Identification of Drought and developing a crop yield model using Meteorological and Geospatial data

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Identification of Drought and developing a crop yield model using Meteorological and Geospatial data

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This is to certify that the work presented in the dissertation entitled *Identification and Prediction of Drought using Meteorological and Geo-Spatial data* submitted by *Karinki Ravi Kiran*, Roll Number 216CE4084, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements of the degree of *Master of Technology* in *Water Resources Engineering*. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

(Mrs.) Sanat Nalini Sahoo
Asst. Professor

Dedication

This work is dedicated to my parents who have been with me in all situations during the period of my study.

Karinki Ravi Kiran

Declaration of Originality

I, ***Karinki Ravi Kiran***, Roll Number **216*CE4084,*** hereby declare that this dissertation entitled "***Identification and Prediction of Drought using Meteorological and Geospatial data"*** represents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any noncompliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

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Abstract

Due to lack of precipitation, drought has been increasing day by day which results in a severe effect on the productivity of rain-fed crops and indirect effect on the economy of the country. Drought is a climatic phenomenon which cannot be eliminated but it can be mitigated by utilizing Spatio-temporal information, which is related to available crop yield data. In this study, drought year was identified by using 1-month Standard Precipitation Index (SPI). This index was in good relation with Normalized Difference Vegetation Index (NDVI) because both are dependent on Precipitation data. Based on this NDVI-SPI, regression models were developed. The obtained NDVI is correlated with different types of crop yield and crop yield models were developed. The highest correlation was found in Anantapur district for Sugarcane crop, Jowar in Chittoor, Horse Gram in Kadapa and Sesamum in Kurnool. The RMSE of predicted yield in a drought year was found to be 5.05% for sugarcane which was about 4.92 t/ha of average yield, 13.3% for Jowar which was about 0.006 t/ha of average yield, 9.04% for Horse gram which was about 0.02 t/ha of average yield and 6% for Sesamum which was about 0.01 t/ha of average yield.

Keywords: **drought indices, SPI, NDVI and Crop Yield**

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Chapter-1

Introduction

1.1 Background of drought

Drought in India has been I focus since 1960's. Out of total area (32,87,263 sq. Km) of the country, drought-prone area is about 5,11,300 sq. Km (IMD). The main cause of drought is the sudden failure of monsoons or excess amount of rainfall in summer seasons. In India average rainfall of 1,170mm per year (India – Rivers catchment, Water Resources of India). Total water amount of water availability in India through rainfall, groundwater potential, surface water potential is about 5107 cu. Km. Out of this amount of water, India receives more than 80% within 4 months and rest of the months are dry (IMD). Along with this water availability, melting of snow in the Himalayas also contributes towards water resources of India. Most of the regions in India are arid, semi-arid and tropical regions. In arid regions, the rainfall gets less than 300mm and in the semi-arid region, the rainfall is in between 450-750mm annually whereas in tropical regions extreme summer heats up to 50° and in winter low to 1° and average rainfall varying in between 300 - 650 mm.

1.2 History of Drought in India before Independence

During 18th, 19th and 20th centuries, tens of millions of deaths has encountered due to Droughts in India. A flattering southwest summer monsoon is more beneficial for agriculture in India. Based on this climatic condition in Indian agriculture is vigorously dependent. In sometimes the failure of monsoons effects in shortage of water which resulting in below-average crop yields. This is mostly true for major drought-prone regions like Maharashtra, Karnataka, Andhra Pradesh, Odisha, Gujarat, Telangana and Rajasthan. Due to major drought effects, one third population is effected in Bengal famine of 1770, five million people died in 1879-1877 and 4.5 million people in 1899 (Nash, 2002 and Collier 2002). Before pre-Independence in India, Agra was greatly struck by drought in 1837-38. Before this drought situation in Agra there are several droughts during 1803-04, 1813-14, 1819, 1825, 1827, 1832-1833. Along with this drought, several factors also affect the economic conditions and leads to depression for 10 years from the 1830s. During 1837 a worst case seen in Doab area between Allahabad and Delhi due to the summer monsoons. Same situation held in districts of Trans-Yamuna as well. In Odisha, the rainfall was scanty in 1865 and the next year 1866 it was greatly hit by famine due to failure of monsoons. People was greatly suffered because of food reserves less than they needed. In Bundelkhand famines were started early in 1896 and suffered a lot. People in this area already suffered from 1895 because of inadequate summer rains. After shortage of rains the provisional government declared 1896 is a drought year. Soon this famine spread over to united provinces, Berar, central provinces, some parts in Bombay, Madras presidencies, upper Burma, Punjab and princely states such as Hyderabad, Rajputana and central Indian Agency.

In 1899-1900 famines in India, because of the failed summer monsoon, affecting central and western India. In this famines, the most affected places are central provinces, Berar, Bombay presidency, Ajmer-Merwara province, Hisar district in Punjab, Rajputana, Hyderabad, Bengal Presidency and North-western Provinces.

1.3 Droughts in India after Independence

After Independence India has suffered from drought in the 69 years. This drought affected can be formulated below in table 1.1.

Apart from these Droughts, Maharashtra has severely affected by drought in 2013 and 2015. In 2013, Maharashtra severely faced low rainfall condition in monsoon season. It was never faced this kind of worst situation in the last 40 years. In 2015 around 90 lakh farmers affected in Maharashtra which is close to the population of Sweden. Highest Suicides number of farmers taken in Maharashtra, India because of their expectations are not satisfied by the monsoons. Due to this 50% of agriculture production has stopped in the state.

Table 1.1: showing affected years in India

Year of Drought	Affected places	No. of people affected
1966	Bihar and Odisha	50 million
1969	Rajasthan, Gujarat, Tamil Nadu, Uttar Pradesh, Andhra Pradesh, Karnataka, Haryana and Madhya Pradesh	15 million
1970	Bihar and Rajasthan	17.2 million
1972	Rajasthan, Himachal Pradesh and Uttar Pradesh	50 million
1979	Eastern Rajasthan, Punjab, Himachal Pradesh and Uttar Pradesh	200 million
1982	Rajasthan, Punjab and Himachal Pradesh	100 million
1983	Tamil Nadu, West Bengal, Kerala, Rajasthan, Karnataka, Bihar and Odisha	100 million
1987	The Whole of eastern and northern India	300 million
1992	Rajasthan, Odisha, Gujarat, Bihar and Madhya Pradesh	NA
2000	Rajasthan, Gujarat, Andhra Pradesh and Madhya Pradesh	More than 100 million

1.4 Drought and its definitions

Drought is a creeping disaster that slowly effects the Nation in different ways. Simply Drought is a complex phenomenon which is difficult to monitor and define because of its inception and its end (Wilhite, 1993).

The drought has many definitions. According to Wilhite and Glantz, (1985) drought depends on timely onset monsoon and also a long-term average balance between precipitation and evapotranspiration in a particular area. According to Dracup et al., (1980) drought is due to "lack of rainfall which is continued to a prolong time period" which affects the plant and animal life and also reduce the supply of water for domestic purposes along with power plant operations in that region. By Mokhtari et al. (2011) drought is a repeated weather event which leads to water shortages, economic losses, and adverse social consequences. According to Gonzalez and Valdes (2006) and Beran and Rodier (1985) drought is a tenacity of rainfall shortage for a specific area and certain duration of time. This effect of drought is further expanded to environment and society (Tsakaris and Vangelis, 2004). In this point of view shortage of rainfall also effects the groundwater conditions which focus on the human demand for water supply (Wilhite, 2004).

The National Commission of Agriculture in India characterized drought into four categories. Meteorological, Agricultural, Hydrological and Socioeconomic droughts. Meteorological is defines where precipitation levels fall below normal. It may be short term and long term. Agricultural drought occurs when there is insufficient rainfall to the crop during growing season. It leads to abnormal growth and wilting of the crop. This is called crop stress period. Hydrological drought has significant effect instream flows, lakes, reservoirs, groundwater conditions when there are less than normal levels (Rathore 2004). Socioeconomic drought occurs when the above three drought effects to human economy and cause problems for people living in.

1.5 Drought Years through rainfall Anomalies during 1871-2017

This rainfall Anomalies developed by Indian Institute of Tropical Meteorology and is based on rainfall data from 306 rain gauges. This rainfall anomaly mostly done in monsoon season (June- September) in India. The results are obtained based on reliable index. There are 19 major flood years (in figure 1.1 anomaly +10% exceeding; blue bars above) during 1871-2015 (1874, 1878, 1892, 1893, 1894, 1910, 1916, 1917, 1933, 1942, 1947, 1956, 1989, 1961, 1970, 1975, 1983, 1988, 1994) and 26 major drought years (in figure 1.1 anomaly -10% exceeding; red bars above) during 1871-2015 (1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002, 2004, 2009, 2014,

2015) defined by All India Summer Monsoon Rainfall (AISMR) which are excess of one standard deviation about mean.

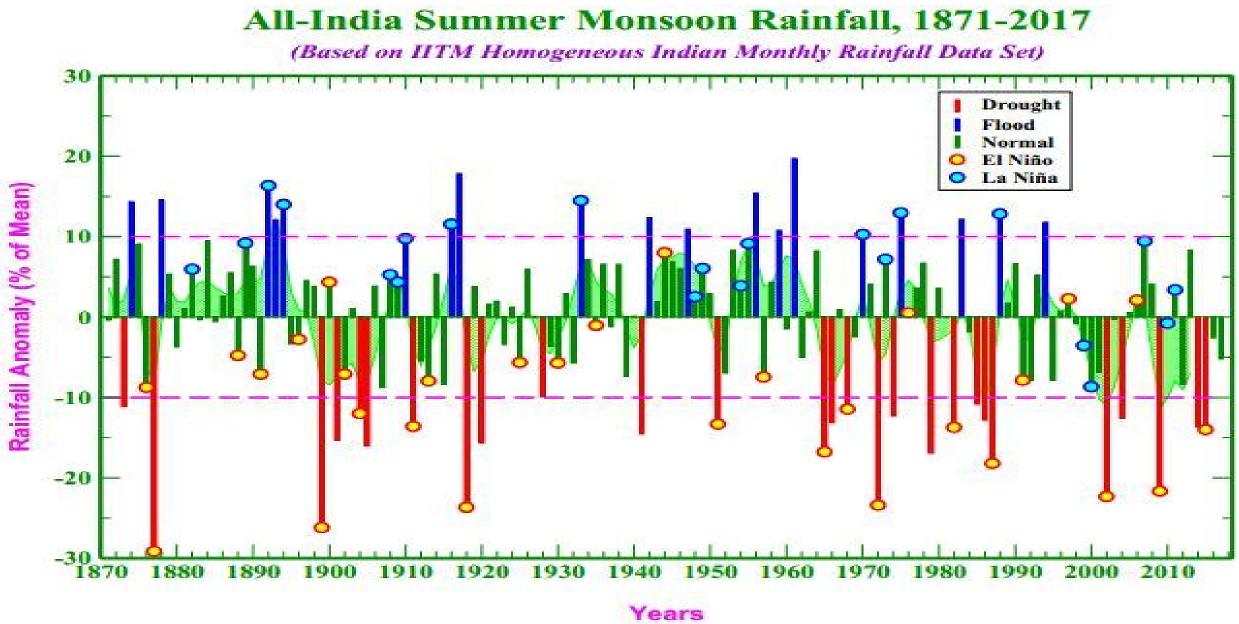

Figure 1.1: Drought and flood through Rainfall Anomaly

1.6 Impacts of Droughts

Drought has many impacts in the sectors of the economy and operates in different time scales. Globally, natural disasters cause 22% of the economic damage and 33% to the people affected by drought (Keshavarz et al., 2013). In Sub-Saharan Africa, where 95% of agriculture is rain-fed, caused more severe drought impact and in 2009 drought has increased its severity due to lack of rainfall and this leads to increase food scarcity for 53 million people in this region (Husak, et al., 2013). Due to direct and indirect effect of droughts, more than 1.3 million human lives were lost and 3.5 million people killed by disasters (obasi, 1994). For countries like India, Agriculture is the backbone to the economy of the country. More than 68% of people dependent on agriculture (Dutta, D., et al., 2015). Most of the agriculture is done based on monsoons and this monsoon is seasonal, external water resources also required for better crop yields (Baharat Kumar, L. and Mohammed Aslam, 2015). According to global consumption of water resource, 70% of water resource is accounts for agriculture and 20% for Industrial purposes and 10% is for domestic use.

Agriculture drought is a natural hazard that occurs when natural water levels fall below the normal level which effects the proper growth of plants in growing season (Wilhite et al., 2007). Agricultural drought decreases the productivity of crops due to a decrease in rainfall and increase in temperature rate which leads to the deficit the soil moisture content. It is a common phenomenon in India and is noticed in the years 1972, 1979, 1982, 2002 (Rainharvesting.org 2006). Drought-prone areas in the country are mainly arid, semi-arid and humid regions. In the year 2002-2003 India has faced severe drought in terms of magnitude, duration, spacing, and dispersion (Patel et al., 2012 and Dutta et al., 2013). In the drought occurrence period, the land was unable to cultivate and this situation affects the environmental condition of human beings, livestock population, plant species and potential biomass (Siddiqui, 2004).

The most commonly used hydro-meteorological variables to identified agricultural drought are precipitation, evaporation, temperature, soil moisture, etc. To identify the drought using these hydro-meteorological variables, meteorological indices are used. A drought index combines the innumerous water supply data into a single data and makes this raw data helpful to the decision makers (Ji and Peters, 2003). The most common meteorological index, using rainfall data, is Palmer Drought Severity Index (PDSI), which is commonly used by the U.S Department of agriculture to emergent out quickly (Palmer, 1965). But this index performs best with uniform topography with large areas. There are some other indices also available such as China Z-Index (CZI, Wu et al., 2001), Rainfall Decile based Drought Index (RDDI, Gibbs and Maher, 1967), Crop Moisture Index (Palmer, 1968), Bhalme and Mooley Drought Index (Bhalme and Mooley, 1980), surface water supply Index (Shafer and Dezman, 1982), etc. Just like PDSI most of these indices developed for certain regions and have certain limitations to use in different climatic conditions. For example, CZI is used in China, RDDI is used in Australia. Hence to overcome these disadvantages Tom McKee, Doesken and Kleist (1993) invented Standard Precipitation Index (SPI) in Colorado climate center to use anywhere in India. The advantage of this index emerges drought sooner than PDSI with different spatial and time scales (NDMC 2006). SPI is applicable for both uniform and non-uniform topography with both large and small areas. Drought severity-area-frequency curves developed in the Kansabati river basin, India by analyzed the spatial and temporal relationships using SPI as a drought severity indicator (Mishra and Desai, 2005). The precipitation data used in calculating the SPI index is obtained from Indian Meteorological Department (IMD) from various meteorological stations in the study area. To ensure more accuracy this index is merged with geospatial index.

For proper utilization of water resources, scientific methods for agricultural practice has to be adopted. In the present scenario, Remote Sensing and GIS techniques play a crucial role in agricultural practices and its implementations by providing different spatial and temporal time scales (Zhang and Hoffman, 2011). With the help of Satellite sensors and continues data sets drought can be monitor and can use to detect its magnitude and duration at the beginning (Thiruvengadachari and Gopal Krishna, 1993). Unlike traditional methods like field survey and sampling questionnaires, Remote Sensing and GIS techniques take less time to get the data for a particular region (Thenkabail, (2004); Brian et al., (2012)). To monitor the drought condition through Remote sensing and GIS, geospatial drought indices are developed. These indices work on the reflectance of different bands with different pixels. The size of the pixel depends on the type of sensors used in the satellite. Generally, vegetation indices are mostly used by the number of scientists for agricultural field mapping, weather impacts, crop yield, calculating biomass, and for determining the strength of vegetation (Tucker et al. (1982); Justice et al. (1985)). There are so many vegetation indices are available but the simplest and efficient one is Normalized Difference Vegetation Index (NDVI), which is commonly used (Liu and Huete, 1995; Son Cru, 2012). But NDVI is not free from defects such as data error during the rainy season, saturation condition on vegetation, etc. so to overcome these defects and for more accuracy, both SPI and NDVI is used in the present study.

