is particularly reliant on this precipitation for crop production since (i) only 28% of Nepal's agricultural land is irrigated from groundwater resources and (ii) the groundwater replenished through the monsoon is subject to rapid depletion during the winter of 2008/09, western Nepal experienced severe drought conditions that were unprecedented in both scale and severity precipitation from November 2008 to February 2009 fell below 50% of average (Wang et al., 2013). Dependency on rainfall for agriculture practice may lead serious issues on the national economy due to long term drought. Rigorous assessment of drought is a big challenge for drought management in Nepal. (Sigdel & Ikeda, 1970). Nepal has experienced economic growth in recent years from international development assistance and remittances but rapid agricultural growth has not experienced by Nepal. Due to lack of proper ground observations for assessment of drought impacts has led to the exploitation of remote sensing images. Satellite imageries are especially recommended in regions where the ground observation data is less precise

## 1.3 Objectives of this study

The study is being carried out to is to develop a method of using RS/GIS for agricultural and metrological drought monitoring and assessment by applying multi temporal and multi resolution remote sensing data. General objectives of this research project can be listed as follows.

i. To identify agricultural and metrological drought in Gandaki province.
ii. To generating agricultural and metrological drought risk map based on its severity levels using NDVI and SPI.
iii. To examining the combine drought risk from agricultural and metrological drought.
iv. To suggest the he relevant policy makers for appropriate and timely actions and provide the information about for maintaining food-security in the country whenever drought prevails

## 1.4 Rationale of the study

The total area of the Gandaki province is about 21914.97sq.km. Most of the food production depend upon the rainfall. Inadequate monsoon may create the drought conditions. Present drought conditions cause the major problems on socio-economic and environment sector. Traditional method for drought assessment is tedious and expensive than modern method where we do perform the drought assessment by using MSS imageries. As frequent information about drought can controls the drought related loss, the real time assessment through effective monitoring using satellite data plays a significant role in mitigating its adverse impacts.

## 1.5 Limitation of the study

- Different versions of Multispectral satellite data were available for years (2005-2015), Some MODIS imageries are affected by cloud, fog. For rigorous drought assessment higher resolution imagery and more than 25 years imageries are essential.
- Gandaki province has only few rainfall stations. Data from these rainfall stations are not enough for proper image interpolation to generate drought severity maps

## 1.6 Outline of the study

This study contains four chapters.

Chapter 1: Introduction highlights the background and objectives of the study. Literature Review covers previous research carried out in the field of drought assessment as well as role of remote sensing and GIS technology in the arena of monitoring, prediction, and assessment of droughts so far. Study area gives a brief overview of the study area.

Chapter 2: Materials and Method explains the data used and the selected methodology adopted for the research. Here acquisition of satellite images and its processing and analyzing has been discussed briefly.

Chapter 3: Results and Discussion gives a critical observation for agricultural and meteorological drought indices and their relationships. It gives a brief discussion based on the results achieved and the analysis carried out.

Chapter 4: Conclusion and Recommendations draws conclusion of this study and gives recommendations for further research.

## 1.7 literature review

### 1.7.1 General

Several numbers of research works have been done in regard to the analysis of agricultural drought assessment using Remote Sensing and GIS. Some literatures have been studied and reviewed and which is explain below.

Droughts are periodically occurring climatic events, which often hit Nepal, resulting significant water shortages, national economic losses and adverse social consequences. During last two decades growth in population and urbanization has added to the huge amount of water and other natural resources. Shofiyati et al., (2009) states that Monitoring of drought is vital in agricultural development, as it will provide useful information on the assessment of drought hazard characteristics and water stress level. It is a common climatic phenomenon in most climatic regimes (Ryu et al., 2019). The local drought magnitude is expected to be worse in the future, due to global warming (Nam et al., 2015). The growth and development of crops and crop yields suffer under the conditions of a continual meteorological drought (Anjum et al., 2017). However, RS technology needs to be incorporated to explain the anomaly in vegetation caused by drought, which provides a promising method for better understanding the spatial extent and intensity of drought (Prodhan et al., 2020).

The drought monitoring has been applied to numerous areas of applied science. For example Joshi & Dongol, (2018) performed Severity of Climate Induced Drought and its Impact on Migration in Ramechhap District. Sigdel & Ikeda, (2010) performed Spatial and Temporal Analysis of Drought in Nepal using SPI and its Relationship with Climate Indices; Thenkabail & Gamage, (2004) use RS Data for Drought Assessment and Monitoring in Southwest Asia. Murad & Islam, (2011) used MODIS Reprojection Tool (MRT) used to reproject the raw satellite images with sinusoidal projected data into the regular GCS.

Shofiyati et al., (2009) applied three steps to get a NDVI range for determining drought condition. They are: a) multi temporal analysis, b) fluctuation of NDVI, and c) normal line diagram analysis. Sigdel & Ikeda, (2010) find out the amount of annual precipitation generally decreases from east to west in Nepal and calculated and obtained the SPI series for Nepal with the two temporal scales SPI-3 and SPI-12. Also, they used RPCA as an extended analysis to identify drought characteristics in the sub-regions. Joshi & Dongol, (2018) was calculated NDVI for 2006 and 2009 using Red and NIR bands of LANDSAT-4 & 5 TM and NDVI for 2016 was calculated from LANDSAT 8 OLI and TIRS sensors. TIRS sensors was used for calculation of Land Surface Temperature (LST).

Reinermann et al., (2019) concludes that The MODIS 250 m remote sensing data seems to be sufficiently resolved to reveal drought patterns for different land cover types in the relatively heterogeneous landscapes for central Europe. Murad, (2010) found that the temporal variations of NDVI anomaly are closely linked with SPI and there is a strong linear relationship between NDVI and SPI and he observed correlation to find out how vegetation stress condition and consequently agricultural production yield is changing with the variability of rainfall. Baniya et al., (2019) identified the drought years with seasonal monsoon and pre-seasonal monsoon where VCI has increased at the rate of 1.14 $yr^{-1}$.

Adhikari, (2018b) recommended that developed and implementation of local site adaption measures should be done in future. The use of RS and GIS tools to access such condition is proposed in this study. Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation indices. Prodhan et al., (2020) find out the use of three or more indices for investigating drought is very significant for making an appropriate plan to reduce the severity of drought impacts on society. Liang et al., (2017) find out limitations of VCI drought index, it has some disadvantages in its performance due to VCI from NDVI is very sensitive to dark and wet soil condition. So, agricultural and meteorological drought prone areas in Gandaki province will be determined by using Remote Sensing and GIS technology and to delineate drought risk areas by using above mentioned data.

### 1.7.2 Meteorological Drought Indices

Different drought indices have been developed to measurement of drought severity. SPI, Reconnaissance Drought Index (RDI), Crop Moisture Index (CMI) and Standardized Precipitation Evapotranspiration Index (SPEI) were employed to study the variation of drought characteristics calculated from these indices (Pathak & Dodamani, 2020). There are several indices that measure how much precipitation for a given period of time has deviated from historically established 9 norms. Other widely used drought indices include Palmer Drought Severity Index (PDSI), and Surface Water Supply Index (SWSI)(Murad, 2010).

### 1.7.3 Standardized Precipitation Index (SPI)

SPI is the most commonly used indicator worldwide for detecting and characterizing meteorological droughts. The SPI indicator, which was developed by McKee et al. (1993), and described in detail by Edwards and McKee (1997), measures precipitation anomalies at a given location, based on a comparison of observed total precipitation amounts for an accumulation period of interest (e.g. 1, 3, 12, 48 months), with the long-term historic rainfall record for that period. The historic record is fitted to a probability distribution (the “gamma” distribution), which is then transformed into a normal distribution such that the mean SPI value for that location and period is zero. For any given region, increasingly severe rainfall deficits (i.e., meteorological droughts) are indicated as SPI decreases below –1.0, while increasingly severe excess rainfall are indicated as SPI increases above 1.0. Because SPI values are in units of standard deviation from the long-term mean, the indicator can be used to compare precipitation anomalies for any geographic location and for any numbers of time-scales. Note that the name of the indicator is usually modified to include the accumulation period. Thus, SPI-3 and SPI-12, for example, refer to accumulation periods of three and twelve months, respectively. Classification of SPI value is shown below.

*Table 1: Classification of SPI values (McKee et al., 1993)*

| SPI Values | Class | Probability |
|---|---|---|
| 2.0 and more | Extremely wet | 0.977-1.00 |
| 1.5 to 1.99 | Very wet | 0.933-0.977 |
| 1.0 to 1.49 | Moderately wet | 0.841-0.933 |
| -.99 to .99 | Near normal | 0.159-0.841 |
| -1.0 to -1.49 | Moderately dry | 0.067-0.159 |
| -1.5 to -1.99 | Severely dry | 0.023-0.067 |
| -2 and less | Extremely dry | 0.000-0.023 |

In this table positive SPI values indicate greater rainfall than mean value and negative SPI value indicate less value than mean value. In dry condition monitoring, the drought part of the SPI range is divided into near normal conditions (0.99 < SPI <-0.99), moderately dry (-1.0 < SPI < -1.49), severely dry (-1.5 < SPI <-1.99) and extremely dry (SPI < -2.0). A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again. By using SPI value and GIS environment the geospatial analysis and spatial extents can be developed.

### 1.7.4 Normalized Difference Vegetation Index (NDVI)

NDVI is indicator that can be used to analysis of different remote sensing measurements, often from a space platform, assessing whether or not the target being observed contains live green vegetation. Tucker first suggested NDVI in 1979 as an index of vegetation health and density (Thenkabail et al., 2004). NDVI is widely used in drought assessment due to its simplicity in calculation, easy to interpret and its ability to partially compensate for the effects of atmosphere, illumination geometry etc. NDVI is a transformation of reflected radiation in the visible and near infrared bands of a sensor system and is a function of green leaf area and biomass. Computation of NDVI is given by:

$$NDVI = \frac{(NIR\ reflectance - Red\ reflectance)}{(NIR\ reflectance + Red\ reflectance)} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \textit{Equation 1}$$

The severity of drought situation is assessed by the extent of NDVI deviation from its long - term mean. Maps produced using relative greenness is quite useful to assess drought situation and hence this indicator is being used widely (Thenkabail & Gamage, 2004). NDVI is a good indicator of green biomass, leaf area index, and patterns of production. NDVI is the most commonly used vegetation index. It varies from +1 to -1. NDVI can be seen from its mathematical definition. NDVI values ranges from 0.3 to 0.8 containing a dense vegetation canopy. Free standing water like: oceans, seas, lakes, rivers, ponds have low reflectance in both spectral bands (at least away from shores). Very low positive or slightly negative NDVI values indicates soil.

### 1.7.5 Vegetation Condition Index (VCI)

Vegetation condition index was first suggested by (Kogan, 1995). It shows, effectively, how close the current month's NDVI is to the minimum NDVI calculated from the long-term record of RS images. VCI enables to separate the short-term signal from the ecological signal.

$$NDVI = \frac{(NDVI-NDVI\ Min)}{(NDVI\ Max-NDVI\ Min)}*100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 2}$$

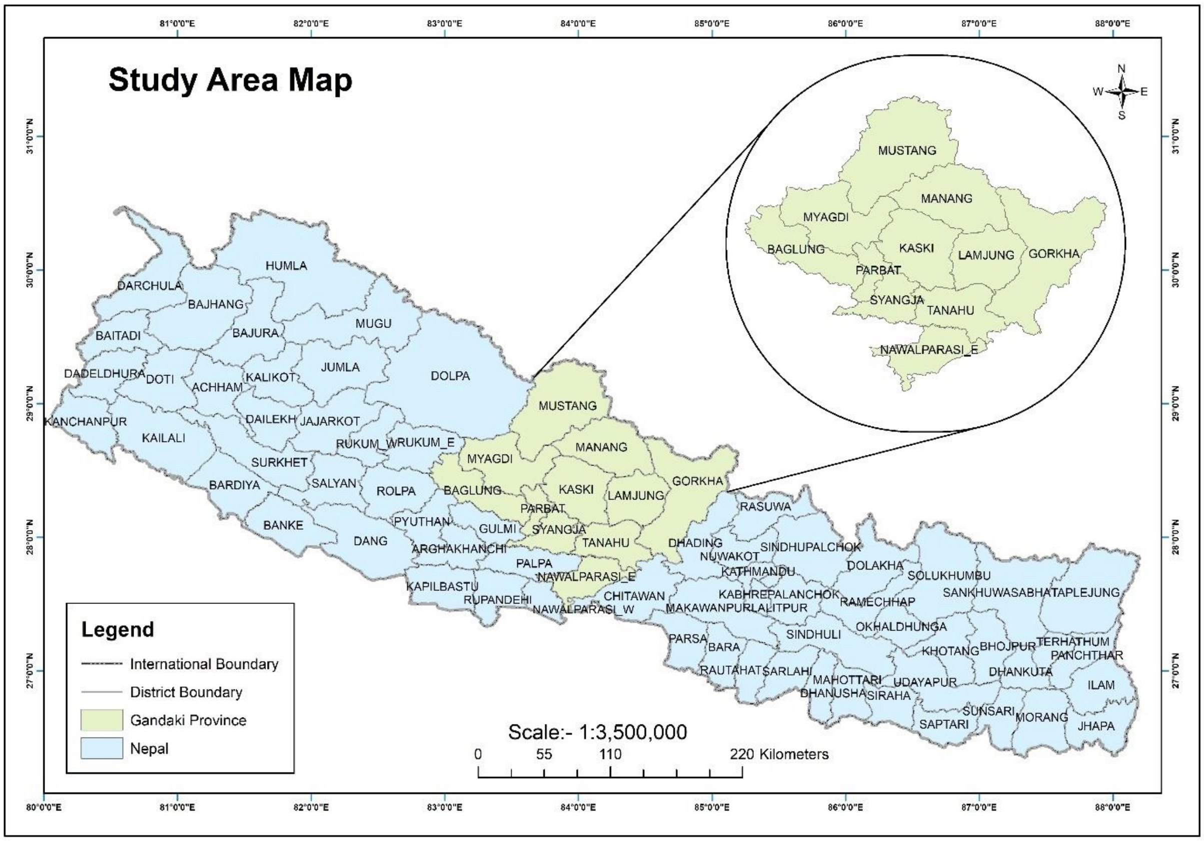
Where, NDVI is the actual value of NDVI, NDVI max and NDVI min are smoothed weekly. NDVI absolute maximum and its minimum. The VCI values between 50 to 100 % indicate optimal or above-normal conditions. At the VCI value of 100% the NDVI value for this month (or week) is equal to $NDVI_{max}$. Different degrees of a drought severity are indicated by VCI values below 50%. The resulting VCI percentage assigned to respective grid cell was reclassified into seven drought severity classes. The VCI allows climate impact on different vegetation types and ecosystems to be compared and has been widely used for this purpose in various countries, including the USA (Seiler et al., 2000; Wannebo & Rosenzweig, 2003).

## 1.8 Location of the Study Area

### 1.8.1 Geography

Gandaki Province is one of the seven federal provinces established by the current constitution of Nepal. Pokhara is the province's capital city. It borders the Tibet Autonomous Region of China to the north, Bagmati Province to the east, Karnali Province to the west, and Lumbini Province and Bihar of India to the south. Gandaki Province lies in the western part of the country. It is bordered by Trishuli River, Budhi Gandaki River and Bagmati Province in the east, Lumbini Province in the west, China in the north and Lumbini Province and Uttar Pradesh of India in the south. It lies between 82˚52' 45" & 85 ˚ 12' 01" east longitude and 27 ˚ 26' 15" & 29 ˚12 '01" North latitude. It has an area of 21914.97sq.km and that is 14.75% of the total area of the country. 38.01% of provincial land is covered by forest. (MoF; 2077) 17.8% land is arable and 24.7% of the Province land is covered by snow, and 0.4% of land is covered by water. Most of the district covers drought prone areas. Sometimes mustang is called desert of Nepal.

Apart from the topographical divisions, administratively there are 11 Districts. As per the new constitutional provision there are 85 local governments composed of 1 Metropolitan City, 26 municipalities and 58 rural-municipalities with 757 wards.

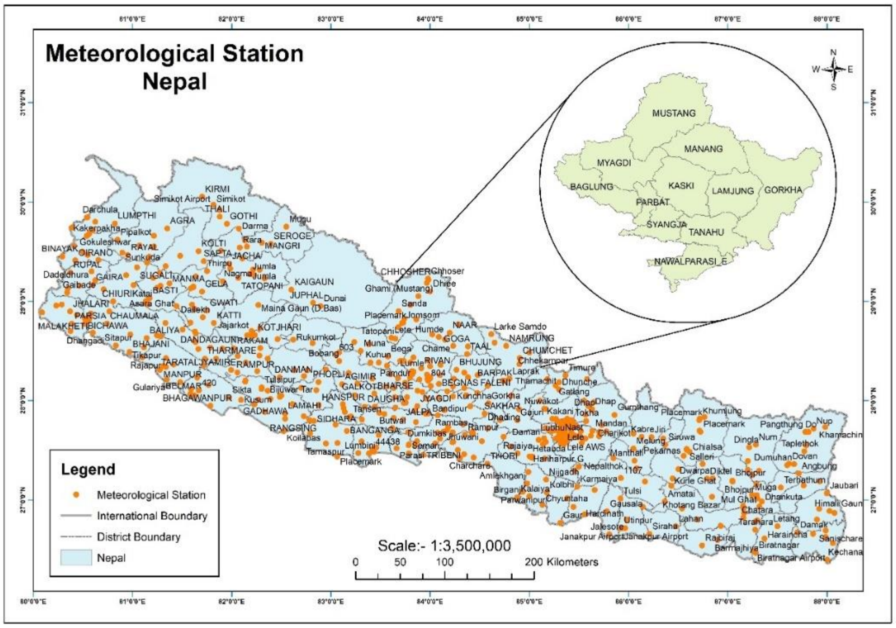



*Map 1: Study area Map*

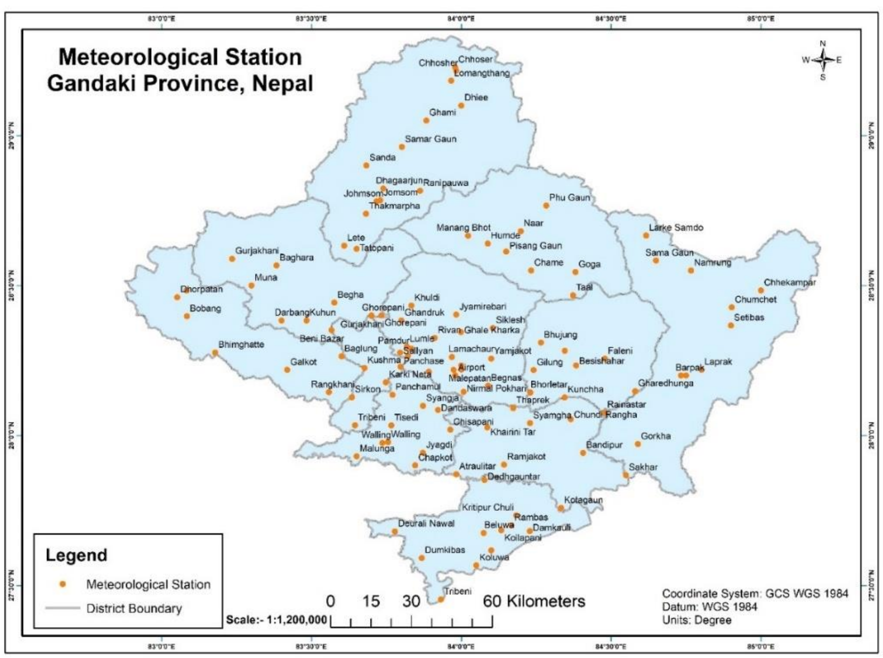
### 1.8.2 Climate

Gandaki Province has climatic variations, which is associated with the diverse nature of its topography and altitude pronounced by terai and valley formed by various rivers and mountains less than 1500 m has sub-tropical climate. Similarly, area ranging from 1500 – 3000 meter has temperate climate and Himalayan regions at an altitude of 3000 to 4500 meters with Alpine climate. In the High Himalayan region of the province we can find Tundra climatic condition. Gandaki Province has an average rainfall of between 2500-250 mm. High Himalayan district

Mustang has the lowest annual rainfall of 146mm. Similarly, Lumle in the Parbat district of the province has highest annual rainfall record (5284mm) (Nepal Outlook, 2020).



