METEREOLOGICAL DROUGHT INSTENSITY ASSESSMENT USING STANDARDIZED PRECIPITATION INDEX

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CANDIDATE'S DECLARATION

I, Ashish Srivastava, Roll No. 2K17/ENE/18 student of M. Tech (Environmental Engineering), hereby declare that the project Dissertation titled "Meteorological Drought Intensity Assessment using Standardized Precipitation Index" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title of recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Meteorological Drought Intensity Assessment using Standardized Precipitation Index" which is submitted by ASHISH SRIVASTAVA, 2K17/ENE/18, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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Date: **SUPERVISOR**

ABSTRACT

Drought is a condition which due to deficiency of moisture in a region due to uneven rainfall, drying up of rivers and loss of ground water. It is estimated that droughts effects around 200 million people are affected from drought every year in India. In 2019 42% of the country's area is under drought with almost 500 million people severely affected in some ways. Droughts have so far affected the region in study adversely throughout the last century. With increasing global warming and ever-changing trends of monsoon the region has seen worst of the droughts in the last 10 to 20 years. Hence, drought identification, evaluation and mitigation require a solid approach to prepare a suitable and effective management plan.

The study focuses on the Uttar Pradesh region of Bundelkhand Plateau, which faces continuous droughts every year. The study is carried out for six districts of Uttar Pradesh viz. Auraiya, Banda, Jalaun, Jhansi, Hamirpur and Lalitpur. To identify drought conditions and classify it Standard Precipitation Index (SPI) was computed. The monthly rainfall data from 1988 to 2018 was collected from various sources. The 3-Month SPI(April-June), 3-Month SPI (July-September) and 6-Month SPI (Oct-Mar) were computed using DrinC software and MS excel. The SPI values were used to categorise drought under four groups based on its severity namely mild, moderate, severe and extreme from 1988 to 2018.

The IMD classification of rainfall involves categorizing drought by computing the percentage deviation of the current rainfall from normal rainfall. Thus, in this study, the SPI values of different years are analysed with actual rainfall and rainfall deviation from normal in low rainfall and drought prone districts. The objective is to evaluate whether SPI can be used as a better indicator than conventionally adopted rainfall deviation-based approach for drought intensity assessment.

The results are represented with the help of bar charts to study the frequency of droughts over the years and categorize it. The SPI vs. Rainfall deviation scatter plots are plotted to examine the validity and relation of SPI with Rainfall deviation method.

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ABBREVIATIONS

PDSI- Palmer Drought Severity Index

SPI- Standardized Precipitation Index

NDVI- Normalized Differential Vegetation Index

VCI- Vegetation Cover Index

NOAA- National Oceanic and Atmospheric Administration

ADVHR-Advanced Very High-Resolution Radiometer

IMD- Indian Meteorological Department

GIS- Geographical Information System

LST- Land Surface Temperature

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CHAPTER-1

INTRODUCTION

Droughts are natural disasters related to water deficiency which has an impact on various activities related to environment such as vegetation, agriculture, wildlife, humanity and local economies. Drought is one of the most important natural disaster related to weather which is often intensified by human activities, since its impacts affect greater areas for time ranging from months to years, thus it has a stern effect on life expectancy, food and grain production for entire population. Between 1967-1991, almost 60 percent were affected from drought out of the 2.7 billion people who suffered from all-natural disasters. Severe droughts took as many as 90,000 lives. In recent times large-scale severe droughts have been noticed across the globe leading to starvation due to restricted food supply and shortage among millions, destruction of ecological resources and heavy losses is economy.

The disaster management actions can be organized into three major stages:

1. Preparedness stage in which prediction of disaster and the zone of risk are identified well in advance before the occurrence of event;
2. Prevention stage during which early forecasting and warning, monitoring and preparation of emergency plans are easily executed before or during the occurrence of event;
3. Action and Mitigation stage where activities are undertaken just after the event which include damage assessment and relief management.

It is estimated that 4 billion people – one half of the world's population will live under conditions of severe water stress by year 2025, with conditions particularly severe in Africa, Middle East and South Asia (Diwan, 2002). India is a large country in terms of geographical area, exhibiting greater agro- climatic variation. The country is susceptible to several natural disasters which are a major constraint to developmental activities. The statistics of the disaster events show the alarming trend (Manikiam, 2003). One of the worst natural calamities that affect India is the large-scale incidence of drought during the south-west monsoon season (June to September). Semi-arid region faces the greatest drought hazard and is characterized by low and uncertain crop yields, mostly rainfed. For most of dry crops, the yields are invariably dependant on residual soil moisture storage (Dhopte, 2002). India being affected by drought in many years in history still lacks adequate drought management and mitigation strategy at national level. In absence of drought severity map, no drought mitigation measures and management would be meaningful. All measures taken to combat disasters in general and drought in particular are ad-hoc in nature. Crop loss assessment due to drought by revenue authority country-wide used by conventional approach has been in practice in spite of its large amount of subjectivity in the estimation of crop loss since there is no other rational approach in its place. This has given rise to many limitations in the existing approaches which did not work satisfactorily in providing remedy to the problem of drought and its management. It is in the light of frequent drought years; the country needs the drought severity map.

1.1 Drought Definitions

Drought is an event when the rainfall for a week is less than half of the normal, when the normal weekly rainfall is more than or equal to 5 mm. Agricultural drought occurs when four continuous weeks of such rainfall occur from October or six continuous weeks during rest of the year. When the certain seasonal rainfall is less than an amount by more than twice the mean deviation. Drought is a period when dry conditions than normal are seen which results in water-scarcity.

According to the Indian Meteorological Department (IMD) drought occurs in an area when the deviation from normal or precipitation deficiency is more than or equal to 26 percent of long-term normal rainfall of that area. Further it is classified in to moderate and severe drought based on the rainfall. A drought event is defined as a year or a period of time during which the total rainfall is less than 75% of the normal rainfall. If the deficit of rainfall lies between 26 percent to 50 percent it is classified as a moderate drought and when it is more than 50 percent it is classified under severe category. A drought prone area is defined as an area in which during long drought periods the probability of occurrence of drought is 0.2 to 0.4. If the probability of occurrence is more than or equal to 0.4 then it is classified as chronically drought area. The Indian summer monsoon rainfall (ISMR), is the area-weighted precipitation having normal of 880 mm. When the deficiency of rainfall is more than 10 percent and when area under drought increases more than 20 percent of the total plains area of the country (which is 32, 87 787 sq. km) then a drought for the whole country is declared.

1.2 Drought Classification

(1) Meteorological drought: It is a condition during which a substantial (more than 25%) deficiency from normal precipitation occurs over a region.

(2) Hydrological drought: Longer duration meteorological drought results in hydrological drought. Hydrological drought marks the decrease in surface water. It also results in drying up of rivers, streams, lakes, reservoir and decreasing levels of underground water. Hydrological drought impacts agriculture and industries as it causes scarcity of water.

(3) Agricultural drought: If there is not sufficient rainfall to retain enough moisture levels in soil which result in reduced plant growth or no growth at all and also wilting of crops then a situation of agricultural drought is marked.

(4) Socio-Economic drought: When there is such scarcity in precipitation that it affects the growth of the country economically it marks socio-economic drought.

1.3 Factors affecting drought

The monsoon rains over India is due to a global process, which is associated to great movements of air over land surface and water. The irregular rainfall distribution and its deficiency leads to scarcity of water, to such severe extent, that it may result in droughts of varying magnitude and intensity. A few factors affecting it are, the sea-surface temperature difference round the Indian sub-continent relative to atmospheric circulation and the large-scale pressure oscillation in atmosphere over the Southern Pacific Ocean. The El Nino also has significant influence on the monsoon events of the Indian sub-continent.

1.4 Drought Impacts

Drought can be referred to as a prominent moderate catastrophe as compared to other normal disasters. It negatively impacts life, economy, horticulture, animals, water bodies, small insects etc.

1.4.1 Economic Impacts of Drought

Areas like agriculture and fish culture or aqua culture, may affect economy of the country. These jobs require water in considerable amount whether it is ground water or surface water. Hence a drought event can bring misfortunes and substantial loss in business due to less crop yield and also improper animal husbandry as there can be reduced grass cover for grazing.

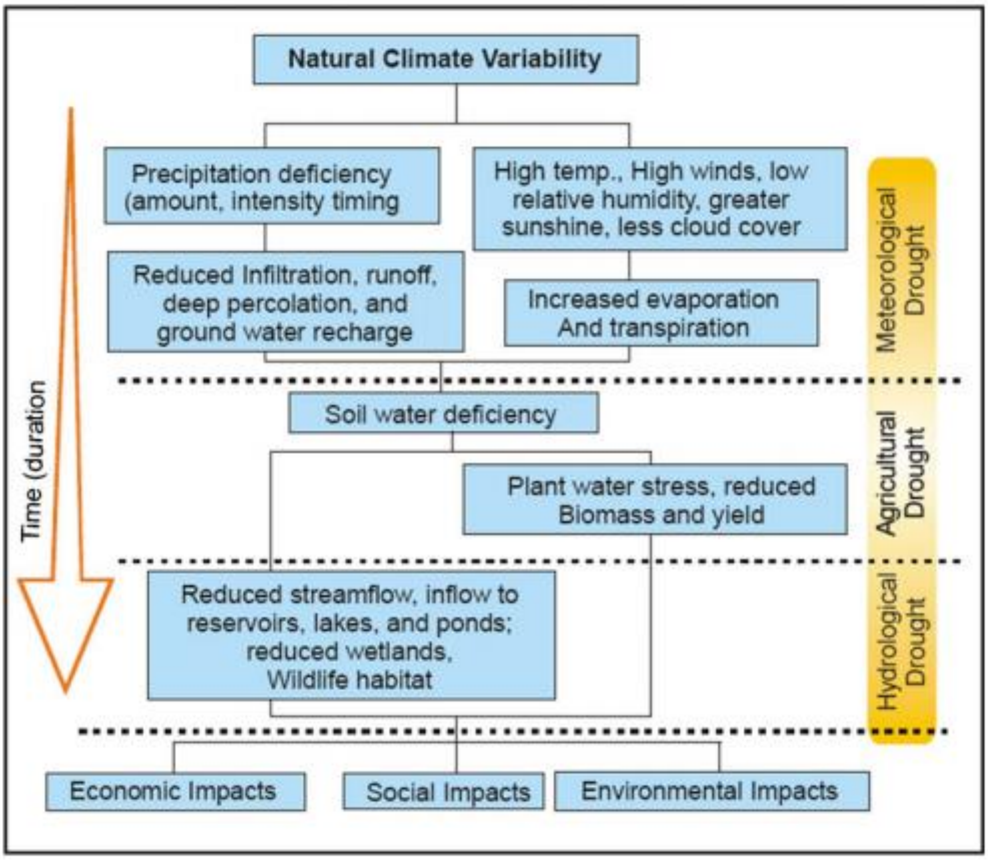

Figure 1.1 Impact of Hydrological, Metrological and Agricultural droughts (Source: National Drought Mitigation Centre)

1.4.2 Environmental Impacts

Drought impacts on the environment can be interpreted by evaluating the loss in green cover, loss of bio-diversity, drying up of wetlands further resulting in restriction on coming migratory birds, loss of various species and extreme drying up of land which leads to cracking and disintegration of soil. If all the above-mentioned impacts continue for a long period then it can pose even bigger challenges.

1.4.3 Impact on society

Drought has huge impacts on society during the time period through which it lasts and also after it. Lack of harvests, increasing loans which result in debts, bring about suicides of farmers which is a major cause of concern in India. Hence, it causes loss of human lives due to hunger and starvation. Water clashes are deemed to happen during drought. All of this can lead to dissatisfaction with the Government in terms of its policies and actions. Drought is known to hit the rural and poor people in some way or other hence, it is a major concern for a country like India where still majority of population is rural poor.

1.5 Droughts in UP

The region of Bundelkhand has faced severe famines and droughts for many periods in its history. It observed "The Panic Famine" of 1873-74. The Indian famine of 1896–1897 initiated in the region during the start of 1895 and escalated to other parts of the country. Central Provinces, the United Provinces, Berar regions of Madras and Bombay presidencies. It also affected Hissar in Punjab, princely states of Central India Agency, Rajputana and Hyderabad. Bundelkhand Region saw drought in the autumn of 1895 due to poor summer-monsoon rains. When the winter monsoon failed as well, the provincial government declared a famine early in 1896. As per the report on drought mitigation strategies for M.P. and U.P. Bundelkhand by the Inter-ministerial Central Team headed by Dr. J. S. Samra, Bundelkhand faced a severe drought event every 15 years in 18th and 19th centuries, the drought amplified by up-to two-three times during the period 1967 to 1993. Severe Drought which resulted in cholera epidemic was observed in Bombay and Bundelkhand Province for many years. However, drought related mortality is not known for the region. The region used to have dense forest cover previously but contrasting times have occurred and it is only left with undulating terrain devoid of vegetation.

Sadly, this region which used to have rich bio-diversity and forest is now amongst the most backward areas of the country. Excluding Jhansi and Sagar districts, 50% of workers in the region are involved in cultivation, farming many of them work as labourers, depicting a higher dependence on land farming activities comparing to the other rural parts of the country. Erratic industrialization has led to very less urbanization. Harsh living conditions prevail particularly for the rural poor who rely mainly on income through agricultural for survival, and are hence most affected due to drought and failure in crops and loss of income. As per the Tendulkar Committee Report 2009 estimations for poverty and HDR 2004- 05 with frequent drought and agricultural failures, poverty levels increased in rural areas with majority of farmers depending on rains for irrigation. There is not adequate supply of water in the region which other-wise has 40% irrigated area. Continuous monsoon failures have sternly affected water availability in rivers and streams. The ever-decreasing surface water and depleting ground water has had adverse effects on drinking water for humans and animals. The flora and fauna have also seen a major decline.

The region has seen high level of migration to other parts due to recurring droughts and depletion of resources. Every year the people of this area have to face utter shortage of water due to monsoon failures. The problem has also affected the urban areas. Water costs have seen a rise and it is now regarded more as a product than resource. Majority of the urban municipal authorities provide water in the urban areas only twice or thrice a week. During the 2002-03 drought, all the 6 and 3 districts of Madhya Pradesh and Uttar Pradesh region of Bundelkhand were affected respectively. During the last ten years there has been persistent occurrence of drought in most the region with huge rainfall deficits. In the Uttar Pradesh regions of Bundelkhand, drought became apparent from 2005 with almost 25% deficiency in rainfall during monsoon. The deficit raised to around 45% in 2006-07 and 55% in 2007-08, resulting in severe (metrological) drought events in Banda, Jhansi and Chitrakoot districts.

Drought influenced almost every districts of Uttar Pradesh Bundelkhand between 2004 and 2007. During the three-year period 2005-2007, hydrological drought or less availability of water was obvious from the level of water in surface water reservoirs – the levels of empty reservoirs dropped abruptly from 28% to 64% in U. P., demonstrating large insufficiency in the supply of water. Seventy percent of the Ponds, tanks, bore-holes and dug-up wells saw huge decline in water levels. Five districts of U.P. were affected by drought during 2009 (Drought Management Division, Ministry of Agriculture, 2009).

1.6 Remote sensing for droughts

Assessment and monitoring of drought using GIS and Remote Sensing depends on various factors which may cause drought and affect it. Based on the contributory factors, drought can be grouped under as Meteorological, Hydrological and Agricultural droughts. A wide-ranging analysis of drought definitions by World Meteorological Organization revealed that droughts are classified based on:

(i) The precipitation in the region,
(ii) Rainfall combination and anomaly with temperature, evapotranspiration
(iii) The moisture present in soil and crop condition,
(iv) Climate conditions and history and effect of climate indices on rainfall

The identification, observation, and reduction of impact of disasters involve attaining continuous and appropriate statistics and data that are not collected in an efficient manner.

Remote sensing systems make it plausible to gather and dispense information continuously and quickly over extensive areas using sensors functioning in various spectral bands, fixed on aircraft and satellites. A satellite orbiting the Earth, is capable in exploring all of the surface in some days and again perform the examination of the same area at periodic intervals whereas an airplane is able to perform thorough examination of a smaller area, if required.

During the past thirty years, developments in the areas of remote sensing (RS) and GIS and have helped the process of analysis of drought risk. Most of the data needed for drought risk assessment include spatial component and changes with time. Hence, using GIS and RS has gained importance. It is obvious that GIS plays a significant assessing drought risk because of the non-one-dimensional nature of natural catastrophes. The benefit of GIS in risk analysis is that creates a conception of hazard through images and also produces potential to analyse the images to evaluate the likely harm caused by drought hazard. Drought risk assessment requires updated and correct data on the terrain and land use. The remotely sensed data from satellites and airplanes generally are the only source of information for extensive areas at decent costs (Wipulanusat et al. 2009). A link can be established between a weather station and GIS so that it keeps receiving meteorological information entered straight into GIS, and then this data is stored and assessed by the system in its data base thoroughly. GIS transforms the data into its codes and analyses the data by different function, it furthers adds drought analysis, early warning feature into drought assessment system (Tao et al. 2011).

1.7 Meteorological drought indices and drought detection

Drought indices are frequently applied to measure the possible danger of incidence and drought severity. They also are used to assess spatial–temporal behaviour. A number of the indices have been used for sensing magnitude and variability of the drought temporally across different areas. Many indices that quantify the amount of precipitation for a given period that which deviates from standards that are established over long periods of time. Some of the extensively used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), and Surface Water Supply Index (SWSI).

I. Palmer Drought Severity Index (PDSI)

PDSI was developed by Palmer (1965) with the aim to measure the cumulative departure in surface water balance. It uses past and present moisture data and potential evapo-transpiration, and converts it into a hydrological system. The soil moisture is calculated by dual-layer and bucket-type prototype. The PDSI is a consistent measure which lies in the range of −10 (dry) to +10 (wet), the values less than −3 depict severe to extreme drought. Further, the PDSI has been extensively in depicting changes in arid regions in past and present climates. Measures to compensate for its problems have directed to new variations in the PDSI, like the self-calibrating PDSI (Sc_PDSI) and PDSI which uses enhanced formulations for evaluating potential evapotranspiration (PE), like the Penman–Monteith equation (PE_pm) in the place of the Thornthwaite equation (PE_th). Basically, four forms of the PDSI are used, to analyse the data, which are the PE_pm (sc_PDSI_pm), PE_pm (PDSI_pm), PDSI with PE_th (PDSI_th) and the sc_PDSI with PE_th (sc_PDSI_th), computed using the available climate data.

In case of meteorological droughts, variation in rainfall is a prime variable in calculating the indices, with the temperature of surface air for taking in consideration evaporation acts as secondary contributors, in a few indices like the PDSI.

II. Crop Moisture Index (CMI)

After the introduction of PDSI, Palmer (1968) presented another index which used weekly average rainfall and temperature for drought assessment known as Crop Moisture Index (CMI). CMI imitates amount of moisture in the short-term through main areas producing crops and is not planned to evaluate longer period drought. CMI recognizes vulnerable areas prone to agricultural droughts. It expresses drought in terms of the amount of computed irregular evapo- transpiration deficits which is the difference between actual and expected weekly evapo-transpiration. The expected weekly ET is the normal value attuned up or down as per the departure of the week’s temperature from the normal value. It is an estimate based on location and is different for different areas showing presence of moisture. Since CMI is developed for short-term requirement of moisture in soil by the crops; hence does not comes in much use during long-term drought monitoring. It isn’t important during initial period of crop growth when it differs from place to place, varying seed germination times and it uses a meteorological method to assess week conditions of the crop and assess moisture settings for the chief crop producing areas. It gives a fast response to the varying circumstances, time and location. It may not be applied when germination of seed is taking place or during a particular season of crop growth. Use of tensiometers for continuous measurement of soil moisture is vital to assess agricultural drought. Water deficit impacts the growth of crop and its development, in one way or another. Moisture levels in crop is very dynamic and influenced by soil and atmospheric microenvironment and is controlled by physiological factors. Crops may bear moderate drought during flowering, and the reduction in yield would produce a decline in crop yield (Nagarajan 2010).