1.7 Objectives

- To Calculate different drought indices like percentage of departure, percent of normal, deciles and SPI using past precipitation data for Rayalaseema region, Andhra Pradesh.
- To estimate monthly NDVI for the study area.
- To identify and predict the drought phenomenon using SPI and NDVI in that region.
- Developing a model to predict crop yield in the region using Meteorological data, geospatial data along with crop yield data.

1.8 Theses Outline

The aim of this work is to identify the drought and developing a crop yield model based on precipitation data and Normalized vegetation index. This study helps to mitigate the agriculture drought and gives a better suggestion for better crop yield. This work comprised of 6 chapters. Chapter 1 deals with history and impacts of drought from the 18^{th} century to 20^{th} century and also change in various definitions of drought from ancient era to modern era. Various literature studies are being carried out all over the world based on both Meteorological and Geospatial drought indices are portrayed in chapter 2. Chapter 3 deals with the location and history of the study area. Chapter 4 deals with the various methodologies adopted in this work and significance of indices in the study area. Chapter 5 portrays the outcomes and discussion of the work. Chapter 6 portrays the conclusion and future scope of the work.

Chapter-2

Literature review

2.1 Introduction

So far many studies have done to identify the drought and predicting crop yield in different ways. Simple and quick methods to identify drought through drought indices is popularly adopted in India as well as all over the world. This is because drought index value is a single number which is more useful than raw data like precipitation, evaporation, stream flows, etc. for decision makers. More than 150 drought indices are developed (Niemeyer 2008) and some other indices are proposed (Cai et al. 2011 and Karamouz et al. 2009). Drought can be categorized in to Meteorological, Hydrological, Agricultural and Socioeconomic drought (Wilhiten and Glantz 1985). In many studies individual studies have been done till today and very few done with combination of Meteorological, Hydrological, Agricultural and Socioeconomic indices. In between combinations of indices several disadvantages are raised and some models failed to predict the crop yield. So I choose this as a challenge task and make several correlations between the combination of meteorological and geospatial data using Remote Sensing and GIS techniques.

2.2 Literature

2.2.1 Literature on Meteorological Indices

According to Wilhite, D. A., and Glantze, M. H. (1985) drought has many definitions. It is not same all over the world. The subdivision of drought into four categories (Meteorological, Agricultural, Hydrological and Socioeconomic droughts) are most helpful to identify the drought in an easy way. Most of the drought studies related to society. The study of drought definitions gives a clear view and helps to use exact definition depends on location.

Gutmann (1998) in his studies made a comparison between Drought indices and he recommended SPI than PDSI because of its simplicity, spatially consistency, probabilistic nature. SPI is user-friendly and is adjusted for different time scales whereas PDSI is complex in nature and is fixed time periods.

Hayes et al. (1999) conducted his studies on southern plains and the southwestern USA and he preferred SPI than PDSI because of more versatile and flexible for different time periods. It is useful for both short term and long term. SPI is used for both uniform and non-uniform topography. It gives drought identity one month before and is no solution for all drought events. By the use of Remote sensing techniques, it plays a better role in the development of society.

Michael. J. et al. (1999), SPI reveal that it would have been a useful tool for detecting and monitoring the drought in the southern plains and southwestern united states. This study has illustrated how the SPI could have been used operationally to follow both the regional and local progression of the drought from its development in late 1995 to its conclusion during the summer and fall of 1996 for most areas (Michael. J. et al. 1999).

Wilhite et al. (2000) conducted his studies in California, 1997 and he signifies that SPI is far better than PDSI because of clear quantitative assessment in duration, intensity, Spatial extent. It is real-time monitoring tool for identification of drought.

Bordi, I. et al. (2001) analysis of SPI is done from 1948 to 1981 in Marche region. Precipitation data is obtained from two different agencies and Comparison has done between obtained results and precipitation shows large-scale and regional scale areas are in good agreement.

Keyantash and Dracup (2002) performed an evaluation among drought indices based on six criteria, i.e. robustness, tractability, transparency, sophistication, extendibility, and dimensionality which shows SPI as the second highest ranked drought index, with a total score of 115 after the rainfall deciles with a score of 116. As a result, this index has been much used by different researchers for drought-related study (Duttaa et al. 2013).

Naresh Kumar, M. et al. (2009) Application of SPI using 39years monthly rainfall data shows better stretching in high rainfall areas compared to low rainfall areas. P values and Shapiro-wilk statistics confirmed the normal distribution of SPI shows dry and wet areas. So it is suggested that SPI is sufficient to estimate and predict the intensity of drought.

Karavitis, C. A. et al. (2011) the main purpose of this study is to better understanding of SPI by the application in Greece. Rainfall data is collected 1947 to 2004 and different time scales were used. SPI is calculated through a software tool and spatial output is converted into statical methods using a statical tool called “SURFER 9”. This index shows onset ending and severity levels. SPI exhibits a forecasting of drought and make protective measures before it hits.

Shah, R. et al (2015) from the study shows that SPI is variation is 50% between wet and dry conditions. SPI is good for agricultural applications as it is probabilistic nature, simple and easy. The only parameter used is rainfall no other climatic parameters temperature, humidity, potential evapotranspiration etc.

2.2.2 Literature on both Meteorological and Geospatial Indices

Ding, M. et al. (2007) from his study, it assessed the temporal and spatial changes of vegetation cover on the Tibetan plateau in China and analyzed the relationship between precipitation and vegetation using 1982 to 1999 data. This study about driving factors of vegetation change is emphasized at the regional scale, which is favorable for production and ecological restoration and is significant for the study of global change. It has a good spatial correlation between NDVI and Precipitation for the medium vegetation grassland and in very less effect forest and desert area. This results proved that it was easy and economical for large areas to identify agricultural drought.

Murali Krishna. T. et al. (2008) from his study in the polar basin in Tamil Nadu, India conclude that the vegetation indices are used to identify the growth levels of plants and NDVI can effectively be used for monitoring growth rate of plants. The maps showing the distribution of NDVI for paddy indicate that the vegetal cover in the year 1999 is much less compared to 1998. It is observed that 60% of the total basin is affected by a reduction in paddy area in samba season and 75% in Bavaria season as indicators of drought condition in 1999.

Jain et al. (2009) from his studies, SPI analysis was carried out in different zones based on rainfall distribution in the southern part Rajasthan, India at 1-month intervals and revealed that 2002 was the most drought-affected year whereas NDVI provides a picture of vegetation stress on a regular basis. SPI and NDVI are correlated with each other as SPI is directly dependent on rainfall and NDVI are indirectly related to vegetation growth.

Zargar, A. et al. (2011) performed his studies on seventy-four drought indices to quantify the drought severity levels and declaring drought indices are used for early warning and monitoring for a variety of operations. This gives a comprehensive overall view of all indices based on characteristics like duration, Magnitude, intensity, severity, geographic extent, and frequency. This study describes the major six frequently used indices like SPI, percent of

Normal, Deciles, PDSI, NDVI, VCI. Among these indices, SPI and NDVI are popularly adopted.

Dutta. et al. (2013) from the study of identify the agricultural drought over Rajasthan using remote sensing based vegetation condition index (VCI) and assesses the performance of VCI by comparing the estimates with meteorological drought indicator SPI and found less than 35% over most of the areas of Rajasthan in 2002 indicating drought-related stress during that year.

Nikbakht, J. et al. (2013) streamflow drought is identified using percent of Normal Index (PNI) in Urima lake in Iran. Results show that worst drought condition is seen in 1999-2000 and 2000-2001. In last 34 years, drought severity has increased. This study is helpful for water resources management in Iran. So it is declared that PNI is a useful index to identify the drought instream flows.

From the study “Assessing agricultural drought at a regional scale using LULC classification, SPI, and vegetation indices” Andres Sierra-Soler, et al. (2015) the changes were observed and detected in the values of NDVI and VCI support the conclusion that vegetation condition was affected by the weather patterns in 2005. This was noticed in the patterns and the very low values of NDVI and VCI in the normal rainfall year 2000. This is consistent with the precipitation analysis (SPI) which indicated clear deficits in precipitation in 2005.

Ganapuram, S. et al. (2015) from his studies drought is analyzed by using Rainfall Anomaly Index (RAI) in Pedda Vagu and Ookacheti Vagu watersheds in Telangana, India. By the use of GIS and Interpolation techniques, this study reveals occurrence magnitude and frequency of drought varies between the basins in 1986 to 2013. RAI helps to identify drought-prone stations and it helps to take vulnerable drought-prone measures prior to occur.

Gandhi, G. M. et al. (2015) NDVI is adopted for the change in vegetation condition in Tamil Nadu, India. Using Multispectral Remote Sensing different classification has done accordingly with a change in NDVI values. Classification is done between forest areas, water bodies, open lands, barren lands, cultivable lands etc. This is a beneficial tool for predicting natural disasters and brings new strategy for an action plan to protect damage. From this forest and barren land cover, vegetation type decreases by 6% and 23% from 2001 to 2006. So the change in vegetation cover can be done easily by supervised classification using NDVI which brings a lot of change in climatic conditions. NDVI gives a better result in densifying the vegetation areas using multispectral Remote Sensing data.

Homdee, T. et al. (2016) performed his analysis on different standard climatic drought indices in Chi river basin, Thailand. Results show that different indices have various effects on different drought conditions. Simply SPI considered precipitation with certain restrictions. Moreover, different indices show different climatic variations with agriculture impact in Thailand.

Sholihah, R. I. et al (2016) Monitoring the agricultural drought in order to reduce food scarcity in Indonesia using vegetation health Index (VHI), Land Surface Temperature (LST) which are derived from NDVI. The results reveal that both indices decreased 50% from 2000 to 2015. This study attempt to find drought using VHI and found that successfully identified agricultural drought.

Khosravi, H. et al. (2017) conducted his studies on vegetation using SPI and NDVI in central Iran. Annual SPI is calculated from 1996 to 2015 and NDVI mapping is done for May 1998, 2000, 2009, 2010, 2011, 2015. There was a good correlation between dense and poor vegetation 2010 and the very poor correlation between both classes in 2000. So SPI and NDVI were used as a better indication for drought.

All these literature are almost out of the country and some are within the country and nowhere the combination of drought indices are applied for small areas. In this study, I used a combination of SPI and NDVI to identify drought and to predict the crop yield for a small area like districts. Some other meteorological indices also used to justify the results of SPI.

2.3 Critical appraisal

- So far different drought indices such as EDI, RAI, SDI, SWSI, etc., are applied for similar type (arid or semi-arid regions) of climatic zones. In the present study, drought indices SPI and NDVI are applied for both combinations of arid and semi-arid regions.
- SPI is the second highest drought index with a total score of 115 indices and also applied for both uniform and non-uniform topography and also it is acceptable in India. It has more advantages than other Meteorological Indices. hence it is used in model equations than other indices

Chapter-3

Study area

3.1 Introduction

Andhra Pradesh state is popularly known as “Rice bowl of India”. The main source of income to the state is Agriculture and more than 60% of population engaged with agriculture and some other works related to agriculture. It is one of the 29 states of India. It is located in the southeastern coast of the country. It is the eighth largest state of India with area wise having 162,970 sq.km. area and is tenth-largest state by population with 49,386,799 inhabitants as per 2011 census of India. This state has a coastal line of 974 km and is second largest coastal line in India after Gujarat. This state is bounded by Telangana in the north-west, Odisha in the north-east, Karnataka in the West, Tamil Nadu in the south and Bay of Bengal in the east. This state consists of three major regions namely, coastal Andhra, Uttar Andhra, Rayalaseema. These three regions consist of 13 districts. Out of 13 districts, 3 districts in Uttar Andhra namely Srikakulam, Vizianagaram, Visakhapatnam; 6 in coastal Andhra namely, East Godavari, West Godavari, Krishna, Guntur, Prakasam and Nellore; and 4 in Rayalaseema namely, Anantapur, Kurnool, Kadapa, Chittoor.

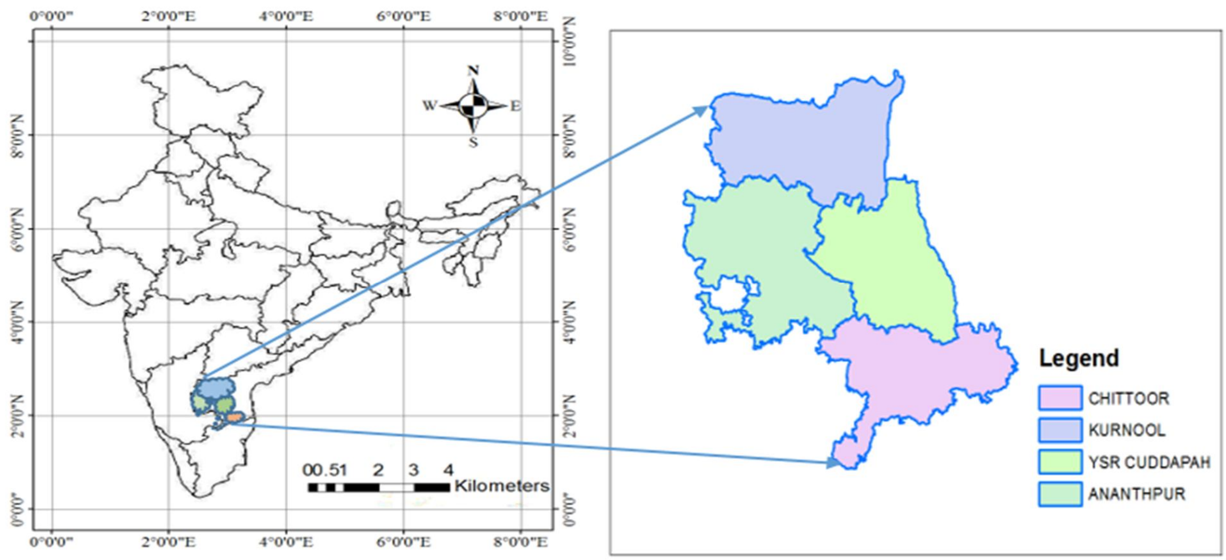

Figure 3.1: Rayalaseema region in Andhra Pradesh, India

This study is focused on Rayalaseema region (Figure 3.1) because it is declared as drought-prone region by the state government administration, Andhra Pradesh and also by observed the previous rainfall statistics. This region consists of four districts namely, Anantapur, Kurnool, Kadapa, Chittoor. During British era, these four districts is under Madras Presidency till 1953. From 1953-1956 these districts became a part of Andhra state. In 1956 Telangana is combined with Andhra state to form Andhra Pradesh. This Rayalaseema region is in rich minerals such as Asbestos, Barites, China clay, Iron ore, diamonds, etc. The longest water canal project in Rayalaseema region is “Handri - Neeva Sujala Sravanthi” project. This project is the major source to facilitate the irrigation needs and apart from irrigation it also satisfies for drinking water facilities for Chittoor district (Govt. of A.P, Water Resource Department). This canal links major rivers like Handri river, Chitravathi river, Papagni river, Penna river, Mandavya river, Bahuda river, Cheyyeru river, Palar river, Vedavati river and some other rivers in Rayalaseema region. Most of these rivers lies in rain shadow regions and hence these are storage of reservoir depends on rainfall in monsoon seasons. So indirectly the farming in this region is completely dependent on rainfall only.

Anantapur district is one of the districts in Rayalaseema region and is located in the Latitude 14° 41′ N and Longitude 77° 39' E. It is the 7th largest district India and largest in Andhra Pradesh in terms of area. The population of this district is 40,83,315 as per the 2011 census. The northern, southern and central part of this district surrounding by large hills. Six major river flows in this district. They are Penna, Chithravathi, vedavathi, Papagni, Swarnamukhi, and Thadakaleru. The average annual rainfall in this district is 381mm. the rainfall is very less due to it located under rain shadow area of Indian Peninsula. The major crops in this region are groundnut, rice, sunflower, cotton, maize, chilies, sesame, and sugarcane.