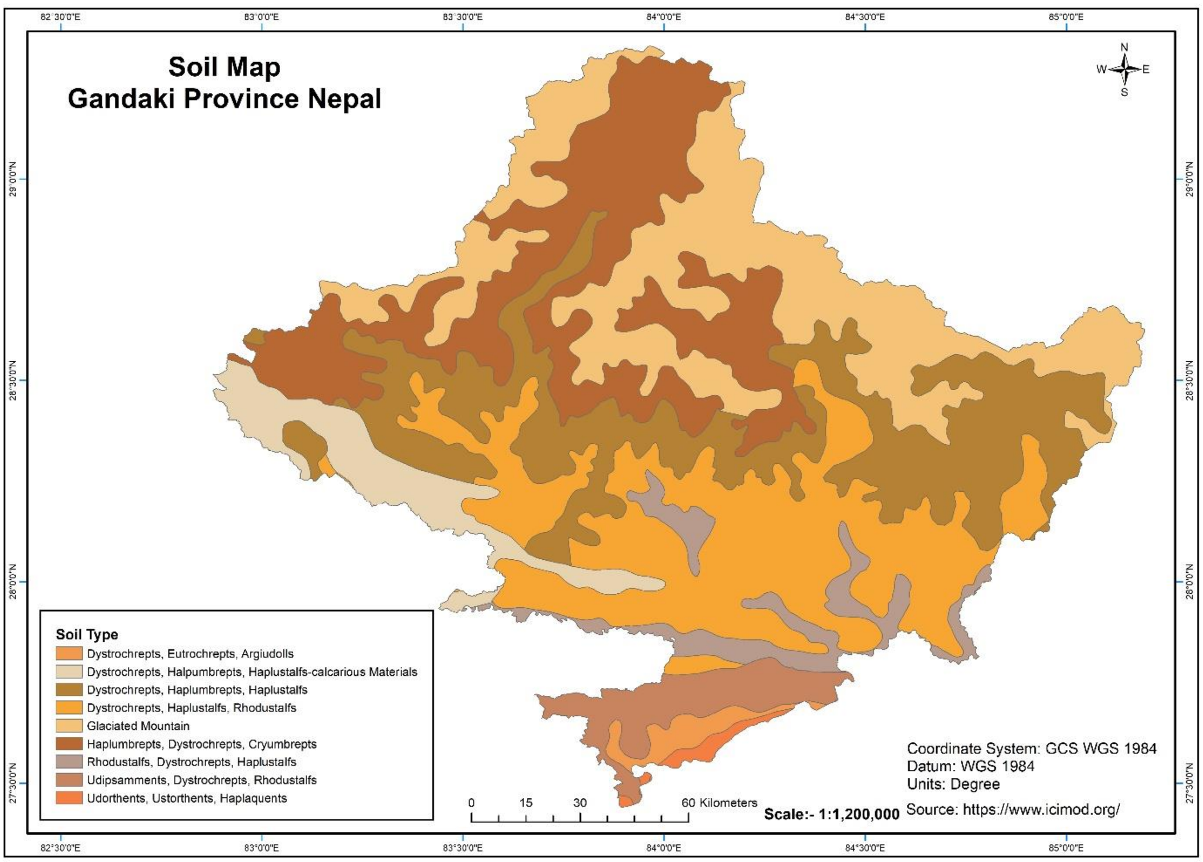

*Map 2: Metrological Stations in Nepal*




*Map 3: Metrological Stations in Gandaki Province*

### 1.8.3 Soil

Nepal is a land of extremes, its physiography ranges from alluvial plains in the tropical-low lands, to very rugged and permanently-snow and ice - covered high mountains. The world's highest mountain peaks occur in Nepal. Climatic conditions can vary so much that tropical and temperate agriculture occurs a few kilometres apart. In such landscapes, topography is an overruling soil forming factor and responsible for a large variability in soil characteristics, distribution and soil depth. Soil map of Gandaki province is presented below.




*Map 4: Soil Map*

### 1.8.4 Social and Cultural Diversity

Total population of the Gandaki Province is 2,403,757. Out of total population 60.11% of the provincial population is residing in the urban area. There are 88 ethnic groups in the province. The major ethnic groups are Brahman Hill (21.6%), Magar (18.9%), Chhetri (13.4%), Gurung (11.4%), Kami (8.7%), Newar (4.1%) etc. Among the 47 spoken languages in the province 73.5% speak Nepali, 9.9% speak Magar and 8.8% speak Gurung (Nepal Outlook, 2020). Gandaki province has multidimensional cultural heritage, cultural diversities of various ethnic, tribal, and social groups inhabiting different altitudes, and it shows various forms: music and dance, art and craft, folklores and folktales, languages and literature; philosophy and religion, festivals and celebrations; and foods and drinks. Religions practiced in Gandaki Province are: Hinduism, Buddhism, Islam, Christianity, Jainism, Sikhism, Bon, ancestor worship and animism. The majority of peoples are different religions have in harmony through centuries.

### 1.8.5 Economy

As per Economic Survey (2019/20), Gandaki Province contributes 9% to national GDP. It is estimated to have a growth rate of 2.7% in the fiscal year 2019/20. There are 512 commercial banks, 220 development banks, 29 finance companies, 518 Microfinance companies. Similarly, there are 182 life and 154 nonlife insurance companies and their branches in the province (Nepal Outlook, 2020).

### 1.8.6 Agriculture

Agriculture and tourism is the mainstay of province economy. Productivity of paddy in the province is 3.76 MT per ha, which is below the national average productivity of 3.8MT per ha. Out of the total paddy production in the country Gandaki Province comprises 7.4%. Similarly, 4.7% of Wheat and 16.0% Maize is produced in the province. (MoF; 2076). According to National Sample Census of Agriculture 2010/11 there are 163926.7 ha of arable land in the province. According to irrigation department only 11.6% of provincial area is useful for agriculture. Out of this area only 45.88% agriculture land is under various irrigation systems i.e. 55% of the provincial agriculture is based on monsoon rain (Nepal Outlook, 2020).

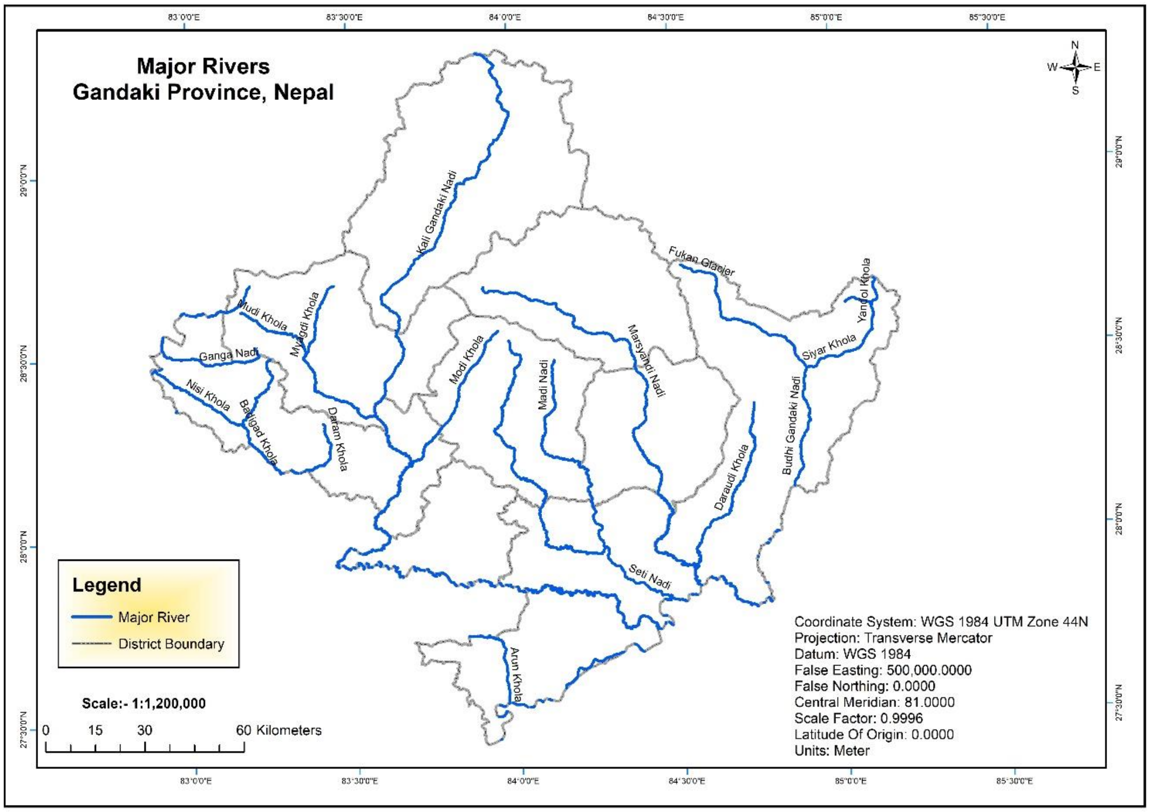
### 1.8.7 Major River System

Kali Gandaki, Budhi Gandaki are the major rivers of Gandaki province. Seti Gandaki, Marsyangdi, Daraudi are also major source of water in Gandaki province. The Budhi Gandaki River is a tributary of Gandaki River in Nepal. It meets the Trishuli at the small named place of Benighat, astride Dhading and Gorkha Districts.

Nepal, as of 2017, plans to build a dam with associated electricity transformers and pylons that would cost $2.5 billion. Such a dam on the river and its reservoir would straddle the Dhading and Gorkha districts.

The Seti Gandaki River, also known as the Seti River or the Seti Khola, is a river of western Nepal, a left tributary of the Trishuli River. Its gorges around Pokhara are a major attraction for tourists worldwide. The Kali Gandaki Gorge or Andha Galchi is the gorge of the Kali Gandaki (or Gandaki River) in the Himalayas in Nepal.

By some definitions, it may be one of the deepest gorges in the world. The upper part of the gorge is also called Thak Khola after the local Thakali people who became prosperous from trans-Himalayan trade. Geologically, the gorge is within a structural graben.




*Map 5: Major rivers in Gandaki Province*

# CHAPTER 2: METHODOLOGY

## 2.1 Data Acquisition

Data have been acquired from different sources. Firstly, NDVI derived from  NASA LPDAAC collection (https://urs.earthdata.nasa.gov)and imageries derived from satellite sources (https://earthexplorer.usgs.gov), precipitation data obtained from ground rainfall stations and world climate data (https://www.worldclim.org), vegetation data are derived from NDVI. Crop production data are acquired from MoALD.

### 2.1.1 Satellite Data

The moderate resolution imaging spectro-radiometer (MODIS), launched on NASA's Earth observing system (EOS) Terra satellite on December 18, 1999 provides a comprehensive series of global observations of the Earth's land, ocean, atmosphere and for satellite measurements of global Land Surface Temperature (LST) in the visible and infrared regions of the spectrum. MODIS (is a key instrument aboard the Terra (originally known as EOS AM-1) and Aqua (originally known as EOS PM-1) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths.

The Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Indices (MYD13Q1) Version 6 data are generated every 16 days at 250 meter (m) spatial resolution as a Level 3 product. The MYD13Q1 product provides two primary vegetation layers. The first is the Normalized Difference Vegetation Index (NDVI) which is referred to as the continuity index to the existing National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) derived NDVI. The second vegetation layer is the Enhanced Vegetation Index (EVI), which has improved sensitivity over high biomass regions. The algorithm chooses the best available pixel value from all the acquisitions from the 16 days period. The criteria used is low clouds, low view angle, and the highest NDVI/EVI value. Along with the vegetation layers and the two quality layers, the HDF file will have MODIS reflectance bands 1 (red), 2 (near-infrared), 3 (blue), and 7 (mid-infrared), as well as four observation layers. The 16-day composite VI is generated using the two 8-day composite surface reflectance granules (MOD09A1) in the 16-day period.

This surface reflectance input is based on the minimum blue compositing approach used to generate the 8-day surface reflectance product. The product format is consistent with the Version 5 product generated using the Level 2 gridded daily surface reflectance product. A frequently updated long-term global Climate Modeling Grid (CMG) Average Vegetation Index product database is used to fill the gaps in the CMG product suite. Validation at stage 3 has been achieved for the MODIS Vegetation Index product suite. Further details regarding MODIS land product validation for the MYD13 data products are available from the MODIS Land Team Validation site. Detailed description of MODIS NDVI data is tabulated as below.

*Table 2: MODIS MYD13Q1 Product Details*

| **Characteristic** | **Description** |
|---|---|
| Collection | Aqua MODIS |
| DOI | 10.5067/MODIS/MYD13Q1.006 |
| File Size | ~92.96 MB |
| Temporal Resolution | Multi-Day |
| Temporal Extent | 2002-07-04 to Present |

| | |
|---|---|
| Spatial Extent | Global |
| Coordinate System | Geographic Latitude and Longitude |
| Datum | Unknown datum based on the custom spheroid sinusoidal |
| File Format | HDF-EOS |
| Geographic Dimensions | 1200 km x 1200 km |
| Number of Science Dataset (SDS) Layers | 12 |
| Columns/Rows | 4800 x 4800 |
| Pixel Size | 250 m |

Eleven years 16 days monthly MODIS NDVI downloaded from NASA LPDAAC and using scale factor 0.0001, suitable conversion in TIFF format and also suitable projection was applied. VCI derived from mean, maximum and minimum NDVI.

#### 2.1.2 Hydro-Meteorological data

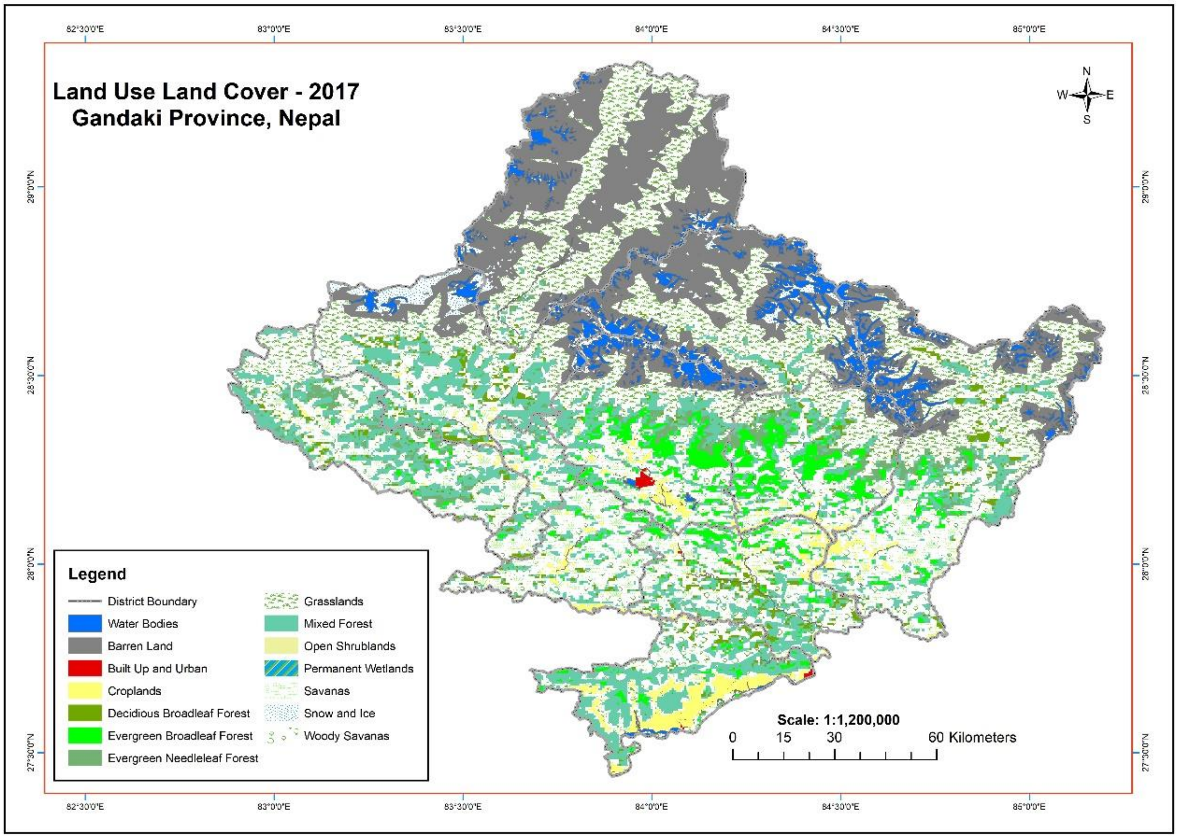
Metrological data are acquired from world climate and DHM, due to some void in DHM data, world climate raster data used for selected coordinates for 11 years (2005 – 2015). Rainfall data are used to analyze to determine the SPI. Monthly rainfall data from 114 rainfall stations has been used to analyzed NDVI and SPI.

### 2.1.3 Crop Yield Data

Crop yield data have been downloaded from central bureau of statistics and from Ministry of Agriculture and Livestock report (https://www.moald.gov.np/).

### 2.1.4 Ancillary Data

#### *2.1.4.1 Land use/Land Cover*




*Map 6: Land use map of Gandaki Province*

## 2.2 Software Used

Following software are used to preparation of data, processing and analysis.

- ERDAS IMAGINE
- ArcGIS Pro
- QGIS
- MODIS Reprojection Tool

- ENVI
- SPI Tool

## 2.3 Data processing and Analysis

The following methodology describing the process of data preparation, analysis and determination of the result for this study. Correlation and regression analysis are used to verify the drought condition inn Gandaki Province. Where NDVI Anomaly and VCI (2005 – 2015) are used to detect agricultural drought and SPI used to detect metrological drought. For better result, district wise NDVI Anomaly correlated with district wise VCI, SPI and crop yield data. After finding the Agricultural and Metrological drought, these droughts were integrated to find out the drought in study area. A schematic presentation of the methodology that has been followed is mentioned in (figure: 2)

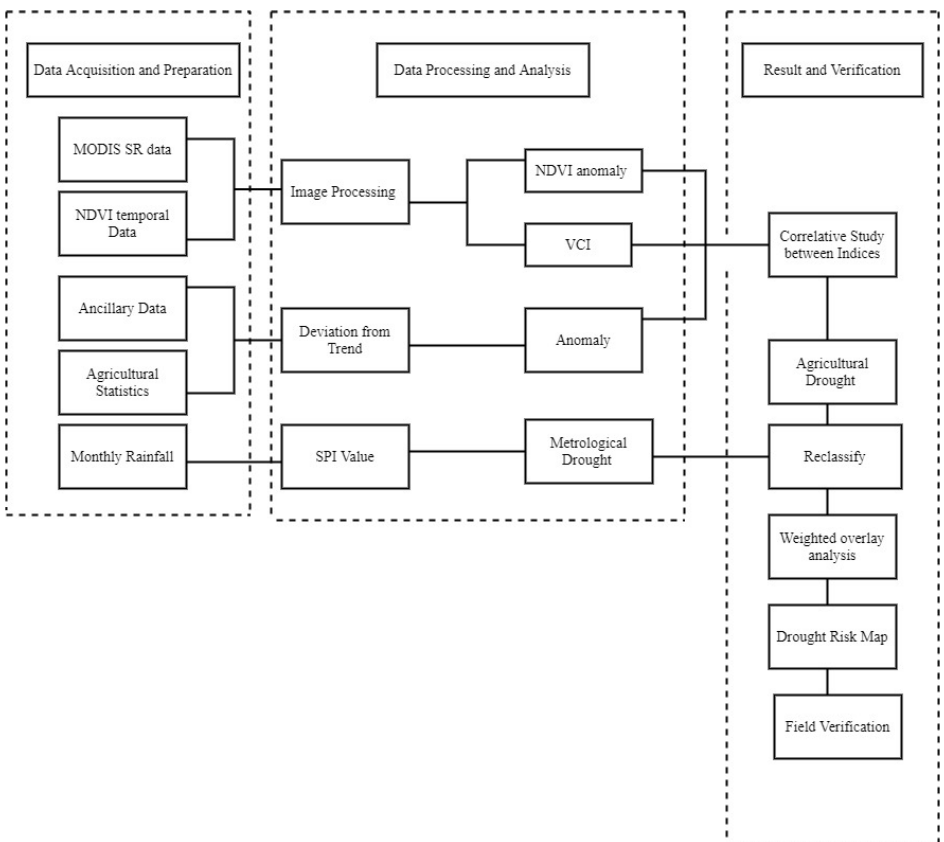



*Figure 2: Schematic presentation of the methodology*

### 2.3.1. Preprocessing of Satellite data

This includes many intermediate steps they are

a) Conversion of HDF format to TIFF format
b) Reprojection and Subset
c) Scale factor
d) Computation NDVI from Batch tool/Model Maker
e) Inherited cloud problem with NDVI &
f) Layer stacking

a) Reprojection and Conversion of HDF format to TIFF format

MODIS images are Hierarchical Data Format (HDF-format). This HDF-EOS format image is exported to "TIFF" format using MRT or using Raster Project Tool. The MRT currently supports MODIS land products in the Integerized Sinusoidal and Sinusoidal projections. After exporting all images, it is subjected to reprojection.

b) Reprojection and Subset

MODIS NDVI are in sinusoidal projections, these imageries and NDVI are reprojected. Using layer of Bangladesh administrative boundary, subset area for all the district in Gandaki Province.

c) Scale factor

Scale factor for satellite imageries are different. For MODIS data All the surface reflectance images have been multiplied by scale factor 0.0001 in model maker or raster calculator tool.

d) NDVI Computation

NDVI has been computed using two bands of surface reflectance images. In Surface reflectance red band and near infrared band are used for calculation of NDVI. Mathematically it can be written as:

*NDVI = (NIR reflectance – Red reflectance) / (NIR reflectance + Red reflectance……Equation 3*

e) Inherited cloud problem with NDVI

Presence of clouds in satellite imageries plays a significant obstacle in image interpretation and land surface analysis. The undetected clouds are the major source of error in image interpretation 2005 images are cloudy and others images are free from cloud effect.

f) Layer stacking

After processing above intermediate steps, all the images are stacked.

### 2.3.2 Post – Processing of satellite data

To derive the seasonal pattern of NDVI for 2005-2015, firstly, average NDVI for each month was computed from following algorithm.

$NDVI_{year}$ = (Average $NDVIm_1$+ Average $NDVIm_2$+…..+ Average $NDVIy_{m12}$)/12……*Equation 4*

Mean NDVI from 2005 – 2015 are computed from following equations

$NDVI_{mean}$ = (Average $NDVIy_1$+ Average $NDVIy_2$+…..+ Average $NDVIy_{11}$)/ 11……….*Equation 5*

Where, Average NDVIy1……….. Average NDVIy11 stands for the yearly average NDVI value for 11 years. To derive NDVI Anomaly, Maximum NDVI from 2005 – 2015 was calculated from

NDVImax i = (NDVI 1, NDVI 2 ………NDVI n)…………………………*Equation 6*

Where, NDVI max i is maximum NDVI in $i^{th}$ year and NDVI 1…..NDVI n is NDVI in month 1 to NDVI in n month in $i^{th}$ year.

After computing NDVI max, from 2005-2015, an average of these NDVI max images was computed to get the mean NDVI max values during past 11 years. Anomaly was then computed as:

Anomaly NDVI i = (NDVI max i – mean NDVI max)…………………………...*Equation 7*

Where, NDVI max = Maximum NDVI of the year and Mean NDVI max = Long term mean maximum NDVI of the range of year. Then the computation of district wise NDVI anomaly for all 11 images, images are subset as district wise for 11 districts of Gandaki Province.

### 2.3.3 Standardized Precipitation Index (SPI)

SPI tool is used developed to quantifying precipitation at different time scales. A SPI value has been interpolated by Inverse Distance Weighted (IDW) method. The interpolated maps are reclassified into different drought severity classes.

The 3-month SPI was found to have the best correlation with the NDVI, indicating lag and cumulative effects of precipitation on vegetation, but the correlation between NDVI and SPI varies significantly between months(Ji & Peters, 2003).