III. Standardized Precipitation Index (SPI)

Even though there are many indices present to compute drought related parameters, assess its severity and classify it, the SPI is the most extensively used index according to Jain(2010). The SPI was computed by Tom McKee, Nolan Doesken, and John Kleist of the Colorado Climatic Centre in 1993. Its computation can be done at different periods and time scales and therefore it can measure water deficiency of different duration. The design of SPI is such that it makes possible to concurrently monitor dry conditions on a specific time scale and wet conditions on a different time-scale. It is calculated by fitting historically available rainfall data to a Gamma probability distribution function for a particular location and period of time, and converting the Gamma distribution to normal distribution with a standard deviation of 1 and a mean of zero. The rainfall difference from the mean of an equal normally distributed function with a mean 0 and a standard deviation of 1 then gives the SPI. The soul premise of the current effort is that using a drought index, such as SPI, leads to more suitable understanding of drought duration, magnitude, and spatial reach in semiarid regions (Karavitis et al. 2011). The SPI is a tool for measuring drought that differs from the PDI. Like the PDI, this index is positive for wet conditions and negative for drought. But the SPI only considers precipitation and is a probability index, while Palmer’s indices uses precipitation, evapotranspiration, and loss due to runoff and are water balance indices.

Table 1.1: SPI based Classification

SPI VALUES	CLASSIFICATION
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

IV. Normalized Difference Vegetation Index (NDVI)

NDVI is an estimate of the greenery or vigour of vegetation. The computation is done by using known radiometric characteristics of plants, using radiation in the visible (red) and near-infrared (NIR) regions. NDVI is determined as:

NDVI= (NIR-RED)/(NIR+RED)

Where NIR and RED are the reflectance in the near infrared and red bands. NDVI is a good indicator of green biomass, leaf area index, and patterns of production because, the visible portion of the spectrum (0.4–0.7 mm) contains most of the red wavelengths when sunlight strikes a plant, chlorophyll present in the plants absorbs the radiations, while a majority of NIR radiation (0.7–1.1 mm) is reflected by the cell structure. Much of the red light is absorbed by healthy plants and they reflect most NIR radiation. Normally, if reflected radiation lies in the NIR wavelengths as compared to the wavelengths in visible region, it would possibly indicate good and dense vegetation cover. If the measure of reflected radiation in visible region differs to the measure of reflected radiation in infrared region by only small amount then the vegetation will be unhealthy. But it may also because of the non-vegetated surfaces. The range of NDVI is from −1 to +1, with approximately zero depicting no green vegetation and values near +1 representing the high vegetation density.

V. Vegetation Condition Index (VCI)

The VCI is a pixel-wise normalization of NDVI that is beneficial for making relative valuations (e.g., pixel-specific) of changes in the NDVI signal by filtering out the influence of local geographic resources to the spatial variability of NDVI (Quiring and Ganesh 2010). VCI is an indicator of the vegetation cover status as a function of NDVI maxima and minima seen for a given ecosystem over a large period of time as per Jain

(2010). It normalises the NDVI and permit comparing various environments. It is used to separate the short-term climate signal from the long-term ecological signal, and, in this sense, it indicates condition of water scarcity better than NDVI. VCI importance lies in its strong inter-relations with vegetation index and the strength and extent of vegetation. VCI is computed as as:

$$VCIj = (NDVIj - NDVImin)/(NDVImax + NDVImin) * 100$$

Where NDVI, NDVImax, and NDVImin are monthly NDVI, multi-year maximum NDVI, and multi-year minimum NDVI, respectively, for each grid cell. A change from zero to hundred is seen is VCI confirming to the vegetation from extremely unfavourable to optimum. During a month which sees extreme dryness, there prevail poor vegetation conditions and VCI value is close to zero. Good vegetation conditions are depicted by a VCI value of around 50, VCI is close to 100 at optimal condition of vegetation. Further, the VCI values show the progression of vegetation and its faintness according to the weather conditions.

CHAPTER-2

LITERATURE REVIEW

Drought is a natural disaster described perfectly by combining the various hydrological and climatological parameters. A relation among these parameters is vital and required in order to prepare a management and mitigation plan for drought events. The climate, weather, precipitation, temperatures, winds, low relative humidity, rain characteristics, which includes distribution of rainy days during the agricultural season, rainfall intensity, and duration play an important role in the drought. There lies a dilemma between a heat wave and a drought, and the difference is highlighted between heat wave and drought, keeping in mind that a typical time scale related with a heat wave and drought. A heat wave generally lasts for a shorter duration of time while a drought is a long-term phenomenon. The heat wave and drought occurring together can have serious social and economic impacts. (Belal, 2014).

Drought assessment is significant because of its socio-economic effects nation-wide. Wide-ranging of technical and scientific papers are available on droughts for drought definition, methods of analysis and management actions. Literature reviews are beneficial to attain knowledge and to notice the implication of the existing magnitude of the problem to be dealt with. (Krishna, 2013).

The IMD method for drought identification is easy and is generally applied, it provides a primary info about the drought situation of a region. The method involves, evaluation of drought based on percentage deficit of rainfall from the long-term average normal rainfall. Herbst et al. (1996) developed a method for estimating drought intensity by using monthly rainfall. The method finds the intensity and time period of droughts. Subramanyam (1964) gave a technique for assessing severity of meteorological drought, it relied on the idea of Aridity Index (Ia). The aridity index is the ratio of yearly water deficiency and yearly water need for evapo-transpiration, as percentage.

The standardized precipitation index (SPI) has attained a greater importance for evaluation, finding the intensity, severity and spatial extent of droughts. The important benefit of the SPI, as compared to other indices, is that the SPI permits both determination and evaluation of drought of varying intensities at different time scales. In a study carried out by N. R. Patel, P. Chopra, (2007) monthly time series of rainfall data (1981–2003) from 160 points was analysed to compute SPI, mainly at 3-month time scales. This 3-month SPI was interpolated to demonstrate severity and spatial extent of meteorological drought.

A similar study carried out by C. Bhuiyan, R.P. Singh, F.N. Kogan (2005) in the hard-rock hilly Aravalli terrain of Rajasthan which suffers with frequent drought due to poor and delayed monsoon, unusually high summer-temperature and inadequate water resources, thorough assessment of meteorological and hydrological data of the Aravalli area was done for the years 1982–2002. Standardised Precipitation Index (SPI) was implemented to measure the rainfall deficit. Standardised Water-Level Index (SWI) was found to carry out ground-water recharge-deficit studies. Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) and Vegetation Health Index (VHI) were found by analysing NDVI taken from data of NOAA AVHRR satellite. Complete analyses of spatial and temporal drought extent during monsoonal and non-monsoonal seasons was done through drought index maps produced in ArcMap in GIS. Investigation and understanding of these maps show that negative SPI anomalies do not always resemble drought like situation.

Aswathi P. V., Bhaskar R. Nikam, Arpit Chouksey, S. P. Aggarwal (2017) monitored meteorological drought in Maharashtra using remote sensing. SPI and EDI were used to carry out drought analysis and classification. The magnitude and occurrence of meteorological drought analysed through SPI from 1901 to 2015. It was found that SPI has restricted validity. Hence, monthly drought is well observed using EDI. The monthly and sub-monthly drought mapped using SPI and EDI, respectively were then compared and evaluated. It was concluded that EDI serves as a better indicator to monitor sub-monthly droughts. The area under drought as calculated by different agricultural drought indices compared with that of the EDI, it was found that the results of SASI were similar as the results of EDI.

In their study, Moumita Palchaudhuri, Sujata Biswas (2013) studied the severity and spatial pattern of meteorological drought Puruliya District, West Bengal, India using multi-temporal SPI. Daily gridded data for the period 1971-2005 from 4 rainfall stations surrounding the study area were collected from IMD, Pune. Geographic Information System (GIS) was used to produce drought extent maps for the different time period. It was found that in 1993 Station 3 showed maximum value of SPI hence was affected by extreme drought, the central region experienced mild and moderate droughts. Severe droughts and extreme droughts occurred in the northwest, northeast and southern regions of the districts.

Dipanwita Dutta ArnabKundu used, NOAA-AVHRR NDVI for evaluating agricultural drought using Vegetation Condition Index. VCI was computed for all the regions of Rajasthan by analyzing the long term NDVI images. The results revealed the incidence of drought related effects on crops in the year 2002. The normal values of VCI and drought year were compared with precipitation and evapo-transpiration based Rainfall Anomaly Index, Yield Anomaly Index and Standard Precipitation Index and a relation was established between them. The coefficient of correlation between VCI and yield of major rainfed crops ($r > 0.75$) also braced the effectiveness of this remote sensing derived index for evaluating agricultural drought.

Md. Rejaur Rahman Habibah Lateh assessed and analysed meteorological drought features of Bangladesh using precipitation, standardized precipitation index (SPI) and geographic information system (GIS). Using monthly values of rainfall SPI was derived and drought was classified. To map the spatial extent of drought in the country interpolation using IDW technique was used and maps were generated in GIS environment. The occurrence of drought with its category of impact were analysed based on 3-month and 6-month SPI. For mapping of drought hazard, a drought hazard index was figured from positions using analytical hierarchy process, weighted sum method and drought occurrence with different magnitudes at different scale of time. Interpolation of the index values was done and it was classified under four groups based on severity.

Rizqi I. Sholihaha, Bambang H used satellite-borne remote sensing data for monitoring drought extent in about 184.486 ha of Subang and Karawang regions of Indonesia. Vegetation Health Index (VHI), a vegetative drought indicex based on remote sensing data, was analysed in this case using long term sequence of 2000, 2005, 2010, and 2015 dry season Landsat data. VHI organizes overall vegetation health, which in turn is appropriate to show agricultural drought extent. It measures either moisture vegetation/vegetation condition (VCI) or thermal condition of vegetation (TCI). Both indices were the derivatives from Normalized Difference Vegetation Index (NDVI) and land surface temperature (LST) data respectively. The results showed that VHI decreased more than 50 percent, from 30.86 in 2000 to 14.66 in 2015. This figure showed drought extent intensified in research area, from mild drought to severe drought. The severity was primarily triggered by the rising LST from 27°C in 2000 to 40°C in 2015. Moreover, there was a decreasing tendency of NDVI values in recent years, leading agricultural fields more susceptible to drought.

In India, Gujarat is a state that usually have to deal with drought once every three years. The monitoring of drought through different drought indices therefore has great potential for mitigating future droughts. The Standard Precipitation Index (SPI) is applied for drought assessment in the Rajkot District, Gujarat, India, by Rahul Rachchh, Neelkanth Bhatt. The standard precipitation index was calculated for time scales of 3 months and 6 months to analyse the effect of water scarcity on the various natural resources. The SPI value provides data about the characteristics of the drought, i.e. the severity, frequency and spatial extent of the Rajkot district. The monthly rainfall data from 5 rain stations called Morbi, Rajkot, Lodhika, Jasdan, Gondal, were collected in the period 1981-2010 to compute the Standard Precipitation Index (SPI). Results suggested that the Rajkot district had seen a severe drought in 1987. It is assessed, once every two years there is a drought in the Rajkot district. It can also be said that since 2005 the Rajkot district has not experienced a major drought.

In a study is carried out in Gubbi Taluk of Karnataka by P.H. Shiva Prakash, P.K. Garg and S.K. Ghosh to prepare a drought severity map in GIS by combining 18 constraints in GIS which cause drought. LISS III images for 1996, 1999 and 2001 were used to identify land-use/landcover. The method comprised of formation of a spatial database and its combination in GIS by computing an appropriate rating and ranking system to create maps depicting severity of droughts

Aditi Sharma (2006) examined the drought on the basis of large historical and meteorological data that involved a complex mutual relationship between the data. The extraction of vital information from these data files required an automatic and competent way. Data extraction and association rule and independent component analysis methods (ICA) were used to extract spatial and temporal drought patterns. The association rule for both the SPI and the VCI was used as parameters in input when creating the rules. Interpolation techniques were used to spatially picture extent of the hazard. The research showed that inverse distance weighting (IDW) was the most effective method because it produced the minimum differences from actual values. It was found that precipitation /

SPI and NDVI were having positive and strong correlations in the north and south regions of Karnataka plateau, but due to forests and land cover classes with vacant land, the correlations were negative in the coastal waters of Karnataka

Parul Chopra (2006) studied drought risk estimation using correlation and regression techniques between SPI (standardized precipitation index) and NDVI (standardized difference vegetation index), precipitation anomalies, and food grain unevenness. SPI values were interpolated to obtain spatial extent maps of meteorological drought. The trend in food yields was traced, and an equivalent NDVI threshold was established for obtaining the risk of agricultural drought. Similarly, rain anomaly and NDVI were correlated, and the IMD threshold for meteorological drought was used to determine the risk of meteorological drought.

Hence, based on the above literature review it can be concluded that there are a number of indices which help in identifying drought and assessing its extent. SPI being easy to compute is thus used in this study to help analyse the drought condition in some parts of Uttar Pradesh.

CHAPTER-3

STUDY AREA AND METHODOLOGY

3.1 Jhansi

Jhansi is a historic city in northern India, situated in the Bundelkhand region on the banks of the River Pushpavati, in Uttar Pradesh between North longitudes 24°11´ and 25°57´and East latitudes 78°10´and 79°25´.

The climate of Jhansi is somewhat extreme with temperatures dropping to 1°C in winter and it can rise up-to 50^{o}C in summers. Generally, the temperature during winter lies in 6^{o} C to 21^{o} C. Whereas in summer the mercury lies in the range of 24^{o} C to 45 ^{o} C. Monsoon season starts in June. The intensity of rains weaken in September monsoon ends in the last week of September. It has a normal rainfall of about 93cm.

3.2 Hamirpur

Hamirpur district lies between 25.07^{o}N and 26.07^{o}N latitude and 79.17^{o}E and 80.021^{o}E longitude. Hamirpur is bounded by districts Kanpur, Jalaun and Fatehpur in north, Mahoba in south, Banda in east and districts of Jhansi and Jalaun on the West.

May and beginning of June are generally the hottest period of the year and maximum temperature in May is around 43^{o} C and minimum around 28^{o}C, the average annual rainfall is about 91cm.

3.3 Auraiya

The district of Auraiya is situated in the southwestern part of Uttar Pradesh 26^{o}21"N and 27 ^{o} 01"N latitude and 78 ^{o}45" and 79 ^{o} 45" longitude. It is bounded on the north by the districts of Kannauj, in the west by Gwalior and Etawah. In the east it is surrounded by Kanpur Dehat, and Jalaun is situated to its south. The total area is calculated to be around 2054 km^{2}.

The average annual rainfall in the district is around 79 cm. About 85% of the annual normal rainfall in the district is received during the south west monsoon months from June to September, August being the rainiest month. In the month of May maximum temperature reaches to 45°C and the minimum around 25°C. During January the maximum and minimum temperature reaches 24^{o}C and 9^{o}C respectively making it the coldest month.

3.4 Banda

The district is located in the Chitrakutdham Division of Uttar Pradesh with its headquarters at Banda and lies between 24^{o} 53'N and 25^{o} 55' N latitude and 80^{o}07'E and 81^{o} 34' E longitude. It is surrounded by Fatehpur district in north, the Chitrakut lies in the east, Hamirpur and Mahoba in the west and in south by Satna, Panna, and Chhatarapur. There are mainly three rivers in the district namely Ken, Baghain and Yamuna.

In Banda, the climate is warm and temperate. The winters are rainier than the summers in Banda. The temperature here averages 26.3 °C. Precipitation here averages 924 mm.

3.5 Lalitpur

Lalitpur is a district of Uttar Pradesh State. It was formed in 1974 from Jhansi. It is surrounded by Jhansi and Madhya Pradesh. It lies between 24°11'N and 25°14'N latitude and 78°10'E and 79°0'E longitude and is surrounded by Jhansi district in the north, Sagar and Tikamgarh in the east and Guna district in south. It is separated by Betwa river in the west. The area of the district is around 5,039 sq. km.

The climate here is fairly mild, and generally warm and temperate ranges between 42^{o}C to 26^{o}C. In winter, there is much more rainfall than in the summer. The average annual temperature is about 25.7 °C. Precipitation here averages 112 cm.

3.6 Jalaun

Jalaun is a district situated in Uttar Pradesh between 26.15°N longitude and 79.35°E latitude. It is a part of Jhansi Division. The area of Jalaun is 4565 km^2. It lies entirely within the level plain of Bundelkhand, and is surrounded by the Yamuna River, on the north, and its tributaries Betwa river, on the south, and the Pahuj, on the west. The central area is hence encapsulated as a land almost having no trees and devoid of vegetation only having a few villages.

Jalaun has been facing severe drought for the last four years with the average rainfall around 399 mm which is far less than the average of about 800 mm.

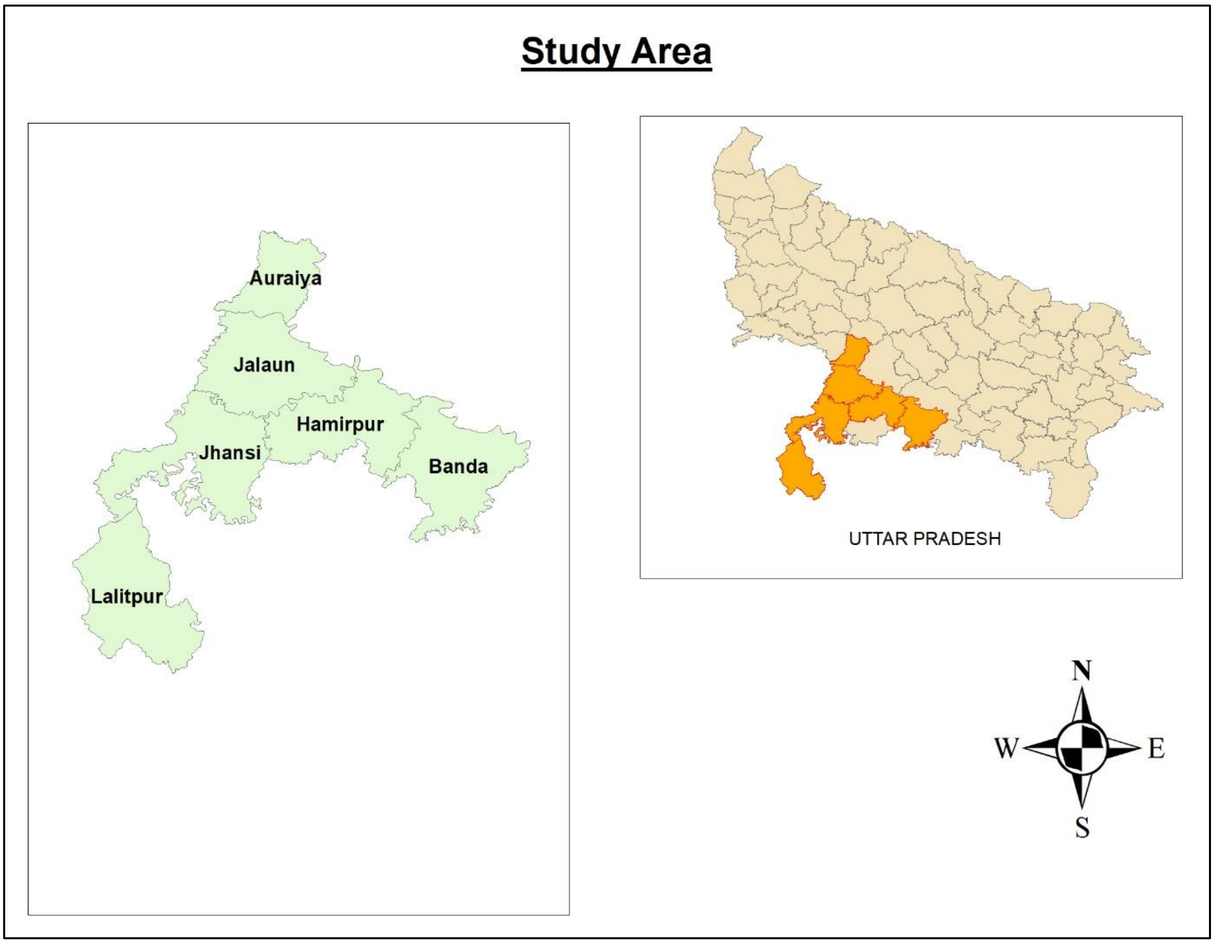

Figure 3.1: Study area

3.7 Collection of data

1. For the selected six districts of Uttar Pradesh the rain fall data is monthly rainfall data for 30 years from 1988-2018 has been obtained from Government of India authorised website www.data.gov.in .
2. The annual average rainfall data is obtained from Indian Metrological Department website.
3. The shape file to be used in GIS software are obtained from the website https://diva-gis.org .
4. The latitude and longitude for each district is taken from google maps.