Kurnool district is referred to as “The Gateway of Rayalaseema”. It is the capital of Andhra Pradesh in between 1953 to 1956. According to 2011 census, it is the 5th population city, with population 4,60,184, in the Andhra Pradesh state. It is located at Latitude 15° 50' N and Longitude 78° 05' E. The average rainfall in this district is about 705mm. It lies on the banks of Tungabhadra river. The major crops in this district are Jowar, Bajra, Maize, Sugarcane, sesamum, cotton, groundnut, etc.

Kadapa district is the “heart of the Rayalaseema region” as it is connected to the four districts of the Rayalaseema region. The population of this district is about 2,884,524 as per 2011 census. It has a population density of 188 persons per square kilometer area. It is located at Latitude 15° 34' N and Longitude 79° 09' E. The average annual rainfall in 710mm. The major rivers that flow in this district are Chitravathi, Papagni, Penna, Kunderu, sagileru, Cheyyeru and Bahuda. Some of the important crops are Paddy, Groundnut, Red gram, cotton and Bengal gram.

Chittoor district is one of the districts in Rayalaseema region and is famous for temples. As per 2011 census data, the population of this district is about 4,170,468. It is located at Latitude 13° 13' N and Longitude 79° 08' E and thirty percent of forest area are covered by the total land area. Its annual rainfall is about 918.1mm. On an average, only 30% land is irrigated and rest of the 70% is dry land which depends on rainfall. The major crops are millets, ragi, bajra, Jowar, groundnut, red gram, horse gram, bean pea, etc., Mostly all crops are dry crops and are rain-fed crops.

3.2 Problem Statement

Rayalaseema region is frequently headed by drought for many years. In recently March 2017 with the rising of the high-temperature reservoir are dried up. The people in this region are moving by selling their belongings.

By the last visit of “Rythu Swarajya Vedika”, a fact-finding committee, released several mandals in this region affected by drought. This says that 70% of the talented farmers are committed to suicide because their crops are not grown and their family’s debt in loans. During Kharif season in 2017, the state government declared 63 mandals in Anantapur, 53 mandals in Chittoor, 36 mandals in Kurnool and 32 mandals in Kadapa are hit by drought. The rainfall received in this region 533.8 mm whereas normal rainfall was 556mm in between June to September. In 2016, the count was 357 mandals from all four districts. The people from this region have to migrate to another region because they don’t have proper food and drinking water. I witnessed this condition at regular intervals. Even though some measures are taken to eradicate this situation but are in vain and still continues.

Chapter -4

Methodology

4.1 Standard Precipitation Index

In this study various meteorological Indices like Standard Precipitation Index (SPI), percent of Normal (p_n), Percentage of Departure (p_d), Deciles or 10%iles and GeoSpatial Index like Normalised Difference Vegetation Index (NDVI) are used. Drought index is a single number to identify drought and useful tool to the decision makers. The most popular drought index is PDSI and which is popularly used in U.S. (Palmer 1965). It is a complex in nature and is apply for water supply demand. Simply it is a hydrological index (Guttman 1999). The major disadvantage of this index is applied for a large areas and for uniform topography.

To overcome the complexity and disadvantages of PDSI, McKee et al. 1993 developed a new index named SPI. It is the second-ranked meteorological index out of 115 indices based on robustness, transparency, sophistication, extendibility, and dimensionality (Keyantash and Dracup 2002). SPI identifies drought faster than PDSI (Jain et al. 2009). SPI is a simple and powerful index and is purely depend on rainfall data only. It is similar to the percent of Normal but the only difference is probabilistic nature. It is well suitable for identification of wet and dry regions. It uses long-term precipitation records to identify drought in short-term and moisture deficiency conditions (Sims et al. 2002). It requires minimum 20 to 30 years of monthly rainfall data and optimum 50 years preferred by Guttman (1994). Many past types of research showing several advantages than PDSI (Szalai and Szinell 2000). Morethan 70 countries are using this index due to its strengths like flexibility, versatile, only single input parameter and also applied for both uniform and nonuniform topography with multiple time scales (Svoboda, M. et al. 2012 and Boken et al., 2005). It is calculated for different time scales (Homdee et al 2016). It is calculated by the frequency of the cumulative distribution of precipitation time series is fitted to a gamma probability function and the obtained distribution is transformed to the normal distribution of standard deviation one with mean zero (Loukas and Vasiliades 2004). It is given by Eq.(1)

$$g(x) = \frac{x^{\alpha-1}.e^{-x/\beta}}{\beta^{\alpha}.\Gamma\alpha}, for\ x > 0 \ldots\ldots (1)$$

$$\Gamma\alpha = \int_0^{\infty} y^{\alpha-1} \;\; e^{-y}$$

Where α > 0 is a shape parameter (statistical), β > 0 is a scale parameter, x is the amount of precipitation and $\Gamma\alpha$ is the gamma function. The maximum likelihood optimum solutions for α and β are estimated by Thom (1966) as

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}}\right.$$

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

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

Where ‘n’ is a number of precipitation observations.

The cumulative probability is given by

$$G(X) = \int_0^{x} g(x)\, dx = \frac{1}{\beta^{\alpha} . \Gamma\alpha} \int_0^{x} x^{\alpha-1} \;\; e^{\frac{-x}{\beta}}$$

Letting $t = x/\beta$ then the above equation changes to

$$G(X) = \frac{1}{\Gamma\alpha} \int_0^{x} t^{\alpha-1} \;\; e^{-t}\, dt$$

Since the gamma function is undefined for x = 0 and precipitation may contain zeros and hence probability becomes as

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

Where q is the zero probability. Now H(x) is transformed to a standard normal random variable with mean is zero and variance is one. For this case, Abromowitz and stegun (1965) provided an alternate solution as

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

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

Where

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

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

$$c_0 = 2.515517$$

$$c_1 = 0.802583$$

$$c_2 = 0.010328$$

$$d_1 = 1.432788$$

$$d_2 = 0.189269$$

$$d_3 = 0.001308$$

The values c_0, c_1, c_2, d_1, d_2, d_3 are constants which are widely used. Based on this distribution categorization has done and the range is shown in table 4.1.

Table 4.1: Classification of SPI (adapted from McKee et al. 1993)

SPI	**Drought category**
>2	Extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.49 to -1.0	moderately dry
-1.99 to -1.5	severely dry
< -2	extremely dry

It is developed for identifying drought in multiple time scales like 1- month, 3- month, 6-month, 9-month, 12-month, 24-month, 48-month, and so on. According to Statistics 1-24 month SPI has a wide range of practical applications (Guttman, 1994 and 1999). Mostly 1-month to 6-month time scales are used for agricultural drought and up to 24-months are used for hydrological drought analysis (Svoboda, M. et al. 2012). The impact of time scales on drought has a lot of significance in water resources. The impacts and different time scales application shown in table 4.2 (Zargar, A. 2011).

Table 4.2: SPI and its Applications

SPI duration	Phenomena	Applications
1-month	Short-term conditions	Short-term soil moisture and crop stress especially in growing season
3-month	Short and medium moisture conditions	A seasonal estimation of precipitation
6-month	Trends in precipitation levels (medium term)	Potential for effectively showing the precipitation over distinct seasons
9-month	precipitation pattern in medium time scales	It is a good indication that substantial impacts can occur in agriculture and other possible sectors
12-month	Long-term precipitation patterns	Applicable for stream flows, reservoir levels, and groundwater levels

According to SPI, drought starts when the value becomes equal to or below -1 and the drought event ends with the positive value (Svoboda, M. et al. 2012). Due to standard deviations, the positive values of SPI shows greater than median precipitation and negative values show less than median precipitation (Edwards and McKee, 1997). The values of SPI has fit in a normal distribution these values lie in one standard deviation approximately 68% of the time, 2 sigmas within 95% of the time, 3 sigmas within 98% of the time (Zarch et al. 2015). This index is widely used because of adaptability to various time scales and climatic conditions. The entire procedure of SPI is set up in a DrinC software and 1-month SPI is calculated through this software.

4.2 Estimation of the percentage of departure (p_d)

The percentage of departure is a meteorological drought index which shows the deviation of precipitation from actual precipitation. For a given time and for a specific area, the percentage of departure is an easy and simple indicator for both wet and dry conditions (Jain et al. 2015). In this method, the dry season is to be identified based on the rate of deviation of yearly precipitation from the long haul yearly mean precipitation. This drought index can be estimated by using Eq. (2) and the classification of drought can be evaluated as per the criteria are given in table 4.3

$$p_d = \frac{p_i - \bar{p}}{\bar{p}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where p_i is the annual precipitation in the present year and $\bar{p}$ is the mean precipitation for the past 'n' years.

Table 4.3: Classification of drought based on percentage departure (adapted from Mahesh, C 2016)

Percentage of departure	classification
≥ 0	No Drought
0 to -25	Mild Drought
-26 to -50	Moderate Drought
≥ -50	Severe Drought

4.3 Estimation of a percent of normal

Another meteorological drought index is a percentage of normal index which interprets the deficient of rainfall from wet season to dry season or vice-versa as precipitation deviates from the normal annual precipitation. It is one of the easiest drought monitoring tools which is usually used by the Television weathercasters and normal people (Hayes 2003 and Morid 2006). It is a simple quantitative measure for any statistical formulation of a percent of normal. Usually, a minimum of mean past 30 years rainfall data is used but for mere accuracy 45 years rainfall data is used.

This index is obtained by dividing a given precipitation by the normal precipitation for the time being considered and the obtained result is multiplied with 100. It is easy to compute and can be easily compared with other areas for any time period. It can be computed on daily, weekly, monthly basis along with seasonal and annual timescales, which will suit various user needs. It makes easy to identify drought and its impacts because of its simplicity and transparency which makes it easy and favorable for communicating drought levels to the public (keyantash and Dracup 2002). However, the distributions for seasons and regions are different and hence this index is not used to compare drought between seasons and regions (Hayes 2006). There is no specified threshold value to specify drought event for this drought index. Generally, a lower percentage of normal less than 100% values indicate dry circumstances. This index is obtained by Eq. (3).

$$p_n = \frac{p}{p_{30}} * 100 \qquad (3)$$

Where p is the annual precipitation and p_{30} is the mean precipitation for the past 30 years.

4.4 Estimation of deciles

The technique for decile estimation depends on dividing the distribution of monthly record precipitation into 10 parts (Gibbs and Maher 1967). The total monthly precipitation values from a long-term record are arranged in a descending order and ranking has been given from top to bottom to construct a cumulative frequency distribution. The obtained distribution is then split into 10 parts (tenths of distribution or deciles). The first decile is the precipitation value not exceeded by the lowest 10% of all precipitation values in a record. The second decile is between the lowest 10 and 20% etc. The severity of drought can be assessed by comparing the amount of precipitation in a month (or during a period of several months) with the long-term cumulative distribution of precipitation amounts in that period (Morid et al. 2006). The deciles are grouped into five classes two deciles per class (as shown in Table 4.4). If precipitation falls into the lowest 20% (deciles 1 and 2), it is classified as much below normal. Deciles 3 to 4 (20 to 40%) indicate below normal precipitation, deciles 5 to 6 (40 to 60%) indicate near normal precipitation, 7 and 8 (60 to 80%) indicate above normal precipitation and 9 and 10 (80 to 100%) indicate much above normal precipitation.

Table 4.4: Classification of drought based on deciles (adapted from Gibbs and Maher 1967)

Class	Percent	Period
Decile 1-2	20% lower	Much below normal
Decile 3-4	20% following	Below normal
Decile 5-6	20% medium	Near normal
Decile 7-8	20% following	Above normal
Decile 9	20% more high	Much above normal

4.5 Normalized Difference Vegetation Index (NDVI)

In the detection of agricultural drought, remote sensing plays a crucial role by providing up to date information in a various range of spatial and temporal scales (Thenkabail 2004). Many scientists considered vegetation index is one of the important key parameters for mapping agricultural drought by estimating weather impacts, crop yield, biomass, etc. (Justice, 1985). This index is accepted to monitoring agricultural drought (Son et al. 2012), for estimating soil moisture (Xin et al. 2006) and vegetation condition (Singh et al. 2003). The most commonly used vegetation index is NDVI because of its efficiency and simple (Liu and Huete, 1995). Tucker in 1979 was first suggested this index as a root to finding the vegetation health and density. The changes in the vegetation cover and agricultural drought trend can be detected by the temporal difference of NDVI over different years (Shulian 2006; Sruthi & Aslam 2015). The basic principle of NDVI is internal mesophyll structure of healthy green leaves reflects in Near-Infrared (NIR) radiation whereas the leaf chlorophyll is on visible red (VR). This is reversed in case of unhealthy or water stressed vegetation as shown in figure 4.1

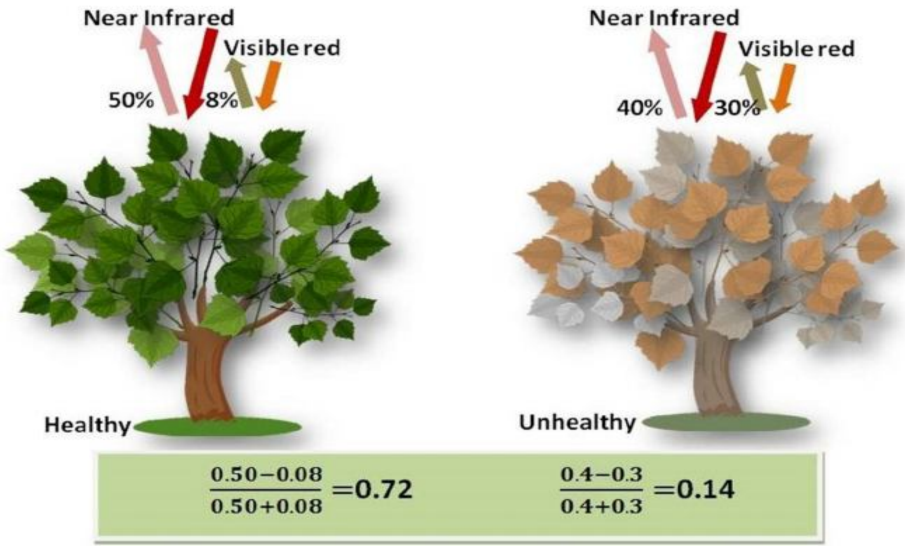

Figure 4.1: Phenomena of Normalized Difference Vegetation Index

Satellite-based NDVI can be calculated by the difference between band reflectance of NIR and VR in the electromagnetic spectrum and is given by Eq. (4)

$$\text{NDVI} = \frac{\text{NIR}-\text{VR}}{\text{NIR}+\text{VR}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

The range of NDVI values is between -1 and +1. In rainfall deficient season, the phenomenon of photosynthesis in plants is reduced as a result of dryness increases and therefore results in lower NDVI values and vice versa for excess rainfall seasons. This shows continuously low NDVI values in non-vegetated areas such as Urban and well-settled areas (Sierra-Soler, 2016). some inadequacy is present with this index such as the effect of clouds in the rainy season, atmospheric noise, satellite orbital drift, change in sensor degradation, saturation effect on dense vegetation, etc. (Kogan 1995) To overcome this effect this index is merged with some other parameter for better accuracy. This is seen that SPI and NDVI has a strong relation because SPI shows wet or dry conditions of vegetation whereas NDVI shows Vegetation growth and Vegetation Stress.