The SPI calculated from CRU gridded precipitation shows similar results, with some discrepancies at longer scales (Guenang & Kamga, 2014). The SDF curves were developed using the minimum cumulative 12-month precipitation values fitted to the Gamma distribution for 1, 3, 6, 9 and 12-month drought durations (Juliani & Okawa, 2017).

Mathematically, SPI is calculated based on equation

$$SPI = (Xi - Xm) / \sigma \quad \text{……………………………………………………} \textit{Equation 8}$$

Where, Xi is monthly rainfall record of the station; Xm is rainfall mean; and σ is the standard deviation. Monthly rainfall data from 2005 to 2015 in rainfall stations Gandaki Province are used as an input to SPI program.

### 2.3.4 Crop Yield Anomaly

To quantify the impact of drought on production of major crops in Nepal. Yield trend can be computed to see for the yield trend over last 11 years (2005-2015). Equation Yield anomaly

$$Y_a = [(Yi - Y_t)/ (Y_t)]^* \ 100 \text{……………………} \textit{Equation 9}$$

Where $Y_a$ is yield anomaly; $Y_i$ is yield in a particular year; $Y_t$ is yield trend in 10 years

### 2.3.5 NDVI Anomaly, Crop Yield and SPI

District wise NDVI anomalies have been correlated with district wise SPI and crop yield anomalies. Liner regression between NDVI, VCI, SPI and crop yield for whole Gandaki province, which assess agriculture and metrological drought.

To compute the frequency of drought, each of the yield equivalent images have been reclassed into Boolean image and all the 11 maps are generated for drought severity classes.

### 2.3.6 Field data collection

Fieldwork has been done for study of agricultural drought in Gandaki Province. During the field data collection phase coordinates and photograph of selected agriculture farm was captured. GPS, topographic maps are used to capture selected ground coordinates of most of the affected area. Before field study following materials and equipments was collect.

- MODIS satellite images for the period of 2005 to 2015
- GPS (Global position system): model name Garmin
- Administrative map and Topographic map of Gandaki Province

## 2.4 Reclassification

The raster image produced using any sort of data is obtained in the stretched form which needs to be reclassified for further computation or analysis. So, it needs to be reclassified.

Reclassification is the process of classification of stretched images into the desired class. Here in our project the images prepared by using MSI, NDVI and SPI are reclassified based upon their classes.

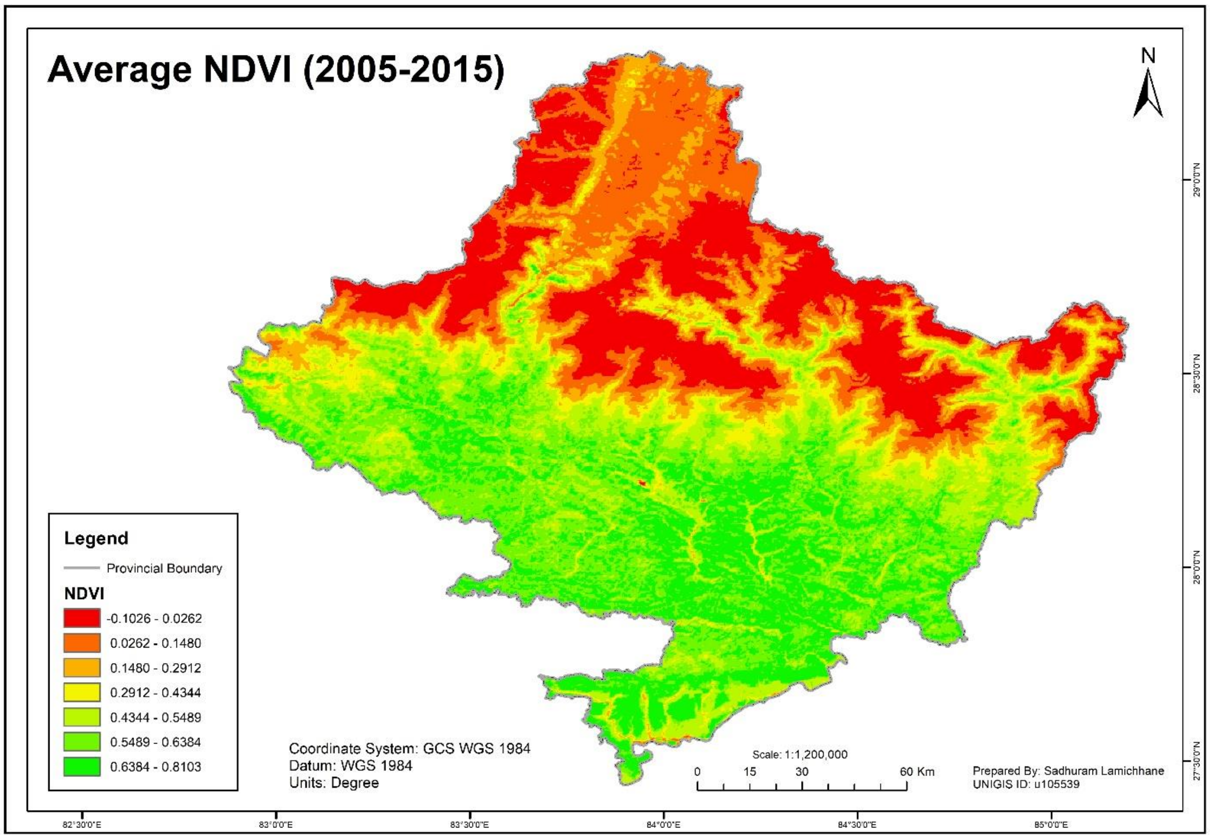
*Table 3: Rank and Weights of Different Parameters for Drought Condition Maps*

| S.N. | Criteria | Classes | Rank | Influences |
|---|---|---|---|---|
| 1 | SPI | Extremely Dry | 1 | 50% |
| | | Very Dry | 2 | |
| | | Moderately Dry | 3 | |
| | | Near normal | 4 | |
| | | Moderately Wet | 5 | |
| | | Severely Wet | 6 | |
| | | Extremely Wet | 7 | |
| 2 | VCI | Extremely Low | 1 | 25% |
| | | Very Low | 2 | |
| | | Moderately Low | 3 | |
| | | Near High | 4 | |
| | | Moderately High | 5 | |
| | | Severely High | 6 | |
| | | Extremely High | 7 | |
| 3 | NDVI Anomaly | Extremely Low | 1 | 25% |
| | | Very Low | 2 | |
| | | Moderately Low | 3 | |
| | | Near High | 4 | |
| | | Moderately High | 5 | |
| | | Severely High | 6 | |
| | | Extremely High | 7 | |

# CHAPTER 3: RESULTS AND DISCUSSION

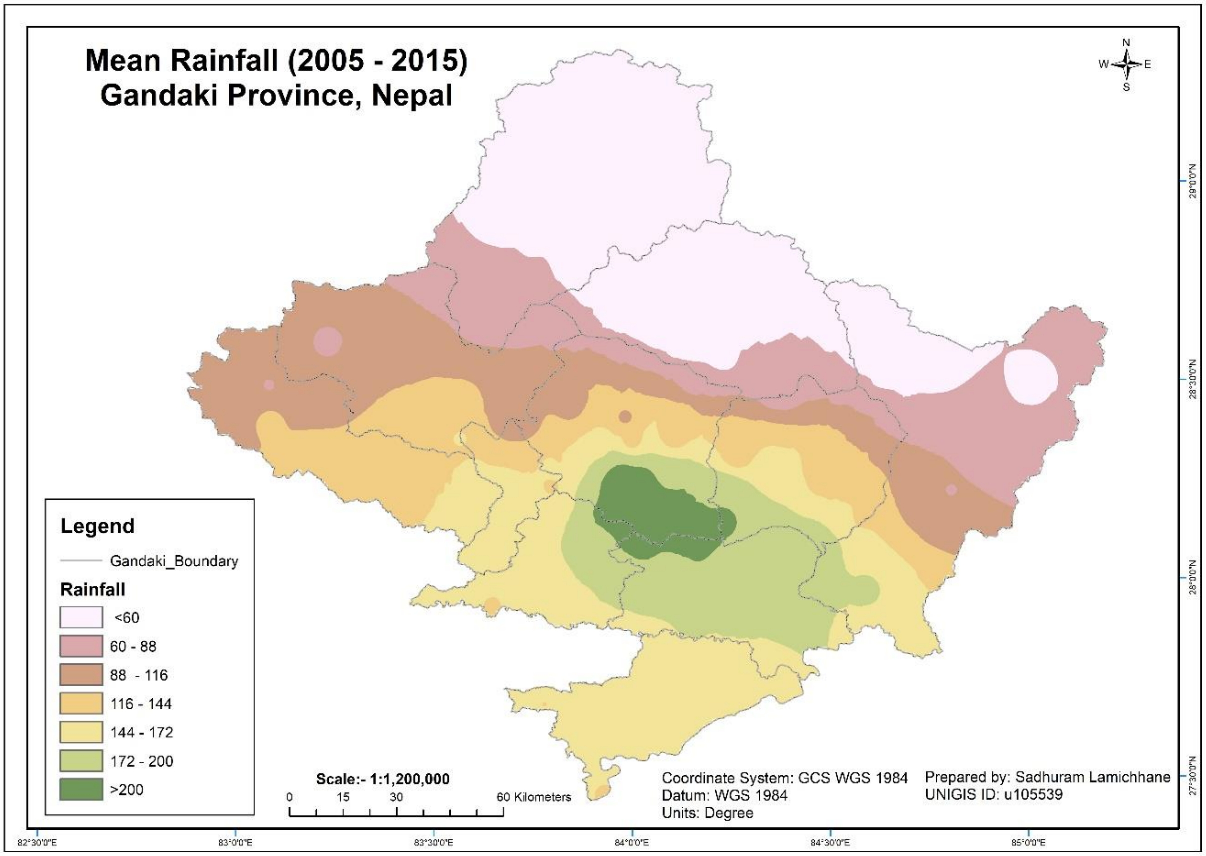
## 3.1 Seasonal Pattern of Rainfall, NDVI

NDVI pattern and Rainfall pattern of the study area of entire study area for period 2005 – 2015 is follows. In this map the pattern of rainfall shows that the northern part north east part i.e. Himalayas of the Gandaki province has lower rainfall area.




*Map 7: Mean NDVI (2005-2015*

In Map: 7 average NDVI of gandaki province can be seen, where NDVI ranges from -0.1026 to +0.8103. Most of the area of kaski, tanahun, syangja, parbat, nawalpur is Positive NDVI and upper part of gorkha, manang, mustang district has negative NDVI value.

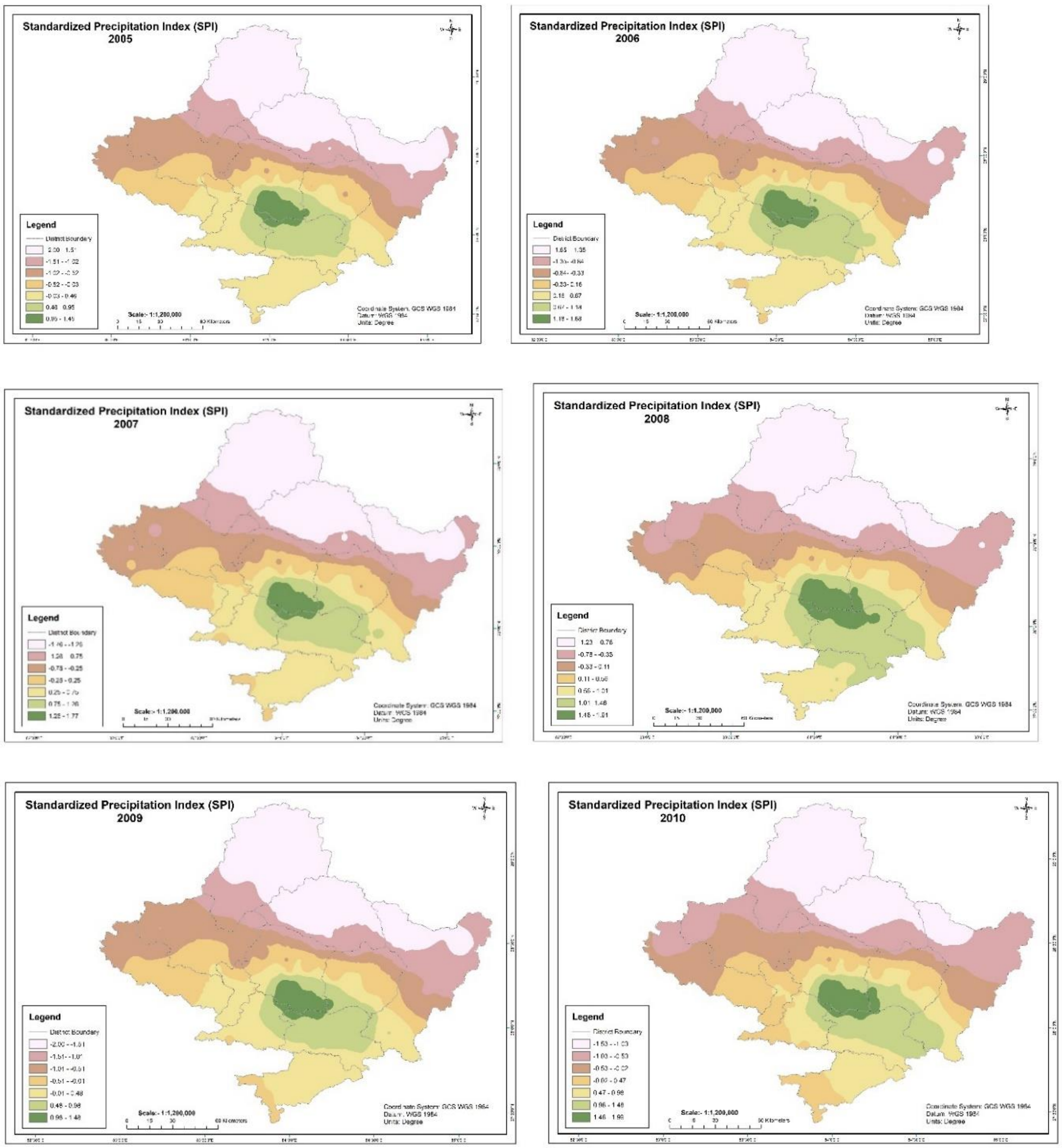



*Map 8: Mean rainfall (2005 – 2015)*

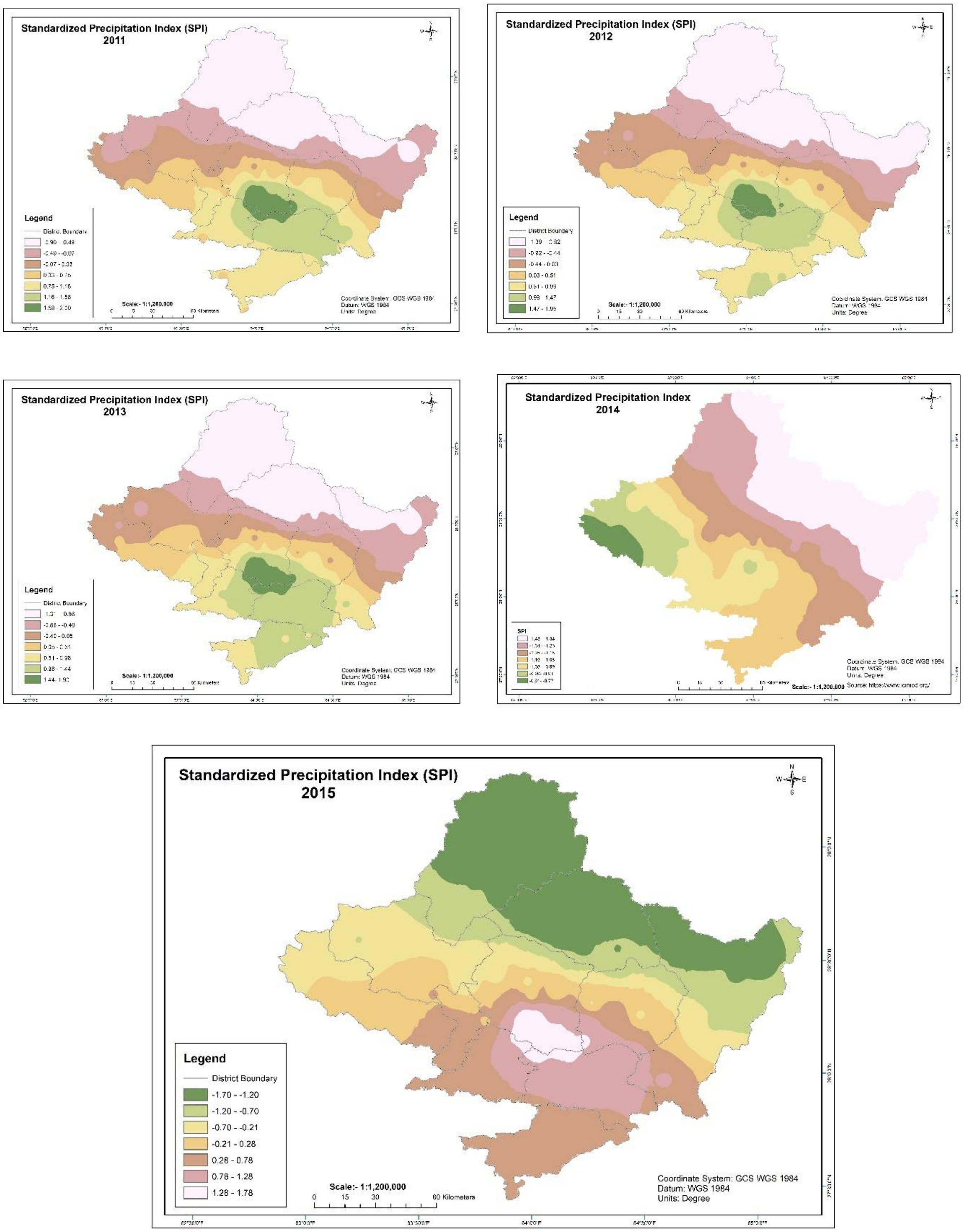
Long term mean precipitation of Gandaki province is calculated from average precipitation of all individual stations. Long term average precipitation is interpolated around study area show that maximum area of Manang, Mustang and Upper part of Gorkha has very low average precipitation. On comparison between Map 7 and 8, The cell has high NDVI values also has high rainfall. In this area irrigation facility is easily accessible for farmer.

## 3.2 SPI and Meteorological Drought

Meteorological drought risk has been identified by interpolating SPI value over 11 years. SPI values selected over all the 11 years to show the pattern of SPI during these years. Following Map 9 and 10 interpolated SPI for year (2005 – 2015) is presented. On comparison all the study period 2011 is wet year then other years. In these years annual average rainfall is higher. 2005, 2009 are severe drought year. 2014 is most of the dry year among study period. Other remaining years 2006, 2007, 2008, 2010, 2012, 2013 and 2015 are normal years.

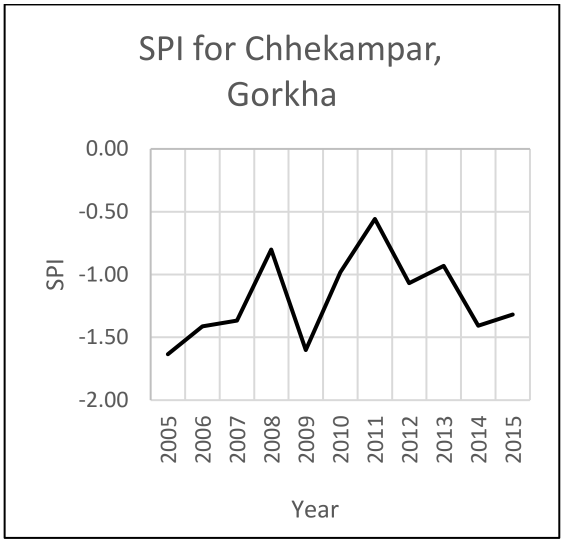


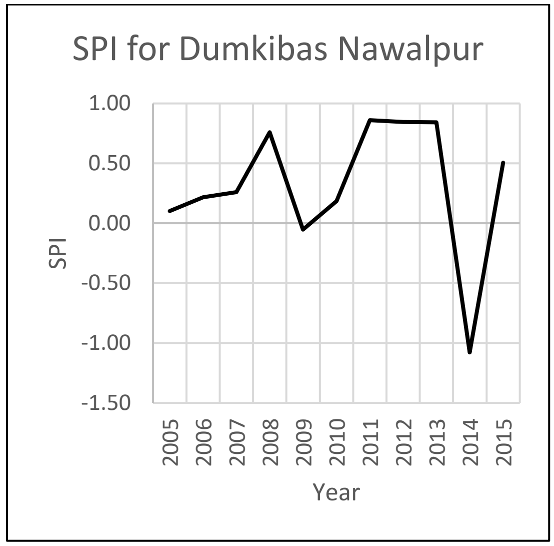

*Map 9: Interpolated SPI for the year 2005 – 2010*

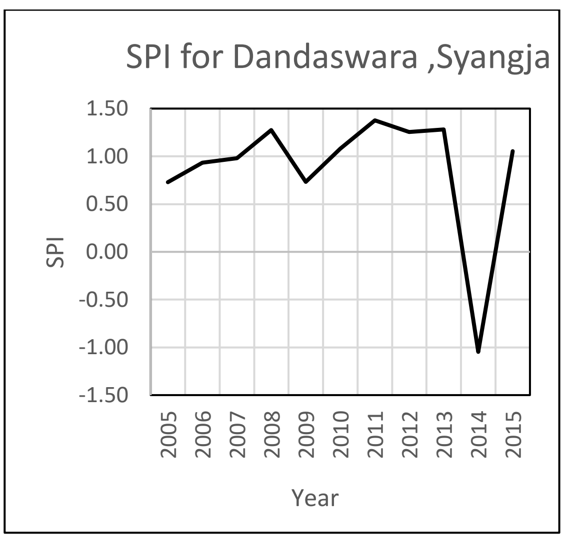


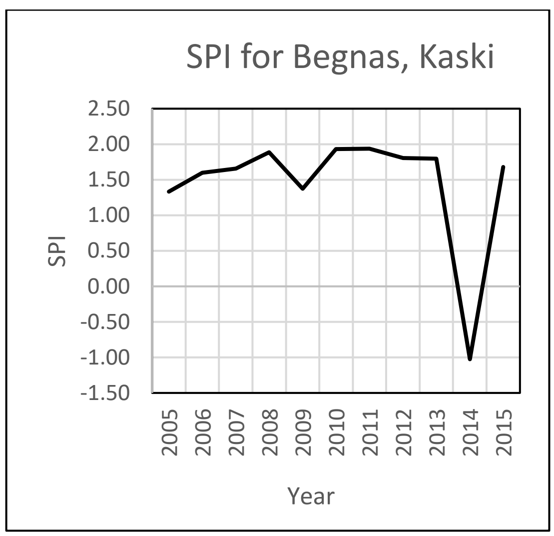

*Map 10: Interpolated SPI for the year 2011 – 2015*

Severe drought years 2005 and 2009, where rainfall amount is lesser in northern part of the study area. Some district Manang, Mustang, Gorkha are highly affected districts. After comparison of interpolated SPI of all years conclude that study year 2014 is drought year, in this year rainfall amount of the whole year is lesser than other years.