3.8 Software and techniques

1. Microsoft excel

   The Microsoft excel software is a very handy tool built to compile, compute, represent, and analyse large datasets.

In this project Microsoft excel has been used to compile rainfall data, calculate total precipitation, plot histograms and scatter plots etc.

2. DrinC

   DrinC (**Dr**ought **In**dices **C**alculator) software provides a user-friendly interface for computing drought indices, suitable for meteorological, hydrological and agricultural drought analysis. The following drought indices are presently calculated in DrinC:

   - Standardised Precipitation Index (SPI)
   - Reconnaissance Drought Index (RDI)
   - Streamflow Drought Index (SDI)
   - Agricultural Standardised Precipitation Index (aSPI)
   - Effective Reconnaissance Drought Index (eRDI)

   The above indices have comparatively small data requirements, while their outcomes can be easily understood and used in strategic planning and operation. The calculation process is performed through a graphical user interface and the available options can be adjusted for fitting drought analysis objectives of any particular case. Furthermore, DrinC includes additional tools, such as the estimation of potential evapotranspiration (PET) through temperature-based methods and the assessment of the aridity index.

   The DrinC software along with Excel is used to calculate SPI values.

3. Arc GIS

   ArcGIS version 10.4 is a state-of-art GIS software platform established by ESRI. The software package can be used in a large space of general yet definite GIS applications and may be drawn-out simply. Geospatial evaluation and hazard mapping of drought can be the initiation for any area and, to decrease the effects of drought, a complete drought hazard mitigation plan can be framed for the study area.

   The Arc GIS is used to represent the spatial extent of drought in the region during different years when drought occurred.

3.9 Analysis of data

The data obtained from various sources is compiled in Excel spreadsheets and analysed accordingly. A large number of data sets needs to be evaluated in order to find the true effect of drought in the region.

The drought was evaluated by the SPI and analysed using severity and frequency of occurrence. Precipitation data is needed, for computation of SPI hence, the monthly rainfall time series data for the period of 1988-2018 was obtained and analysed.

To assess and analyse meteorological drought, the SPI method given by Mckee et al. (1993, 1995) was used. A thorough explanation of the SPI is provided in Guttman (1998, 1999), Hayes et al. (1999) and Lloyd Hughes and Saunders (2002). SPI permits for the determine a drought condition at a given time scale of interest with historical data (>30 years). Theoretically, SPI is analogous to a Z score, but is not the difference from the mean and divided by the standard deviation. It is a probability index where the probability of observed precipitation is converted into an index for any time scale (3-, 6-, 12-, 24- and 48-month time scales). The description for calculating SPI is given in Appendix.

The annual average rainfall for all the districts as shown in Table 3.1 has been used and monthly averages are calculated in excel. The rainfall deviation from normal was calculated using the formula:

$$\text{Percent Rainfall Deviation} = \frac{\text{Actual rainfall} - \text{Normal rainfall}}{\text{Normal rainfall}} \text{ X } 100$$

which expresses the actual rainfall as percent deviation from normal. The normal rainfall is the average of the long-term actual rainfall. The severity of drought is then classified based on percent rainfall deviation as per National Disaster Management Authority Manual for drought management as shown in Table 3.2.

The analysis of the current study is also laying emphasis on assessing the sensitivity of SPI to actual rainfall and the deviation of rainfall from normal and the subsequent trends of SPI in normal years as well as drought years.

The Percent Rainfall Deviation is compared with 3 Month SPI (April-June) and 3 Month SPI (July-Sep) to evaluate the different drought situation classified by both the methods.

Table 3.1: Average Normal Precipitation Over Districts

District Normal Rainfall (mm)						
	Jhansi	Banda	Auraiya	Hamirpur	Lalitpur	Jalaun
January	17	20	23	24	27	21
February	8	10	7	8	4	5
March	8	8	9	9	10	9
April	2	1	3	2	3	2
May	5	5	6	3	5	6
June	94	62	51	63	82	66
July	287	264	237	254	389	232
August	309	356	283	336	377	333
September	177	140	145	158	182	165
October	35	50	70	47	34	62
November	5	3	1	1	5	2
December	6	5	10	11	10	9
Annual Normal Rainfall	955	924	835	916	1128	912

Table 3.2: Drought Classification Based on Rainfall Deviation

Percent Rainfall Deviation	Drought Condition
25% or less	Normal
25% - 50%	Moderate
50% or more	Severe

3.10 Presentation of data

The data available is assessed, compiled and presented such that analysis of results can be done easily. For this purpose, the intensity of drought from 1988 to 2018 is interpreted using SPI values is represented using bar charts for each district.

Scatter plots for 3-month SPI versus deviation from normal rainfall for last ten years were plotted for positive and negative rainfall deviation to understand sensitivity of SPI.

To represent spatial extent of drought using SPI values maps were plotted using Arc GIS. The Inverse Distance weighted (IDW) interpolation technique was used to map the spatial extent of drought features from the data of a location. This interpolation method is intuitive and simple. Also, it is easy to compute the interpolated values in short time. Thus, IDW is an extensively applied technique to interpolate the point data and figure the spatial extent.

CHAPTER-4

RESULTS AND DISSCUSSIONS

4.1 Drought Classification Using SPI

The results and discussions in this study, are based on the 3-month SPI (April-May-June) and 3-month SPI (July-Aug-Sept) used as a seasonal drought index to represent short-term drought during the summer season and the 6-month SPI (Oct-Mar) is used for intermediate-term drought during the winter season in the region. The values of 3-Month SPI (April-May), 3-Month ((July-Aug-Sept), and the 6-month SPI (Oct-Mar) are represented in Tables: A, D, G, J, M, P in the appendix section.

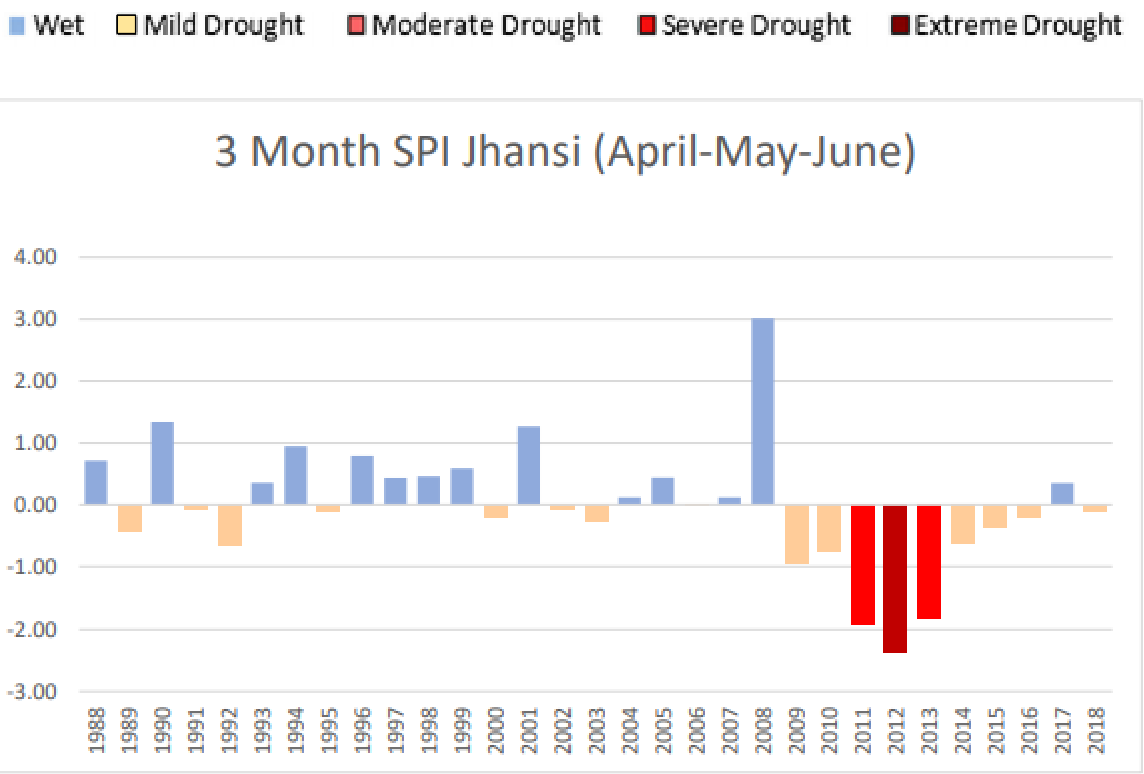

Figure 4.1: 3-Month SPI(April-June) based drought distribution in Jhansi

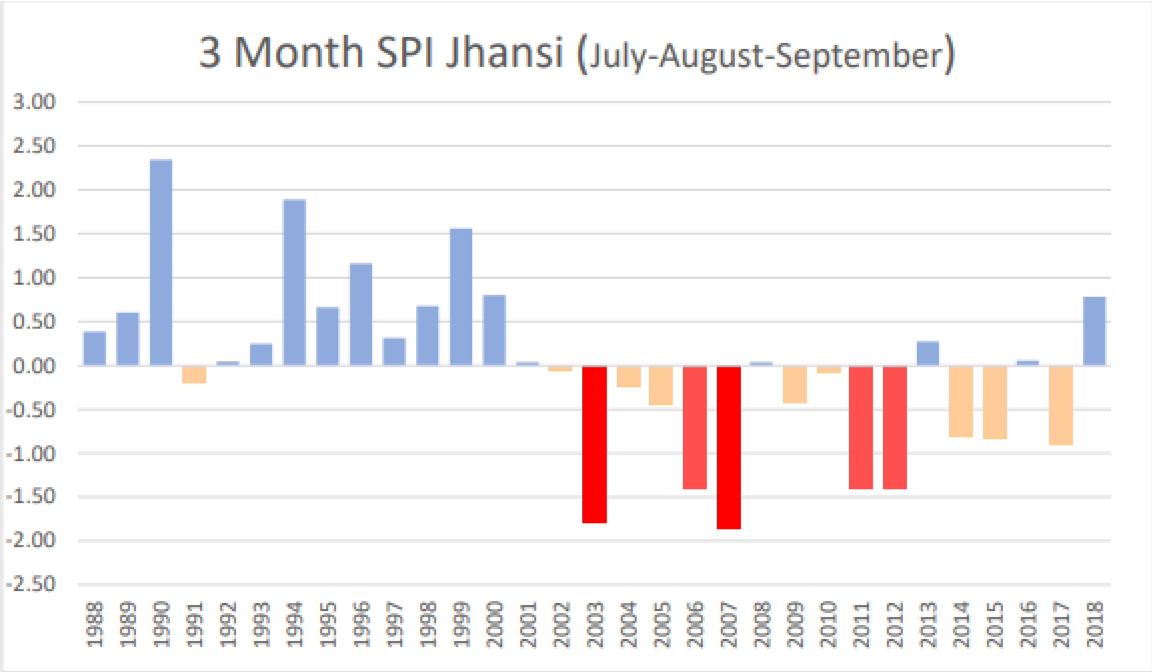

Figure 4.2: 3-Month SPI(July-September) based drought distribution in Jhansi

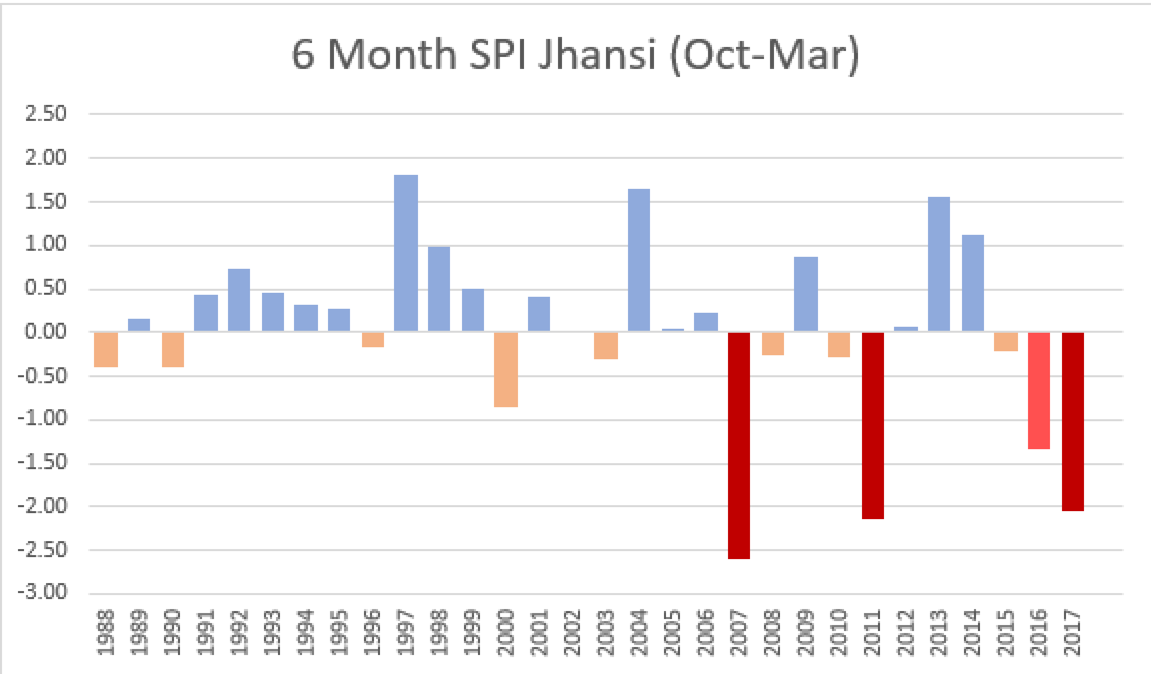

Figure 4.3: 6-Month SPI(Oct-Mar) based drought distribution in Jhansi

In Jhansi it can be seen by the SPI data that during the period of 1988-2018 there occurred a total of 17 drought events and in the last ten years there can be seen a more prominent occurrence of drought as nine of the ten years have seen a drought episode with 2011,2013 being severely hit and 2012 facing extreme drought based on 3-month SPI (April-May-June) values.

A total of 14 drought events during 1988-2018 and 7 in the last ten years with 2003,2007 being severely hit by drought, can be interpreted from 3-month SPI (July-Aug-Sept) values. 12 drought events from the 6-month SPI (Oct-Mar) values during 1988-2018 and 6 during last ten years have been drought hit with 2007,2011 and 2017 experiencing extreme drought episodes. Hence, it can be said that during most of the years in the past thirty years the district of Jhansi has been affected by drought with 2007,2008,2011,2012 and 2013 being the worst affected years as per Table 4.1 and Figure 4.1, 4.2 and 4.3.

Table 4.1: Category wise Drought during 1988-2018 in Jhansi

District	SPI	Year	Drought Category				Total
			Mild	Moderate	Severe	Extreme	
Jhansi	3 Month (April-June)	1988-2000	1989,1991, 1992,1995,2000 (5)				5
		2001-2010	2002, 2003,2006,2009,2010 (5)				5
		2011-2018	2014,2015,2016,2018 (4)		2011,2013 (2)	2012 (1)	7
		Total					17
	3 Month (July-Sept)	1988-2000	1991 (1)				1
		2001-2010	2002,2004, 2005,2009,2010 (5)	2006 (1)	2003,2007 (2)		8
		2011-2018	2014,2015,2017 (3)	2011,2012 (2)			5
		Total					14
	6Month (Oct-Mar)	1988-2000	1988,1989,1990,1996 (4)				4
		2001-2010	2003,2008,2010 (3)			2007 (1)	4
		2011-2018	2015 (1)	2016 (1)		2011,2017 (2)	4
		Total					12