4.5.1 Flow Chart

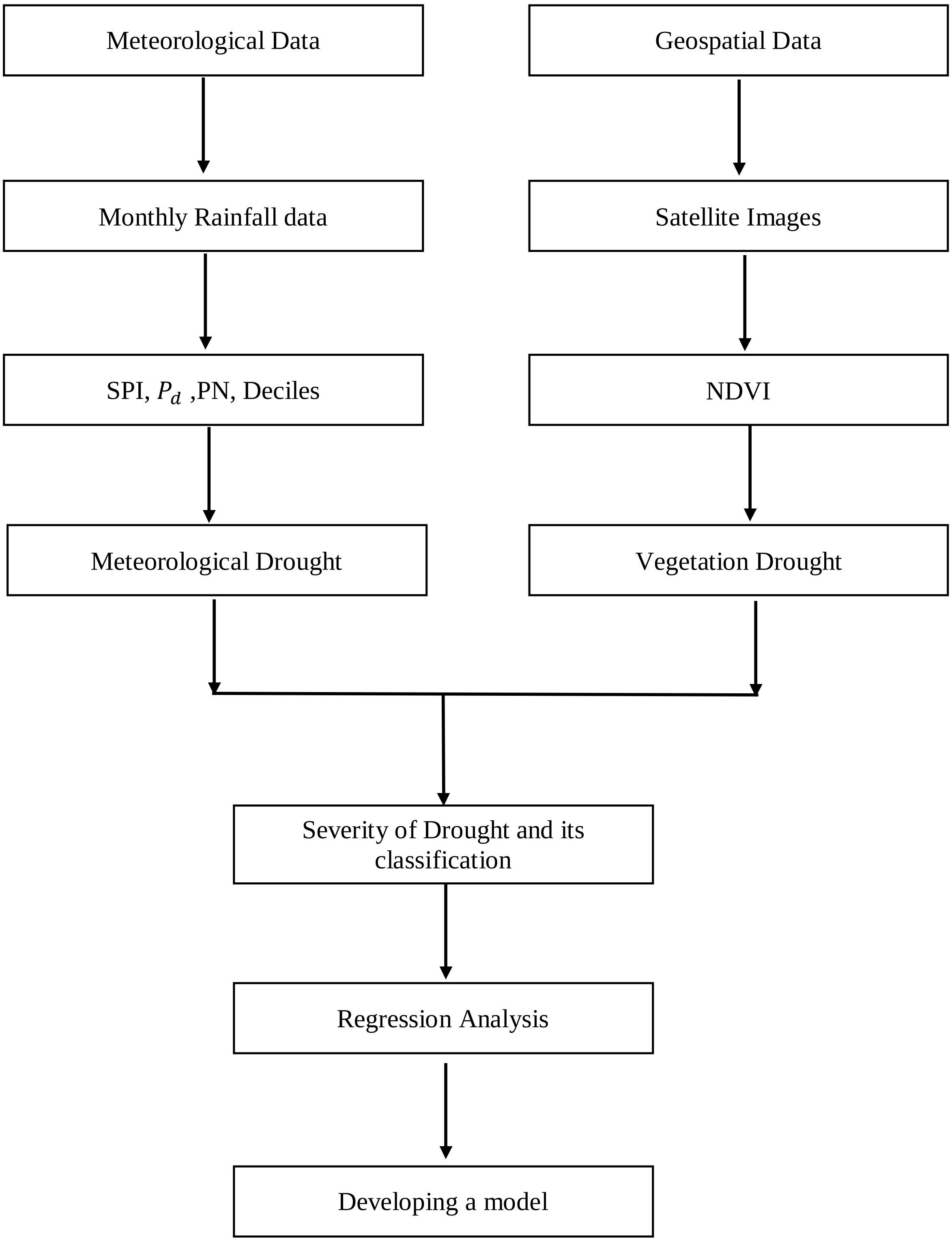

Figure 4.2: Flow chart to develop a Geospatial model

4.6 Data Collection

Mean monthly precipitation data from 1901 to 2016 is collected from “Customized Rainfall Information System (CRIS), Hydro met division, Indian Meteorological Department (IMD)”, India. This data is used to calculate SPI, percent of Normal, Percentage of departure, Deciles. SPI is calculated using a software “DrinC”. Remaining indices are called through an MS-Excel.

Landsat 7 (ETM+ sensors) and Landsat 8 (OLI sensors) Satellite data is collected from USGS (United States Geological Survey) Earth Explorer website (https://earthexplorer.usgs.gov/) and is processed in Arc Map 10.3 software. The data of the year 2016 is collected from Earth explorer and is processed in Arc Map 10.3 software to extract the vegetation information by NDVI. Different bands and their wavelengths along with their characteristics are shown in table 4.5

Crop yield statics for the year 2016 is collected from data.gov.in, open government data (OGD) platform India (https://data.gov.in). This data is used for correlation between NDVI and Crop Yield for suitability of better crop model.

Table 4.5: Characteristics and usage of bands of Landsat satellite (Gandhi et al. 2015)

Band	Name of the Band	Wavelength (µm)	Characteristics and usage
1	Visible blue	0.45 - 0.52	Maximum water penetration
2	Visible Green	0.52 - 0.60	Good for measuring plant vigor
3	Visible Red	0.63 - 0.69	Vegetation Discrimination
4	Near Infrared	0.76 - 0.90	Biomass and shoreline mapping
5	Middle Infrared	1.55 - 1.756	The Moisture content of the soil
6	Thermal Infrared	10.4 – 12.5	Soil moisture and Thermal Mapping
7	Middle Infrared	2.08 - 2.35	Mineral mapping

4.7 Software Used

4.7.1 Introduction for DrinC

DrinC (Drought indices Calculator) is a user friendly software for calculating drought indices like SPI, Deciles, Reconnaissance Drought Index (RDI), Streamflow drought index (SDI). It is a specialized software for simple interface and clear outputs for better comparison. This software is developed at the "center for the Assessment of Natural Hazards and Proactive Planning and the Laboratory of Reclamation Works and Water Resources Management, National Technical University of Athens".

4.7.2 Input data and File Management

The input data of mean monthly or annual rainfall data is set up in a Ms-excel of .xls format to calculate drought indices. We can also calculate Potential Evapotranspiration (PET) by Thorn Thwaite method using temperature data. Note that minimum 30 years' data is required. For calculation SPI, this software is widely used because of different time scales. Software is able to recognize the required data automatically in a given data file and rest of the is ignored. Overall view of this software can be shown in figure 4.3

If the data is monthly precipitation, then the file format should be arranged in the form of months present in a water year i.e. starting with the name of the month if not at least first letter of each month. If annual data is present, then it should be in one column i.e. one value per year.

4.7.3 Calculation Process

The calculation of drought indices is defined in indices window (menu>process> calculate indices). High light the relevant index by making suitable tick on the at each box will be calculated (figure 4.4). The output may be saved in a separate file or in the same file for all indices. For each index will have different output options.

4.7.4 Results table

The output will be present in the form of excel sheet or in table format in another window for easy processing (menu>process>output data tables).

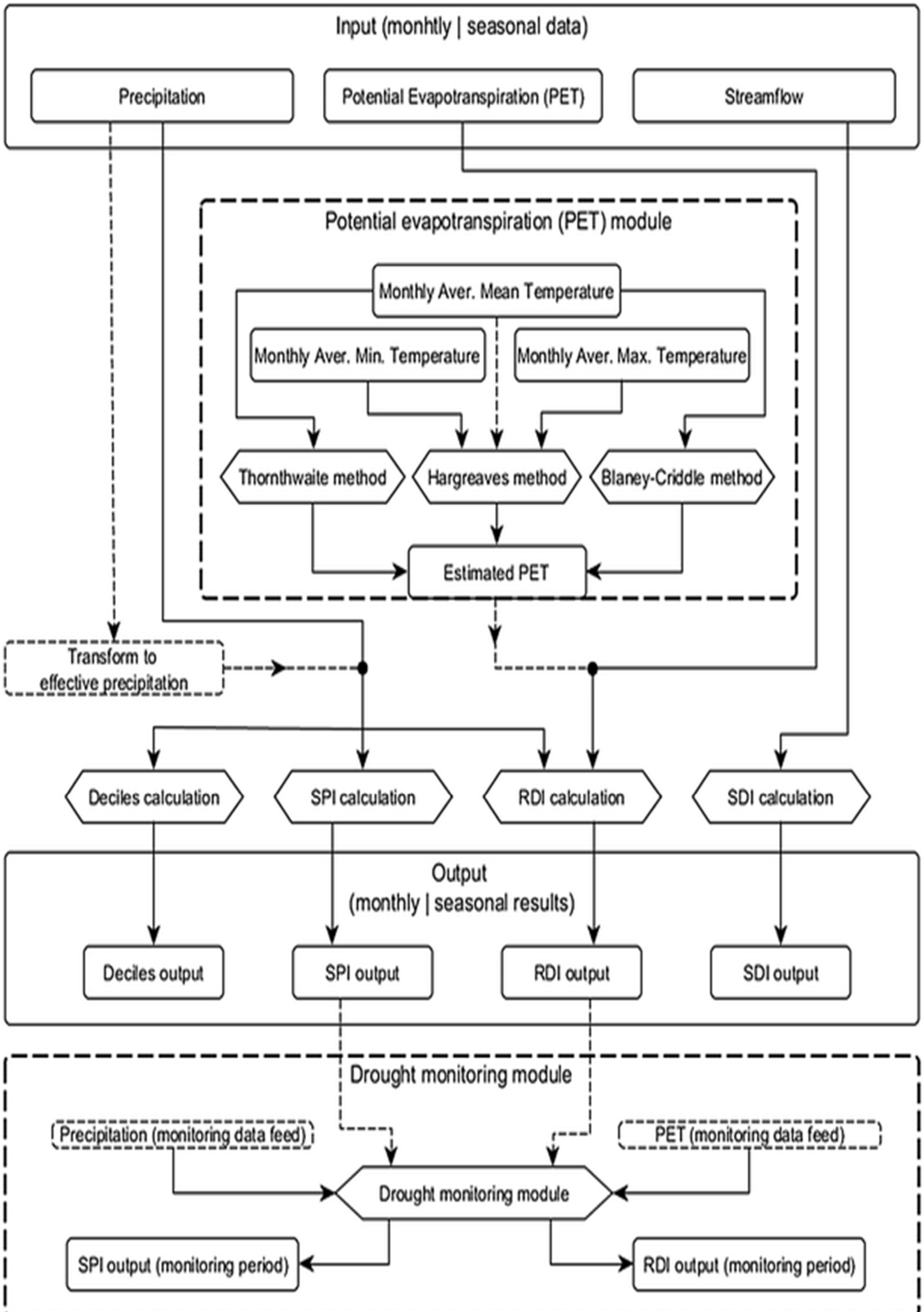

Figure 4.3: Flow chart for workflow in DrinC

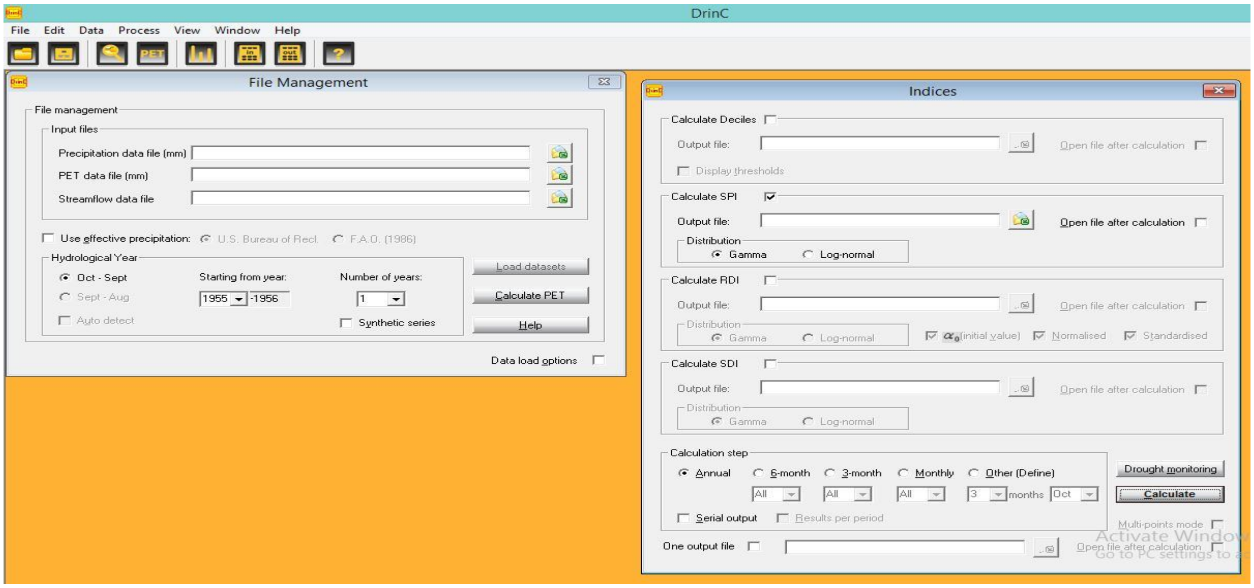

Figure 4.4: File management and selection of Indices in DrinC

4.7.5 Introduction to Arc Map

Arc Map is a primary component of Esri's ArcGIS Suite. It consists of geospatial processing programs and is mainly used to view, edit, create and analyze geospatial data. Arc Map helps to create maps to the user by exploring data within a data sets. Arc Map can work with different data types such as Geodatabases, shape files, Arc/ info coverages, web mapping services, image formats. ArcGIS has three distinct sections such as ArcMap, Arc Catalog, and Arc Toolbox. ArcMap is for interactive data editing, making maps. Arc Catalog is for browsing, accessing and managing data i.e. tiles. Arc Toolbox is to perform geo-processing operations on spatial data.

Arc Map interface consists of Table of contents, display area, status bar, toolbars (Figure 4.5). Each interface has a specific task as listed below.

Table of Contents- displays legends, selection, and source of information.

Display area- This shows the displayed data view of map i.e. displays data (view) Map view displays map layout (Layout).

Status Bar- This shows at bottom of the display and showing status, coordinate information, etc.

Toolbars- shows organized sets of commands and tools. Toolbars can be docked type or Floating type and can be turned on and off. You can also mark out by click on "Customize" option.

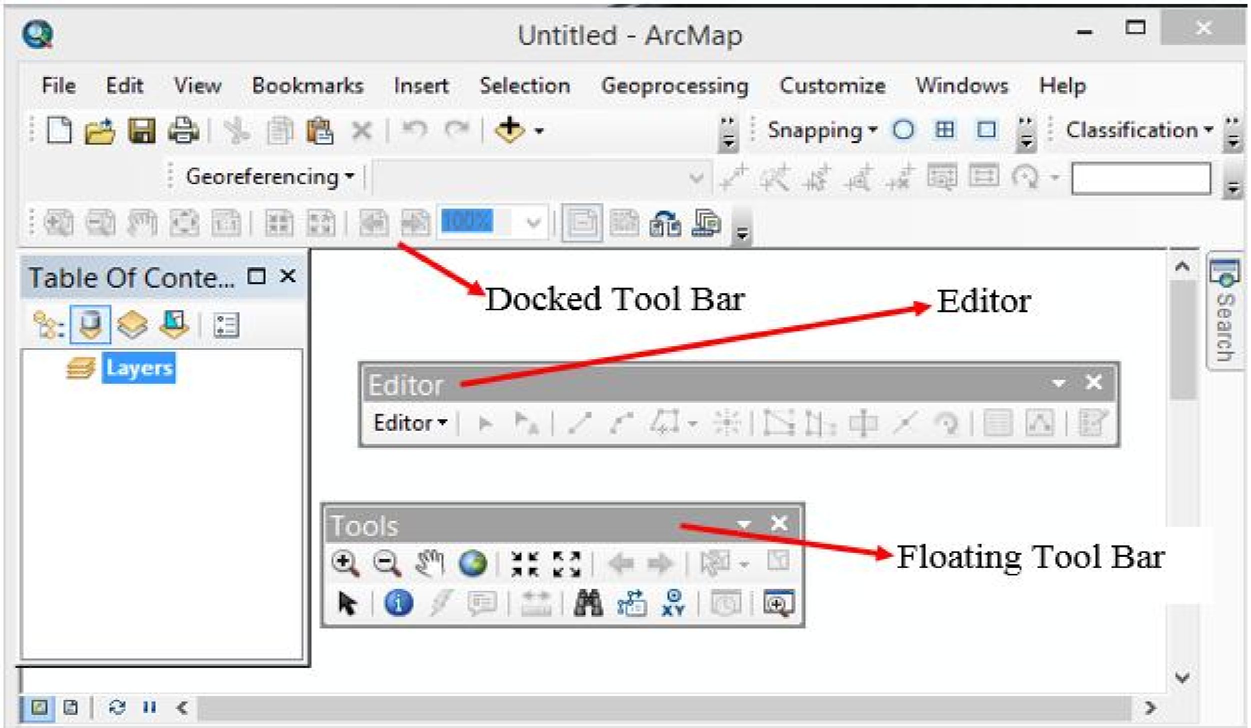

Figure 4.5: Different Toolbars used in Arc Map

For better use make all docked over together and don't open all toolbars at a time because these toolbars cover all the screen and make difficult to find out required option. Some of the commonly used toolbars are standards tools such as new, save, open, etc., draw, editor, layout etc.