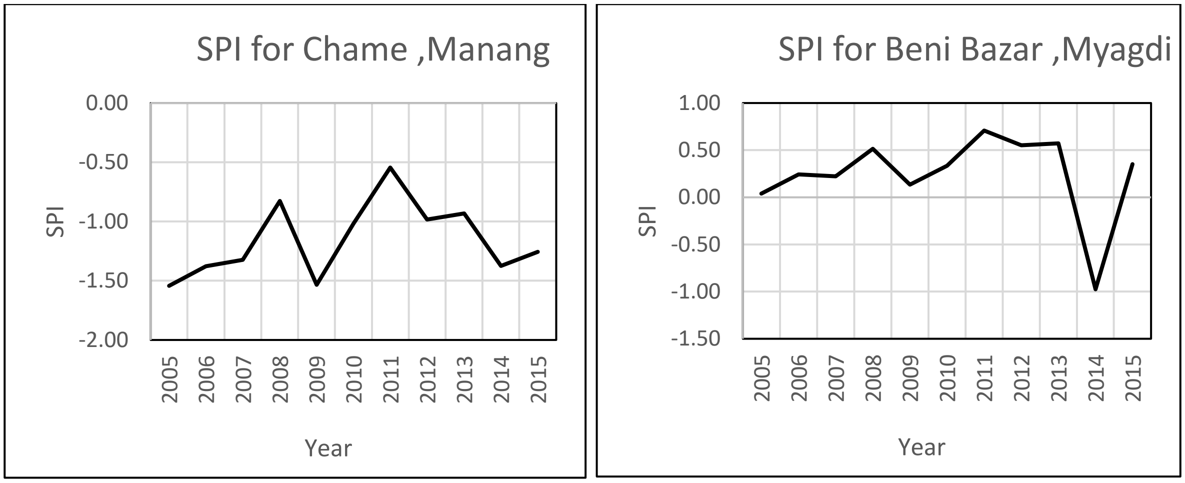
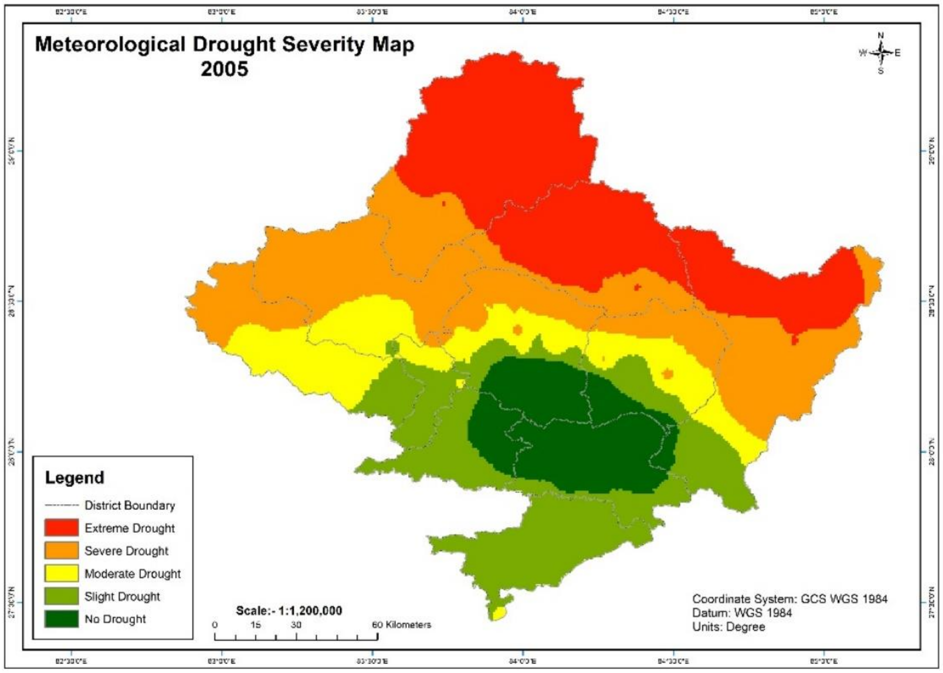



*Figure 3: 12 months SPI of different rainfall station of Gandaki Province*

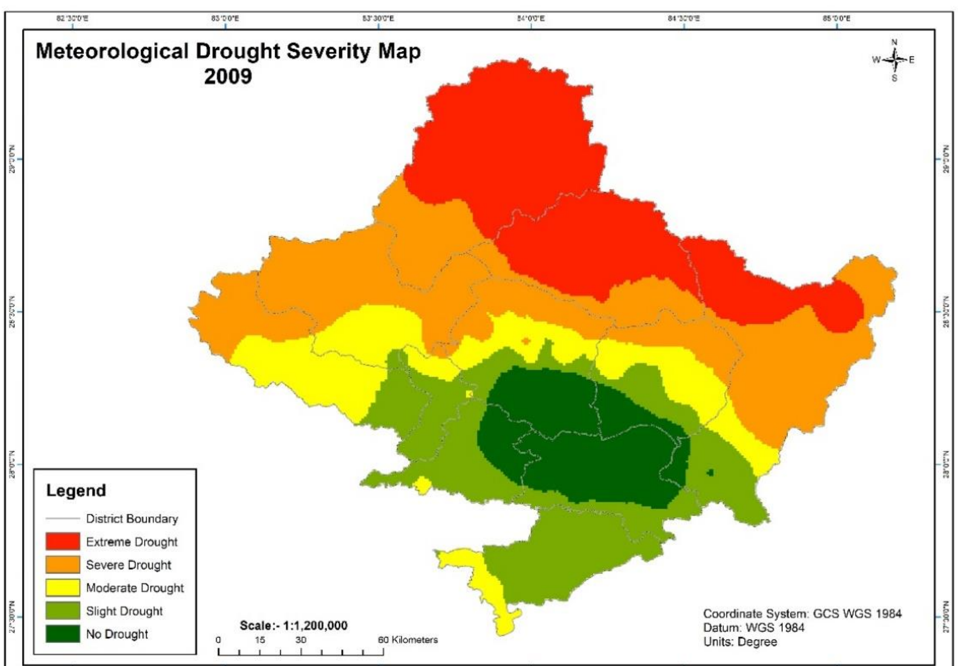
In this figure 3, twelve months for some selected rainfall station is presented. In map 9 and 10 drought years wet, drought and normal years is presented. It can be seen that during the drought years of 2005, SPI values are low for the northern part of the Gandaki province and in 2014 most of area shows low SPI value. This low SPI value indicates there has been low precipitation in these areas during monsoon season. Severe drought years 2005 & 2009 where SPI of large area was found to be below 1.48 and negative SPI value goes to -2.00, which is considered to be a situation of severe drought. For normal years the SPI value reached up to a value greater than1.99 at large area of Gandaki province. For normal years 2006 and 2007 most of the station has negative SPI value then other normal years. Remaining 12 Months SPI is presented in APPENDIX – B.

### 3.3 SPI and drought severity

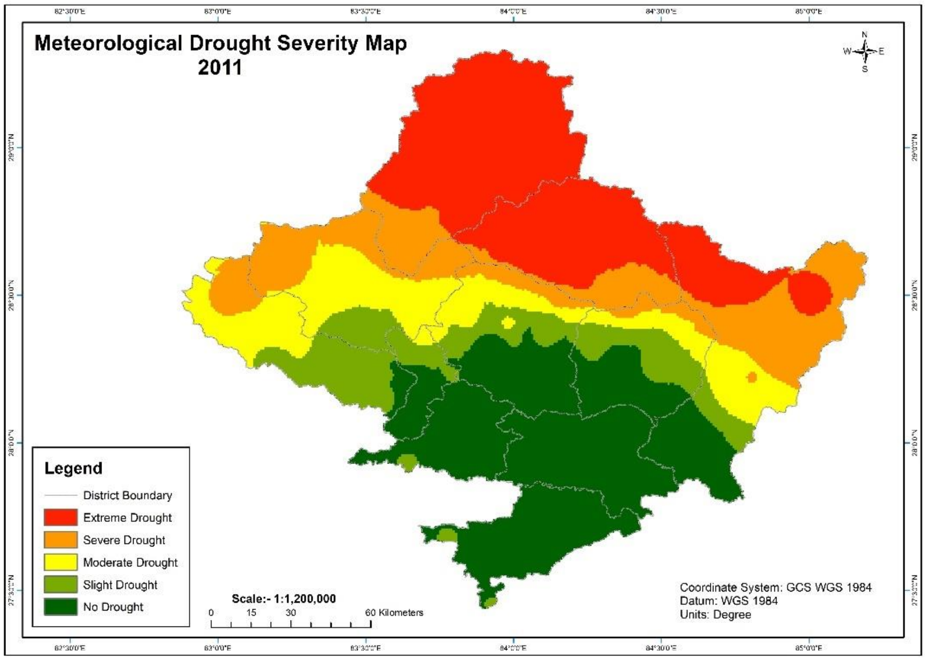
After the interpolation of SPI, some selected drought years were reclassification in GIS with different severity classes as presented in Map 11, 12, 13 and 14. Year 2014 had drought class up to extreme drought. In both the year dominating drought class is moderate drought.



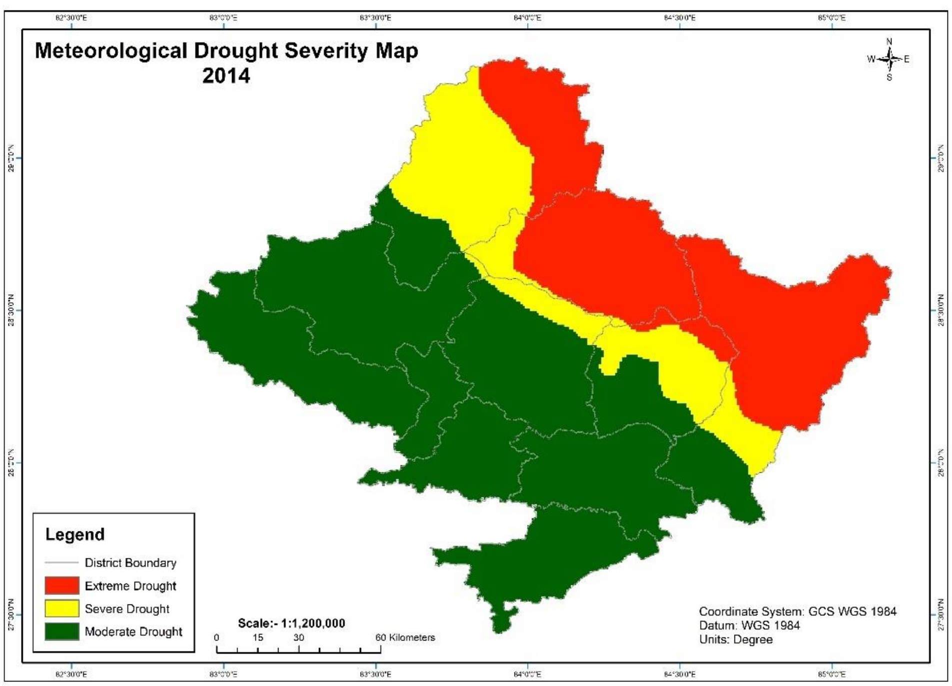

*Map 11: Meteorological Drought Risk Map – 2005*




*Map 12: Meteorological Drought Risk Map 2009*




*Map 13: Meteorological Drought Risk Map 2011*



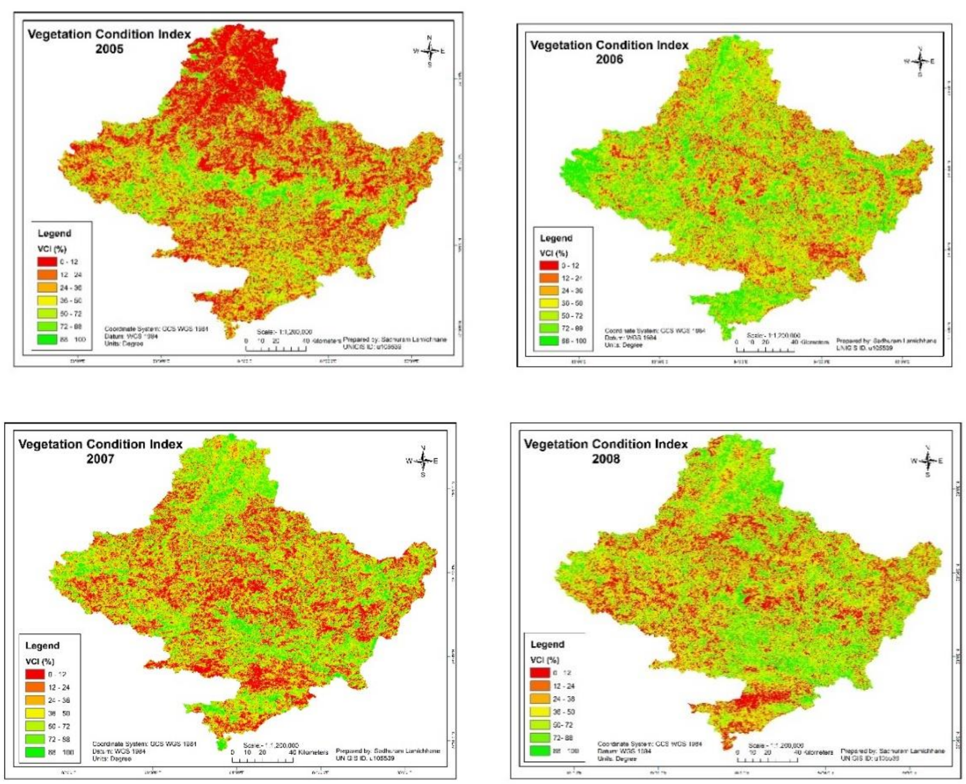

*Map 14: Meteorological drought severity for drought year*

Interpolated SPI is used to quantify different drought types. Since SPI can be calculated at different time scales, it often serves as indicator of different drought types. Severe drought is represented in Map 14.

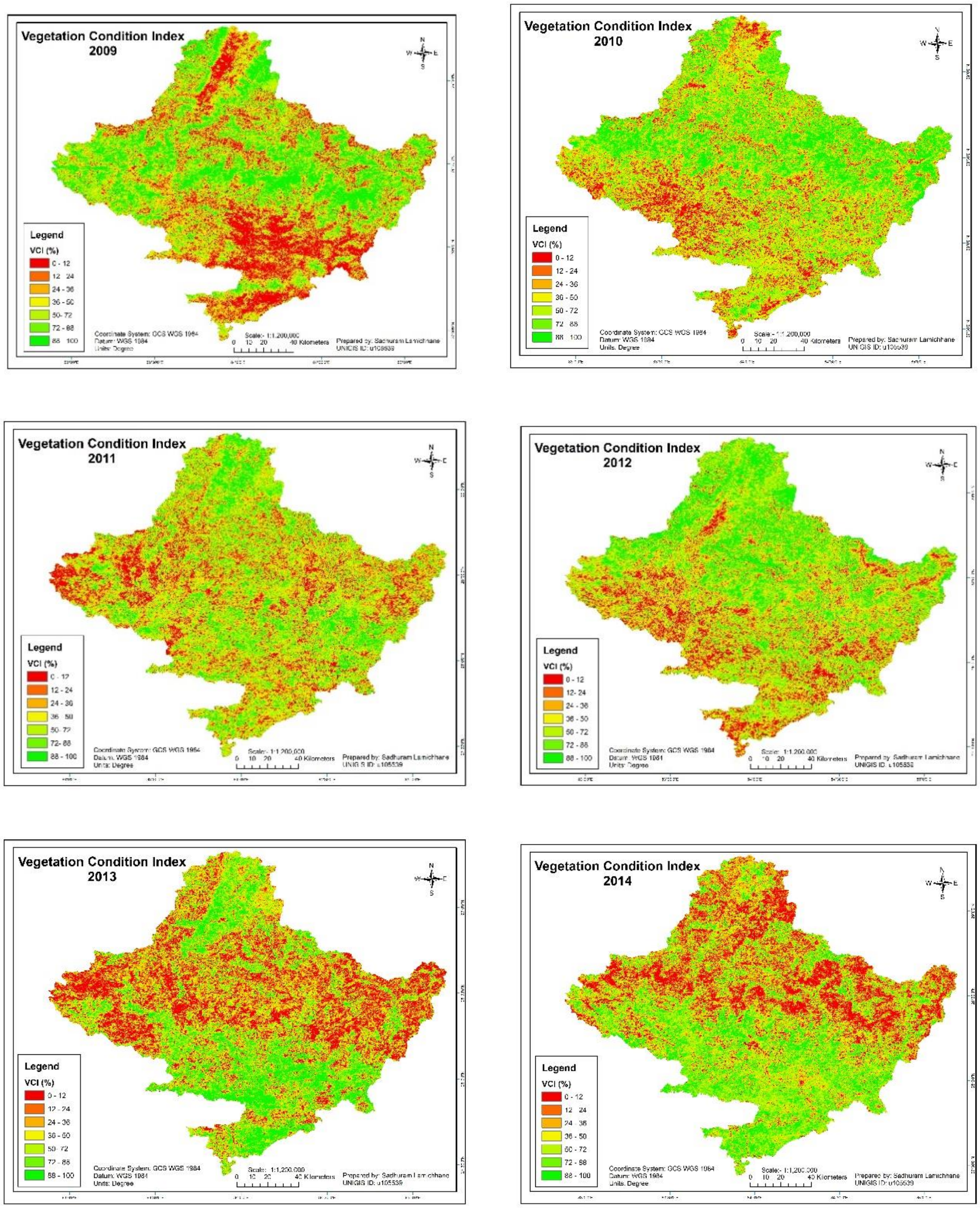
## 3.4 NDVI Anomaly, VCI and Agricultural drought

### 3.4.1 Vegetation Condition Index

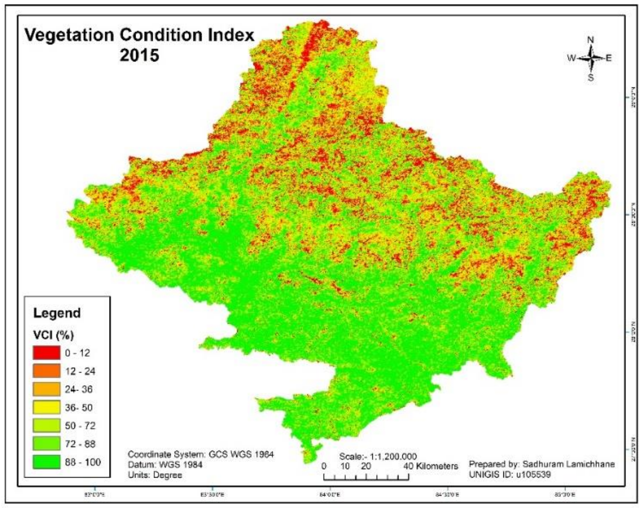
The VCI compares the current NDVI to the range of values observed in the same period in previous years. Lower and higher values indicate bad and good vegetation state conditions, respectively. Vegetation indices of study area from 2005 -2015 was computed and which shows the vegetation condition of the study area. Map 15, 16 and 17 represents that as VCI of study period for drought severity years and wet years.