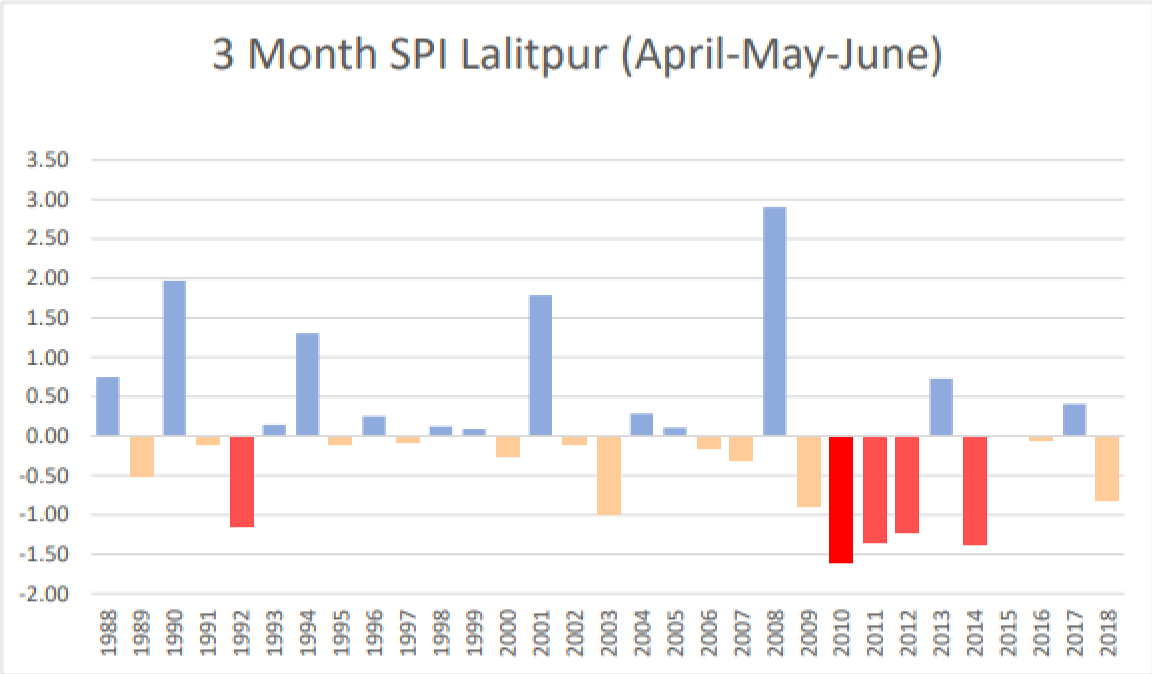

Figure 4.4: 3-Month SPI(April-June) based drought distribution in Lalitpur

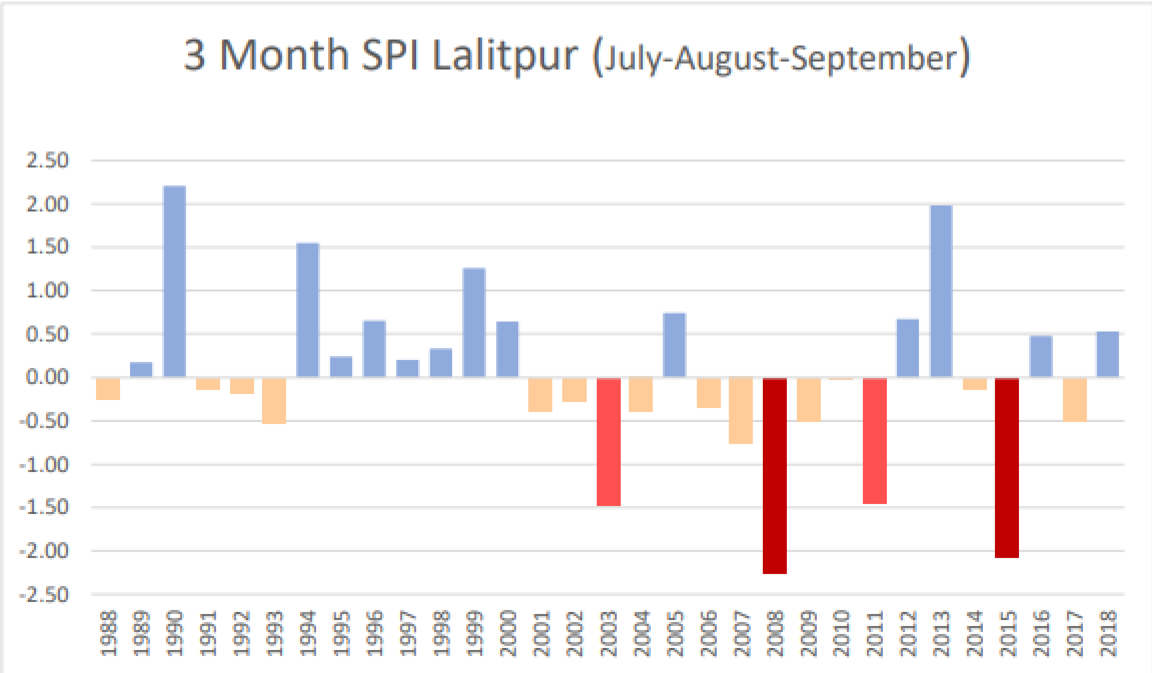

Figure 4.5: 3-Month SPI(July-September) based drought distribution in Lalitpur

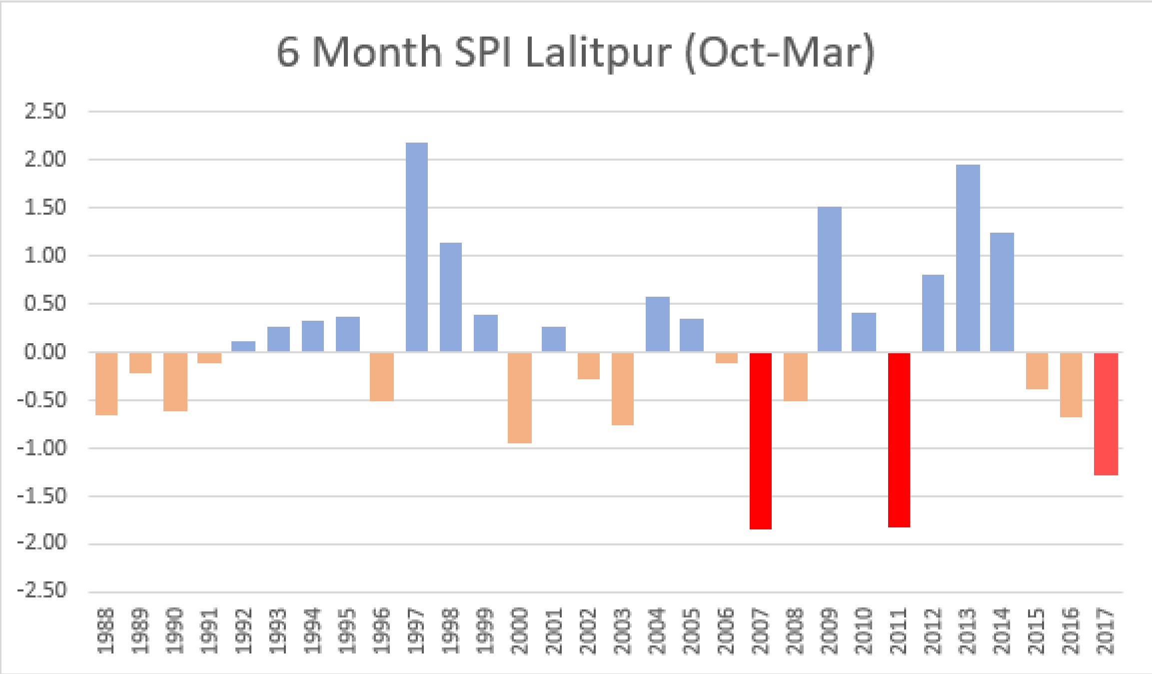

Figure 4.6: 6-Month SPI(Oct-Mar) based drought distribution in Lalitpur

In Lalitpur with the help of SPI data, it can be inferred that during the period of 1988-2018 there occurred a total of 20 drought events and in the last ten years a more prominent occurrence of drought is there with all of the ten years have experiencing droughts of mild, moderate intensities, 2010 and 2011 affected by severe drought and 2012 facing extreme drought based on 3-month SPI (April-May-June) values (Figure 4.4).

A total of 17 drought events during 1988-2018 and 6 in the last ten years with 2015 being severely hit by drought can be interpreted from 3-month SPI (July-Aug-Sept) values. 15 drought events from the 6-month SPI (Oct-Mar) values during 1988-2018 and 5 during last ten years have been drought hit with 2007,2011 experiencing severe drought episodes. Hence, it can be said that during most of the years in the past thirty years Lalitpur has been affected by drought with 2008,2010,2011,2012,2013 and 2015 being the worst affected years as per Table 4.2 and Figure 4.5, 4.6.

Table 4.2: Category wise Drought in Lalitpur (1988-2018)

District	SPI	Year	Drought Category				Total
			Mild	Moderate	Severe	Extreme	
Lalitpur	3 Month (April-June)	1988-2000	1989,1991,1995,1997, 2000 (5)	1992 (1)			6
		2001-2010	2002,2006,2007,2009, (4)	2003 (1)	2010 (1)		6
		2011-2018	2015,2013, 2016,2018 (4)	2012,2014 (2)	2011, (1)	2012 (1)	8
		Total					20
	3 Month (July-Sept)	1988-2000	1988,1991,1992,1993 (4)				4
		2001-2010	2001,2002, 2004,2006,2007, 2009,2010 (7)	2003 (1)		2008 (1)	9
		2011-2018	2014,2017 (2)	2011(1)		2015 (1)	4
		Total					17
	6Month (Oct-Mar)	1988-2000	1988,1989,1990,1991, 1996,2000 (5)				5
		2001-2010	2002,2003,2006, 2008(5)		2007 (1)		6
		2011-2018	2015,2016 (2)	2017 (1)	2011 (1)		4
		Total					15

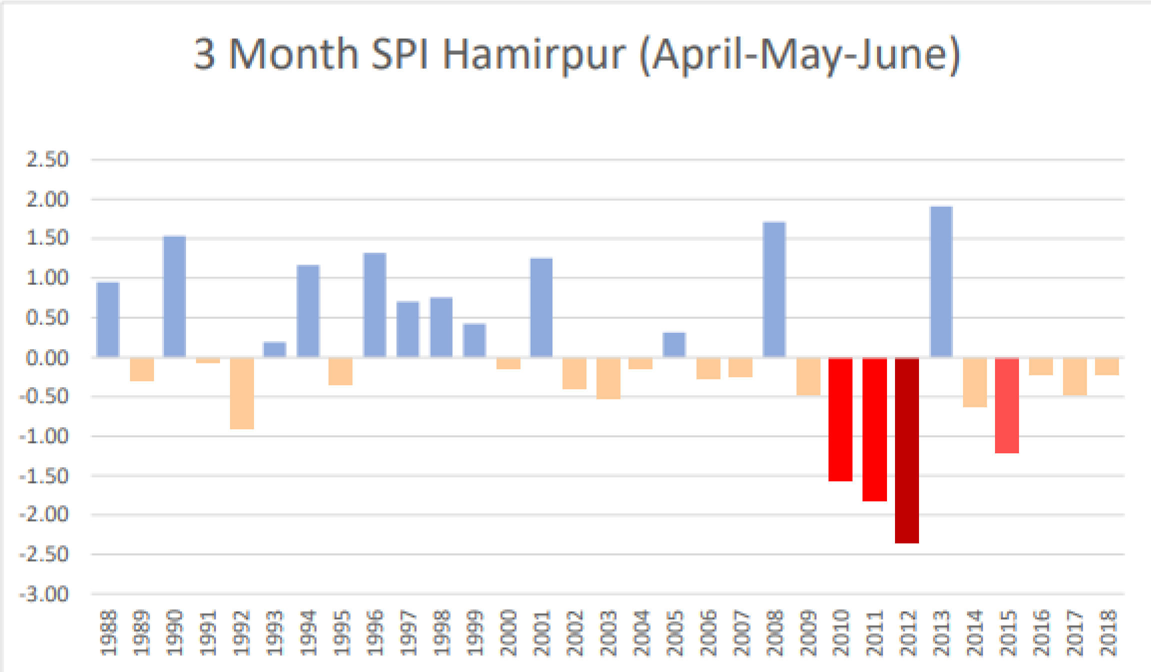

Figure 4.7: 3-Month SPI(April-June) based drought distribution in Hamirpur

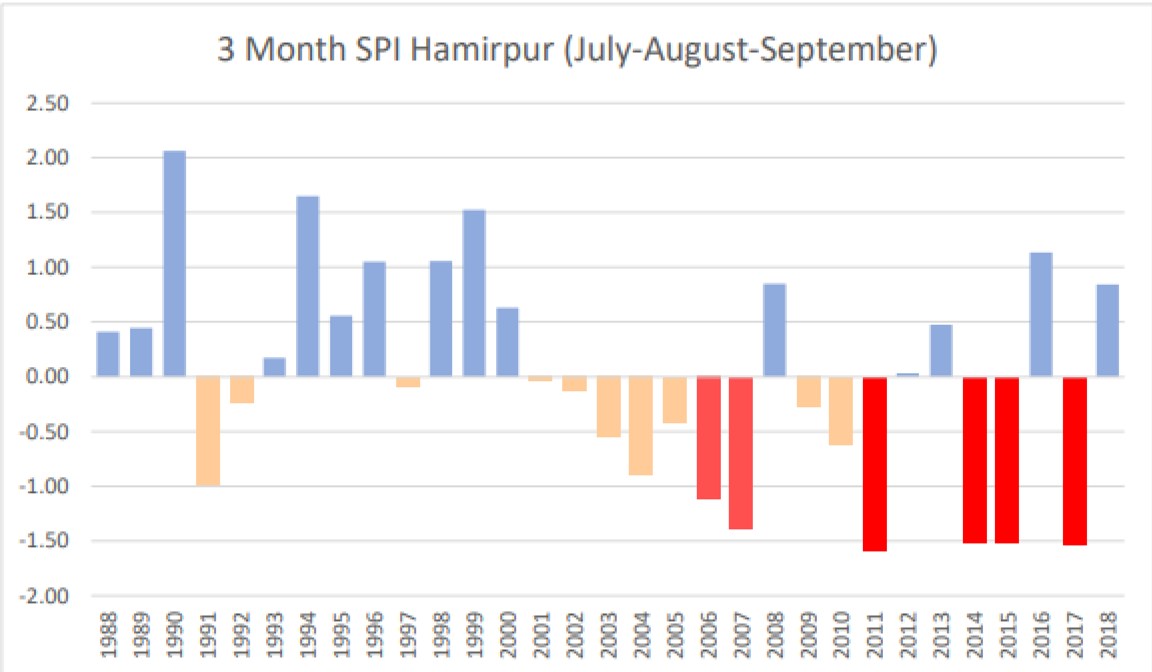

Figure 4.8: 3-Month SPI(July-September) based drought distribution in Hamirpur

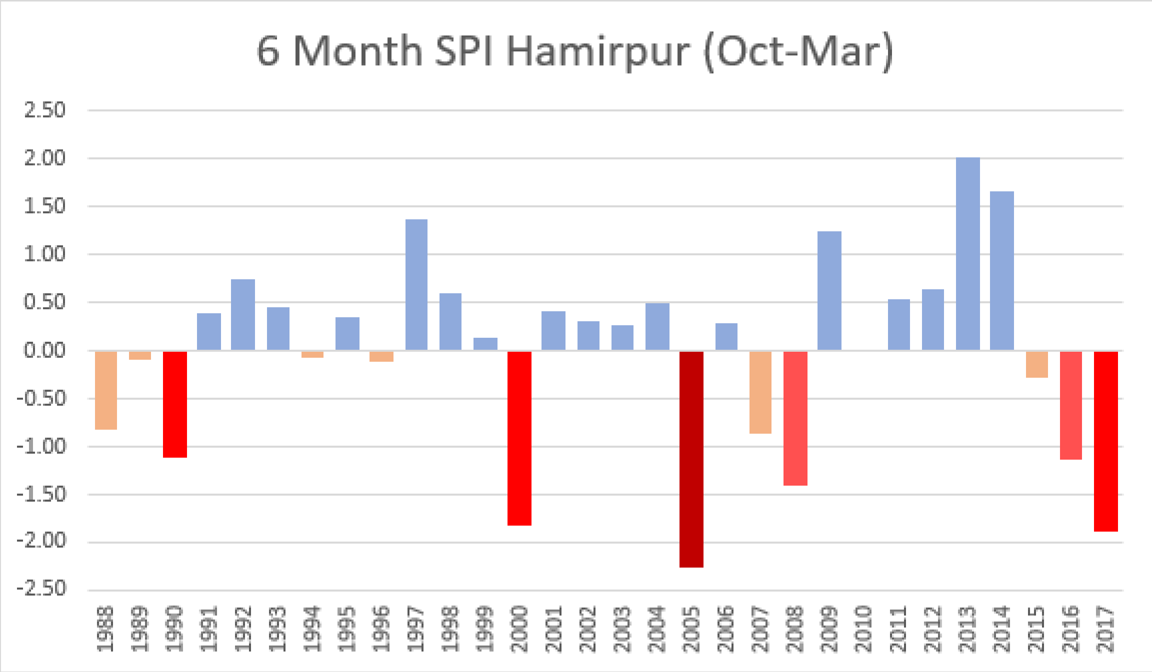

Figure 4.9: 6-Month SPI(Oct-Mar) based drought distribution in Hamirpur

In the case of Hamirpur as can be observed by the SPI data that during the period of 1988-2018 a total of 18 drought events took place and in the last ten years nine of the ten years have seen a drought episode with 2010 and 2011 being severely hit and 2012 facing extreme drought from Figure 4.7 based on 3-month SPI (April-May-June) values.

A total of 16 drought events during 1988-2018 and 6 in the last ten years with 2011,2014,2015 and 2017 are severely hit by drought as can be interpreted from 3-month SPI (July-Aug-Sept) values. 12 drought events from the 6-month SPI (Oct-Mar) values during 1988-2018 and 3 during last ten years have been drought hit with 2006 experiencing extreme drought episode. Hence, it can be said that during most of the years in the past thirty years the district of Hamirpur has been affected by drought with 2010,2011,2012,2014,2015 and 2017 being the worst affected years as per Table 4.3 and Figure 4.8 and 4.9.

Table 4.3: Category wise Drought in Hamirpur (1988-2018)

District	SPI	Year	Drought Category				Total
			Mild	Moderate	Severe	Extreme	
Hamirpur	3 Month (April -June)	1988-2000	1989,1991,1992,2000 (4)				4
		2001-2010	2002,2003,2004, 2006, 2007,2009 (6)		2010 (1)		7
		2011-2018	2014,2016,2017, 2018 (4)	2015 (1)	2011 (1)	2012 (1)	7
		Total					18
	3 Month (July-Sept)	1988-2000	1992,1997 (2)	1991 (1)			3
		2001-2010	2001,2002,2003,2004,2005, 2009,2010 (7)	2006,2007 (2)			9
		2011-2018			2011,2014, 2015,2017 (4)		4
		Total					16
	6 Month (Oct-Mar)	1988-2000	1988,1989,1994,1996 (4)	1990 (1)	2000(1)		6
		2001-2010	2007 (1)	2008 (1)		2005 (1)	3
		2011-2018	2015 (1)	2016 (1)	2017 (1)		3
		Total					12

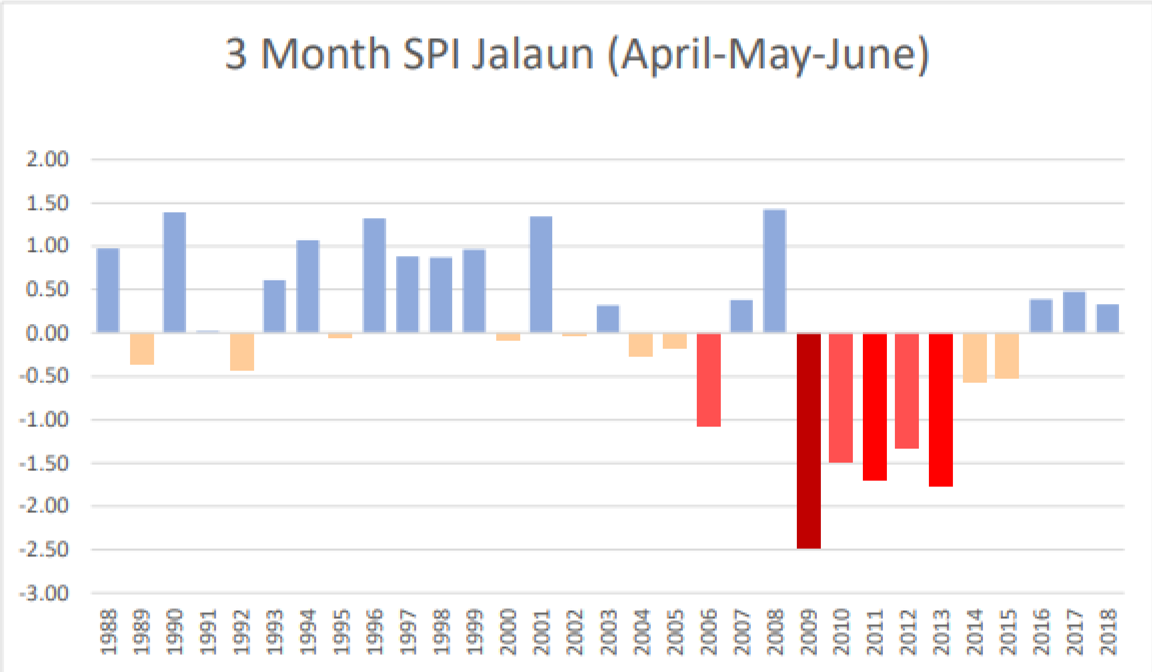

Figure 4.10: 3-Month SPI(April-June) based drought distribution in Jalaun

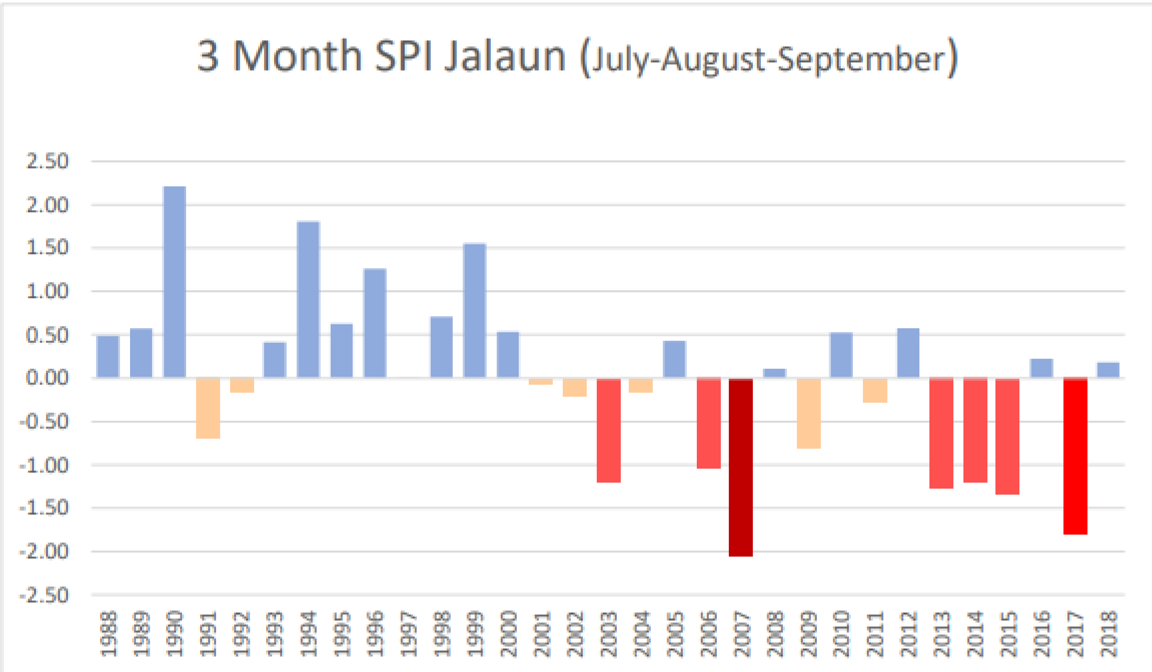

Figure 4.11: 3-Month SPI(July-September) based drought distribution in Jalaun

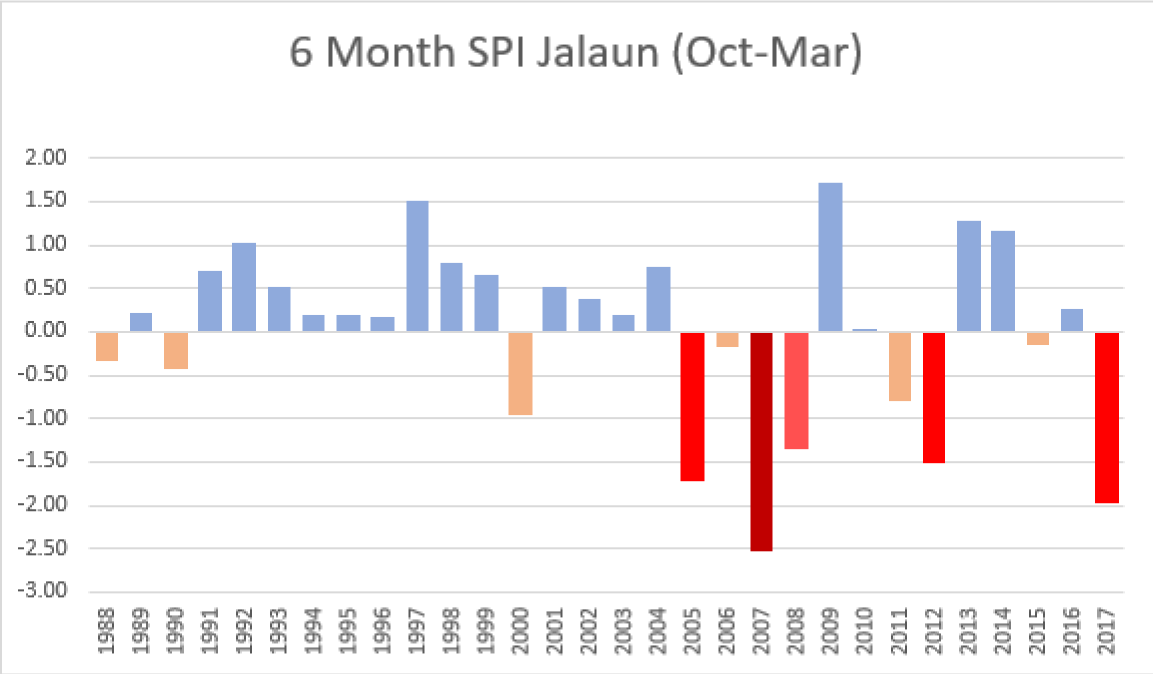

Figure 4.12: 6-Month SPI(Oct-Mar) based drought distribution in Jalaun

In Jalaun by observing the SPI data it can be inferred that during the period of 1988-2018 there were a total of 15 drought events and in the last ten years there has been recurrent occurrence of drought as seven of the ten years have seen a drought episode with 2011,2013 being severely hit and 2009 facing extreme drought (Figure 4.10) based on 3-month SPI (April-May-June) values.