After extraction of tiles which are downloaded from Earth explorer, these can be added by right click on "Table of Contents" and then click add data option. In Table of Contents, it shows different layers with different data frames for a particular order of map extent and map projection. It can have multiple data frames but only one active at a time.

In Arc Map, the data is displayed in a data frame called Layers. These layers have the graphical representation of Spatial data. The layers have vector data or Raster data types. Vector data is a combination of point, lines, polygon, etc. whereas Raster data is image format in the form Pixels. In this study, we used Raster data (images and grids) sets. After adding data, the next process is to make a null vector of spatial data and then Mosaic, masking, calculation of NDVI. Generally, spatial data is obtained by selecting the corresponding tiles or by selecting the spatial coordinates. Here spatial data is obtained by selecting the corresponding coordinates for the study area hence there is no need of georeferencing.

4.7.6 Add Data

Data is added by click on the file menu then click on add data option or by simply "Add icon" on the toolbar (or) by click on Catalog option. The following steps are shown below to add data.

Click Add data button > connect folder > select required data > click ok.

(or) open Catalog (Figure 13) > select folder > select required > drag to display area.

4.7.7 Create a shape file

Add "IND.adm 2" map file by click on "Add" icon and then right click on map file which is added in the table of contents, it opens a dialogue box showing attribute table and so on. click on "open attribute table" and highlight the study area (Ex: Anathpur) and then close. Now the study area is highlighted. Now again right click on "IND.adm 2" and go for "selection" and then click on "create a layer from selected features" then the study area is separated from the base file as shown in figure 4.6

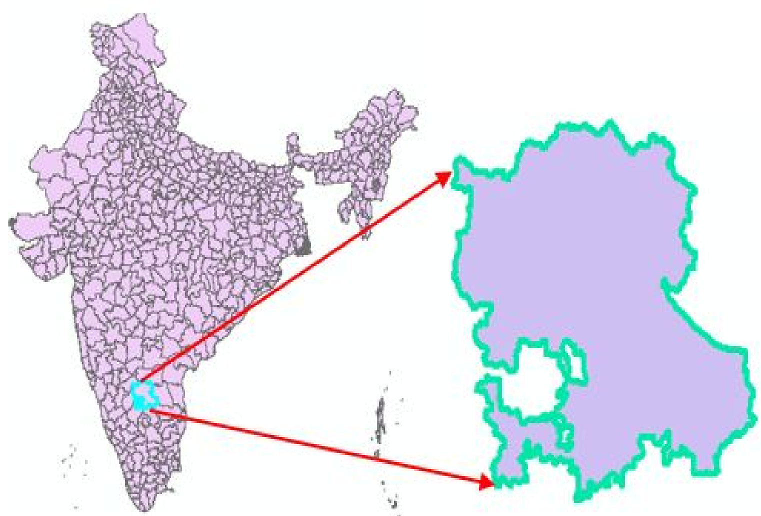

Figure 4.6: Creating a shape file

4.7.8 Making of Null Raster Image

By making Null Raster Image (Figure 4.7) we can remove the background i.e. making pixels as zero so that it useful merge two different tiles into a single one. Steps to follow to make null raster shown as follow.

Arc toolbox > Data management tools > Raster > Raster dataset > copy raster then make a band value is zero and then click ok. After making null data set go for the mosaic.

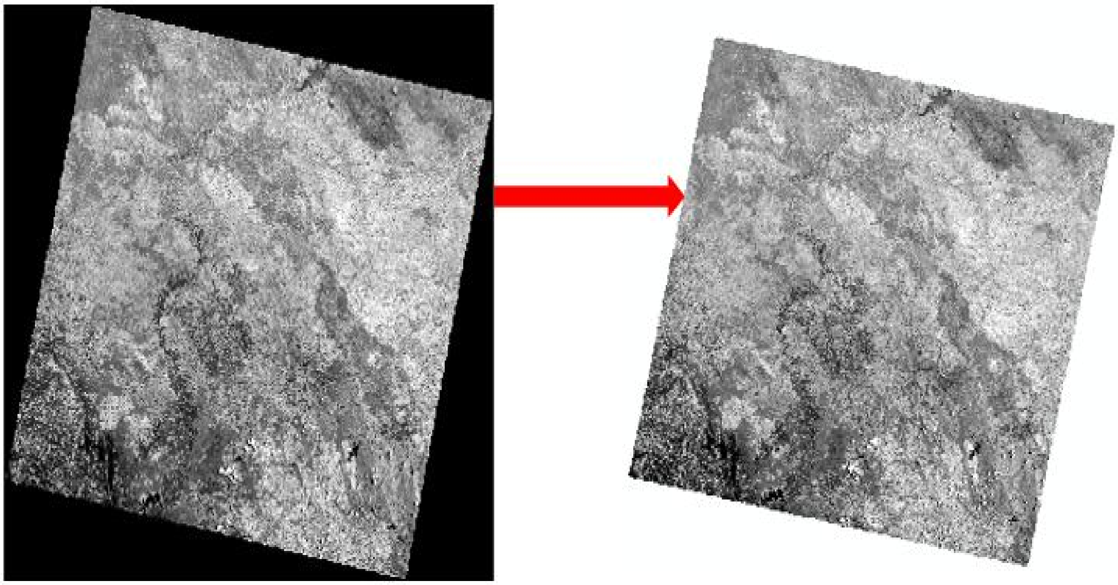

Figure 4.7: Initial Raster file to null raster file

4.7.9 Mosaic

Mosaic is the process of combining more than two tiles/bands into a single composite tile/band. If the shape file is exceeding the data set, then we go for mosaic by making two or more bands into a single composite band. The following steps are shown below for making mosaic.

Go to Arc tool box > Data management tools > Raster > Raster data set > Mosaic to New Raster. After entering the details in Mosaic to New Raster dialogue box then click ok. Output comes as a composite band as shown in figure 4.8. After Completion of Mosaic, the next step is to extract the shape file from the composite band. To do this go for Masking.

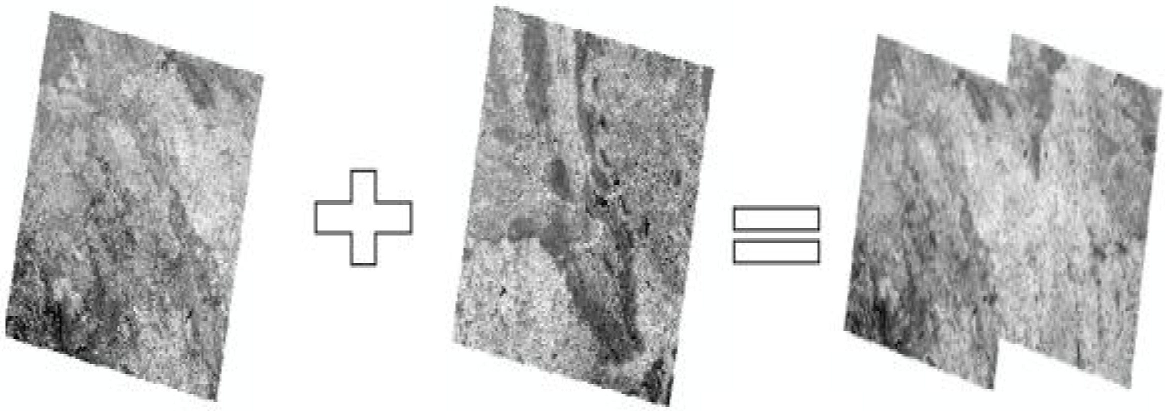

Figure 4.7: Composite band after mosaic to new raster

4.7.10 Masking

Masking is the process to extract the required shape file from the composite band. After Mosaic, the shapefile is extracted from the composite band to calculate NDVI. For masking, go to Arc tool box> Spatial Analyst tools > Extraction > Extraction by the mask. (figure 4.8). The same procedure is applied for different bands and these bands are used to calculate NDVI.

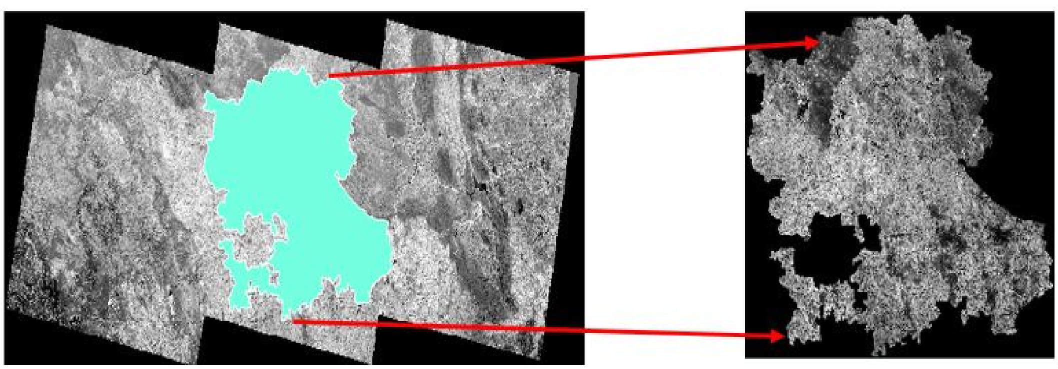

Figure 4.8: Extraction of the study area by masking

4.7.11 Calculation of Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index is a vegetation Index which shows healthy growth of vegetation. To calculate this index the steps to follow.

Go to Arc toolbox > Spatial Analyst tools > Map algebra > Raster Calculator > double click on float and apply NDVI = (NIR- IR) / (NIR + IR) then click ok. The output of the raster calculator gives the range of NDVI values for the required study area which is shown in figure 4.9. This procedure is applied for images of different years and corresponding NDVI values were obtained.

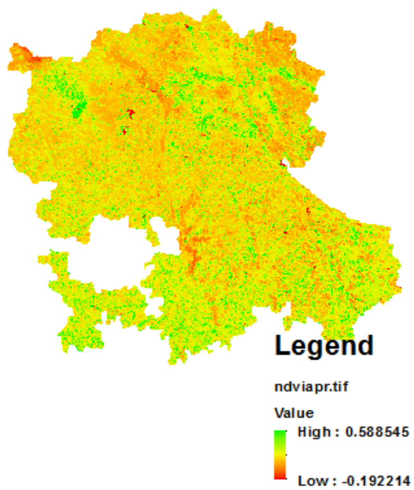

Figure 4.9: Normalized Difference Vegetation Index for the study area

Chapter- 5

Results and discussion

5.1 Anantapur District

1-month SPI values were calculated for the years 2014, 2015 and 2016 (Figure 5.1(a)) to observe the drought stress condition of vegetation. In view of clear analysis, SPI is mostly considered in monsoon season (Jun-Oct) of all the three years as shown in figure 5.1(b). As SPI is an indicator of dryness and Wetness of vegetation so it can easily detect the drought stress and identify agricultural drought year. From Fig. 5.1 it was observed that in Anantapur district drought event starts from -1 (negative) and ends with a +1 (Positive). In 2014 SPI values are nearer to negative when compared to the values in 2015 and all SPI values in 2015 are positive. It shows that 2014 and 2015 are both in near normal condition but when compared to 2014 and 2015 dry period is more in 2014 than 2015. In 2016, the SPI values were increased more towards negative than in 2014. It is observed that vegetation stress is more in 2016 due to lack of rainfall. This results that 2016 has a more drought event when compared to 2014 and 2015. Hence 2016 is identified as an agricultural drought year in Anantapur district because of more dryness.

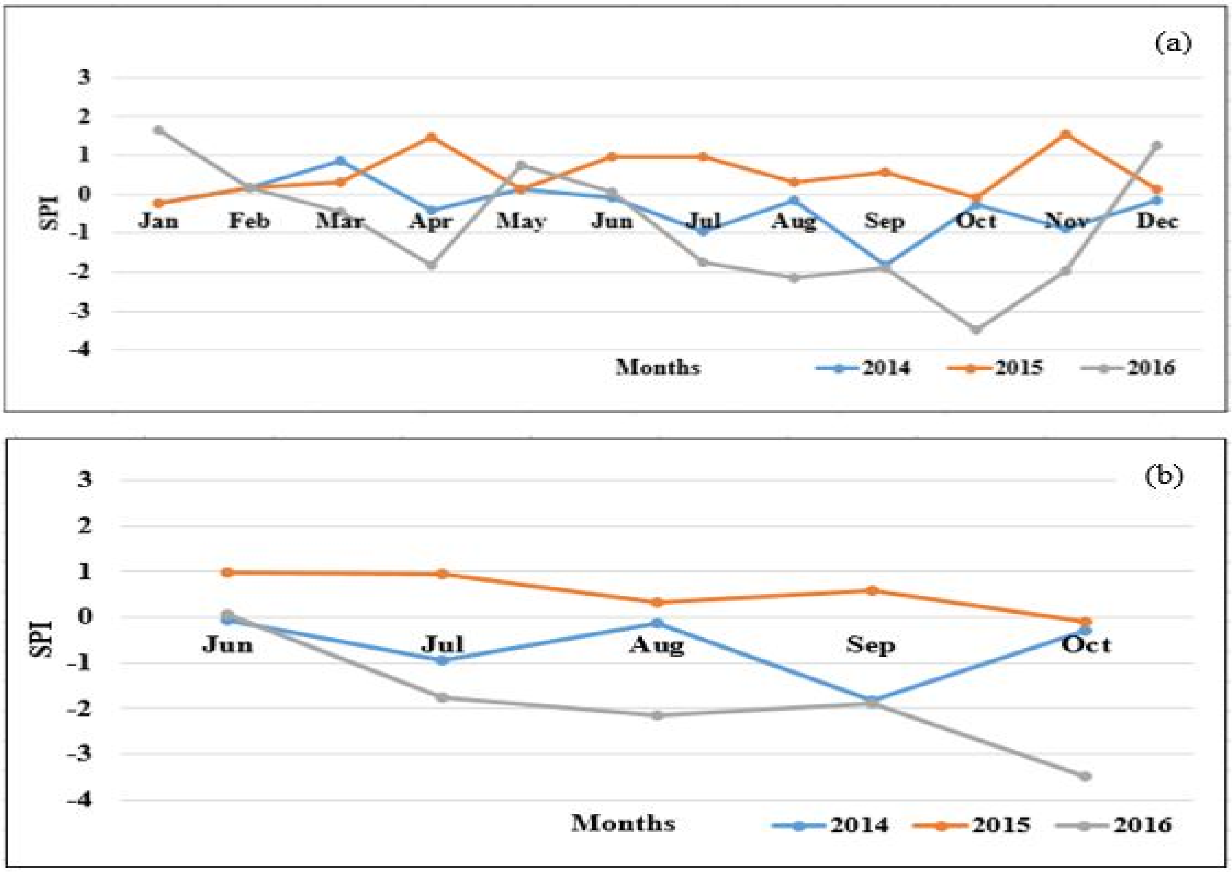

Figure 5.1: Variation of SPI in Anantapur district (a) different Years and (b) Monsoon season for the same years

The results obtained from 1 month SPI is cross-checked with other meteorological indices for better accuracy. Other Meteorological indices used are Percentage of Departure, Percent of Normal and Deciles. In Percentage of Departure, from the classification table 4.3, drought event starts when precipitation level falls in negative side. So from the figure 5.2, it was observed that 2014 and 2016 is a drought year when compared to 2015. According to Percent of Normal, precipitation levels fall below 100 percent considered as a drought event. From the observation in figure 5.3, 2014 and 2016 are drought years as precipitation falls below 100 whereas 2015 falls above 100. In deciles classification drought event lies in 1-2 and 3-4. From figure 5.4, 2014 and 2016 lies 2 and 1 deciles so these are drought years and 2015 falls in decile 6 which is a non-drought year. From all these indices it was observed that the results obtained from SPI match well with the results obtained from other indices.