*Map 15: Vegetation Condition Index 2005 - 2008*

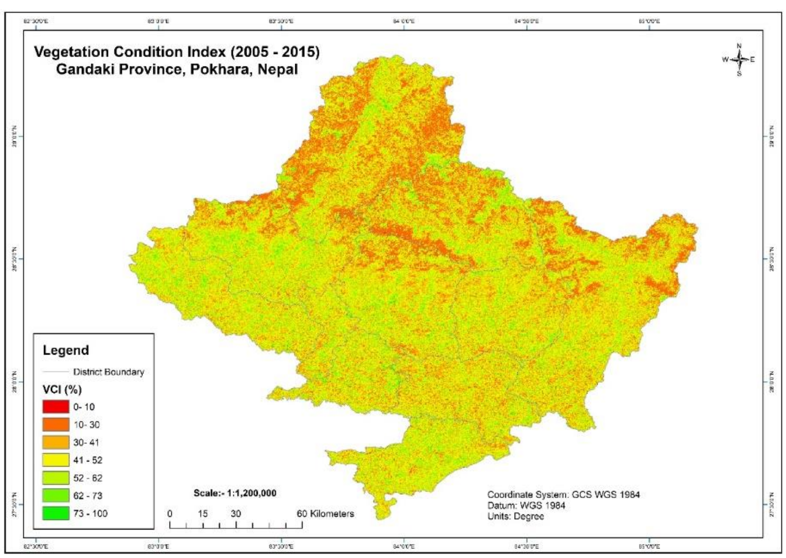



*Map 16: Vegetation Condition Index 2009 – 2014*




*Map 17: Vegetation Condition Index 2015*

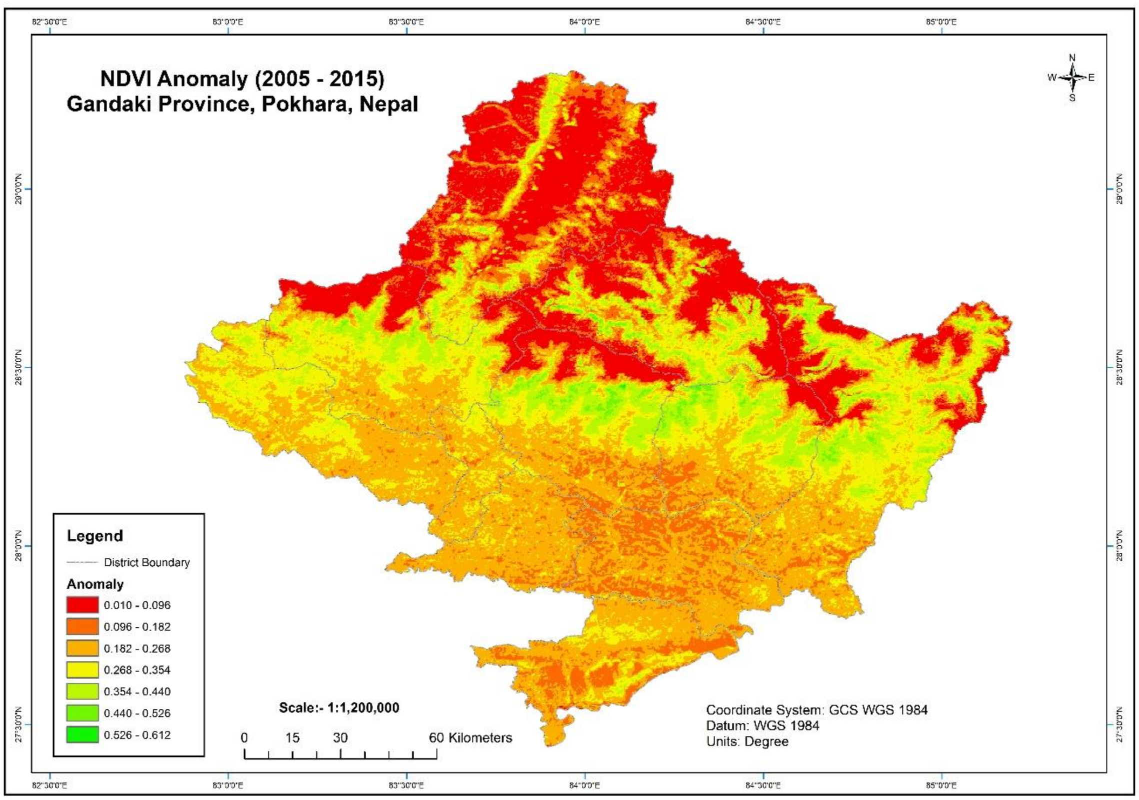
In map (15 -17) VCI of study period is presented. Most of the area of Year 2007, 2008, 2013 and 2014 shows unhealthy vegetation. These years contained bad vegetation condition. Most of the area of study year 2010, 2011, 2012 and 2015 contained healthy vegetation. Northern part of the study area has bad vegetation, where rainfall is also low in this area. Vegetation condition index of study period is shown below.




*Map 18: Vegetation Condition Index 2005– 2015*

### 3.4.2 NDVI Anomaly

The vegetation indicator NDVI anomaly provide alternative measures of the relative vegetation health. These indices can be used to monitor the areas where vegetation may be stressed, as a proxy to detect potential drought. NDVI anomaly of study period is presented below. NDVI anomaly ranges from -100% to +100% or -1 to +1. Positive value represents the wet and negative value represent dry region. NDVI anomaly (2005 – 2015) is presented in map 19. NDVI anomaly for every year is presented at APPENDIX – A.

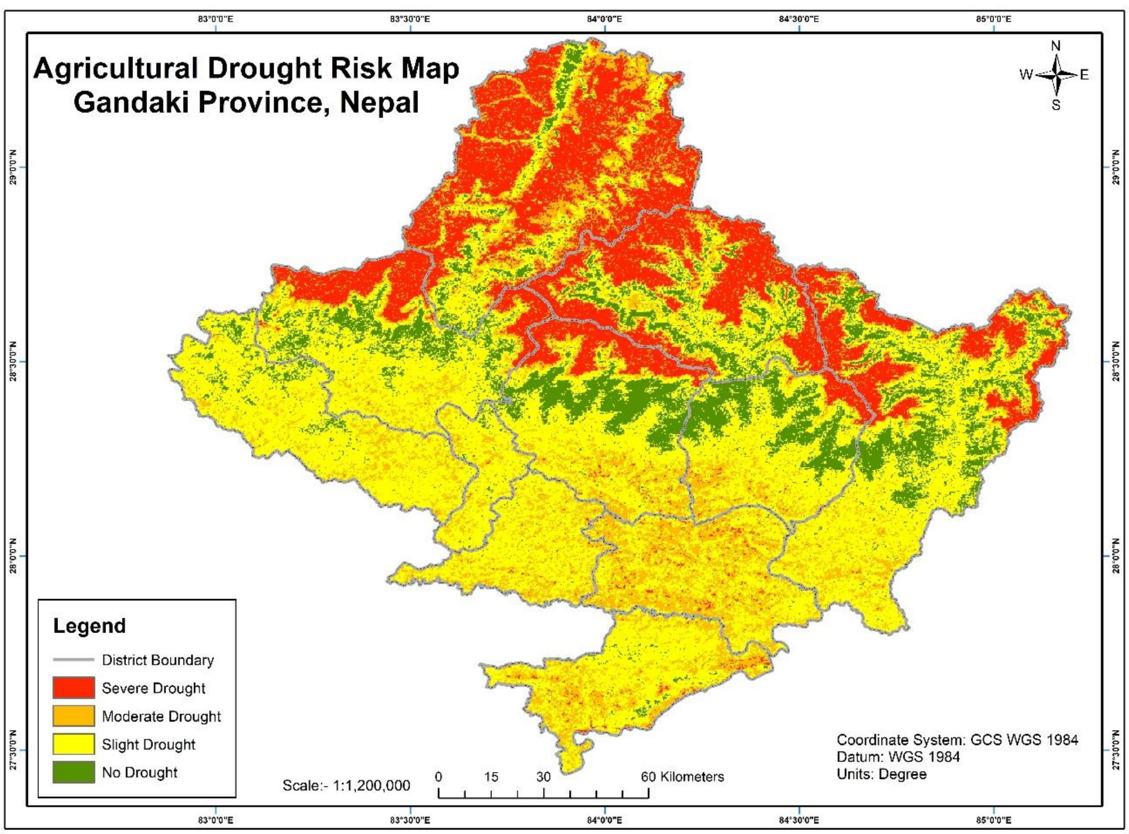



*Map 19: NDVI anomaly of study period (2005 – 2015)*

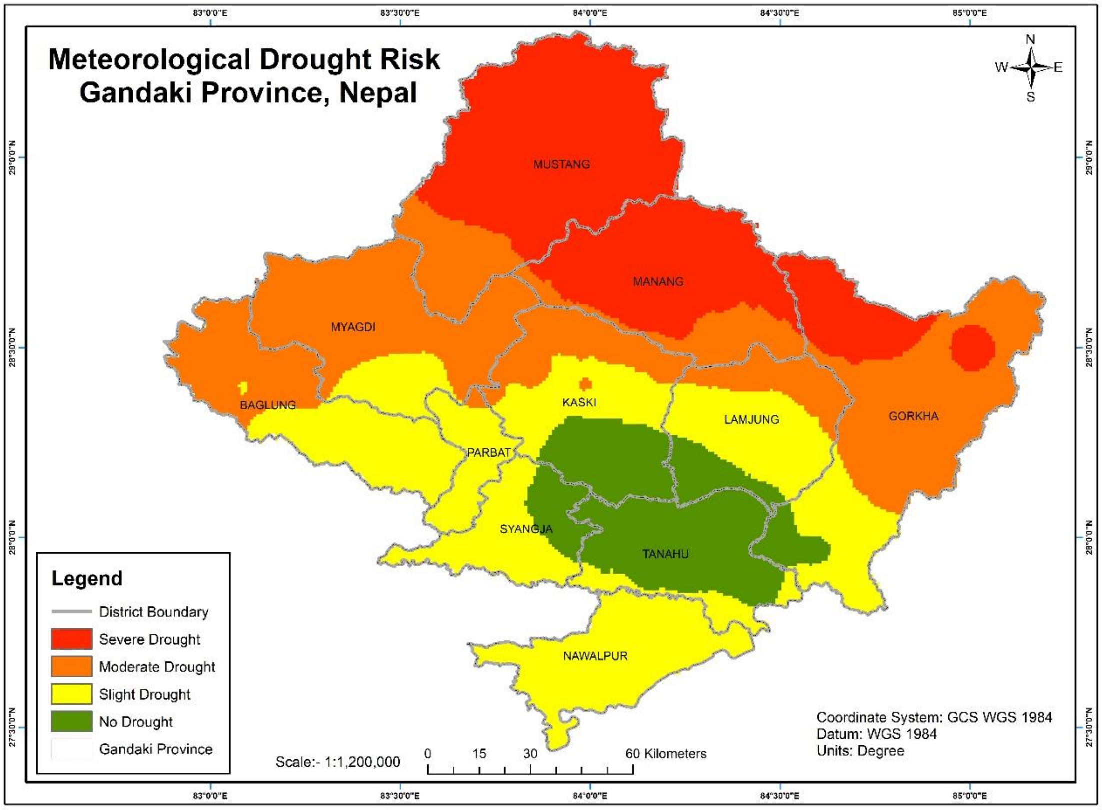
In map 19, most of area of northern part of Gandaki province has negative value of NDVI anomaly. Himalayan region of Manang, Mustang, Gorkha, Kaski has negative value of NDVI anomaly, which represent bad vegetation condition and dry region.

### 3.4.2.1 NDVI Anomaly, Vegetation Condition Index based Agricultural Drought Risk Map

Percentage of VCI (0%, 12%, 24%, 36%, 50%, 72%, 88%, 100%) and the related NDVI anomalies have been computed to define the severity of agricultural drought. 0% to -10% yield equivalent NDVI anomalies have been classed into slight drought, 12% to 24% yield equivalent NDVI anomalies as moderate drought, 24% to 36% yield equivalent NDVI anomalies as severe drought and above 36% of yield equivalent NDVI anomalies very severe drought. But these computations based on district level yields gave a wrong picture of agriculture drought. Therefore, approximate NDVI equivalent threshold from VCI for the region as a whole was computed and agriculture drought risk was thus delineated as slight, moderate and severe drought. Agricultural drought risk map is presented in Map 20.




*Map 20: Agricultural drought risk map*



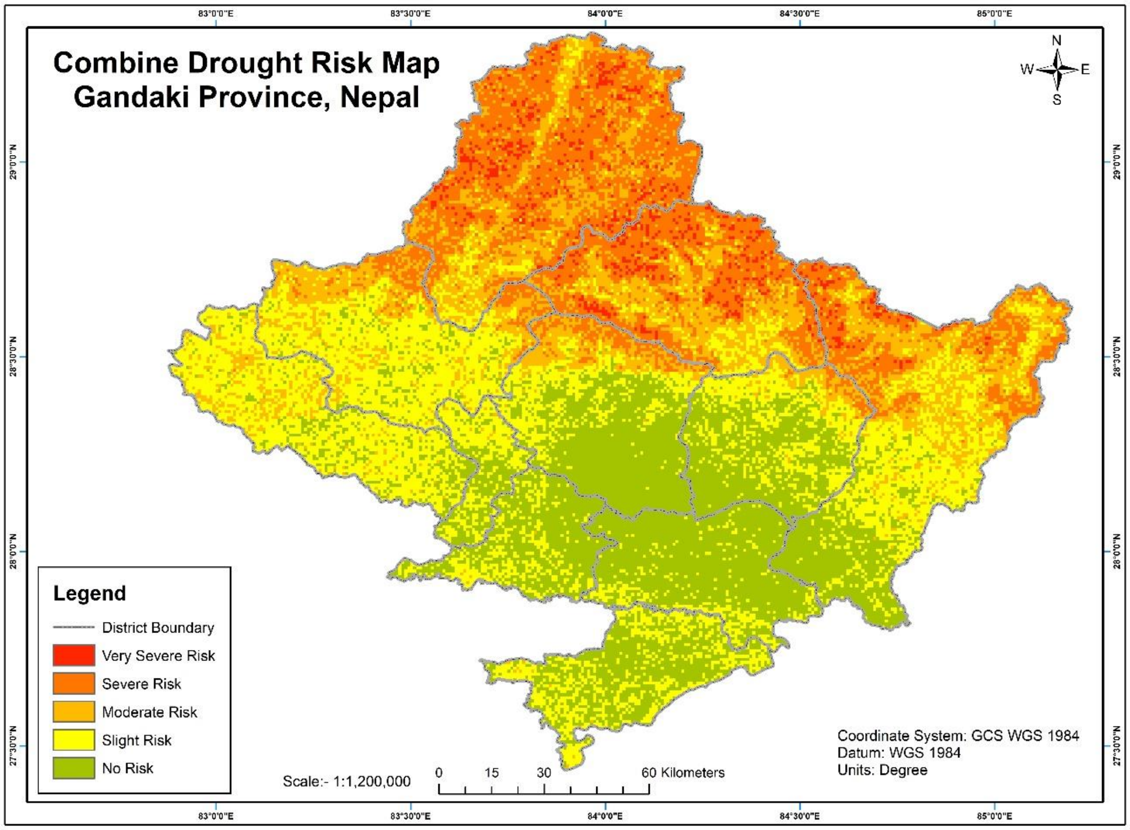

*Map 21: Meteorological drought risk map*

*Table 4: Area affected by Agricultural and Meteorological Drought*

| Drought Class | Meteorological Drought | | Agricultural Drought | |
|---|---|---|---|---|
| | Area ($km^2$) | % of Area | Area ($km^2$) | % of Area |
| Severe Drought | 5450.89 | 24.87 | 4518.48 | 20.62 |
| Moderate Drought | 7052.80 | 32.18 | 4100.45 | 18.71 |
| Slight Drought | 6650.47 | 30.35 | 10568.84 | 48.23 |
| No Drought | 2760.37 | 12.60 | 2726.75 | 12.44 |
| Total | 21914.54 | 100 | 21914.54 | 100 |

## 3.5 Combine Drought Risk Classification

Combine drought risk map, which has been obtained by superimposing the risk maps generated from agriculture and meteorological drought.




*Map 22: Drought risk areas delineated by combined drought risk*

Table 5 and Map 22 shows the percentage area affected by the combined risk. Slight and moderate risk areas encompass 29.74% and 19.40% of total geographical area. Severe and very severe risk prevails in nearly 19.25% and 2.38% of the area which comprises of province that are major producers of cereal crops as well as different vegetable.

*Table 5: Area facing both agricultural and meteorological drought*

| Drought Class | Area ($km^2$) | % of Area |
|---|---|---|
| Very Severe Risk | 521.19 | 2.38 |
| Severe Risk | 4219.33 | 19.25 |
| Moderate Risk | 4252.10 | 19.40 |
| Slight Risk | 6518.38 | 29.74 |
| No Risk | 6403.57 | 29.22 |
| Total | 21914.54 | 100.00 |

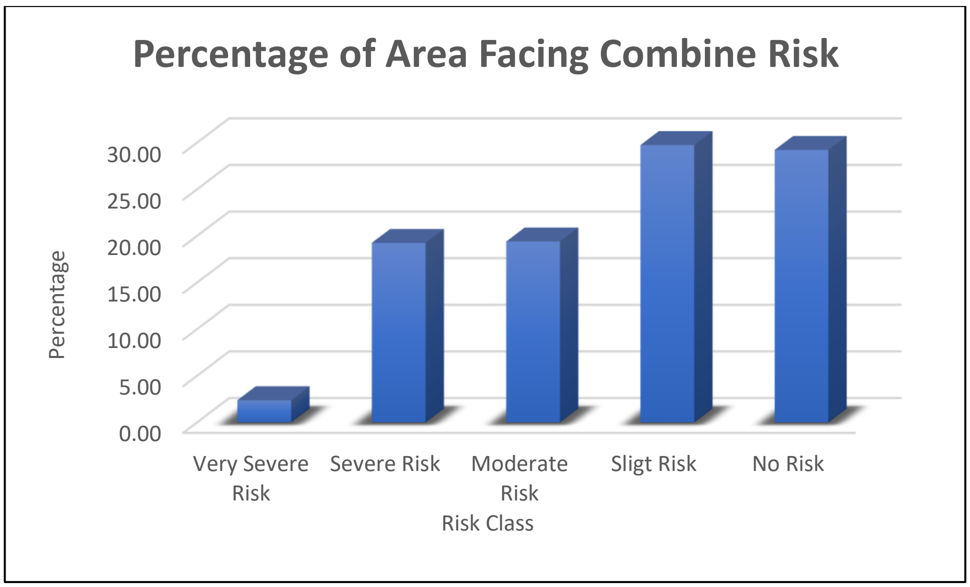
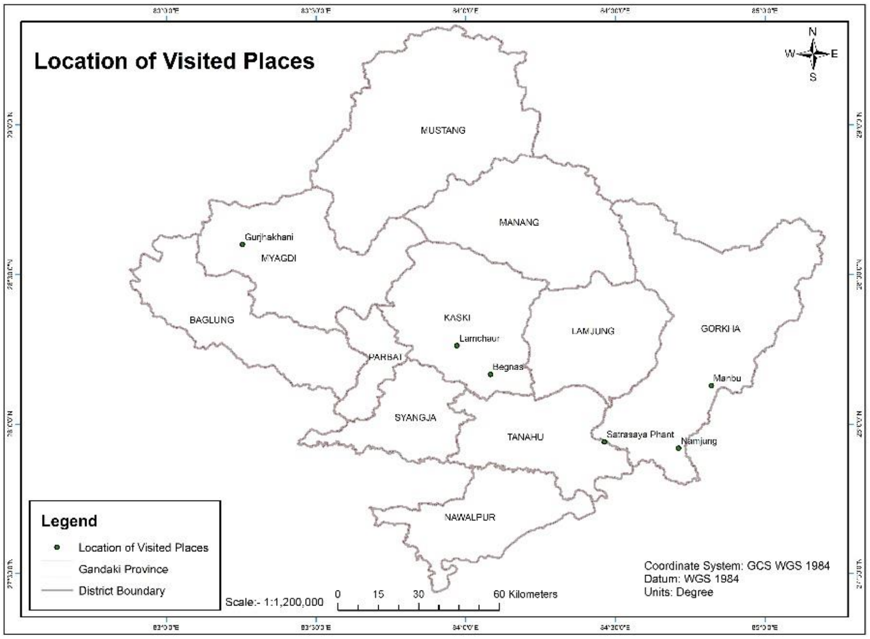



*Figure 4: Area facing a combined drought risk*

## 5.6 Field Verification of the Result

For the verification of the result found I have visited 6 study areas areas in four classes drought coverage area. I had visited Namjung, Satrasaya Phant, Tanahun, Gurjakhani, Lamachaur, kaski and Beganas Kaski.




*Map 23: Location of Visited Places*

Slight Drought: Namjung and Manbu Gorkha face slight drought risk facing area in the Gandaki province. The drought duration is not so high. At the time of low precipitation people irrigate their land by canal.

Moderate drought: I have visited Gurja khani, myagdi. Drought occurs in this region mainly in the transplanting period and in heading period. For short time period drought occurs frequently. People irrigate their land by surface water or ground water. Irrigation facilities is not adequate agricultural crop production is reduce by drought.

No drought: I have visited Satrasaya phant, Begnas and Lamachaur kaski. No drought occurs in this region. This area has healthy vegetation and land irrigated by surface water.

# CHAPTER 4: CONCLUSION AND RECOMMENDATION

## 4.1 Conclusion

The major objective of this study was to identify the severe drought area in Gandaki province at time period of (2005 – 2015) by using RS/GIS technology and techniques. Also, to delineated the drought risk area by integration of multispectral satellite imageries and metrological data. Crop yield data has not been available for all study area. In this project work the derived satellite indices integrating with meteorological derived index called Standardized Precipitation Index.

The seasonal pattern of rainfall and NDVI obtained from 2005 – 2015 of data, suggest that the northern and north-west part of Gandaki province is a low rainfall area, where SPI value is low and the corresponding NDVI values is also low. Thus, it can verify that NDVI/SPI shares a strong correlation where water is a major limiting factor for plant growth.

In some places metrological drought occurred, where agricultural drought has not been influenced due to adequate irrigation facility, well management practices of people and state. From the research it is justify that the north western and northern part is water limiting areas which are suspect by drought. It is also achieved that SPI had shown significant relation with NDVI anomaly and VCI, where SPI can be used as crop production indicator and vegetation health condition. status.

Combination of drought risk states Slight and moderate risk areas encompass 29.74% and 19.40% of total geographical area. Severe and very severe risk prevails in nearly 19.25% and 2.38% of the area which comprises of province that are major producers of cereal crops as well as different vegetable. Due to uneven temporal variation of drought with respect to crop production and vegetation health status, drought planning is necessary for better production. This planning will help tom decrease massive losses of crop production.

The research methodology gives better spatial information from satellite data, which help for accurate mapping, analysis of the spatial extent of drought conditions and temporal variation of drought risk over the different time frame.

## 4.2 Recommendations

This research work described and deals with meteorological and satellite indices. Some recommendations are given below for future research.

1.NDVI, VCI and SPI value for only 11 years. But for better result extra parameters like EVI, SPEI, TCI should be needed and these parameter value should be more than 25 years.

2. Drought from socio-economic aspect should be studied. Because these aspects play vital role in delineating drought prone areas.

3. Less rainfall station is not appropriate to represent the whole Gandaki province rainfall condition. Thus, it is recommended to use maximum number of rainfall station data to identify meteorological drought.