A total of 14 drought events during 1988-2018 and 5 in the last ten years with 2007 and 2017 being severely hit by drought as can be interpreted from 3-month SPI (July-Aug-Sept) values. 11 drought events from the 6-month SPI (Oct-Mar) values during 1988-2018 and 4 during last ten years have been drought hit with 2008,2013 and 2018 experiencing extreme drought episodes. Hence, it can be said that during most of the years in the past thirty years the Jalaun has been affected by recurrent drought with 2008,2009,2010,2011,2013 and 2017 being the worst affected years as per Table 4.4.

Table 4.4: Category wise Drought in Jalaun (1988-2018)

District	SPI	Time Period	Drought Category				Total
			Mild	Moderate	Severe	Extreme	
Jalaun	3 Month (April-June)	1988-2000	1989,1992,1995,2000 (4)				4
		2001-2010	2002,2004,2005 (3)	2006 (1)	2010 (1)	2009 (1)	6
		2011-2018	2014,2015 (2)	2012 (1)	2011,2013 (2)		5
		Total					15
	3 Month (July-Sept)	1988-2000	1991,1992 (2)				2
		2001-2010	2001,2002,2004,2009 (4)	2003,2006 (2)		2007 (1)	7
		2011-2018	2011 (1)	2013,2014, 2015 (3)		2017 (1)	5
		Total					14
	6Month (Oct-Mar)	1988-2000	1988,1990,2000 (3)				2
		2001-2010	2006 (1)	2008 (1)	2005 (1)	2007 (1)	5
		2011-2018	2011,2015 (2)		2012(1)	2017(1)	4
		Total					11

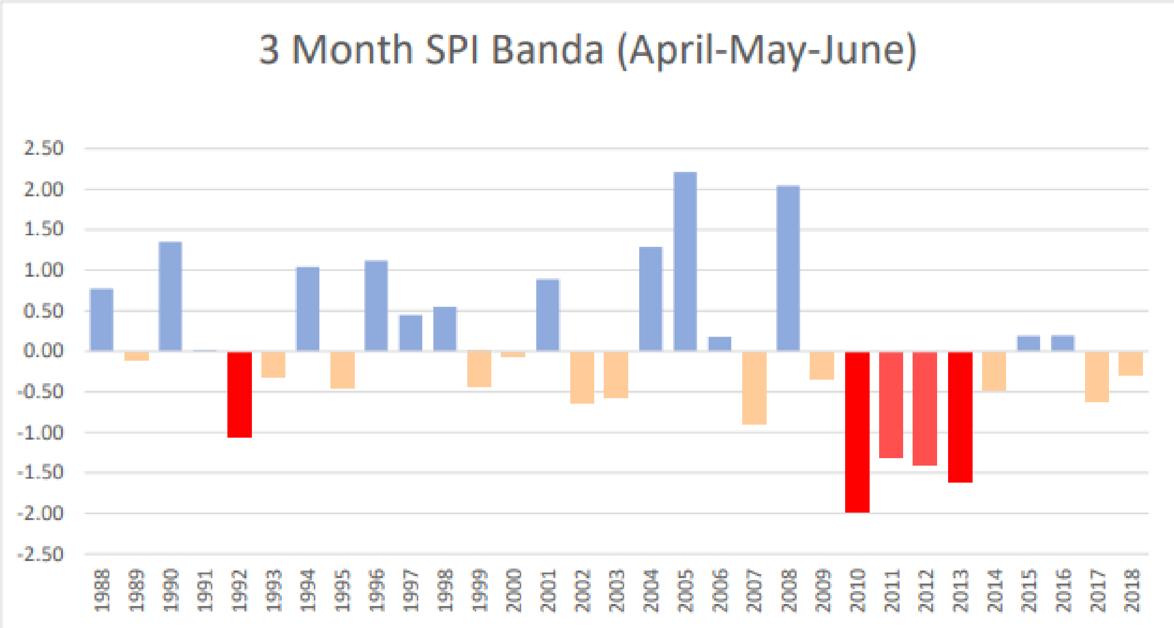

Figure 4.13: 3-Month SPI(April-June) based drought distribution in Banda

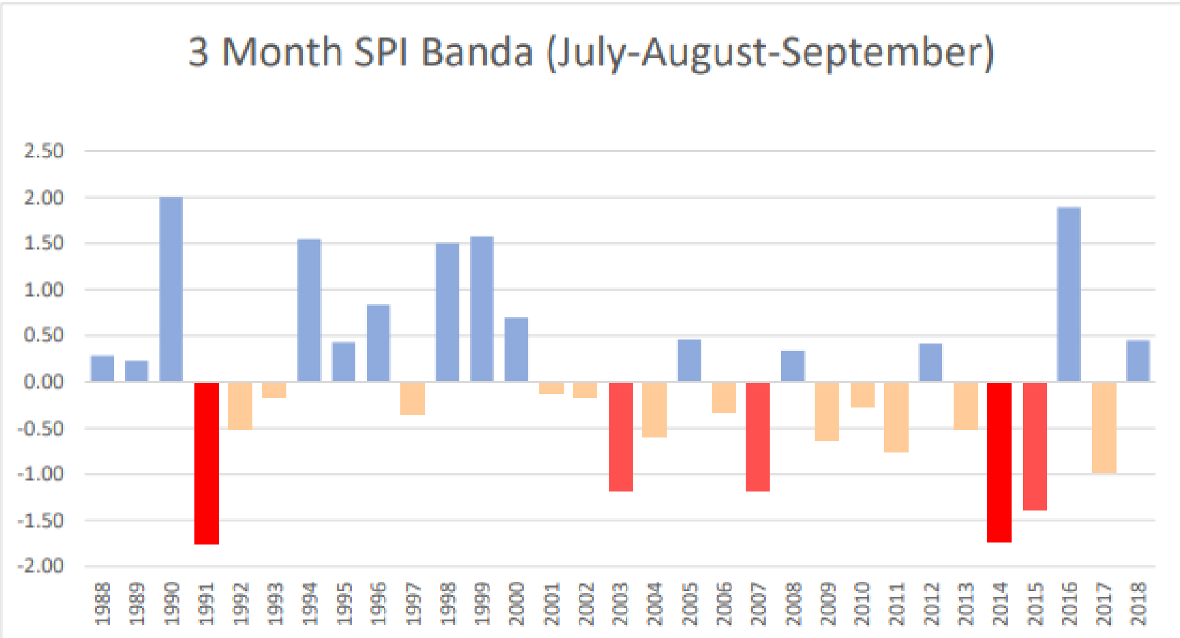

Figure 4.14: 3-Month SPI(July-September) based drought distribution in Banda

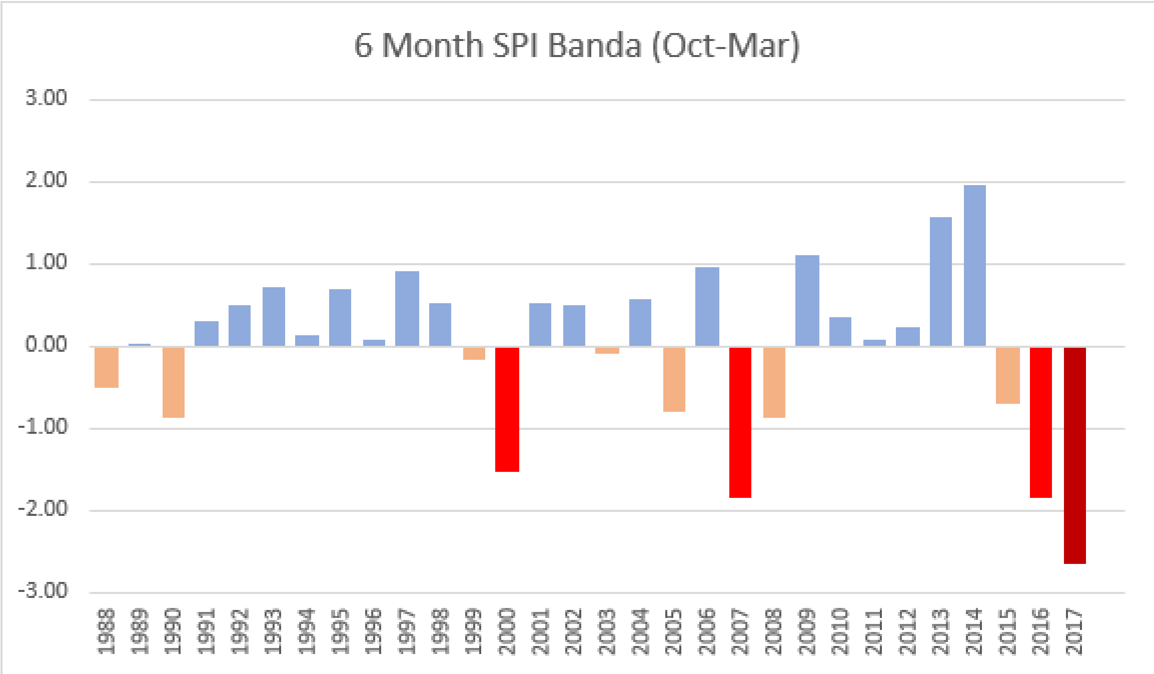

Figure 4.15: 6-Month SPI(Oct-Mar) based drought distribution in Banda

In Banda it can be seen by the SPI data that during the period of 1988-2018, 15 drought events and in the last ten years recurrent droughts occurred as 8 of the ten years have seen a drought episode with 2010,2013 being severely hit based on 3-month SPI (April-May-June) values, also from Figure 4.13.

A total of 17 drought events during 1988-2018 and 7 in the last ten years with 2015 being severely hit and 2014 experiencing extreme drought conditions as can be interpreted from 3-month SPI (July-Aug-Sept) values. 12 drought events from the 6-month SPI (Oct-Mar) values during 1988-2018 and 4 during last ten years have been drought hit with 2016 and 2017 experiencing severe drought. Hence, it can be said that during most of the years in the past thirty years Banda has been affected by drought with 2007,2010,2013, 2014, 2015 and 2017 being the worst affected years as per Table 4.5 and from Figure 4.14 and 4.15.

Table 4.5: Category wise Drought in Banda (1988-2018)

District		SPI	Year	Drought Category				Total
				Mild	Moderate	Severe	Extreme	
Banda		3 Month (April-June)	1988-2000	1989,1993,1995, 1999,2000 (5)	1992 (1)			6
			2001-2010	2002,2003,2007,2009 (4)		2010 (1)		5
			2011-2018	2014,2017,2018 (3)	2011,2012 (2)	2013 (1)		6
			Total					15
		3 Month (July-Sept)	1988-2000	1992,1993,1997 (3)		1991 (1)		4
			2001-2010	2001,2002,2004,2006 2009,2010 (5)	2003,2007 (2)			7
			2011-2018	2011,2013 (2)	2017 (1)	2015, (1)	2014 (1)	5
			Total					16
		6Month (Oct-Mar)	1988-2000	1988,1990,1999 (3)		2000(1)		4
			2001-2010	2003,2005,2009 (3)	2008 (1)	2007 (1)		5
			2011-2018	2015 (1)		2016 (1)	2017 (1)	3
			Total					12

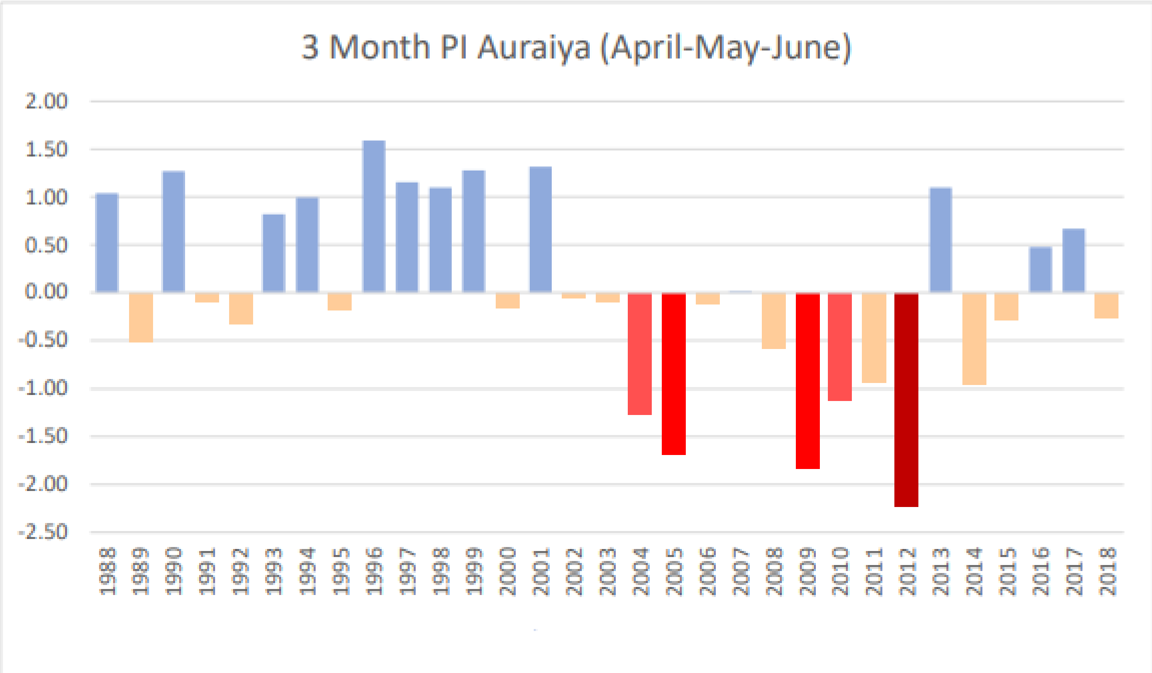

Figure 4.16: 3-Month SPI(April-June) based drought distribution in Auraiya

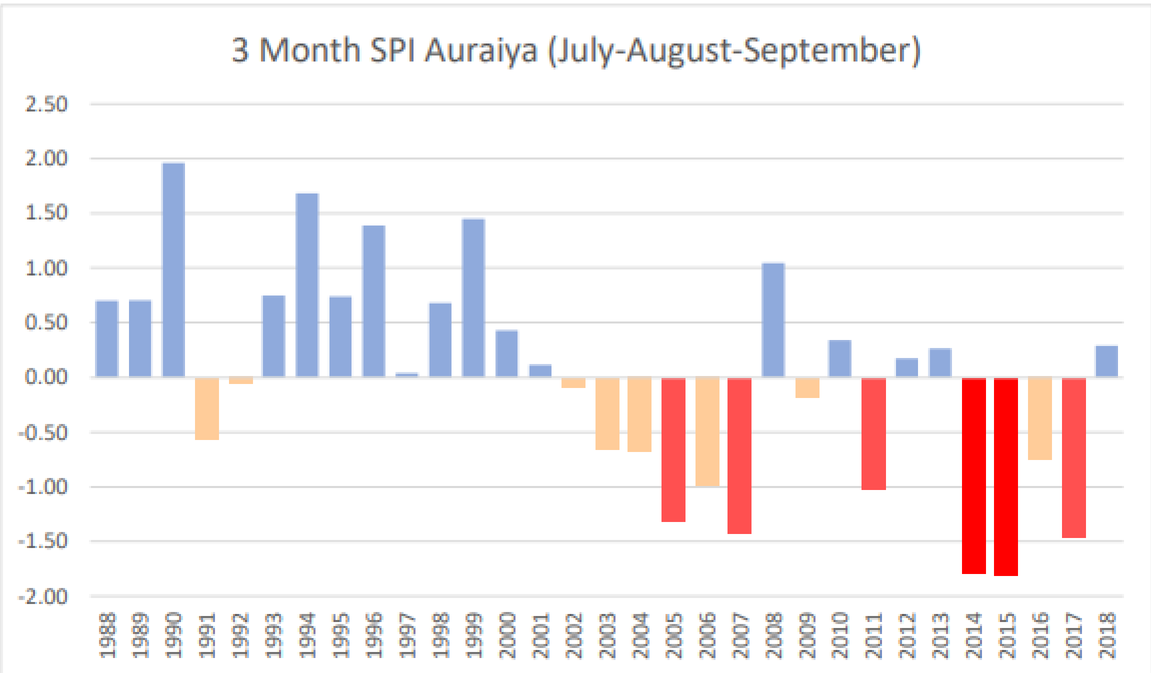

Figure 4.17: 3-Month SPI(July-September) based drought distribution in Auraiya

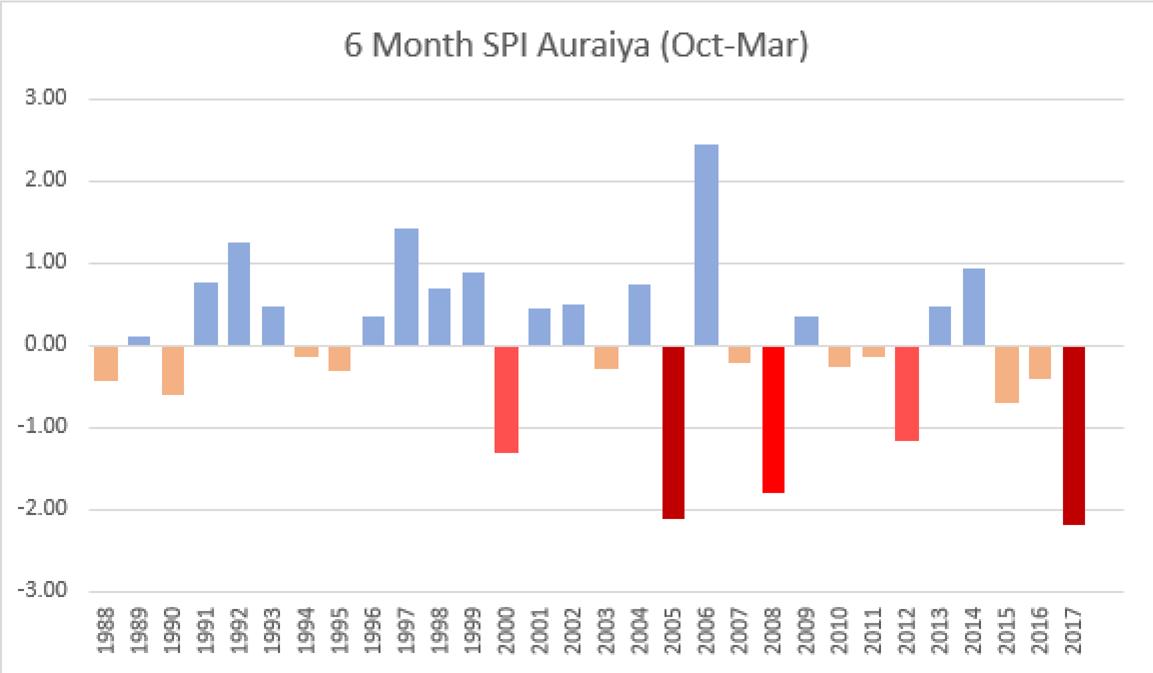

Figure 4.18: 6-Month SPI(Oct-Mar) based drought distribution in Auraiya

In Auraiya it can be seen by the SPI data that during the period of 1988-2018 there occurred a total of 18 drought events and in the last ten years 7 years oversee a drought episode with 2005,2009 being severely hit and 2012 facing extreme drought from Figure 4.16 and based on 3-month SPI (April-May-June) values.