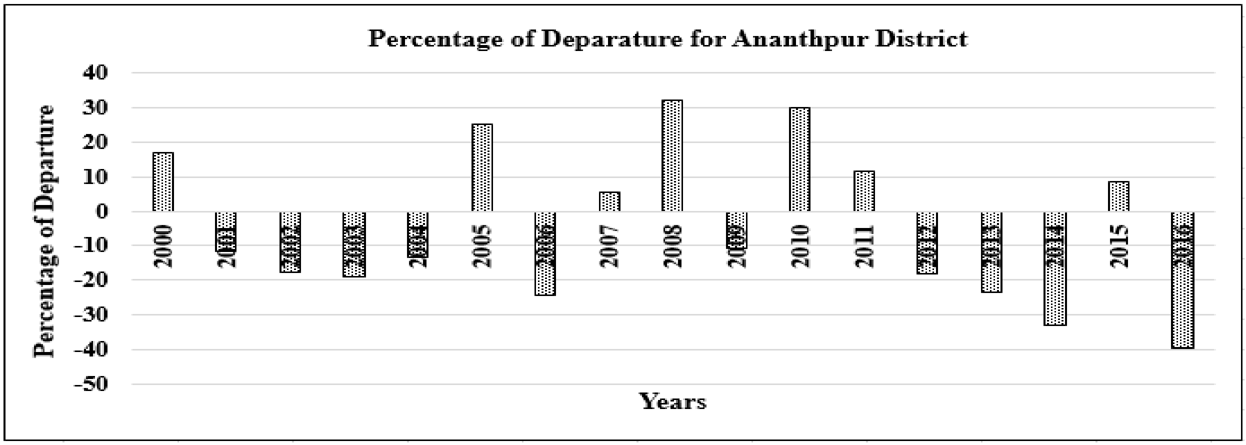

Figure 5.2: Drought and Non-Drought years in Anantapur District using Percentage of Departure

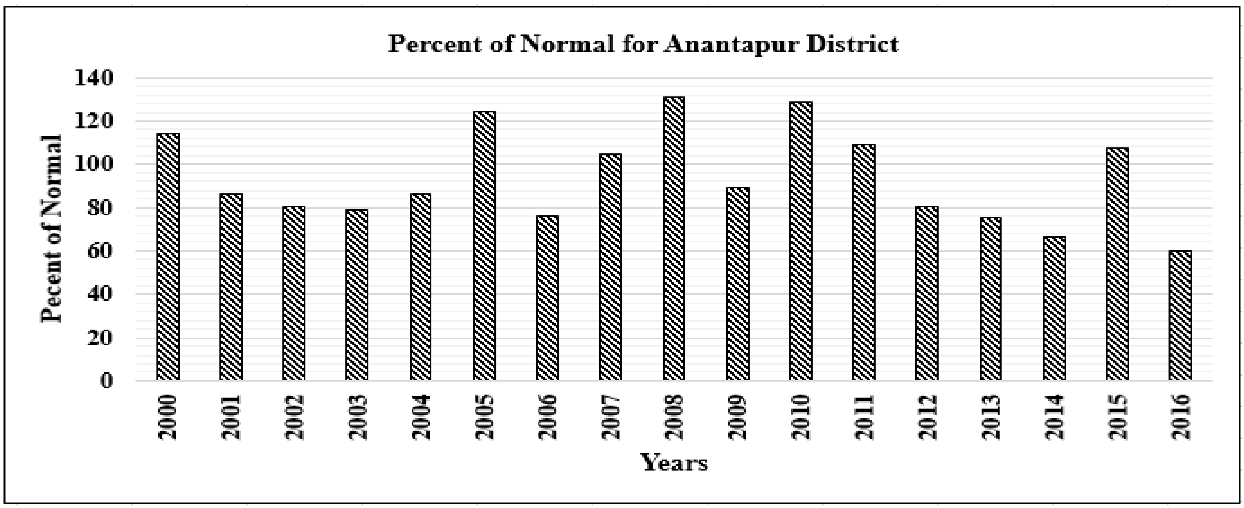

Figure 5.3: Drought and Non-Drought years in Anantapur District using Percent of Normal.

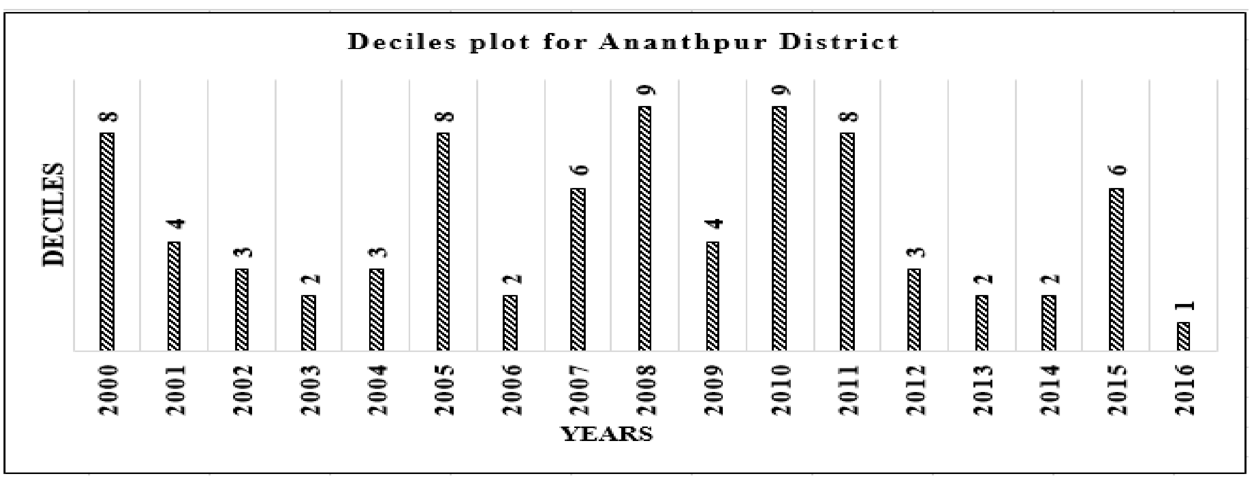

Figure 5.4: Drought and Non-Drought years in Anantapur District using Deciles

5.2 Chittoor District

1 month SPI values were calculated for Chittoor district as shown in figure 5.5(a). In the year 2014, SPI values are near normal to moderately dry condition. In the year 2015, most of the SPI values are in positive and only two values in July and September are in negative side (Figure 5.5(b)). This shows that drought event occurs only in months of July and September which is a minor effect in vegetation stress. So the year 2015 is a non-drought year. In 2016, SPI values fall in negative side indicating that it was a drought year. So it was observed that 2014 and 2016 are drought years due to less rainfall when compared to 2015. Due to lack of rainfall, dryness and vegetation stress increases and hence 2014 and 2016 are agricultural drought years in Chittoor district.

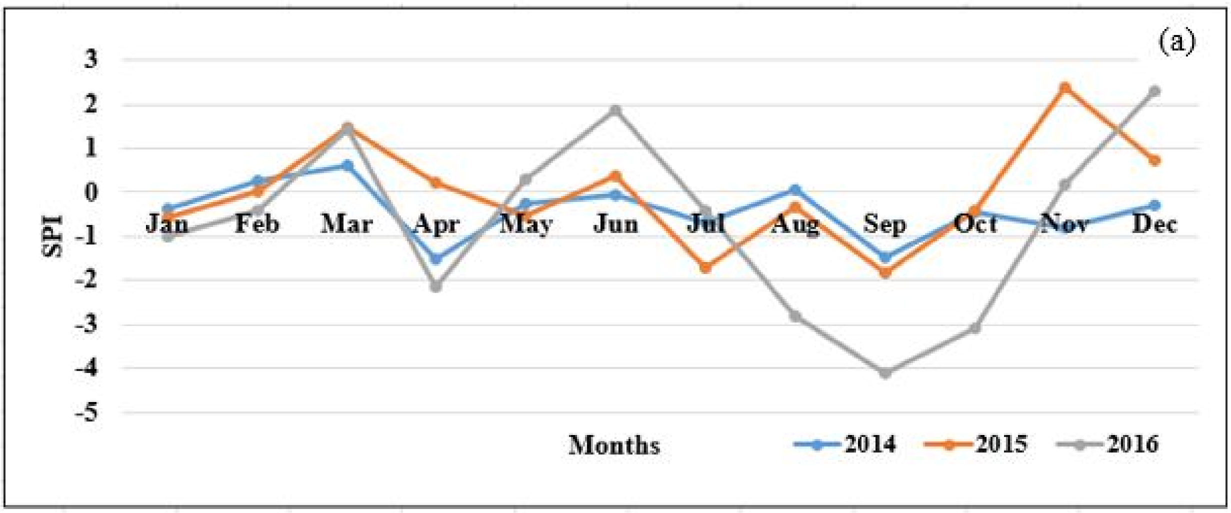

Figure 5.5: Variation of SPI in Chittoor district (a) for different Years and (b) Monsoon season for the same years

To justify the results for SPI, other meteorological indices like Percentage of Departure, Percent of Normal and Deciles are also calculated. From the classification of Percentage of Departure shown in figure 5.6 it was observed that 2015 is not a drought year whereas 2014 and 2016 are drought years. Same case was observed in Percent of Normal (figure 5.7), 2015 is above the 100 percent whereas 2014 and 2016 below the marked level. In deciles classification (figure 5.8), 2015 is in decile 9 whereas 2014 and 2016 both are in decile1 which is a drought event. So from all these indices shows results from SPI matches well with the result obtained by other indices.

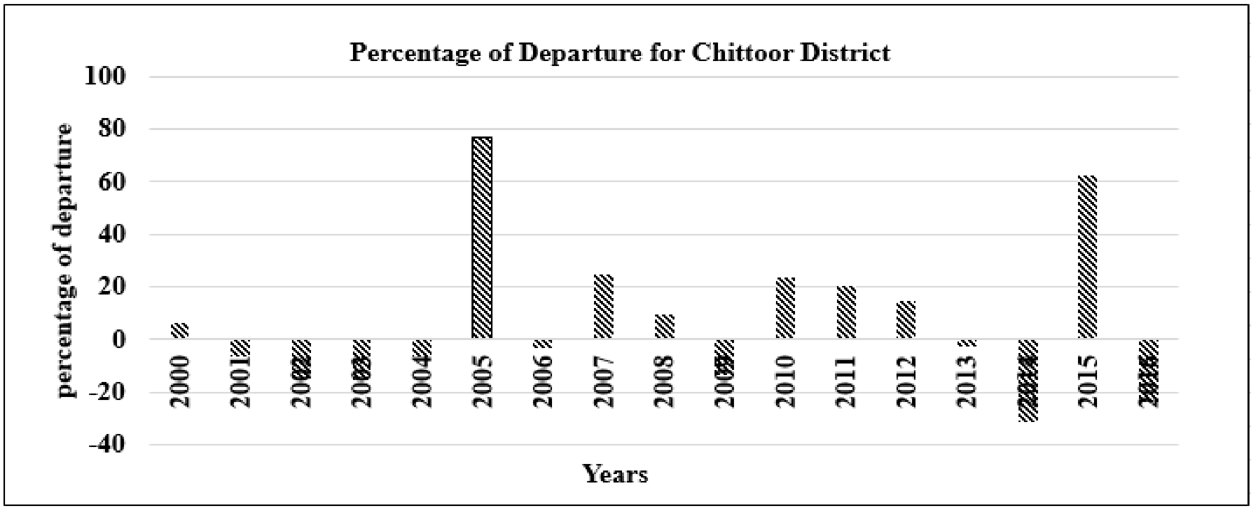

Figure 5.6: Drought and Non-Drought years in Chittoor District using Percentage of Departure.

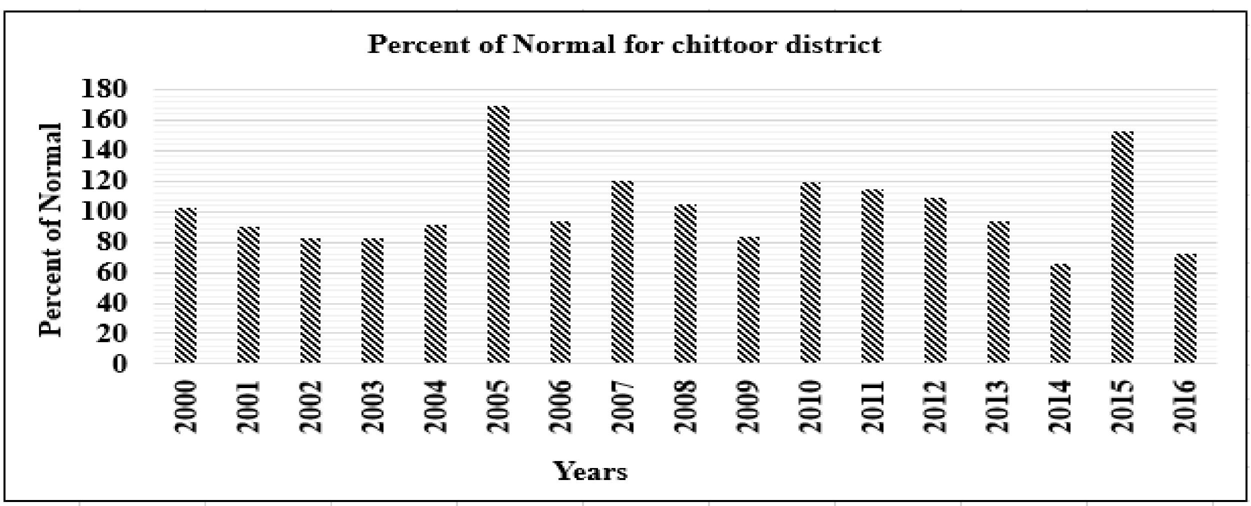

Figure 5.7: Drought and Non-Drought years in Chittoor District using Percent of Normal.