# REFERENCES


1) Adhikari, S. (2018a). Drought Impact and Adaptation Strategies in the Mid-Hill Farming System of Western Nepal. *Environments*, *5*(9), 101. https://doi.org/10.3390/environments5090101

2) Adhikari, S. (2018b). Drought Impact and Adaptation Strategies in the Mid-Hill Farming System of Western Nepal. *MDPI*, *5*(9), 12. https://doi.org/10.3390/environments5090101

3) Anjum, S., Ashraf, U., Zohaib, A., Tanveer, M., Naeem, M., Ali, I., Tabassum, T., & Nazir, U. (2017). Growth and developmental responses of crop plants under drought stress: A review. *Zemdirbyste-Agriculture*, *104*, 267–276. https://doi.org/10.13080/z-a.2017.104.034

4) Baniya, B., Tang, Q., Xu, X., Haile, G., & Chhipi-Shrestha, G. (2019). Spatial and Temporal Variation of Drought Based on Satellite Derived Vegetation Condition Index in Nepal from 1982–2015. *Sensors*, *19*(2), 430. https://doi.org/10.3390/s19020430

5) Belal, A.-A., El-Ramady, H. R., Mohamed, E. S., & Saleh, A. M. (2014). Drought risk assessment using remote sensing and GIS techniques. *Arabian Journal of Geosciences*, *7*(1), 35–53. https://doi.org/10.1007/s12517-012-0707-2

6) Guenang, G. M., & Kamga, F. M. (2014). Computation of the Standardized Precipitation Index (SPI) and Its Use to Assess Drought Occurrences in Cameroon over Recent Decades. *JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY*, *53*, 15.

7) Heim, R. (2002). A Review of Twentieth–Century Drought Indices Used in the United States. *Bulletin of the American Meteorological Society*, *83*. https://doi.org/10.1175/1520-0477(2002)083<1149:AROTDI>2.3.CO;2

8) Ji, L., & Peters, A. (2003). Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices. *Remote Sensing of Environment*, *87*, 85–98. https://doi.org/10.1016/S0034-4257(03)00174-3

9) Joshi, N., & Dongol, R. (2018). Severity of climate induced drought and its impact on migration: A study of Ramechhap District, Nepal. *Tropical Agricultural Research*, *29*(2), 194. https://doi.org/10.4038/tar.v29i2.8289

10) Juliani, B. H. T., & Okawa, C. M. P. (2017). Application of a Standardized Precipitation Index for Meteorological Drought Analysis of the Semi-Arid Climate Influence in Minas Gerais, Brazil. *Hydrology*, *4*(2). https://doi.org/10.3390/hydrology4020026

11) Kogan, F. N. (1995). Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*, *15*(11), 91–100. https://doi.org/10.1016/0273-1177(95)00079-T

12) Lang, T., & Barros, A. (2003). Winter storms in the central Himalayas. *Journal of the Meteorological Society of Japan*, *82*, 829–844.

13) Liang, L., Sun, Q., Luo, X., Wang, J., Zhang, L., Deng, M., Di, L., & Liu, Z. (2017). Long-term spatial and temporal variations of vegetative drought based on vegetation condition index in China. *Ecosphere*, *8*(8), e01919. https://doi.org/10.1002/ecs2.1919

14) McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration of time scales. *Eighth Conference on Applied Climatology, American Meteorological Society, Jan17-23, 1993, Anaheim CA*, 179–186.

15) McKee, T., Doesken, N., & Kleist, J. (1993). *THE RELATIONSHIP OF DROUGHT FREQUENCY AND DURATION TO TIME SCALES*.

16) Mishra, A., & Singh, V. (2011). Drought modeling—A review. *Journal of Hydrology - J HYDROL*, *403*, 157–175. https://doi.org/10.1016/j.jhydrol.2011.03.049

17) MoE. (2010). National Adaptation Programme Action (NAPA). *Ministry of Environment, Government of Nepal*.

18) Murad, H. (2010). *AGRICULTURAL AND METEOROLOGICAL DROUGHT ASSESSMENT USING REMOTE SENSING AND GIS IN NORTH-WEST REGION OF BANGLADESH*. http://lib.buet.ac.bd:8080/xmlui/handle/123456789/4155

19) Murad, H., & Islam, A. K. M. S. (2011). DROUGHT ASSESSMENT USING REMOTE SENSING AND GIS IN NORTH-WEST REGION OF BANGLADESH. *3rd International Conference on Water & Flood Management*, 8.

20) Nam, W.-H., Hayes, M., Svoboda, M., Tadesse, T., & Wilhite, D. (2015). Drought hazard assessment in the context of climate change for South Korea. *Agricultural Water Management*, *160*, 106–117. https://doi.org/10.1016/j.agwat.2015.06.029

21) Nepal Outlook. (2020, June 6). *Gandaki Province: A Data Overview*. http://www.nepaloutlook.com/gandaki-province/#:~:text=Gandaki%20Province%20has%20an%20average,administratively%20there%20are%2011%20Districts.

22) Patel, N. R., Chopra, P., & Dadhwal, V. K. (2007). Analyzing spatial patterns of meteorological drought using standardized precipitation index. *Meteorological Applications*, *14*(4), 329–336. https://doi.org/10.1002/met.33

23) Pathak, A. A., & Dodamani, B. M. (2020). Comparison of Meteorological Drought Indices for Different Climatic Regions of an Indian River Basin. *Asia-Pacific Journal of Atmospheric Sciences*, *56*(4), 563–576. https://doi.org/10.1007/s13143-019-00162-5

24) Prodhan, F. A., Zhang, J., Bai, Y., Pangali Sharma, T. P., & Koju, U. A. (2020). Monitoring of Drought Condition and Risk in Bangladesh Combined Data From Satellite and Ground Meteorological Observations. *IEEE Access*, *8*, 93264–93282. https://doi.org/10.1109/ACCESS.2020.2993025

25) Reinermann, S., Gessner, U., Asam, S., Kuenzer, C., & Dech, S. (2019). The Effect of Droughts on Vegetation Condition in Germany: An Analysis Based on Two Decades of Satellite Earth Observation Time Series and Crop Yield Statistics. *Remote Sensing*, *11*(15), 1783. https://doi.org/10.3390/rs11151783

26) Ryu, J.-H., Han, K.-S., Lee, Y.-W., Park, N.-W., Hong, S., Chung, C.-Y., & Cho, J. (2019). Different Agricultural Responses to Extreme Drought Events in Neighboring Counties of South and North Korea. *Remote Sensing*, *11*(15), 1773. https://doi.org/10.3390/rs11151773

27) Saji, N., & Yamagata, T. (2003). Possible impacts of Indian Ocean Dipole mode events on global climate. *Climate Research*, *25*, 151–169. https://doi.org/10.3354/cr025151

28) Seiler', R. A., Kogan, F., & We, G. (2000). *MONITORING WEATHER IMPACT AND CROP YIELD FROM NOAA AVHRR DATA IN ARGENTINA*. 9.

29) Shofiyati, R., Kiyoshi, H., & Wikantika, K. (2009). *Model Development Using Remote Sensing and GIS for Monitoring and Assessment an Application of Agricultural Drought in Upper Brantas Watershed, Indonesia*.

30) Shrestha, A., Wake, C., Dibb, J., & Mayewski, P. (2000). Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters. *International Journal of Climatology*, *20*, 317–327. https://doi.org/10.1002/(SICI)1097-0088(20000315)20:3<317::AID-JOC476>3.0.CO;2-G

31) Sigdel, M., & Ikeda, M. (1970). Spatial and Temporal Analysis of Drought in Nepal using Standardized Precipitation Index and its Relationship with Climate Indices. *Journal of Hydrology and Meteorology*, *7*(1), 59–74. https://doi.org/10.3126/jhm.v7i1.5617

32) Sigdel, M., & Ikeda, M. (2010). Spatial and Temporal Analysis of Drought in Nepal using Standardized Precipitation Index and its Relationship with Climate Indices. *Journal of Hydrology and Meteorology*, *7*(1), 59–74. https://doi.org/10.3126/jhm.v7i1.5617

33) Thenkabail, P. S, Gamage, M. S. D. N., & Smakhtin, V. U. (2004). *The use of remote sensing data for drought assessment and monitoring in Southwest Asia*. International Water Management Institute.

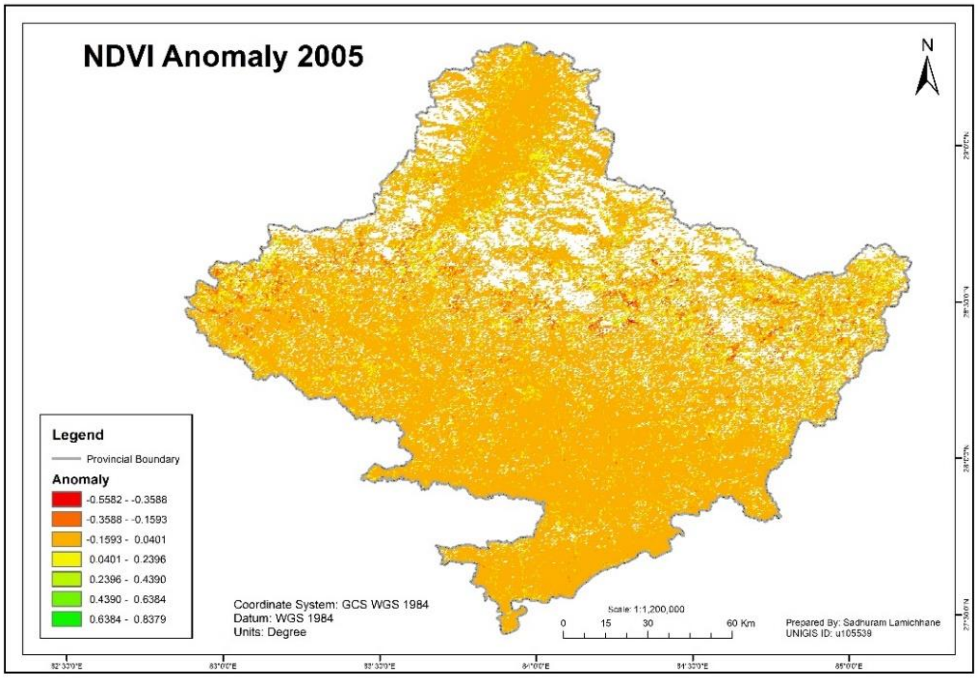
34) Thenkabail, Prasad Srinivasa, & Gamage, M. S. D. N. (2004). *The use of remote sensing data for drought assessment and monitoring in Southwest Asia*. International Water Management Institute.

35) Wang, S.-Y., Yoon, J.-H., Gillies, R. R., & Cho, C. (2013). What Caused the Winter Drought in Western Nepal during Recent Years?*,+. *Journal of Climate*, *26*(21), 8241–8256. https://doi.org/10.1175/JCLI-D-12-00800.1

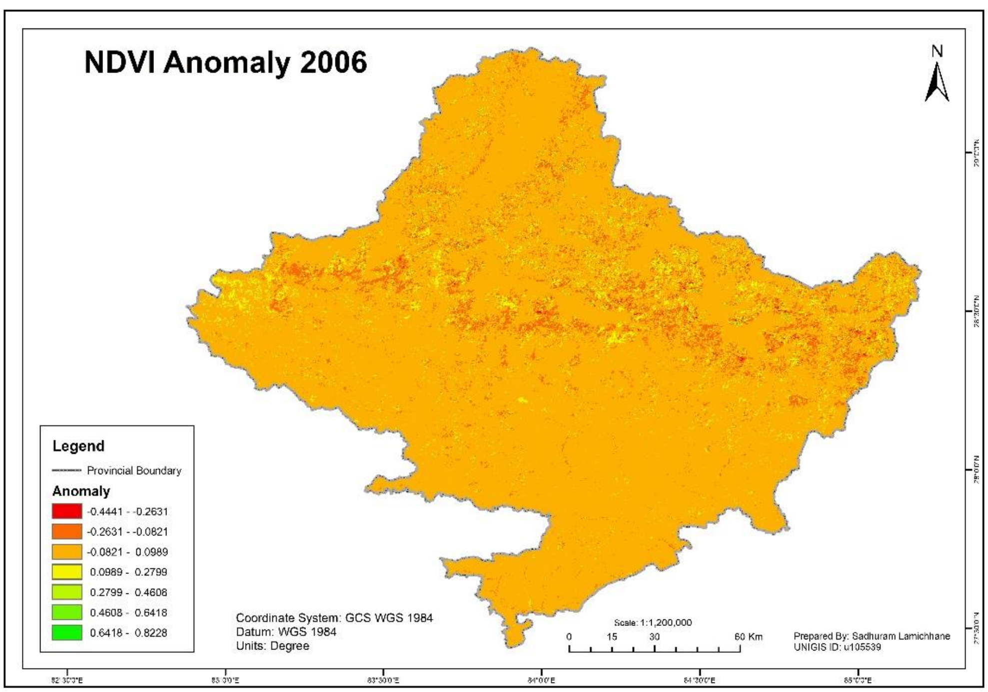
36) Wannebo, A., & Rosenzweig, C. (2003). Remote sensing of US cornbelt areas sensitive to the El Ni@o-Southern Oscillation. *International Journal of Remote Sensing*, *24*(10), 2055–2067. https://doi.org/10.1080/01431160210154786

37) Wilhite, D., & Glantz, M. (1985). Understanding: The Drought Phenomenon: The Role of Definitions. *Water International - WATER INT*, *10*, 111–120. https://doi.org/10.1080/02508068508686328

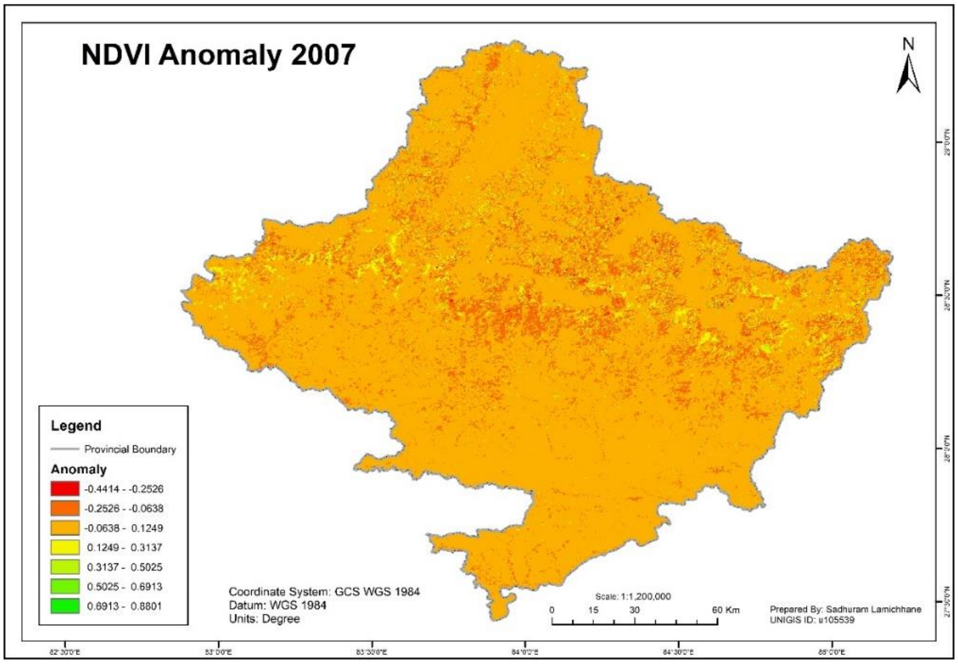
# APPENDIX – A: NDVI Anomaly for All Years