A total of 15 drought events during 1988-2018 and 6 in the last ten years with 2014 and 2015 being severely hit by drought as can be interpreted from 3-month SPI (July-Aug-Sept) values. 15 drought events from the 6-month SPI (Oct-Mar) values during 1988-2018 and 5 during last ten years have been drought hit with 2005,2008 and 2017 experiencing extreme drought episodes. Hence, it can be said that during most of the years in the past thirty years the district of Auraiya has been affected by drought with 2007,2009,2012,2014,2015 and 2017 being the worst affected years as can be seen through Table 4.6 and Figure 4.17 and 4.18

Table 4.6: Category wise Drought in Auraiya (1988-2018)

District	SPI	Time Period	Drought Category				Total
			Mild	Moderate	Severe	Extreme	
Auraiya	3 Month (April-June)	1988-2000	1989,1991,1992,1995, 2000 (5)				5
		2001-2010	2002,2003,2006,2008 (4)	2004,2010, (2)	2005,2009 (2)		8
		2011-2018	2011,2014,2015,2018 (4)			2012 (1)	5
		Total					18
	3 Month (July-Sept)	1988-2000	1991,1992 (2)				2
		2001-2010	2002,2003,2004,2009, 2006 (5)	2005,2007 (3)			8
		2011-2018	2016 (1)	2011,2017 (2)	2014,2015 (2)		5
		Total					15
	6Month (Oct-Mar)	1988-2000	1988,1990,1994,1995 (4)	2000(1)			5
		2001-2010	2003,2007,2010 (2)		2008 (1)	2005 (1)	5
		2011-2018	2011,2015,2016 (3)	2012 (1)		2017(1)	5
		Total					15

4.2 Scatter Plots between SPI and Rain fall Deviation

Scatter Plots of 3-Month SPI vs. Deviation from normal rainfall for 2009-2018 using excel for both positive and negative rainfall deviations as shown in the Figures 4.19 to 4.2.l. As it is known that the monsoonal rainfall is very critical for crop sowing and growth for different crops. Rainfall pattern during this period plays a vital role in agricultural produce.

It is clear from Figure 4.19 that even at negative rainfall deviations of -30% to -40% as shown the SPI values tend to be very negative around -2.0 which represent severe to extreme drought condition. Where as in the same area from Figure 4.20 in which SPI is plotted during a wetter period the SPI values are found to be more in accordance but still negative rainfall deviations of around -60% to -80% which represent extreme drought conditions correspond to a lower SPI of around -1.5 to -1.8 rather it should be near -2.0 and above.

Negative rainfall deviations in Hamirpur district (-75% to -95%) represent extreme dryness, but the SPI values corresponding to -70% and -80% represent only a severe case of drought and at -92% SPI drops to -2.35 correctly depicting an extreme drought as shown in Figure 4.21 The Figure 4.22 for 3-month SPI (July-Aug) represent the values of SPI in better agreement with Negative Rainfall Deviations.

Similar observations can be made from Figure 4.23 for Jalaun where negative rainfall deviations of above -80% which otherwise represent very dry conditions and extreme drought are only once indicated under the same. Similar analysis can be made through Figures 4.24 to 4.29 for Jhansi, Lalitpur and Banda where also very high negative deviation from rainfall greater than -70% are not exactly referred under extreme condition but under severe condition with values less than -1.5.

In the case of positive rainfall deviations which indicates that actual rainfall is greater than normal rainfall with the positive SPI values representing wetness, the extent of positive SPI did not correspond with the extent of the positive deviation. The rainfall deviations of 100 to 400% which represent fairly wet conditions are only shown by SPI values of 1.5-3 a particular case being the year 2008 when during April-June good rainfall can be seen which otherwise correspond to the drier months as can be seen through Figures 4.21, 4.25, 4.27, 4.29.

On the other hand, during the period of high rainfall in the area from July-August the SPI values are better distributed and stretched between +2.5 to -2.5 correctly representing the drought conditions reported by both positive and negative rainfall deviation conditions as can be seen through the Figures 4.22, 4.24, 4.28, 4.30. The SPI values for all the districts during this period for most of the year can be seen in accordance.

To bring more clarity on the inter-relation of rainfall deviations and SPI deviation values of high and low percentage are represented in Tables provided in Appendix. Even the very less amount of precipitation which is surely not enough for keeping moisture of optimum level in soil have led to the SPI values around -1.5 which otherwise must have represented very high level of dryness with SPI of less than and near -2.0. In the same way, excess rainfall events are represented by SPI near 1.5. This tendency of very high rainfall events not representing a greater SPI and very less rainfall not representing less SPI and can be seen in all the districts during all the time scale of SPI calculation.

Hence, from this analysis we can infer that the SPI values are under-valued for high rainfall levels and over-valued for less rainfall levels particularly during dry spells of April-June. Whereas, during the period of ample rainfall the SPI values give a fair representation in agreement to the deviations from normal.

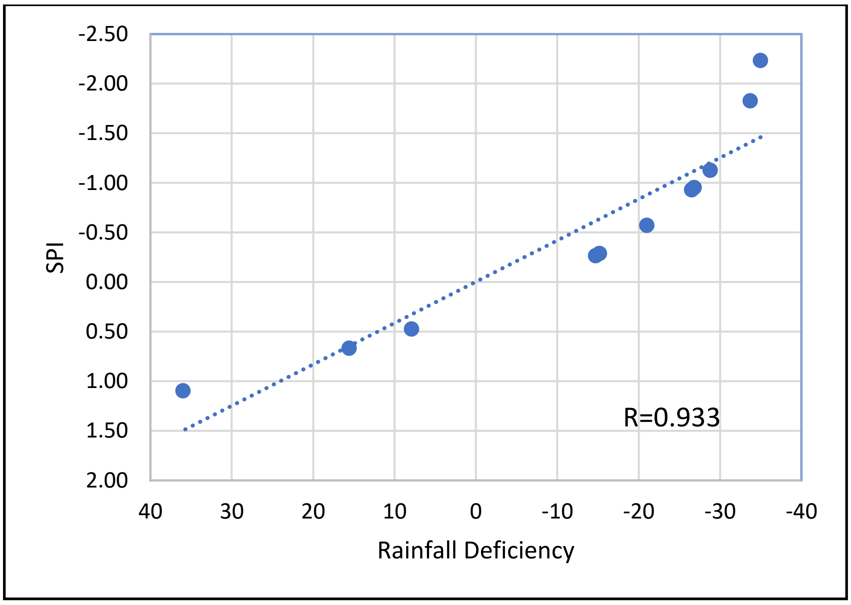

Figure 4.19 Scatter plots of 3-Month (April-June) SPI vs. deviation from normal rainfall for Auraiya

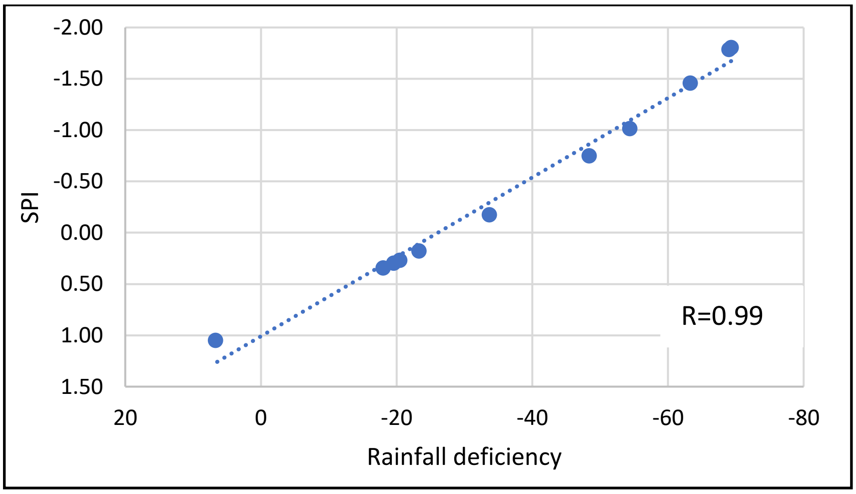

Figure 4.20 Scatter plots of 3-Month (July-September) SPI vs. deviation from normal rainfall for Auraiya

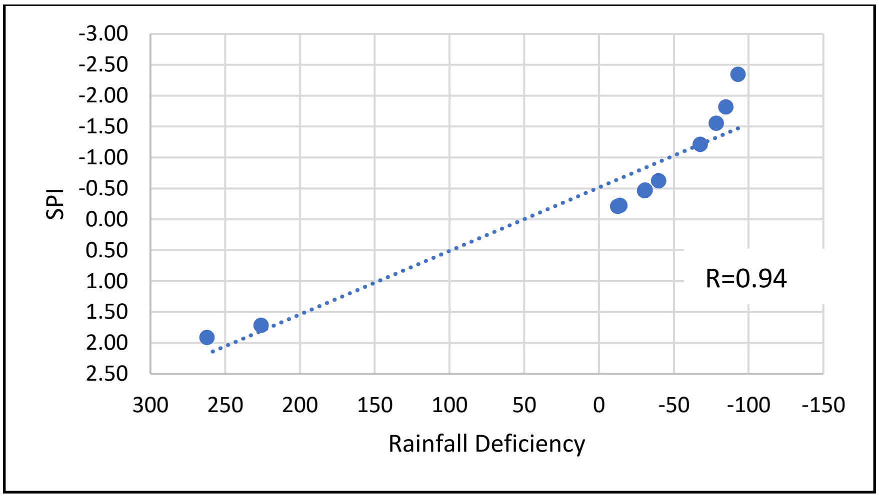

Figure 4.21 Scatter plots of 3-Month (April-June) SPI vs. deviation from normal rainfall for Hamirpur.

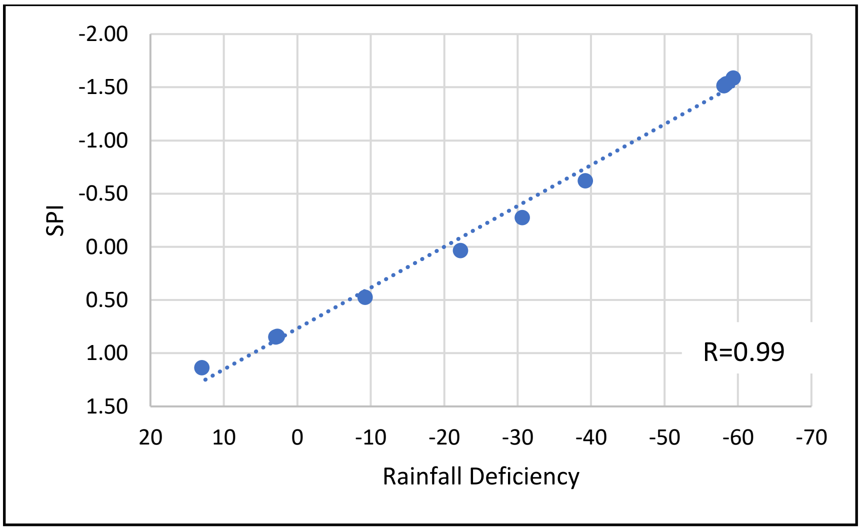

Figure 4.22 Scatter plots of 3-Month (July-September) SPI vs. deviation from normal rainfall for Hamirpur

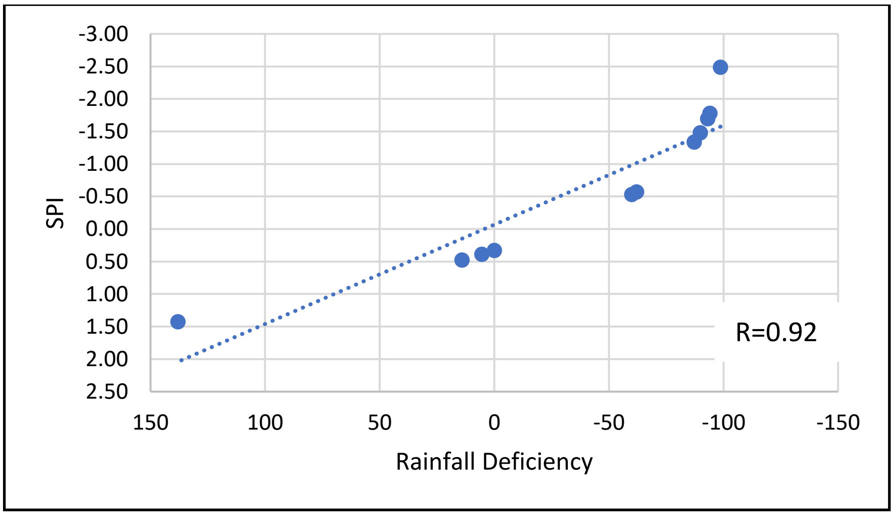

Figure 4.23 Scatter plots of 3-Month (April-June) SPI vs. deviation from normal rainfall for Jalaun

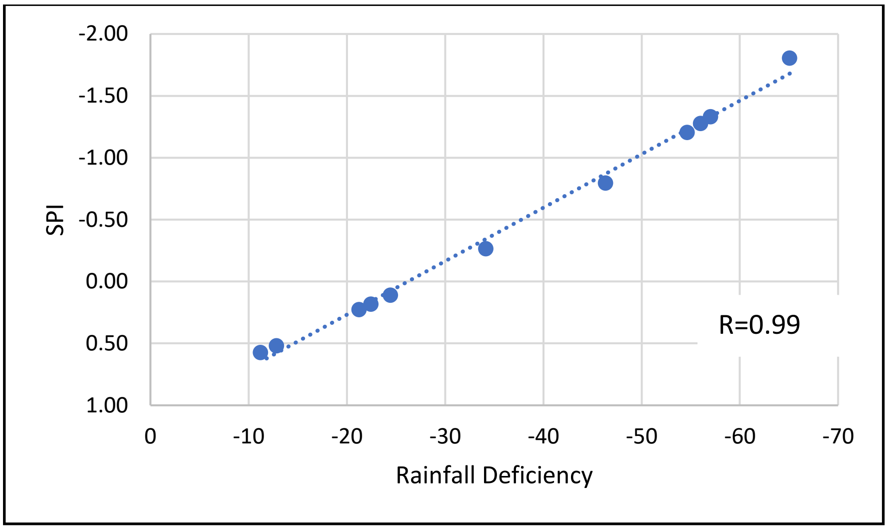

Figure 4.24 Scatter plots of 3-Month (July-September) SPI vs. deviation from normal rainfall for Jalaun.

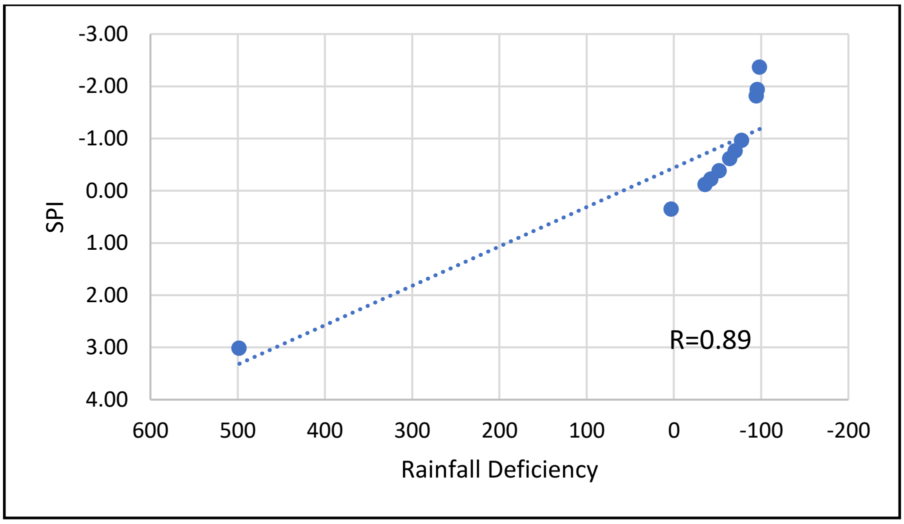

Figure 4.25 Scatter plots of 3-Month (April-June) SPI vs. deviation from normal rainfall for Jhansi

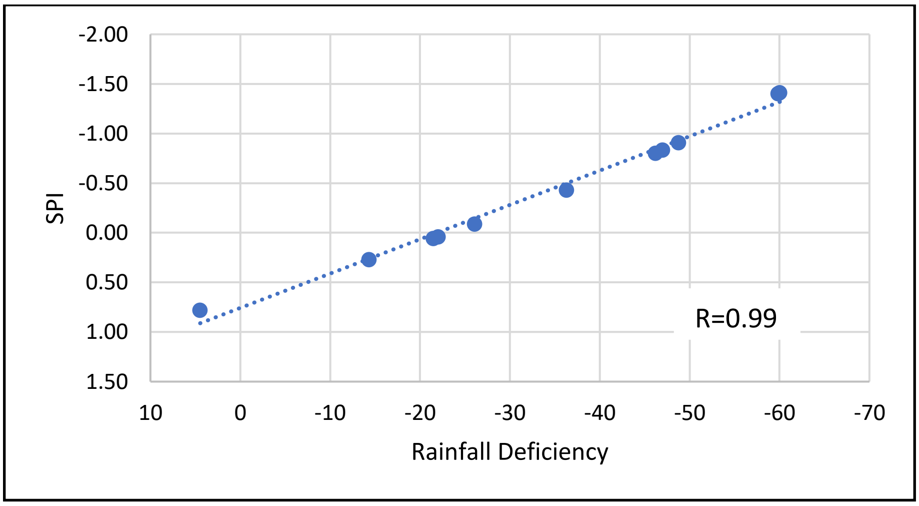

Figure 4.26 Scatter plots of 3-Month (July-September) SPI vs. deviation from normal rainfall for Jhansi