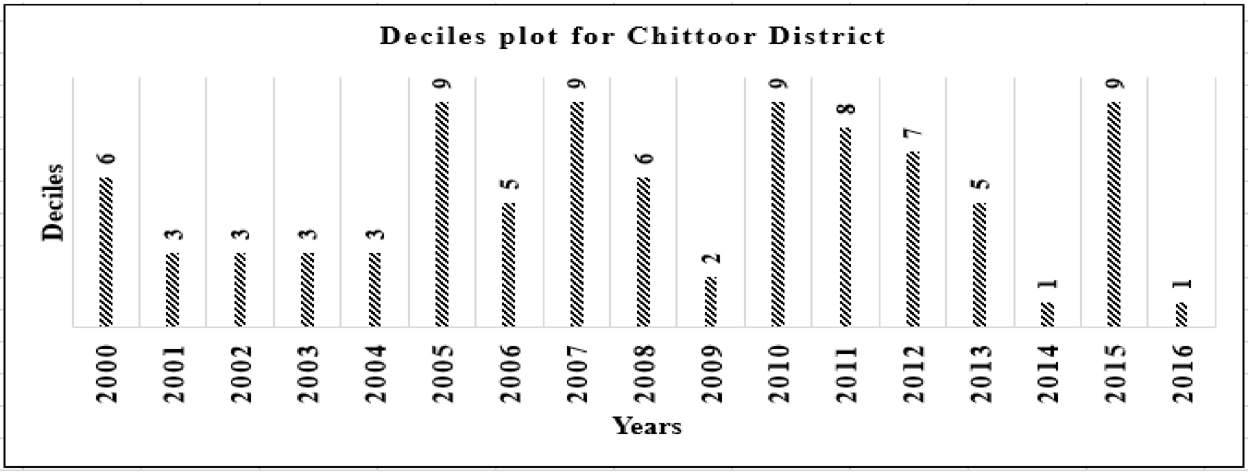

Figure 5.8: Drought and Non-Drought years in Chittoor District using Deciles

5.3 Kadapa District (YSR Kadapa)

1-month SPI values were calculated for Kadapa district for the years 2014, 2015 and 2016 as shown in figure 5.9. From the plot of SPI (Figure 5.9 (a)) in Kadapa district, it was observed that 2016 is a drought year. For clear analysis in monsoon season (Jun-Oct), the same is shown in figure 5.9 (b). In 2014, more SPI values lies between 0 to -1 showing that near normal condition to moderately dry condition prevailed during that year. In the year 2015, SPI values lie between 0 to 1 showing near normal to moderately wet condition and in 2016, these values vary from normal to extremely dry condition. It shows that 2014 and 2016 are drought years when compared to 2015. Hence 2014 and 2016 are identified as agricultural drought years.

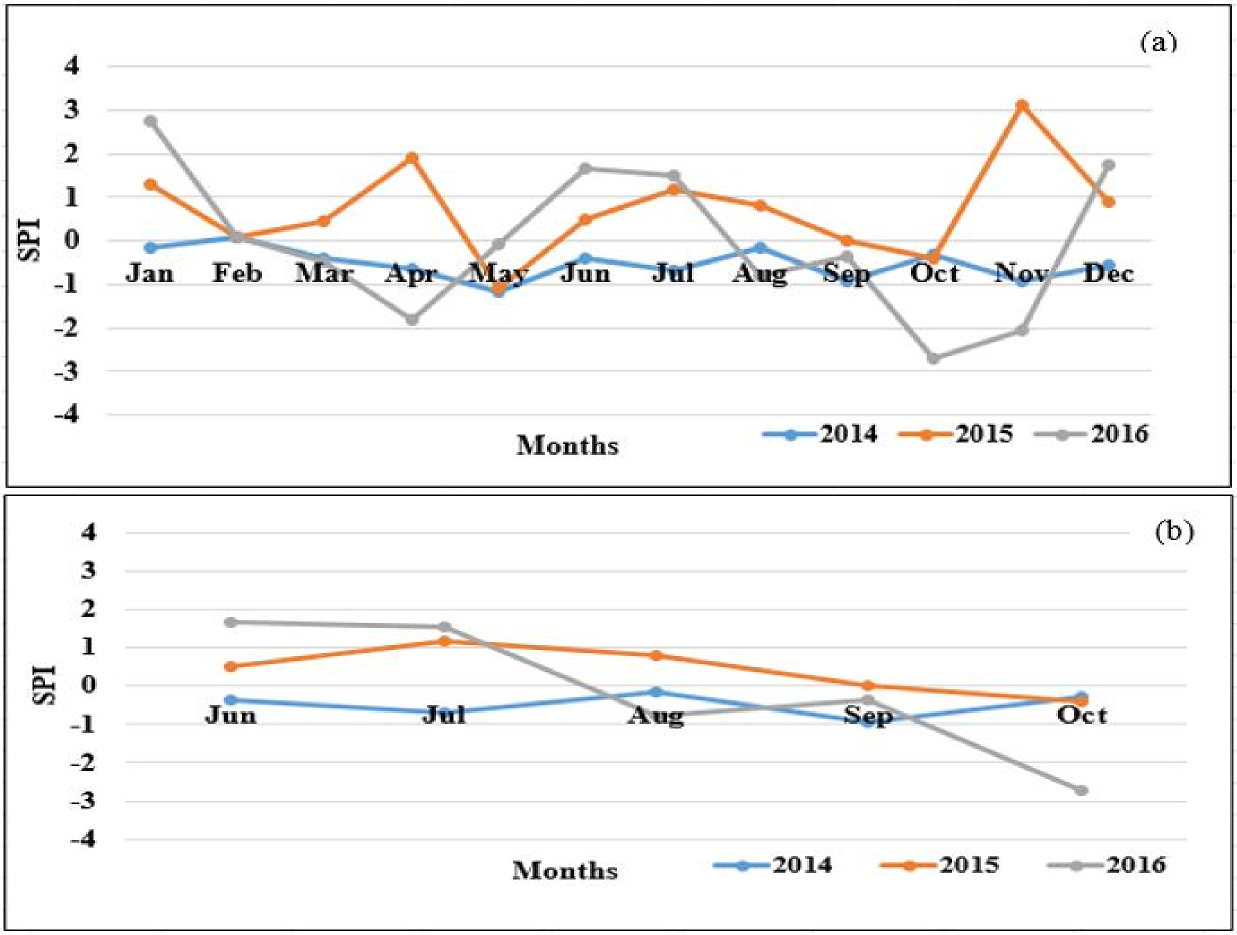

Figure 5.9: Variation of SPI in YSR Kadapa district (a)for different Years and (b) In monsoon season for the same years

The results obtained from 1-month SPI is cross-checked with other meteorological indices for better accuracy. Other Meteorological indices used are Percentage of Departure, Percent of Normal and Deciles. In Percentage of Departure, from table 4.3, drought event starts when precipitation level falls in negative side. So from the figure 5.10, it was observed that 2014 and 2016 is a drought year when compared to 2015. According to Percent of Normal, precipitation levels fall below 100 percent considered as a drought event. From the observation in figure 5.11, 2014 and 2016 are drought years as precipitation falls below 100 whereas 2015 falls above 100. In deciles classification, drought event lies in 1-2 and 3-4. From figure 5.12, it can be referred that, 2014 and 2016 lie in 1 and 2 deciles respectively hence are drought years and 2015 falls in decile 6 which is a non-drought year. From all these indices it was observed that the results obtained from SPI match well with the result obtained from all other indices.

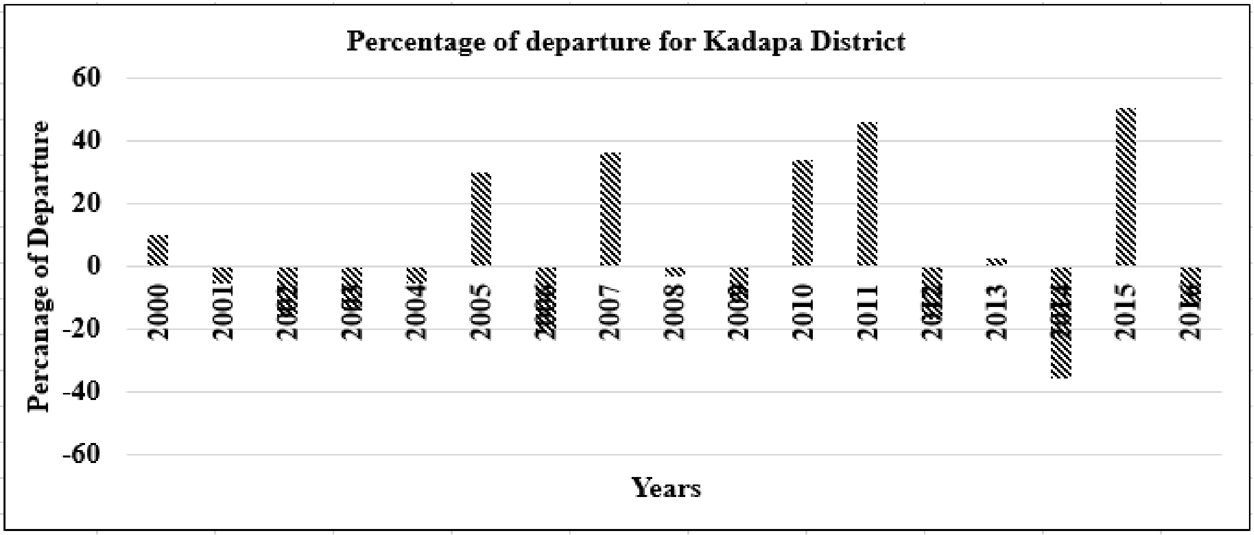

Figure 5.10: Drought and Non-Drought years in YSR Kadapa District using Percentage of Departure.

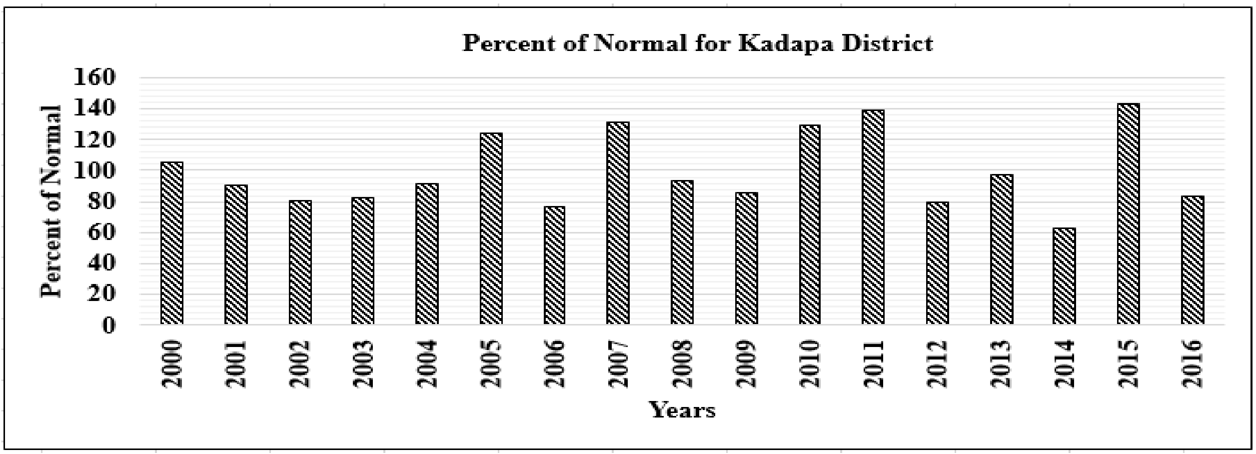

Figure 5.11: Drought and Non-Drought years in YSR Kadapa District using Percent of Normal

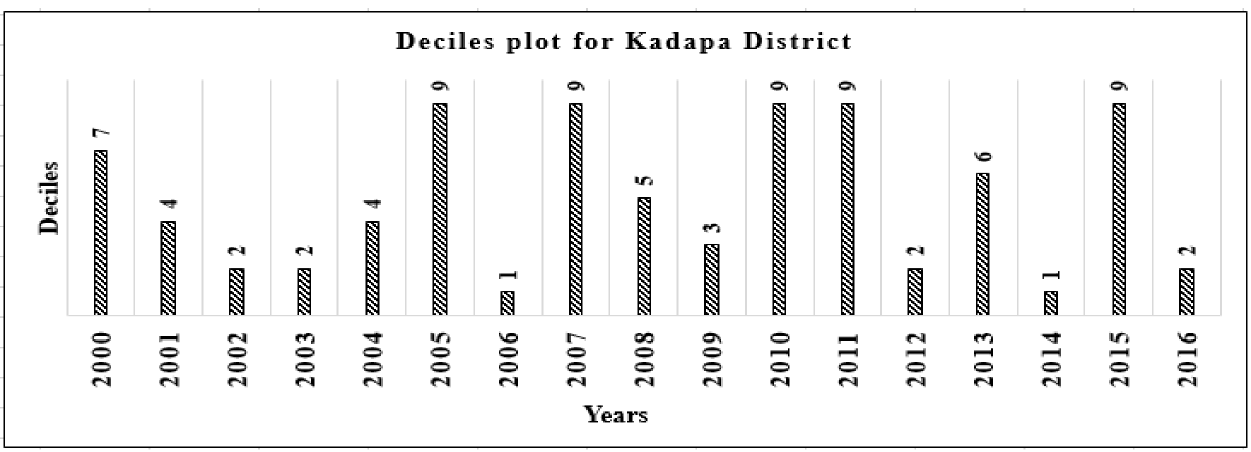

Figure 5.12: Drought and Non-Drought years in YSR Kadapa District using Deciles

5.4 Kurnool District

1-month SPI values were calculated for the years 2014, 2015 and 2016 are shown in figure 5.13 (a). For better analysis, a separate figure is shown in 5.13 (b) showing the SPI values only in the monsoon season. But from the figure 5.13 (b) it is difficult to identify drought year as all the SPI values are very nearer to Zero in all the three years. So here entire SPI values for the whole year is considered for better identification of drought year. From the plot 5.13 (a) showing SPI values in Kurnool district, it can be observed that more SPI values lie near to -1 so it was observed that 2015 is a drought year when compared to 2014 and 2016. From the plot, all SPI values vary from near normal to moderately wet in the year 2014 and 2016 but in the year 2015 SPI values are near to negative so it was identified as agricultural drought year when compared to 2014 and 2016 years.

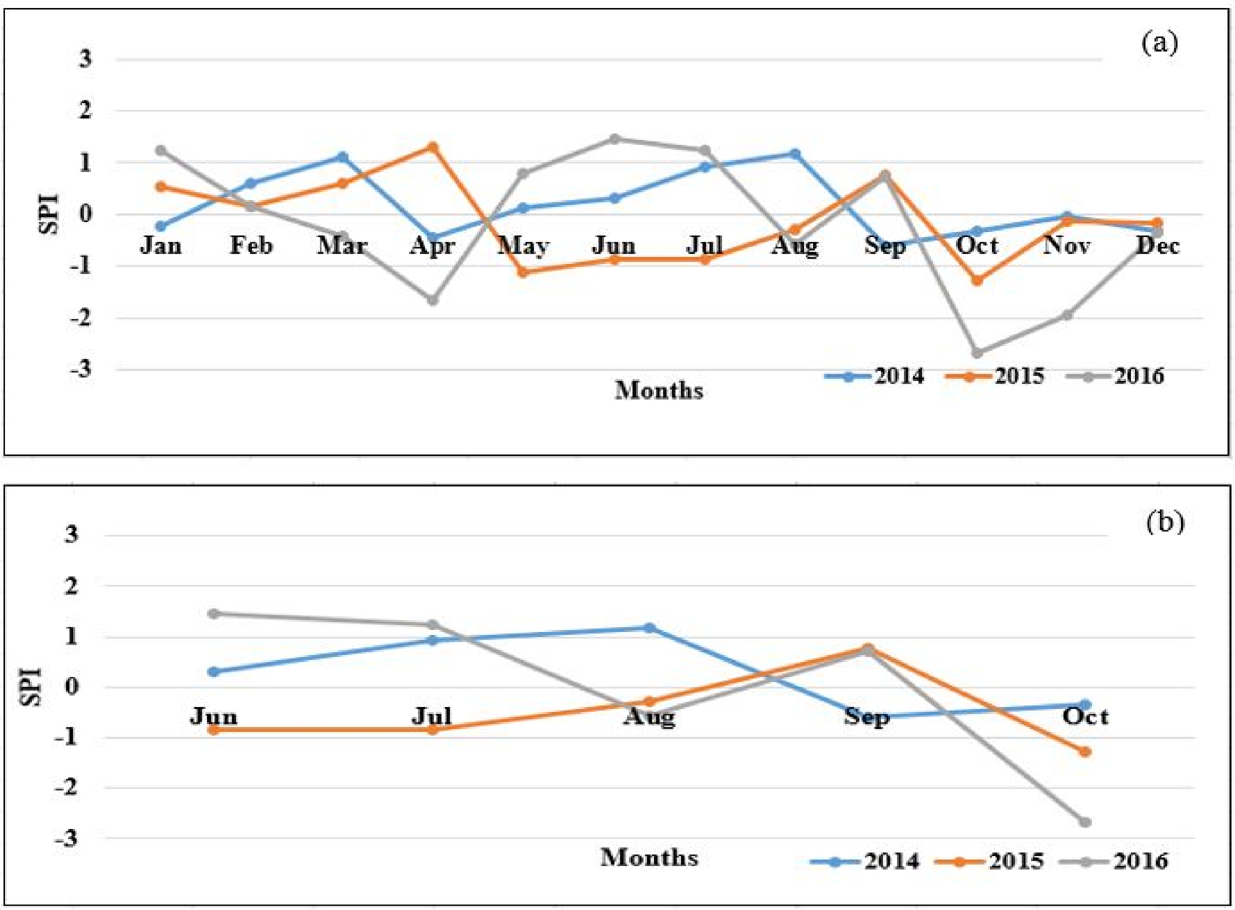

Figure 5.13: Variation of SPI in Kurnool district (a)for different Years and (b) in the Monsoon season for the same years

For better accuracy, the obtained SPI values are cross-checked with other meteorological indices like Percentage of Departure, Percent of Normal and Deciles. From Fig. 5.14, the classification Percentage of departure shows that 2015 is a drought year and 2014 and 2016 are non-drought years. Since the Percent of Normal values lies below 100 is termed as a drought year, 2015 PN is a drought year (Fig. 5.15), and 2014 and 2016 are much nearer to 100 which are non-drought years. From deciles classification, 2015 falls on drought category 2 and the deciles 2014 and 2016 fall in deciles 7 and 5 showing non-drought years (Fig. 5.16). This shows that the results which are obtained from Percentage of Departure, Percent of Normal, Deciles are same as the results of SPI.