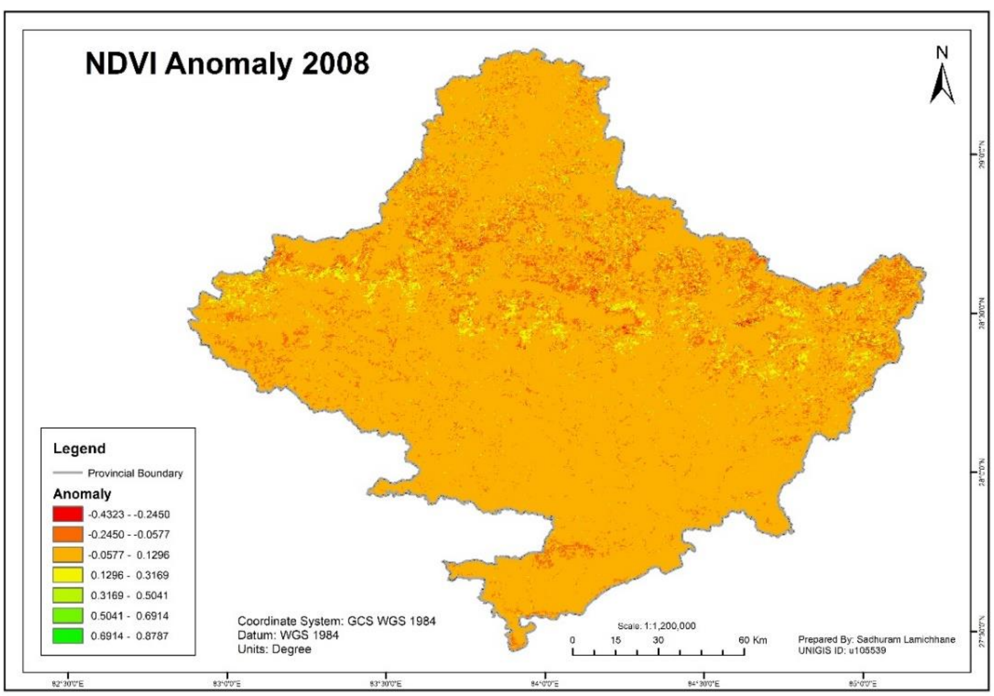

*Map A.1: NDVI Anomaly 2005*



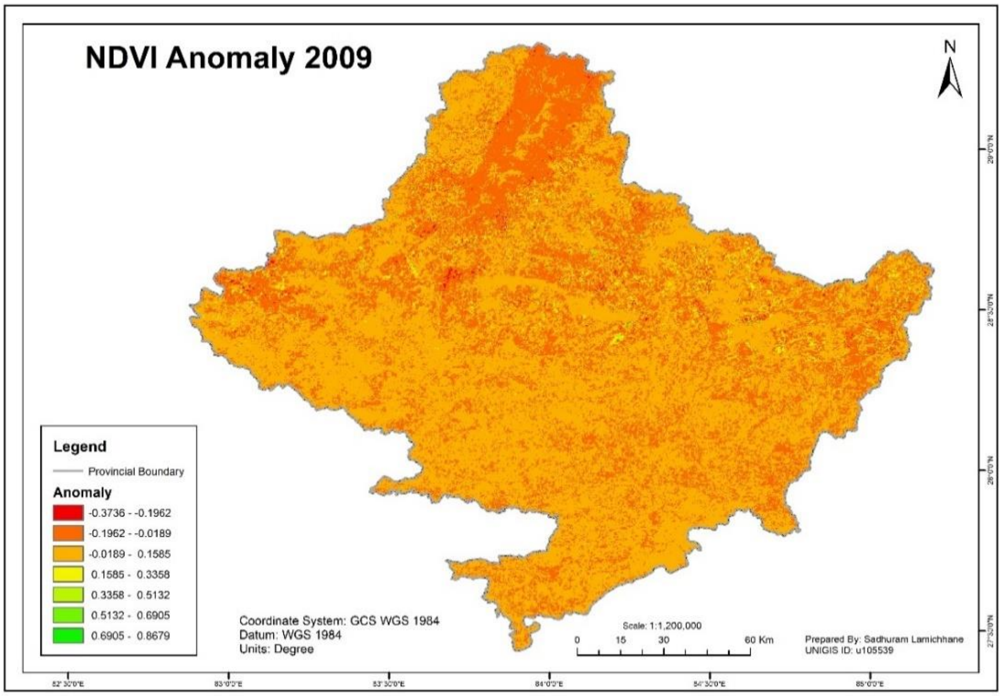

*Map A. 2: NDVI Anomaly 2006*



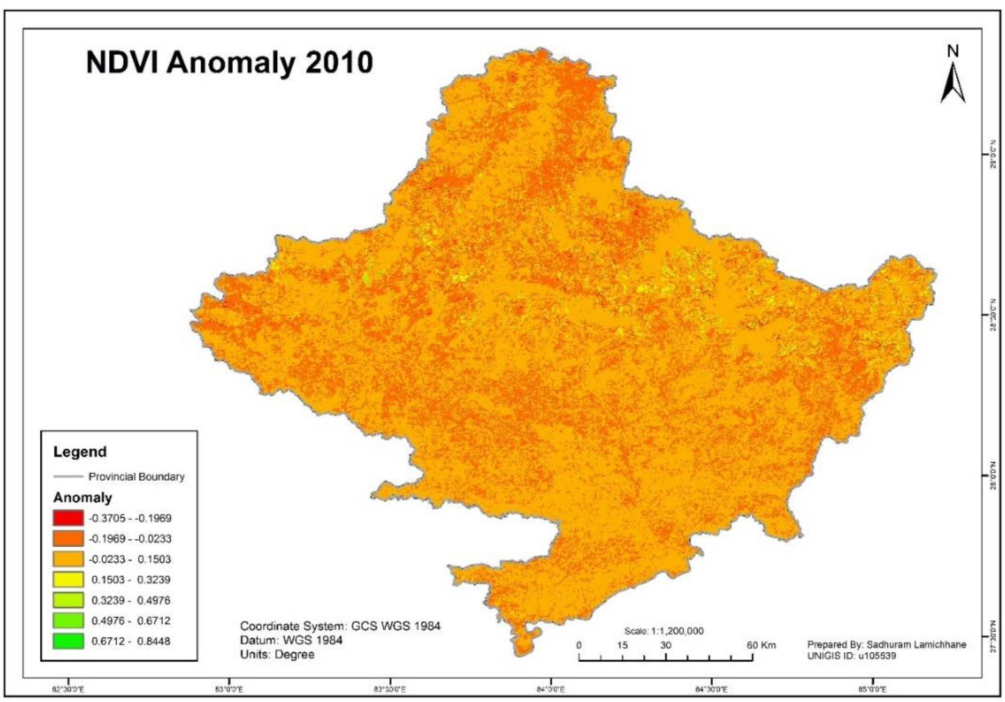

*Map A. 3 : NDVI Anomaly 2007*



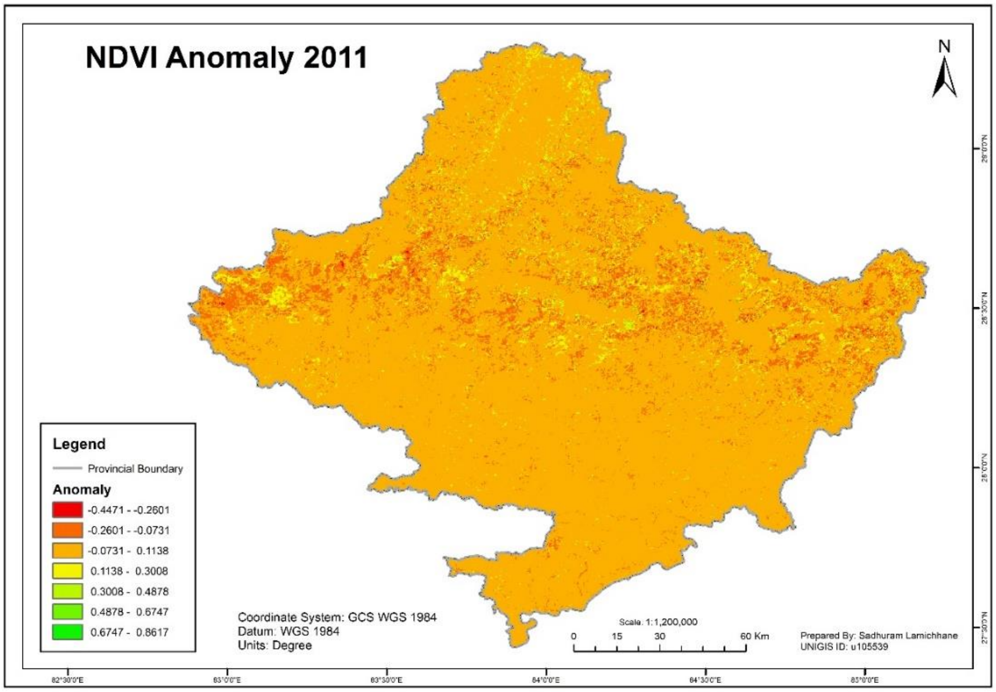

*Map A. 4: NDVI Anomaly 2008*



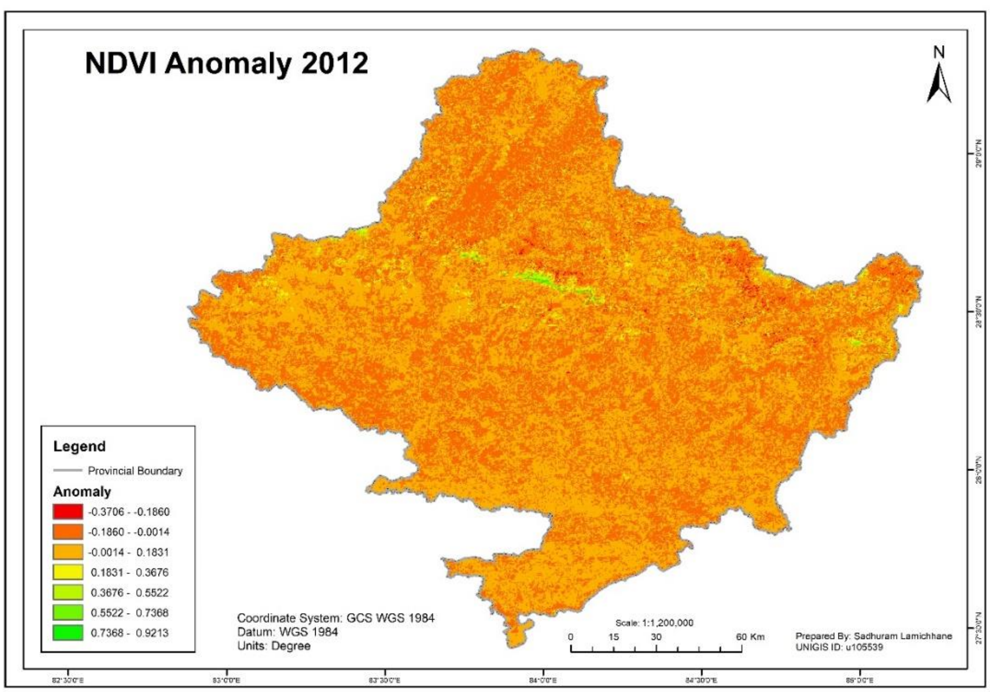

*Map A. 5: NDVI Anomaly 2009*



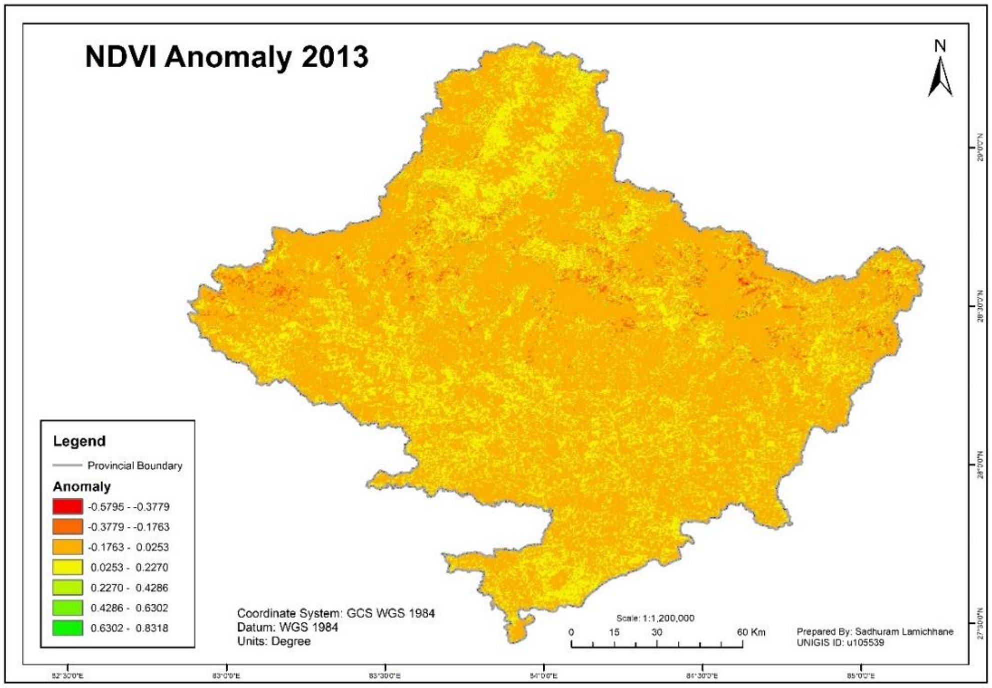

*Map A. 6: NDVI Anomaly 2010*



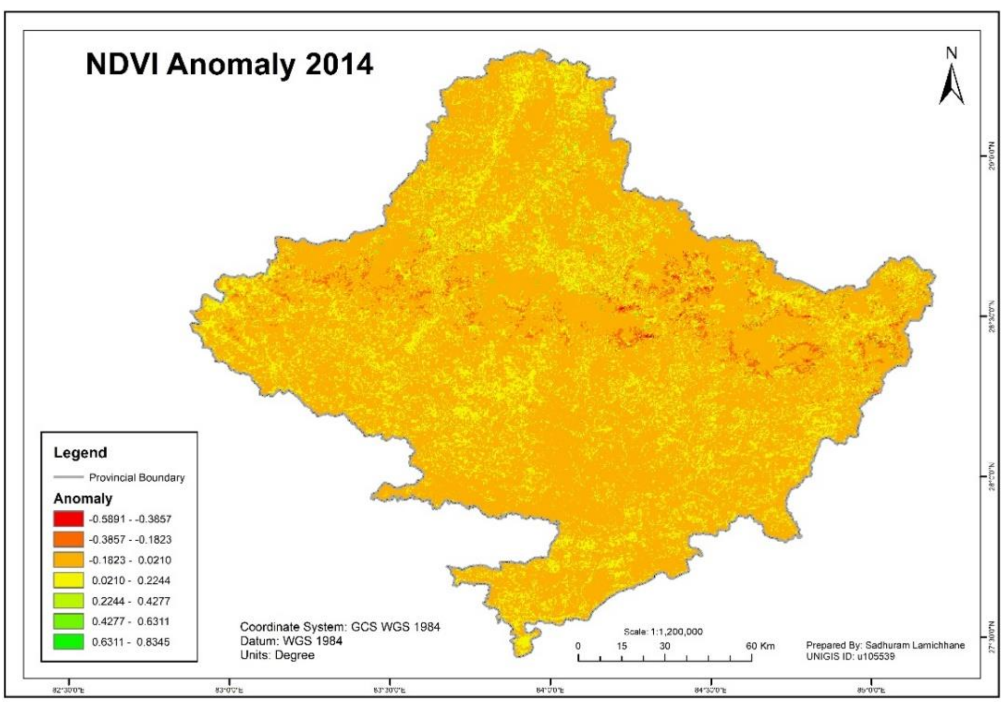

*Map A. 7: NDVI Anomaly 2011*



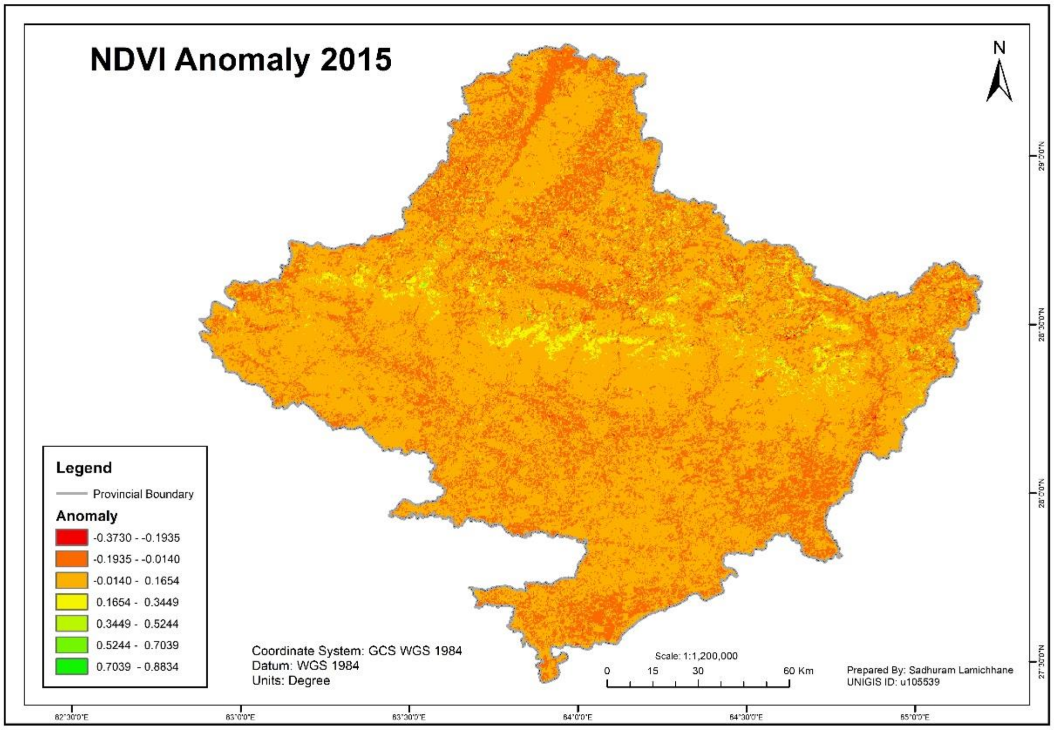

*Map A. 8: NDVI Anomaly 2012*




*Map A. 9: NDVI Anomaly 2013*




*Map A. 10: NDVI Anomaly 2014*




*Map A. 11: NDVI Anomaly 2015*

# APPENDIX – B: SPI for Selected Coordinates

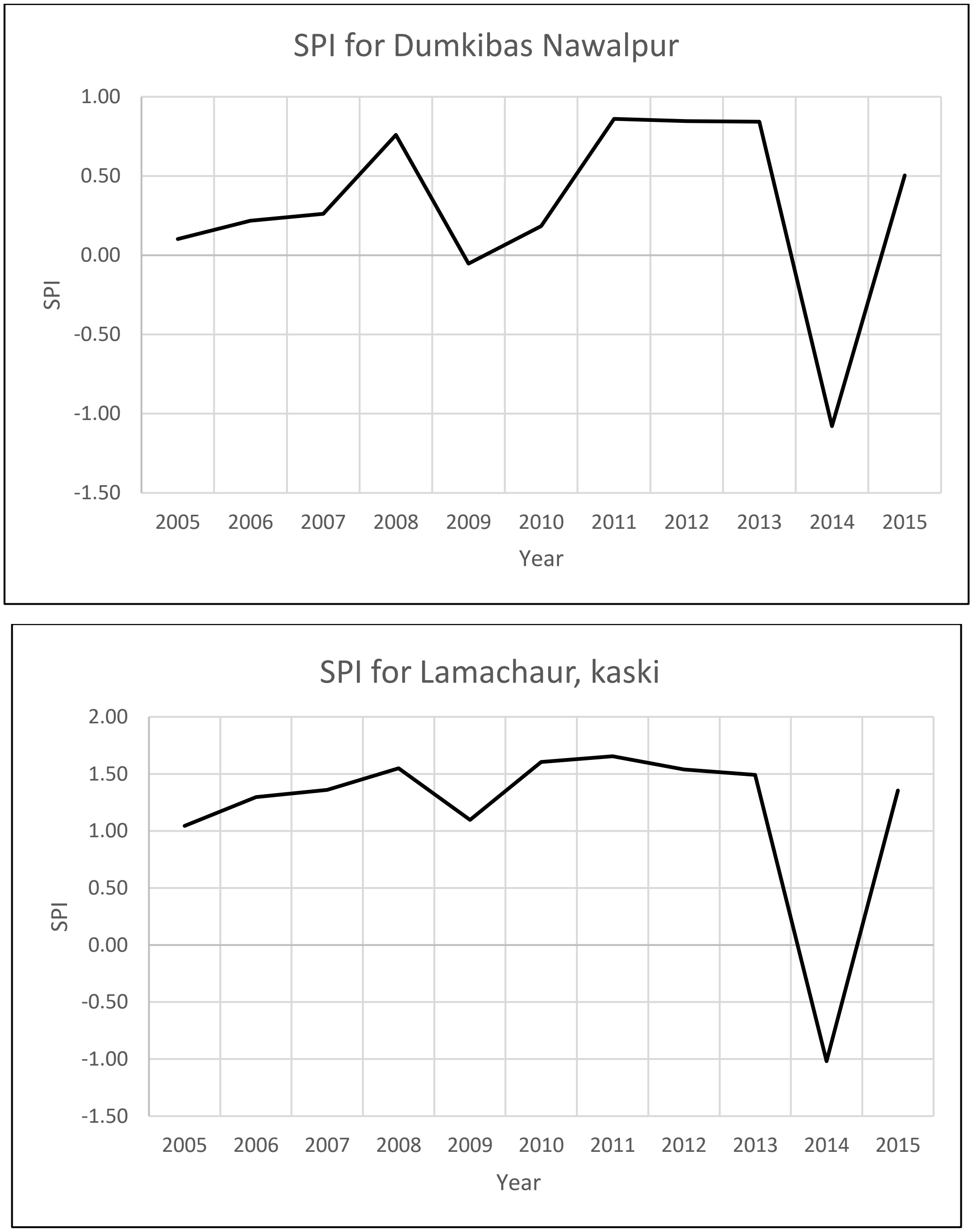
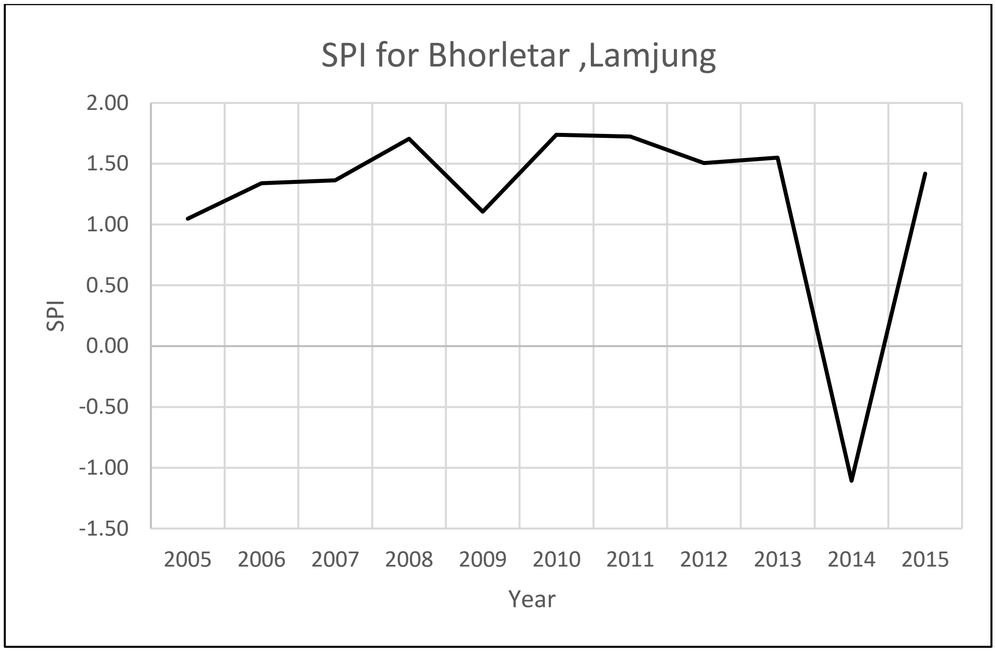



*Figure B. 1: 12 Month SPI Dumkibas and Lamachaur*



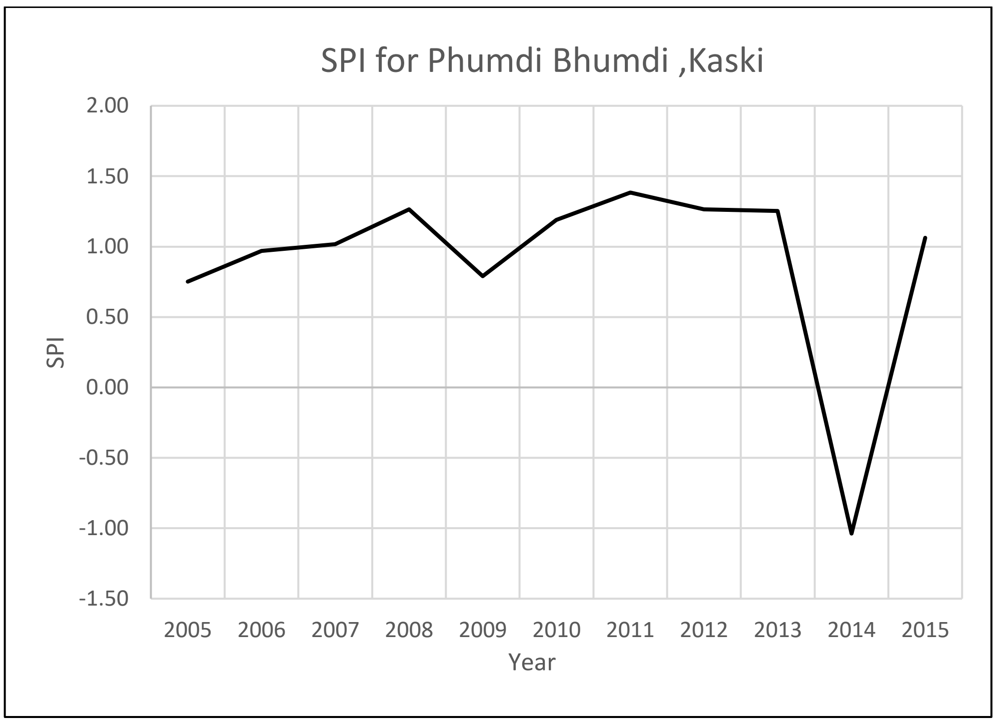
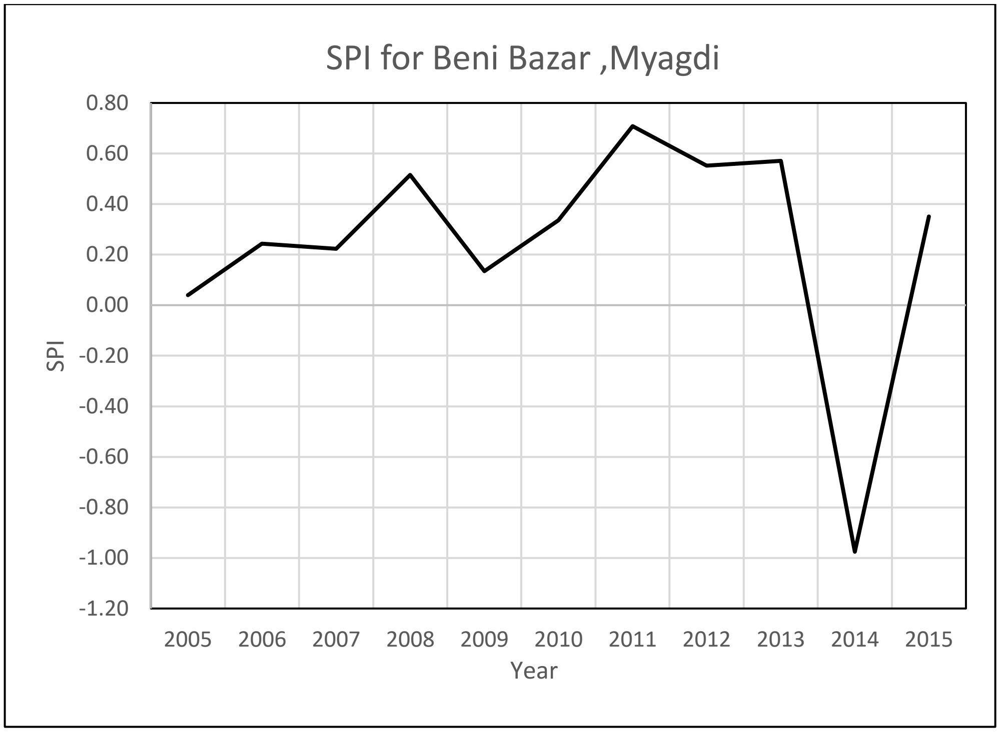