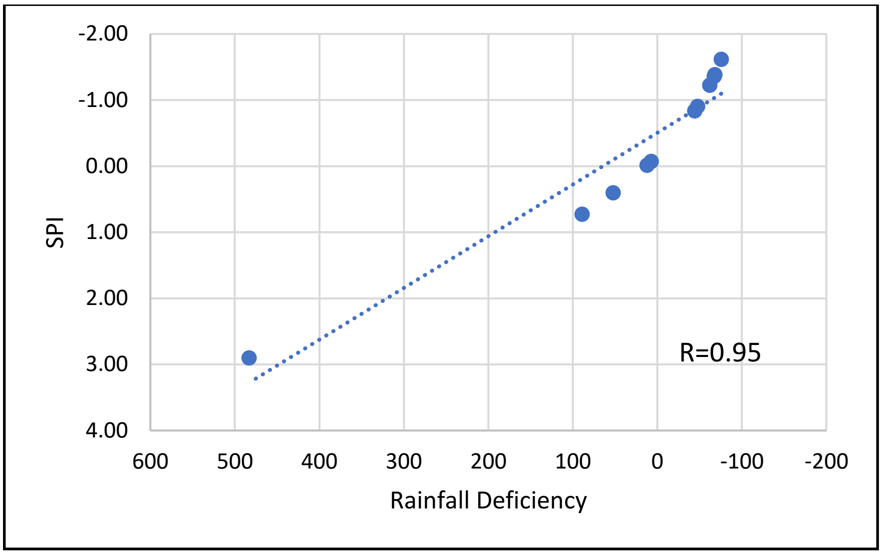

Figure 4.27 Scatter plots of 3-Month (April-June) SPI vs. deviation from normal rainfall for Lalitpur

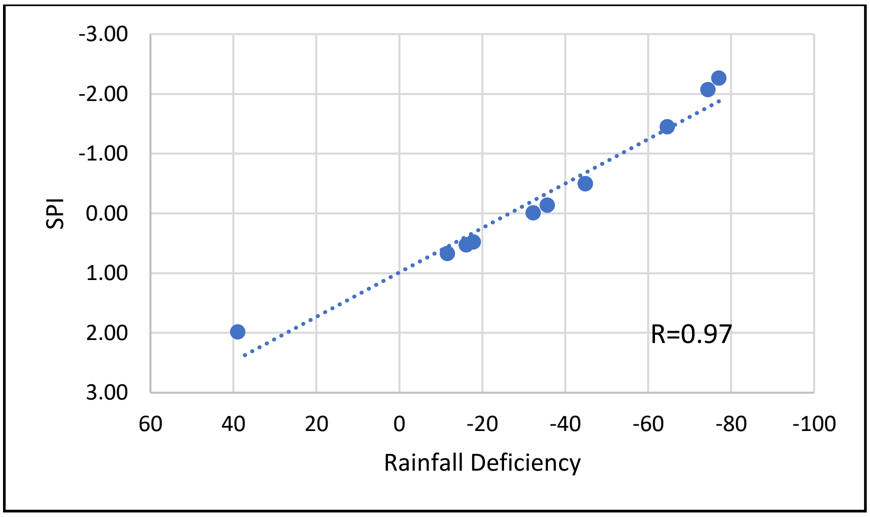

Figure 4.28 Scatter plots of 3-Month (July-September) SPI vs. deviation from normal rainfall for Lalitpur

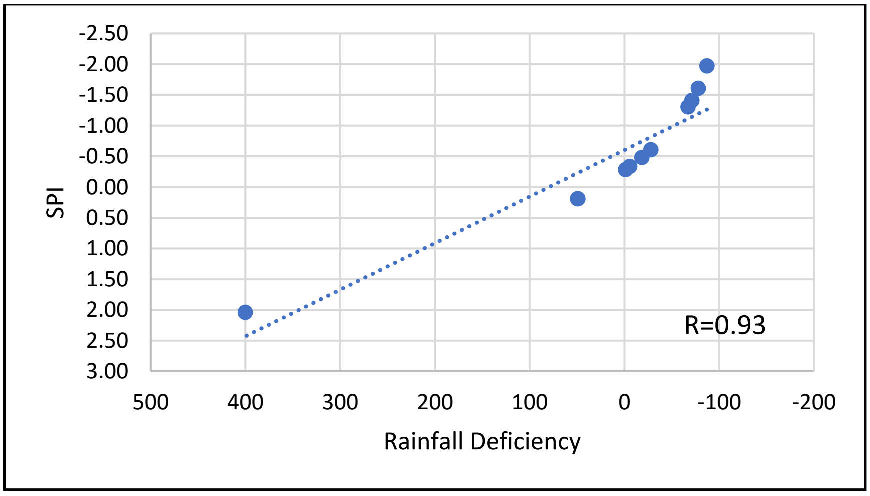

Figure 4.29 Scatter plots of 3-Month (April-June) SPI vs deviation from normal rainfall for Banda

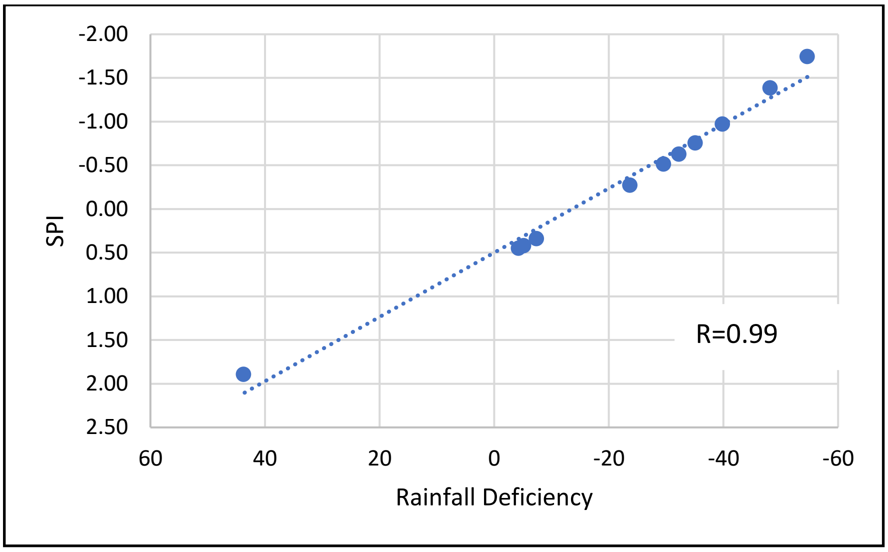

Figure 4.30 Scatter plot of 3-Month (July-September) SPI vs. deviation from normal rainfall for Banda

4.3 Spatial Variation of Drought During Severe Drought Years

Spatial Variation of drought for the years in which there has been severe to extreme droughts in the region are plotter using GIS. The years 2009, 2011, 2012 are taken based on 3-Month SPI(April-June). 2014,2015 and 2017 saw severe to extreme drought based on 3-Month SPI (July-Sep), hence is considered. For 6-Month SPI(Oct-Mar) 2007, 2011 and 2011 are considered to plot spatial extent maps. The maps show the distribution of drought affect depicting that almost entire region is prone to severe to extreme droughts.

The Spatial maps are shown in Figure 4.31- Figure 4.33.

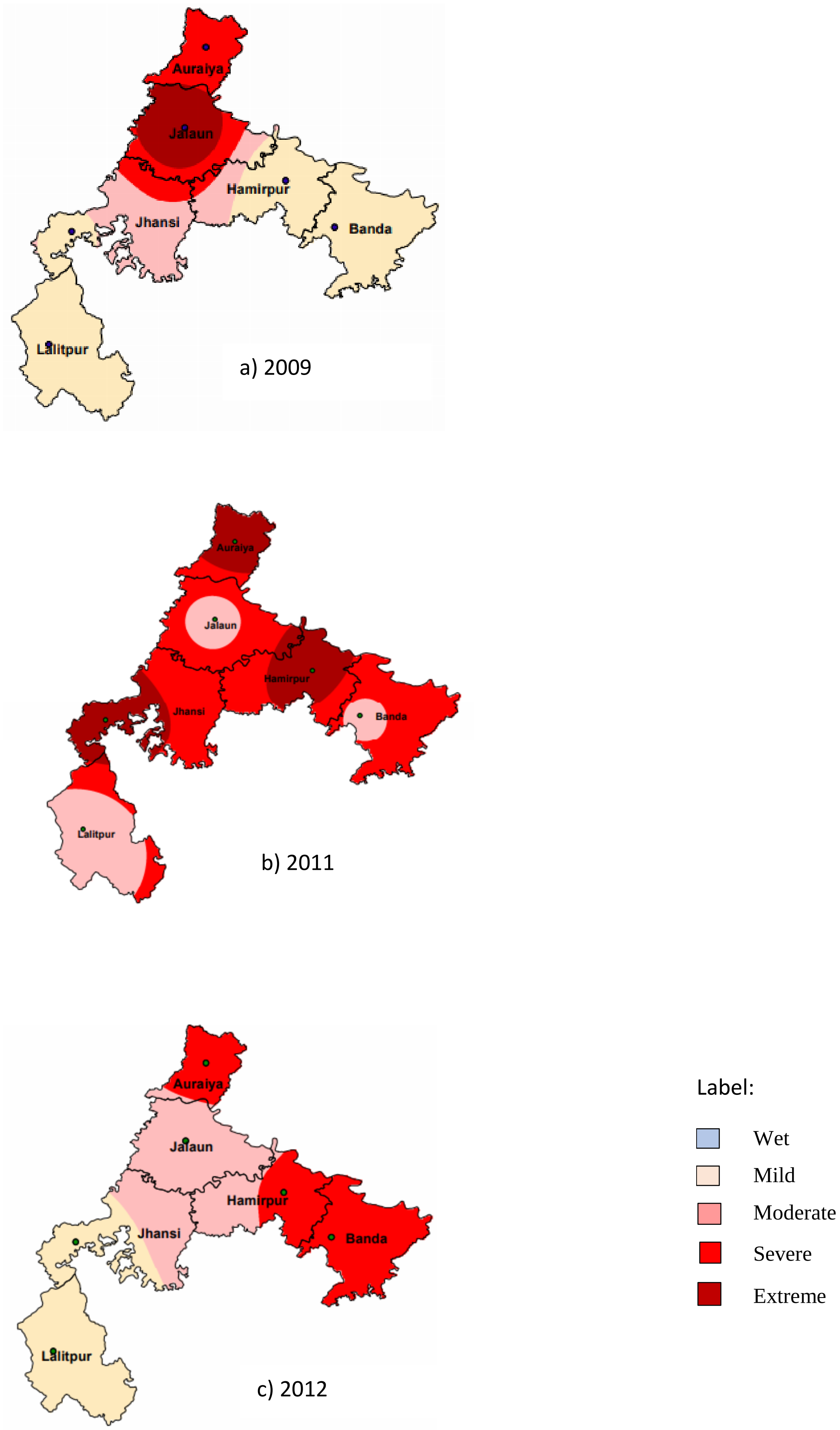

Figure 4.31 Spatial variation of Drought Based on 3-Month SPI (April-June)

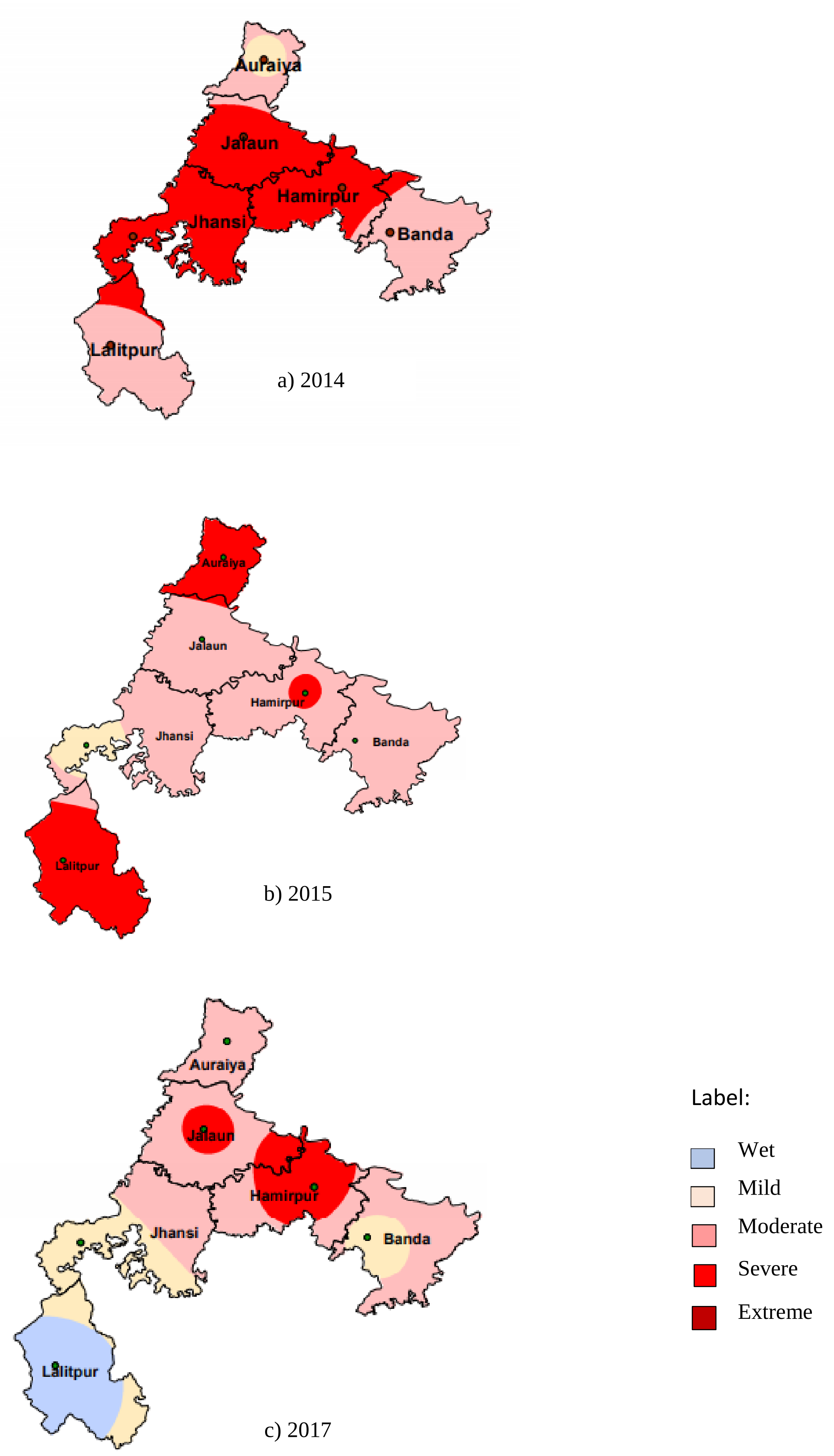

Figure 4.32 Spatial variation of Drought Based on 3-Month SPI (July-Sep)

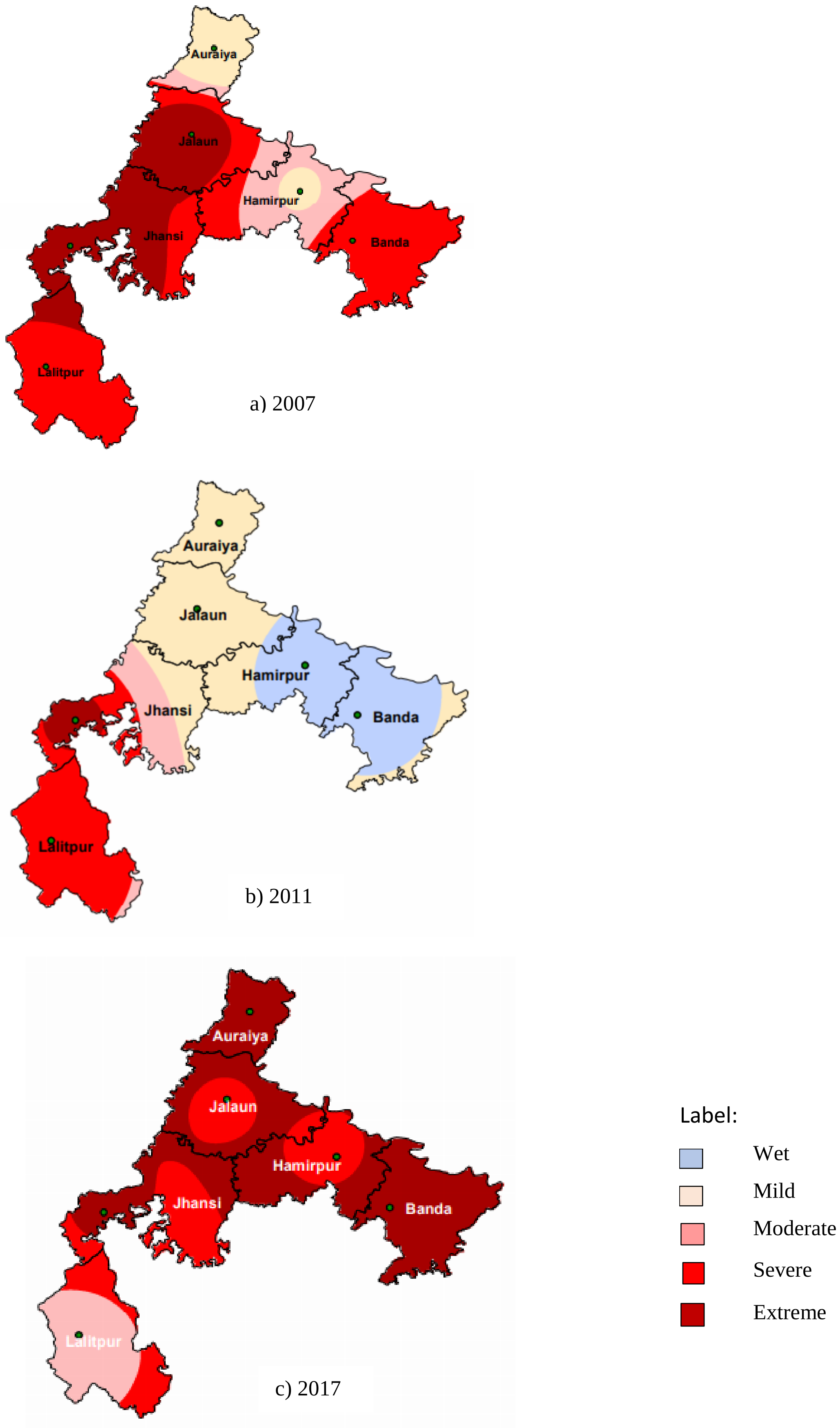

Figure 4.32 Spatial variation of Drought Based on 6-Month SPI (Oct-Mar)

CHAPTER-5

SUMMARY AND CONCLUSION

5.1 Conclusion

The main objective of this project is to assess the frequency of meteorological drought in the study area using Standardized Precipitation Index. The SPI values using monthly precipitation data from 1988 to 2018 are computed. 3-Month SPI (April-June), 3-Month SPI (July-Sep), 6-Month SPI (Oct-Mar) are found and drought categorised under four severity levels viz. mild, moderate, severe and extreme.

- It is found that the during years 2009,2010,2011,2012,2013 almost all the districts are severely and extremely affected by drought with 2012 being the worst year with SPI values below -2 and less based on 3-Month SPI (April-June).
- In the years 2007,2011,2014,2015 and 2017 severe and extreme drought has affected all the districts as classified by 3-Month SPI (July-Sep) with 2014 and 2015 being the worst affected years having SPI values in Range of -1.5 to -3.
- The drought in the 6-month period is due to less rainfall during receding south-west monsoon and the region depends on winter agriculture but as can be seen from the results that most of the past ten years have been drought affected. 2008,2012 and 2018 have seen extreme drought events based on 6-Month SPI (Oct-Mar).

To ascertain the validity of SPI in the region, the SPI values for the last ten years for April-June and July-September are compared with the rainfall deviation from mean. Scatter plots are plotted to see the variation in SPI and Rainfall deficiency.

It is found that when there is very low rainfall the SPI values under-estimate the drought situation like in 2010,2011 and 2013 for Hamirpur, Jalaun, Jhansi, Lalitpur and Banda rainfall deviations of -60% to -90% are only represented by SPI values of severe drought stations with values lying between -1 to -2. Similarly, during very high rainfall the SPI values also under estimate the condition of wetness during period of very high rainfall as can be inferred from the rain fall deviation and SPI value during 2008 when there is more than ample rainfall reaches to a maximum of 3 and lies below it most of the times.

However, it is found from this study that during the period of July-August-September during which there is more rainfall than April-May-June the drought condition suggested by the SPI values are better co-related to the rainfall deviation and are distributed as shown in scatter plots. As can be seen through the “R” values represented on graph. The R value is the coefficient of correlation, the more the value of R is near to 1 the better the correlation among the parameters. For SPI (July-Aug-Sept) R is nearly 0.99 for most of the districts hence depicting better sensitivity of SPI in wetter regions.

Hence, it can be concluded that SPI values under estimate the drought situation during low rainfall and under estimate the wetness during very high rainfall in dry regions during dry spells. Therefore, SPI as the only indicator for metrological drought analysis and assessment shall be interpreted cautiously.

5.2 Agreement of results with earlier studies

To an extent the results are in agreement to some studies conducted earlier. Wu et al. 2006, discovered that the application of SPI of short time scales in arid and the areas with distinct dry season fails to detect the occurrence of drought situation. This behaviour of SPI is attributed to its non-normal distribution caused by higher frequency of no rain cases. Histograms of drought frequency classes derived by Morid et al. 2006, showed that percent normal rainfall has higher frequency in extreme drought and severe drought, whereas SPI have higher frequency in normal class. The result indicated that for the cases of low percent normal rainfall which represents lower and lower rainfall, the corresponding SPI values tend to be higher indicating normal situation. Interpretation of 1-month SPI can lead to misleading assessment, as there are many examples with small rainfall deviations leading to large positive or negative SPI values. Actual precipitation of 15.2 mm against the normal of 2.5 mm leads to SPI of +3.11. Similarly, 371.9 mm of precipitation which is above the normal by 211.6 mm, gave rise to SPI value of 1.97. In another station, 24.9 mm of precipitation against 10.4 mm of normal which is 239% of normal, has resulted in the SPI value of 1.43. February 1996 SPI of -1.76 over South-eastern Plains Climate Division in New Mexico represents zero rainfall situations (http://www.drought.unl.edu/monitor).

5.3 Future Scope and Recommendations

The SPI index is recommended by the World Meteorological Department as a primary index to be used to classify drought. The computation of SPI makes it easy to compute but also introduces the drawback that it does not includes various other climatic and soil related parameters. But since the classification can be done easily, the SPI is widely used in other countries. In India where regions like Bundelkhand, Rajasthan, Gujarat and Maharashtra are prone to frequent droughts the SPI can be helpful in classifying drought into more sub-categories as compared to rainfall deficiency method of classification. Hence, proper mitigation plan can be made and water can be made available to farmers, villagers based on the drought severity which could help in saving of water during acute shortages and provision of water in areas which need it the most.

APPENDIX

Table A: SPI values Jhansi (1988-2018)

Year	3-Month A-M-J	3-Month J-A-S	6-Month O-M
1987 - 1988	0.71	0.38	-0.11
1988 - 1989	-0.45	0.60	-0.40
1989 - 1990	1.34	2.34	0.15
1990 - 1991	-0.10	-0.19	-0.39
1991 - 1992	-0.65	0.05	0.44
1992 - 1993	0.36	0.25	0.73
1993 - 1994	0.95	1.89	0.44
1994 - 1995	-0.10	0.66	0.31
1995 - 1996	0.79	1.16	0.27
1996 - 1997	0.43	0.31	-0.17
1997 - 1998	0.46	0.68	1.82
1998 - 1999	0.59	1.56	0.97
1999 - 2000	-0.20	0.80	0.49
2000 - 2001	1.27	0.04	-0.84
2001 - 2002	-0.08	-0.05	0.42
2002 - 2003	-0.27	-1.79	0.01
2003 - 2004	0.12	-0.24	-0.30
2004 - 2005	0.44	-0.45	1.65
2005 - 2006	-0.01	-1.40	0.05
2006 - 2007	0.12	-1.86	0.22
2007 - 2008	3.01	0.04	-2.61
2008 - 2009	-0.96	-0.43	-0.26
2009 - 2010	-0.76	-0.09	0.87
2010 - 2011	-1.94	-1.41	-0.27
2011 - 2012	-2.37	-1.40	-2.14
2012 - 2013	-1.81	0.27	0.07
2013 - 2014	-0.61	-0.80	1.56
2014 - 2015	-0.38	-0.83	1.11
2015 - 2016	-0.22	0.06	-0.20
2016 - 2017	0.35	-0.91	-1.33
2017 - 2018	-0.12	0.78	-2.05

Table B: Jhansi, April-June

Year	Rainfall Deficiency	SPI
2008	498.21	3.01
2009	-77.52	-0.96
2010	-70.29	-0.76
2011	-95.74	-1.94
2012	-98.31	-2.37
2013	-94.55	-1.81
2014	-63.96	-0.61
2015	-51.98	-0.38
2016	-42.47	-0.22
2017	3.1683	0.35
2018	-35.64	-0.12

Table C: Jhansi, July-September

Year	Rainfall Deficiency	SPI
2008	-22.09	0.04
2009	-36.29	-0.43
2010	-26.09	-0.09
2011	-60.02	-1.41
2012	-59.82	-1.40
2013	-14.32	0.27
2014	-46.19	-0.80
2015	-46.98	-0.83
2016	-21.49	0.06
2017	-48.77	-0.91
2018	4.46	0.78

Table D: SPI values Lalitpur (1988-2018)

Year	3-Month A-M-J	3-Month J-A-S	6-Month O-M
1987 - 1988	0.75	-0.25	-0.37
1988 - 1989	-0.52	0.18	-0.66
1989 - 1990	1.97	2.21	-0.21
1990 - 1991	-0.10	-0.13	-0.60
1991 - 1992	-1.16	-0.18	-0.11
1992 - 1993	0.14	-0.52	0.11
1993 - 1994	1.30	1.55	0.26
1994 - 1995	-0.11	0.24	0.33
1995 - 1996	0.25	0.65	0.36
1996 - 1997	-0.08	0.21	-0.50
1997 - 1998	0.12	0.33	2.18
1998 - 1999	0.09	1.26	1.13
1999 - 2000	-0.26	0.64	0.39
2000 - 2001	1.78	-0.39	-0.94
2001 - 2002	-0.10	-0.28	0.26
2002 - 2003	-0.99	-1.47	-0.27
2003 - 2004	0.29	-0.39	-0.77
2004 - 2005	0.11	0.74	0.58
2005 - 2006	-0.17	-0.34	0.35
2006 - 2007	-0.31	-0.77	-0.11
2007 - 2008	2.90	-2.26	-1.85
2008 - 2009	-0.90	-0.50	-0.51
2009 - 2010	-1.62	-0.01	1.52
2010 - 2011	-1.36	-1.45	0.41
2011 - 2012	-1.22	0.67	-1.82
2012 - 2013	0.73	1.98	0.81
2013 - 2014	-1.38	-0.14	1.95
2014 - 2015	-0.01	-2.07	1.24
2015 - 2016	-0.07	0.47	-0.37
2016 - 2017	0.40	-0.50	-0.67
2017 - 2018	-0.84	0.53	-1.27

Table E: Lalitpur, April-June

Year	Rainfall Deficiency	SPI
2008	483.22	2.90
2009	-47.78	-0.90
2010	-75.56	-1.62
2011	-67.22	-1.36
2012	-62.22	-1.22
2013	88.89	0.73
2014	-68.22	-1.38
2015	12.22	-0.01
2016	7.22	-0.07
2017	52.22	0.40
2018	-44.44	-0.84

Table F: Lalitpur, July-September

Year	Rainfall Deficiency	SPI
2008	-2.26	-77.0359
2009	-0.50	-44.884
2010	-0.01	-32.2785
2011	-1.45	-64.6308
2012	0.67	-11.5823
2013	1.98	38.9135
2014	-0.14	-35.7068
2015	-2.07	-74.4409
2016	0.47	-17.8586
2017	-0.50	-44.884
2018	0.53	-16.192

Table G: SPI values Hamirpur (1988-2018)

Year	3-Month A-M-J	3-Month J-A-S	6-Month O-M
1987-1988	0.95	0.41	0.02
1988 - 1989	-0.30	0.44	-0.83
1989 - 1990	1.53	2.06	-0.09
1990 - 1991	-0.06	-0.99	-1.11
1991 - 1992	-0.89	-0.24	0.39
1992 - 1993	0.19	0.17	0.75
1993 - 1994	1.16	1.65	0.45
1994 - 1995	-0.34	0.55	-0.06
1995 - 1996	1.32	1.05	0.35
1996 - 1997	0.70	-0.08	-0.10
1997 - 1998	0.75	1.06	1.38
1998 - 1999	0.42	1.52	0.59
1999 - 2000	-0.13	0.63	0.13
2000 - 2001	1.25	-0.04	-1.83
2001 - 2002	-0.39	-0.13	0.41
2002 - 2003	-0.52	-0.55	0.30
2003 - 2004	-0.13	-0.90	0.28
2004 - 2005	0.31	-0.41	0.50
2005 - 2006	-0.27	-1.12	-2.25
2006 - 2007	-0.25	-1.39	0.29
2007 - 2008	1.71	0.85	-0.87
2008 - 2009	-0.47	-0.27	-1.41
2009 - 2010	-1.55	-0.62	1.24
2010 - 2011	-1.82	-1.58	0.01
2011 - 2012	-2.35	0.04	0.54
2012 - 2013	1.91	0.47	0.65
2013 - 2014	-0.62	-1.52	2.02
2014 - 2015	-1.21	-1.51	1.66
2015 - 2016	-0.23	1.14	-0.29
2016 - 2017	-0.46	-1.53	-1.14
2017 - 2018	-0.21	0.84	-1.88

Table H: Hamirpur, April-June

Year	Rainfall Deficiency	SPI
2008	226.029	1.71
2009	-30.73	-0.47
2010	-78.34	-1.55
2011	-84.70	-1.82
2012	-92.94	-2.35
2013	262.20	1.91
2014	-39.85	-0.62
2015	-67.64	-1.21
2016	-13.82	-0.23
2017	-30.29	-0.46
2018	-12.38	-0.21

Table I: Hamirpur, July-September

Year	Rainfall Deficiency	SPI
2008	2.96	0.85
2009	-30.62	-0.27
2010	-39.21	-0.62
2011	-59.33	-1.58
2012	-22.21	0.04
2013	-9.19	0.47
2014	-58.11	-1.52
2015	-58.04	-1.51
2016	12.99	1.14
2017	-58.38	-1.53
2018	2.72	0.84

Table J: SPI values Jalaun (1988-2018)

Year	3-Month A-M-J	3-Month J-A-S	6-Month O-M
1987 - 1988	0.98	0.49	0.16
1988 - 1989	-0.36	0.57	-0.33
1989 - 1990	1.39	2.21	0.22
1990 - 1991	0.02	-0.69	-0.43
1991 - 1992	-0.43	-0.16	0.70
1992 - 1993	0.61	0.42	1.02
1993 - 1994	1.07	1.81	0.52
1994 - 1995	-0.06	0.63	0.19
1995 - 1996	1.32	1.26	0.18
1996 - 1997	0.88	0.00	0.16
1997 - 1998	0.87	0.70	1.51
1998 - 1999	0.96	1.55	0.78
1999 - 2000	-0.08	0.53	0.65
2000 - 2001	1.34	-0.06	-0.97
2001 - 2002	-0.03	-0.20	0.51
2002 - 2003	0.32	-1.19	0.38
2003 - 2004	-0.27	-0.15	0.20
2004 - 2005	-0.18	0.43	0.74
2005 - 2006	-1.07	-1.04	-1.71
2006 - 2007	0.38	-2.04	-0.17
2007 - 2008	1.42	0.11	-2.53
2008 - 2009	-2.49	-0.79	-1.35
2009 - 2010	-1.48	0.52	1.71
2010 - 2011	-1.70	-0.26	0.03
2011 - 2012	-1.34	0.57	-0.81
2012 - 2013	-1.78	-1.28	-1.51
2013 - 2014	-0.57	-1.20	1.27
2014 - 2015	-0.53	-1.33	1.16
2015 - 2016	0.39	0.23	-0.14
2016 - 2017	0.47	-1.80	0.27
2017 - 2018	0.33	0.18	-1.98

Table K: Jalaun, April-June

Year	Rainfall Deficiency	SPI
2008	138.10	1.42
2009	-98.67	-2.49
2010	-89.86	-1.48
2011	-93.10	-1.70
2012	-87.16	-1.34
2013	-94.05	-1.78
2014	-62.02	-0.57
2015	-60	-0.53
2016	5.40	0.39
2017	14.05	0.47
2018	0	0.33

Table L: Jalaun, July-September

Year	Rainfall Deficiency	SPI
2008	-24.45	0.11
2009	-46.32	-0.79
2010	-12.82	0.52
2011	-34.13	-0.26
2012	-11.20	0.57
2013	-56	-1.28
2014	-54.63	-1.20
2015	-57.01	-1.33
2016	-21.26	0.23
2017	-65.08	-1.80
2018	-22.43	0.18

Table M: SPI values Auraiya (1988-2018)

Year	3-Month A-M-J	3-Month J-A-S	6-Month O-M
1987 - 1988	1.04	0.70	0.24
1988 - 1989	-0.50	0.70	-0.43
1989 - 1990	1.27	1.96	0.10
1990 - 1991	-0.09	-0.56	-0.59
1991 - 1992	-0.32	-0.06	0.77
1992 - 1993	0.82	0.75	1.26
1993 - 1994	0.99	1.68	0.48
1994 - 1995	-0.17	0.74	-0.15
1995 - 1996	1.59	1.39	-0.31
1996 - 1997	1.16	0.04	0.34
1997 - 1998	1.10	0.68	1.42
1998 - 1999	1.28	1.45	0.70
1999 - 2000	-0.16	0.43	0.89
2000 - 2001	1.31	0.12	-1.30
2001 - 2002	-0.06	-0.08	0.45
2002 - 2003	-0.10	-0.66	0.50
2003 - 2004	-1.26	-0.68	-0.28
2004 - 2005	-1.67	-1.31	0.73
2005 - 2006	-0.12	-0.99	-2.11
2006 - 2007	0.01	-1.42	2.45
2007 - 2008	-0.57	1.05	-0.22
2008 - 2009	-1.83	-0.18	-1.80
2009 - 2010	-1.13	0.34	0.36
2010 - 2011	-0.93	-1.02	-0.27
2011 - 2012	-2.23	0.18	-0.12
2012 - 2013	1.10	0.27	-1.16
2013 - 2014	-0.95	-1.79	0.48
2014 - 2015	-0.29	-1.81	0.95
2015 - 2016	0.48	-0.75	-0.70
2016 - 2017	0.67	-1.46	-0.40
2017 - 2018	-0.27	0.29	-2.18

Table N: Auraiya, April-June

Year	Rainfall Deficiency	SPI
2008	-21	-0.57
2009	-33.72	-1.83
2010	-28.8	-1.13
2011	-26.52	-0.93
2012	-34.98	-2.23
2013	36	1.10
2014	-26.82	-0.95
2015	-15.18	-0.29
2016	7.92	0.48
2017	15.6	0.67
2018	-14.7	-0.27

Table O: Auraiya, July-September

Year	Rainfall Deficiency	SPI
2008	6.68	1.05
2009	-33.67	-0.18
2010	-18.01	0.34
2011	-54.39	-1.02
2012	-23.31	0.18
2013	-20.48	0.27
2014	-69.06	-1.79
2015	-69.31	-1.81
2016	-48.41	-0.75
2017	-63.28	-1.46
2018	-19.60	0.29

Table P: SPI values Banda (1988-2018)

Year	3-Month A-M-J	3-Month J-A-S	6-Month O-M
1987 - 1988	0.77	0.28	0.37
1988 - 1989	-0.11	0.23	-0.51
1989 - 1990	1.35	2.00	0.03
1990 - 1991	0.02	-1.76	-0.87
1991 - 1992	-1.05	-0.51	0.29
1992 - 1993	-0.32	-0.17	0.50
1993 - 1994	1.04	1.55	0.72
1994 - 1995	-0.46	0.43	0.13
1995 - 1996	1.12	0.84	0.70
1996 - 1997	0.45	-0.35	0.09
1997 - 1998	0.55	1.50	0.92
1998 - 1999	-0.44	1.58	0.52
1999 - 2000	-0.05	0.70	-0.15
2000 - 2001	0.89	-0.14	-1.53
2001 - 2002	-0.63	-0.17	0.53
2002 - 2003	-0.56	-1.19	0.50
2003 - 2004	1.29	-0.61	-0.08
2004 - 2005	2.21	0.46	0.56
2005 - 2006	0.18	-0.33	-0.79
2006 - 2007	-0.89	-1.18	0.97
2007 - 2008	2.04	0.34	-1.85
2008 - 2009	-0.33	-0.63	-0.88
2009 - 2010	-1.97	-0.27	1.10
2010 - 2011	-1.30	-0.76	0.36
2011 - 2012	-1.41	0.42	0.09
2012 - 2013	-1.60	-0.52	0.23
2013 - 2014	-0.48	-1.75	1.57
2014 - 2015	0.19	-1.39	1.96
2015 - 2016	0.20	1.89	-0.70
2016 - 2017	-0.60	-0.98	-1.85
2017 - 2018	-0.28	0.45	-2.64

Table Q: Banda, April-June

Year	Rainfall Deficiency	SPI
2008	399.85	2.04
2009	-5.88	-0.33
2010	-87.06	-1.97
2011	-67.35	-1.30
2012	-71.32	-1.41
2013	-77.94	-1.60
2014	-18.53	-0.48
2015	49.12	0.19
2016	49.41	0.20
2017	-27.94	-0.60
2018	-1.32	-0.28

Table R: Banda, July-September

Year	Rainfall Deficiency	SPI
2008	-7.36	0.34
2009	-32.21	-0.63
2010	-23.68	-0.27
2011	-35.09	-0.76
2012	-5.12	0.42
2013	-29.54	-0.52
2014	-54.63	-1.75
2015	-48.14	-1.39
2016	43.76	1.89
2017	-39.82	-0.98
2018	-4.24	0.45

Computation of SPI

Procedure and Formula for Computation of SPI

1. The transformation of the precipitation value in to standardized precipitation index has the purpose of
   a. Transforming the mean of the precipitation value adjusted to 0
   b. Standard deviation of the precipitation is adjusted to 1.0
   c. Skewness of the existing data has to be readjusted to zero

   When these goals have been achieved the standardized precipitation index can be interpreted as mean 0 and standard deviation of 1.0
2. Mean of the precipitation can be computed as

$$Mean = \overline{X} = \frac{\sum X}{N} \qquad \textbf{(A1)}$$

Where N is the number of precipitation observations
In EXCEL the mean is computed as Mean=AVERAGE (first:last)

3. The standard deviation for the precipitation is computed as

$$s = \sqrt{\frac{\sum (X - \overline{X})^2}{N}} \qquad \textbf{(A2)}$$

   In EXCEL the standard deviation is computed as s=stdevp(first:last)
4. The skewness of the given precipitation is computed as

$$skew = \frac{N}{(N-1)(N-2)} \sum \left(\frac{X - \overline{X}}{s} \right)^3 \qquad \textbf{(A3)}$$

5. The precipitation is converted to lognormal values and the statistics U, shape and scale parameters of Gamma distribution are computed.

$$\log mean = \overline{X}_{\ln} = \ln(\overline{X}) \qquad \textbf{(A4)}$$

$$U = \overline{X}_{\ln} - \frac{\sum \ln(X)}{N} \qquad \textbf{(A5)}$$

$$shapeparameter = \beta = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \qquad \textbf{(A6)}$$

$$scaleparameter = \alpha = \frac{\overline{X}}{\beta} \qquad \textbf{(A7)}$$

The Equations A1 to A8 is computed using built functions provided by EXCEL software.

The resulting parameters are then used to find the cumulative probability of an observed precipitation event . The cumulative probability is given by:

$$G(x) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx}{\beta^{\alpha}\Gamma(\alpha)} \qquad \textbf{(A8)}$$

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

$$H(x) = q + (1-q)G(x) \qquad \textbf{(A9)}$$

Where q is the probability of zero

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 following Edwards and Mc Kee (1997); we employ the approximate conversion provided by Abromowitz and Stegun (1965) as an alternative

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

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) 0.5 < H(x) \leq 1 \qquad \textbf{(A10)}$$

Where

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

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} 0.5 < H(x) \leq 1.0 \qquad \textbf{(A11)}$$

$$c_0 = 2.515517$$
$$c_1 = 0.802583$$
$$c_2 = 0.010328$$
$$d_1 = 1.432788 \qquad \textbf{(A12)}$$
$$d_2 = 0.189269$$
$$d_3 = 0.001308$$

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