*Figure B. 2: 12 Month SPI Bhorletar and Phumdi Bhumdi*



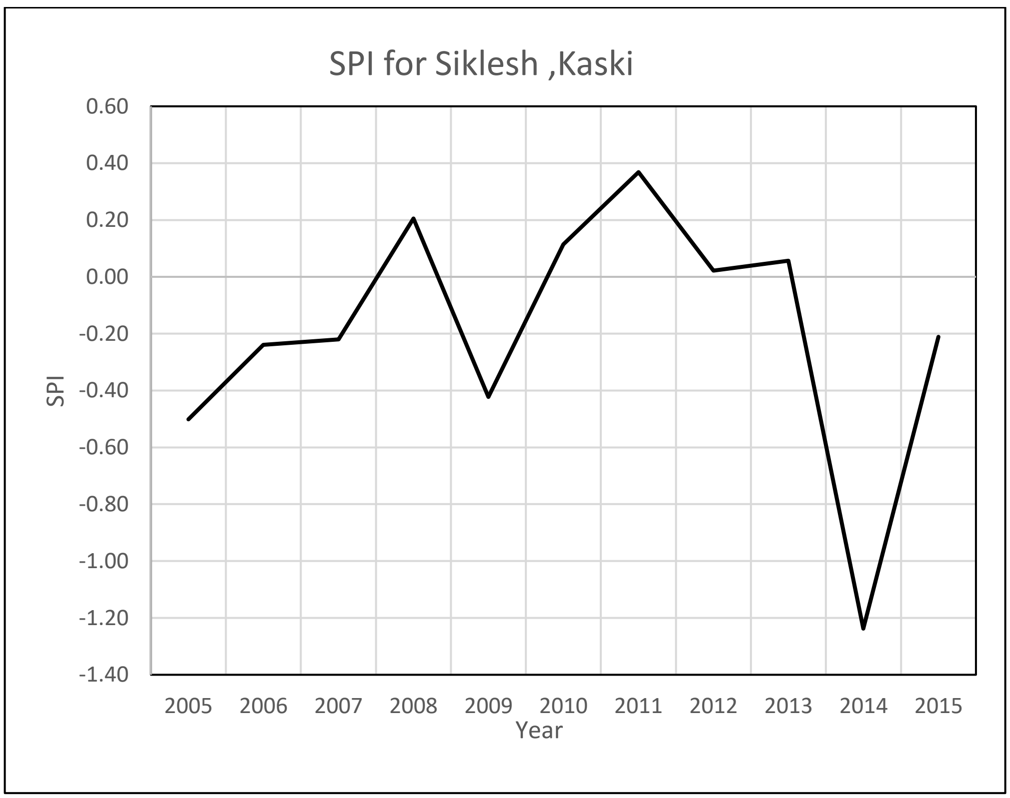
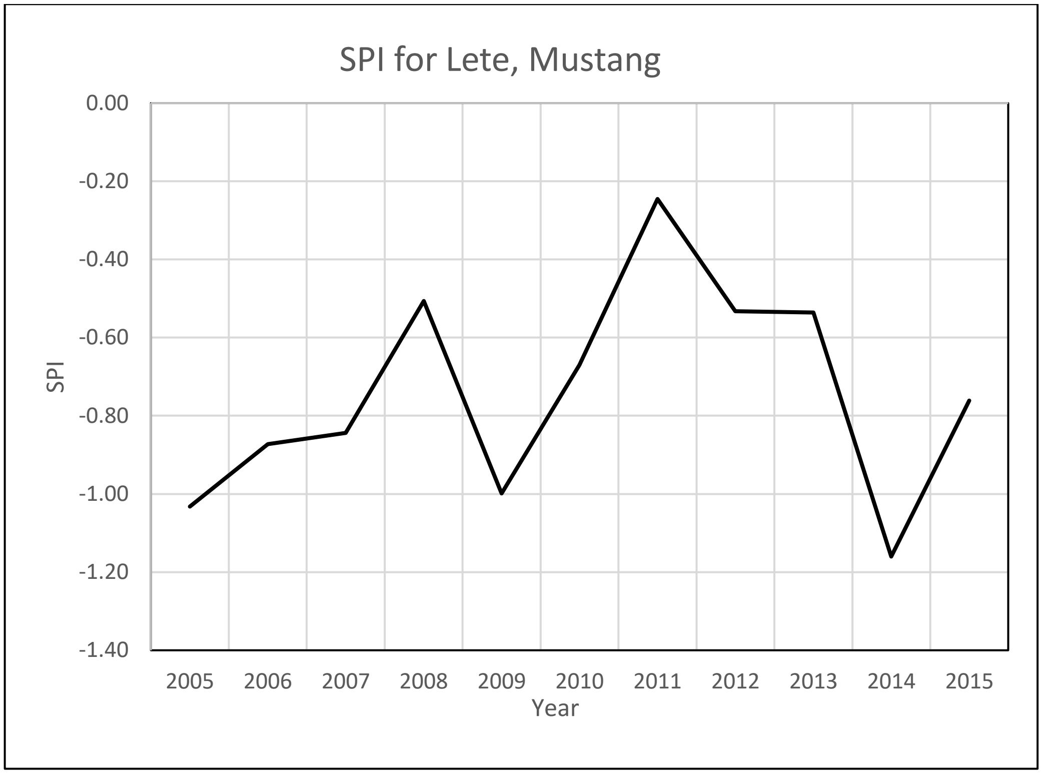




*Figure B. 3: 12 Month SPI Beni Bazar and Siklesh*



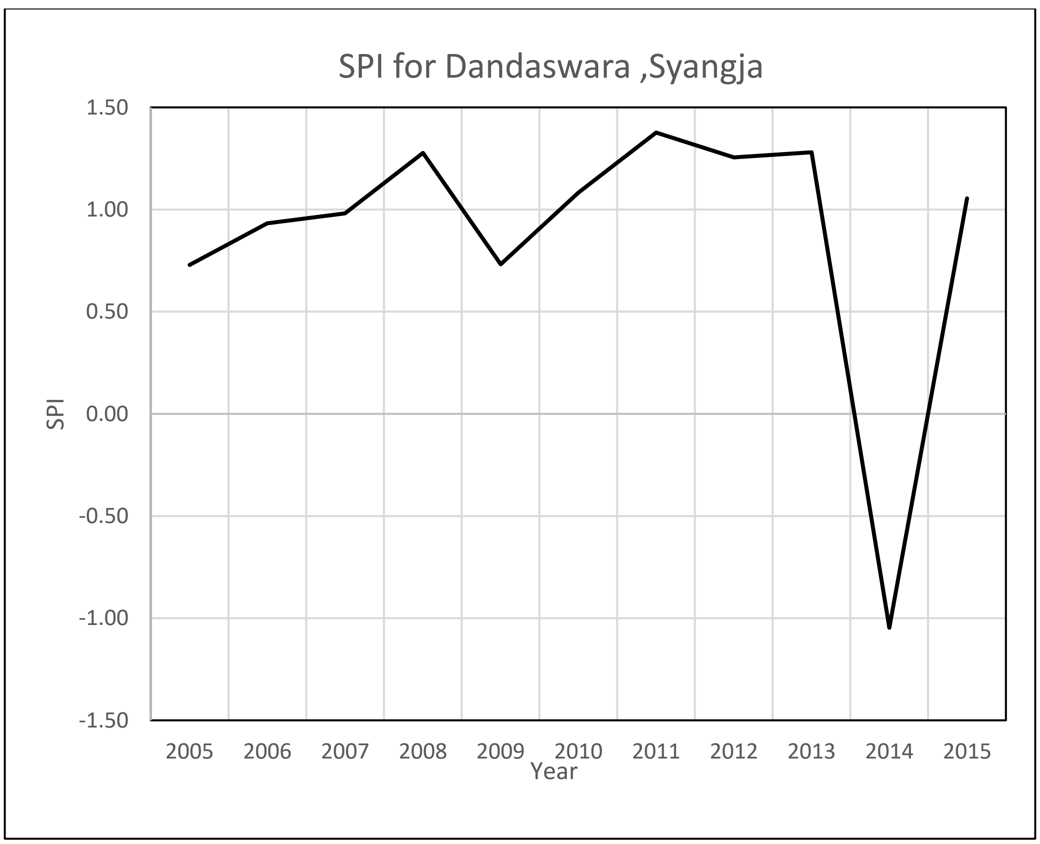




*Figure B. 4: 12 Month SPI Lete and Dandaswara*

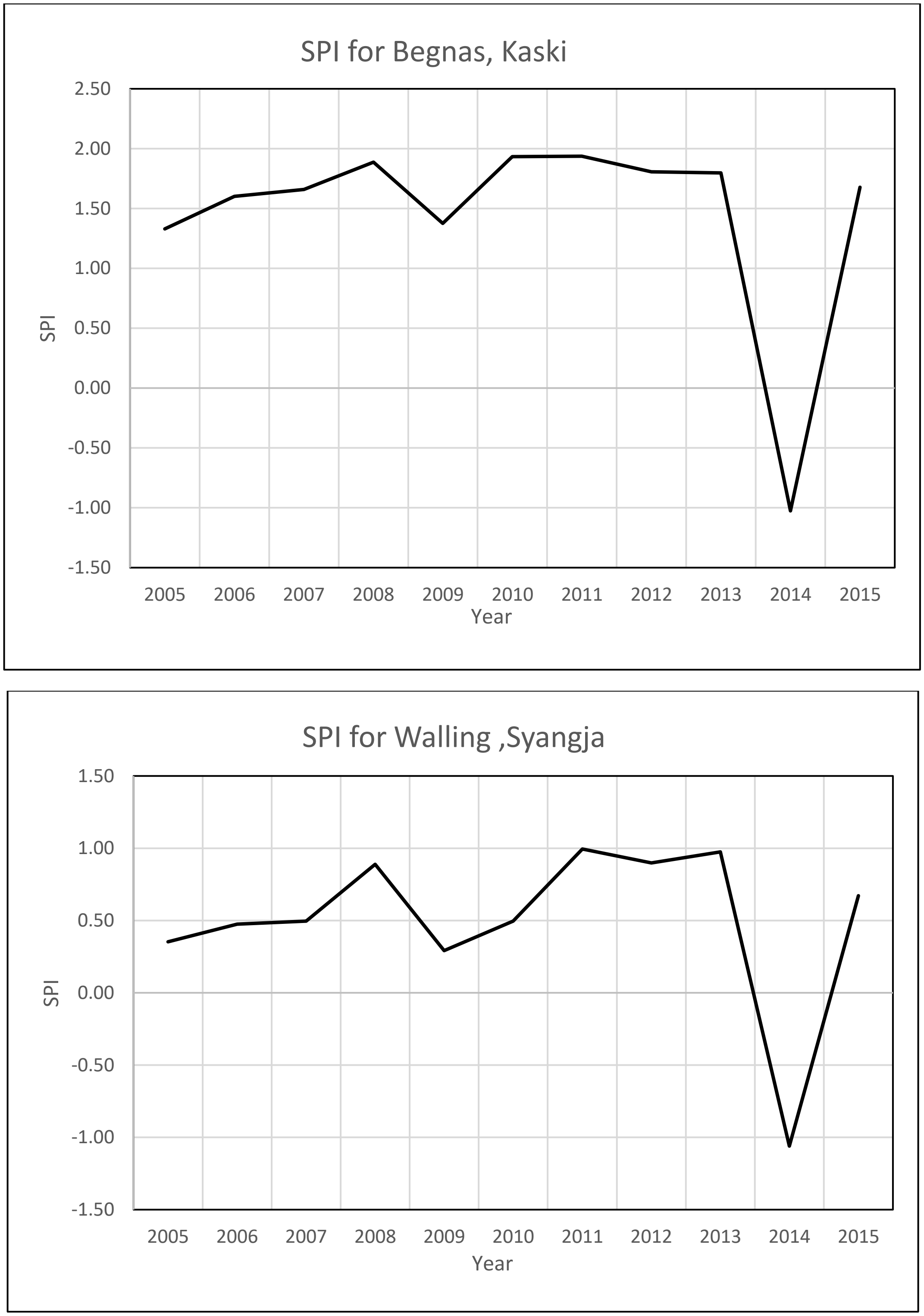
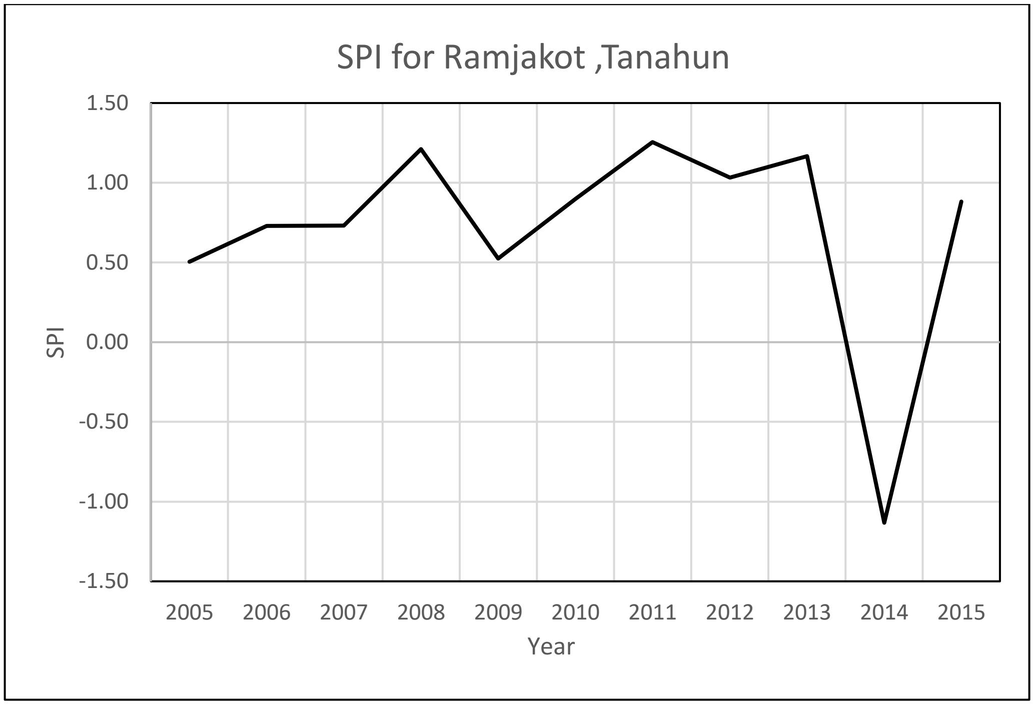



*Figure B. 5: 12 Month SPI Begnas and Walling*



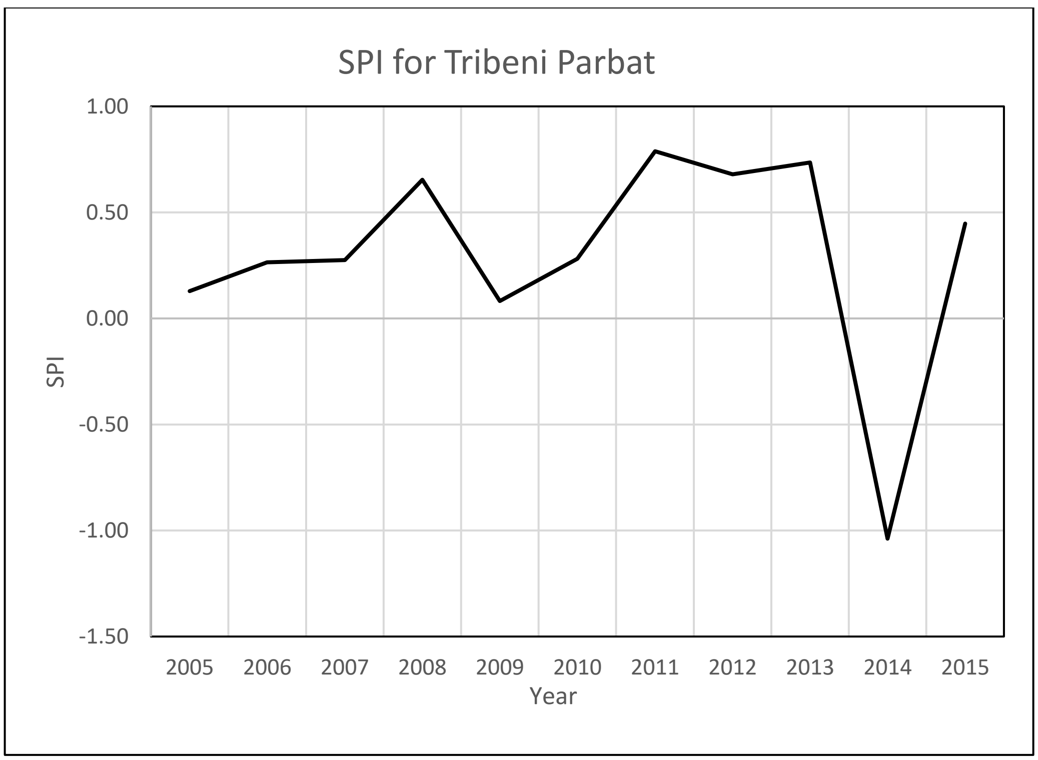
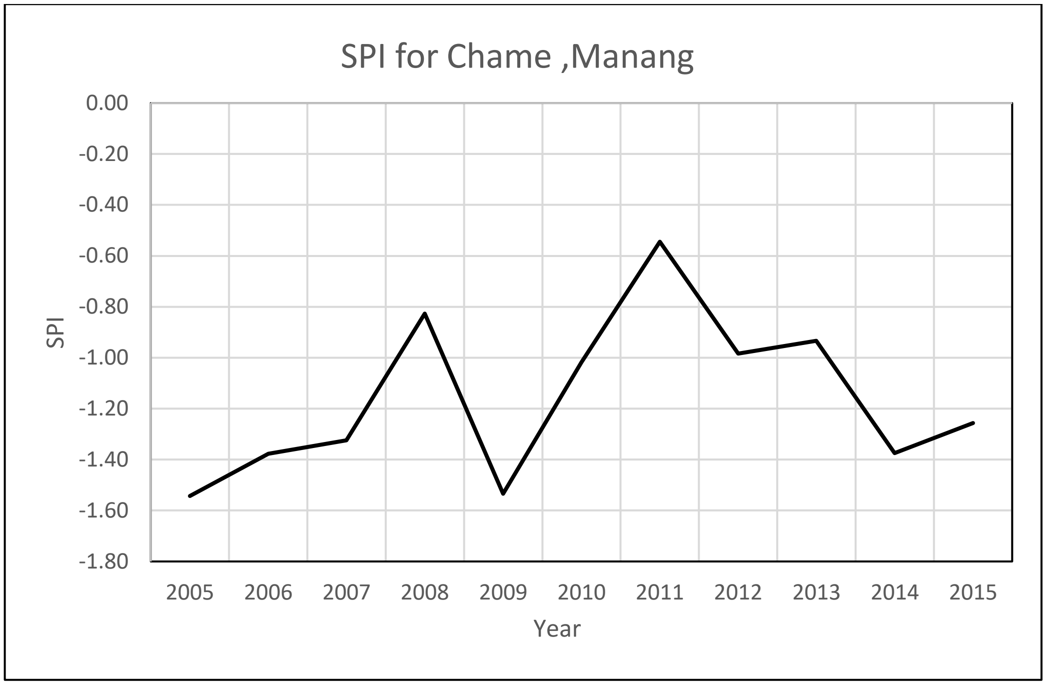




*Figure B. 6: 12 Month SPI Ramjakot and Tribeni*



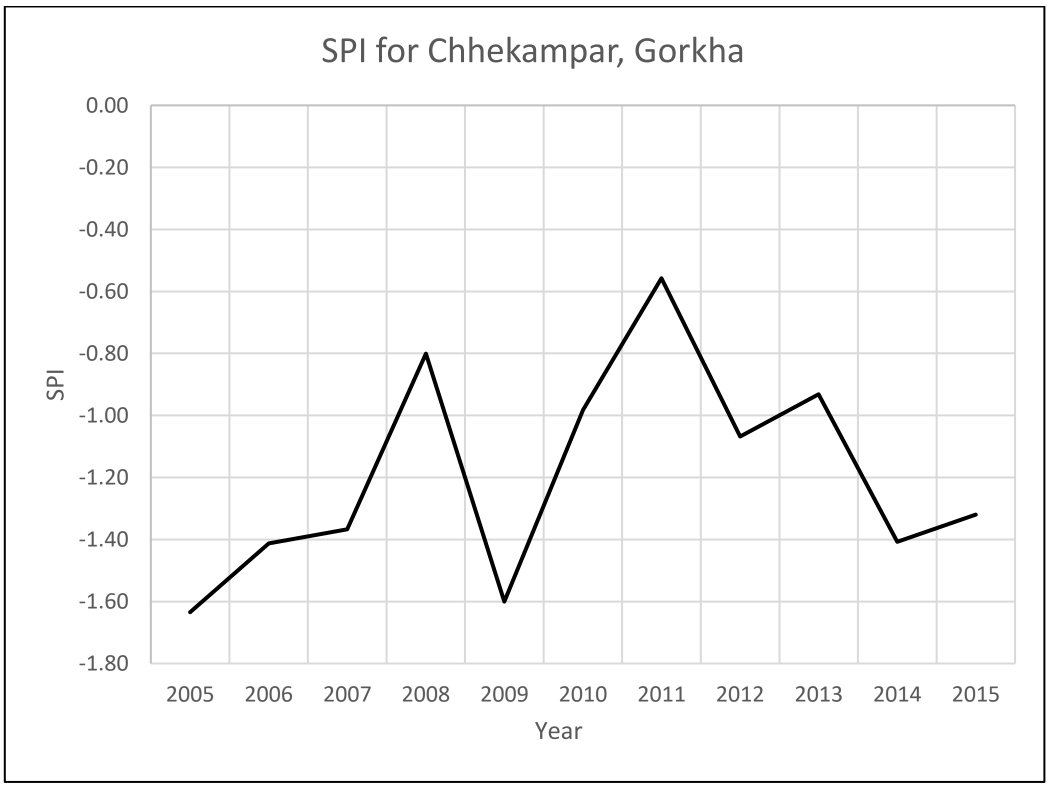




*Figure B. 7: 12 Month SPI Chame and Chhekampar*