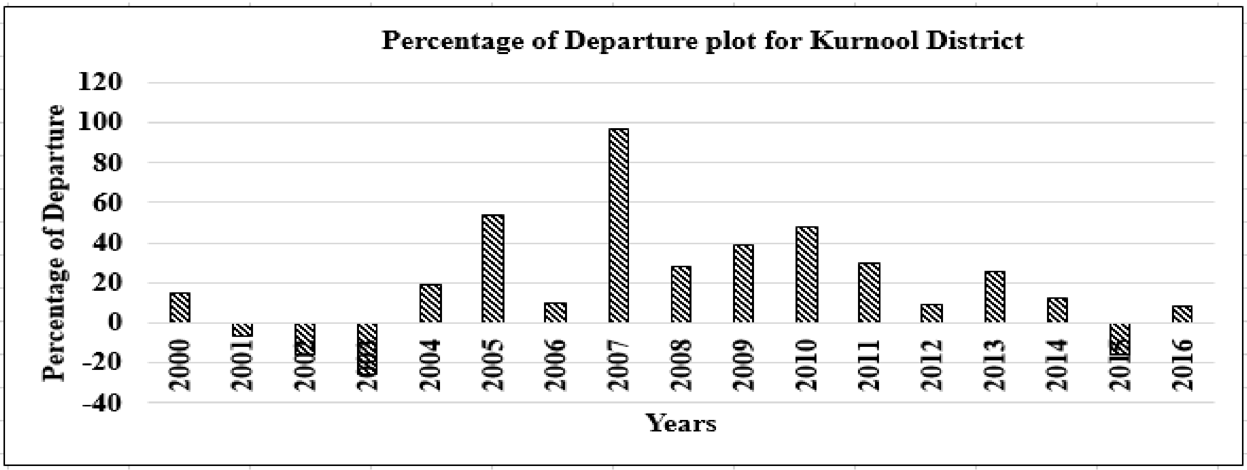

Figure 5.14: Drought and Non-Drought years in Kurnool District using Percentage of Departure.

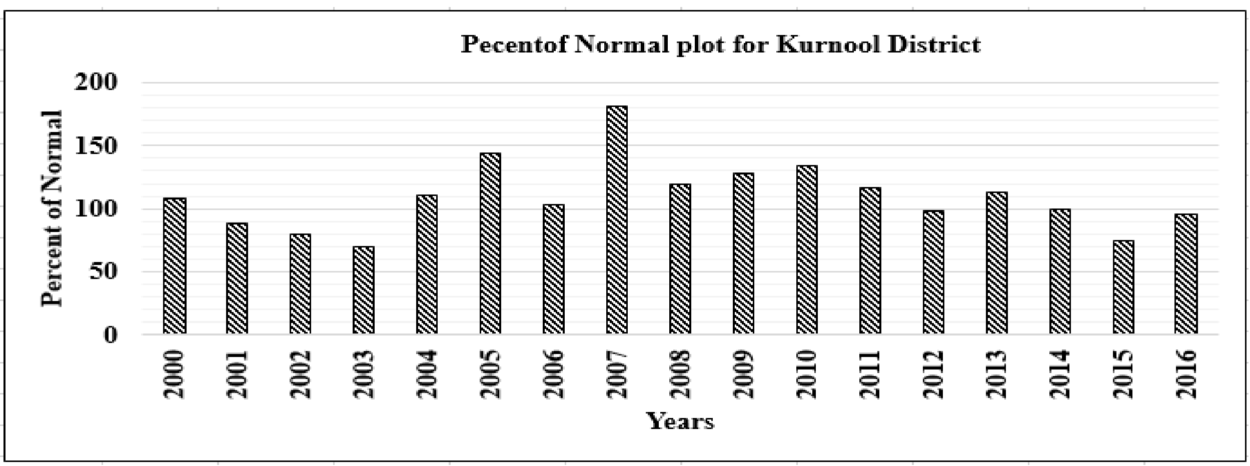

Figure 5.15: Drought and Non-Drought years in Kurnool District using Percent of Normal.

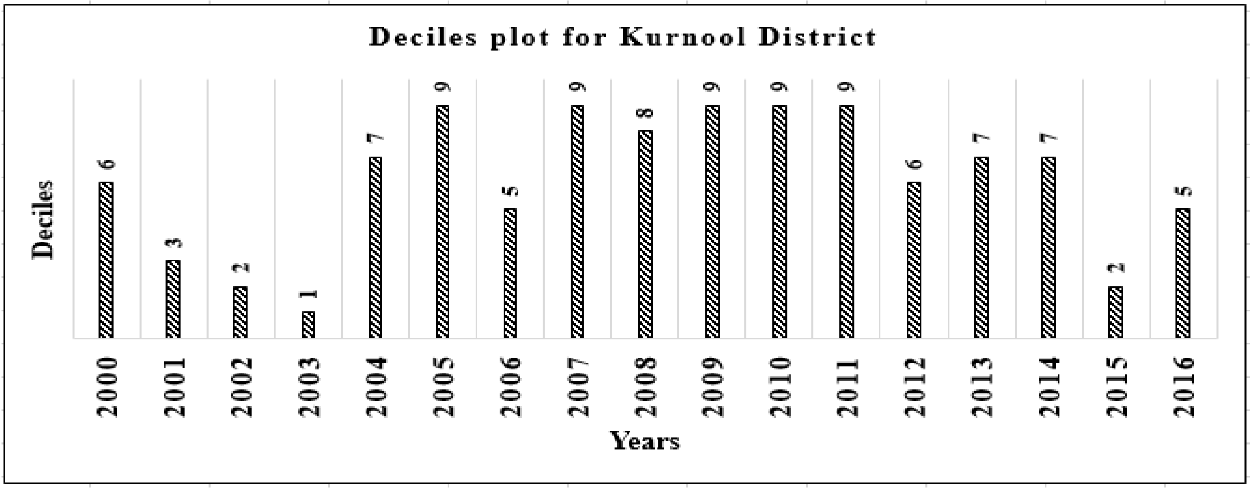

Figure 5.16: Drought and Non-Drought years in Kurnool District using Deciles.

5.5 Normalized Difference Vegetation Index

NDVI is a useful tool for monitoring of vegetation drought. The phenomenon involved with this index is the mesophyll present in the healthy leaves of a plant reflects in the near infrared radiation and leaf chlorophyll and other pigments absorbed in the visible radiation. This was reversed in unhealthy plant and water-stressed plants. So NDVI can be obtained by the difference between NIR and VR band in the Electromagnetic Spectrum. The growth of vegetation depends on rainfall. More is the rainfall, healthier is the vegetation and vice versa. Due to errors in the data while collecting NDVI values, it may be deviating from the original. To overcome this disadvantage, NDVI is correlated with other indices. On the other hand, SPI depends on rainfall and rainfall is the cause to change in NDVI values. So it shows that NDVI and SPI are in good correlation. NDVI is calculated for the year 2016 for the Anantapur (figure 5.17(a), (b)), Chittoor (figure 5.18 (a), (b)), Kadapa (figure 5.19), Kurnool (figure 5.20) and these values are correlated with values of SPI in the same year for developing a geospatial drought model and the obtained model equations are tabulated in table 5.1.

5.5.1 NDVI Model Equations

Table 5.1: Regression models for Prediction of NDVI in all Districts

DISTRICTS	NDVI MODELS	SEE
1) ANANTAPUR	NDVI = 0.9337 + 0.4294 * SPI	0.005
2) CHITTOOR	NDVI = -0.7147 - 0.286947 *SPI	0.004
3) YSR KADAPA	NDVI = 0.224973 -0.03787 * SPI	0.001
4) KURNOOL	NDVI = 0.1916 -0.042699*SPI	0.002

SEE = Standard Error of Estimation

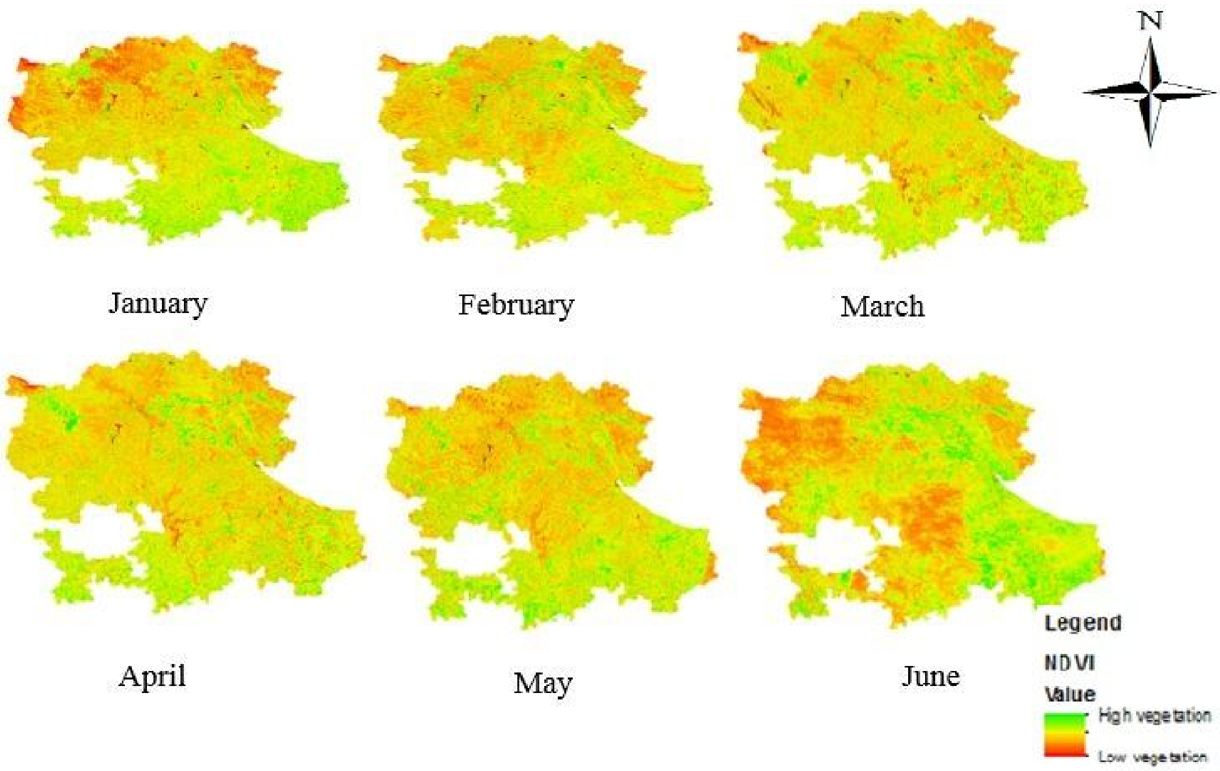

Figure 5.17 (a): Variation of NDVI in Anantapur District for different months (Jan-Jun) in 2016

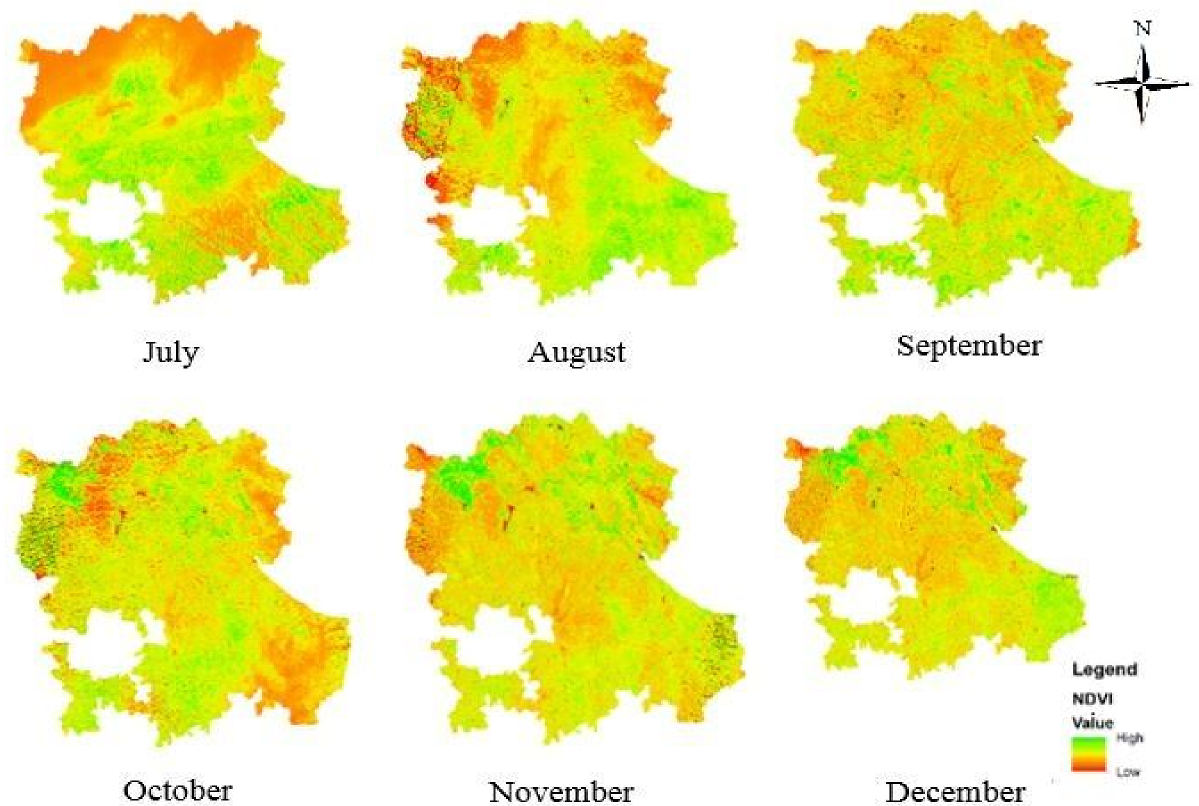

Figure 5.17(b): Variation of NDVI in Anantapur District for different months (Jul-Dec) in 2016

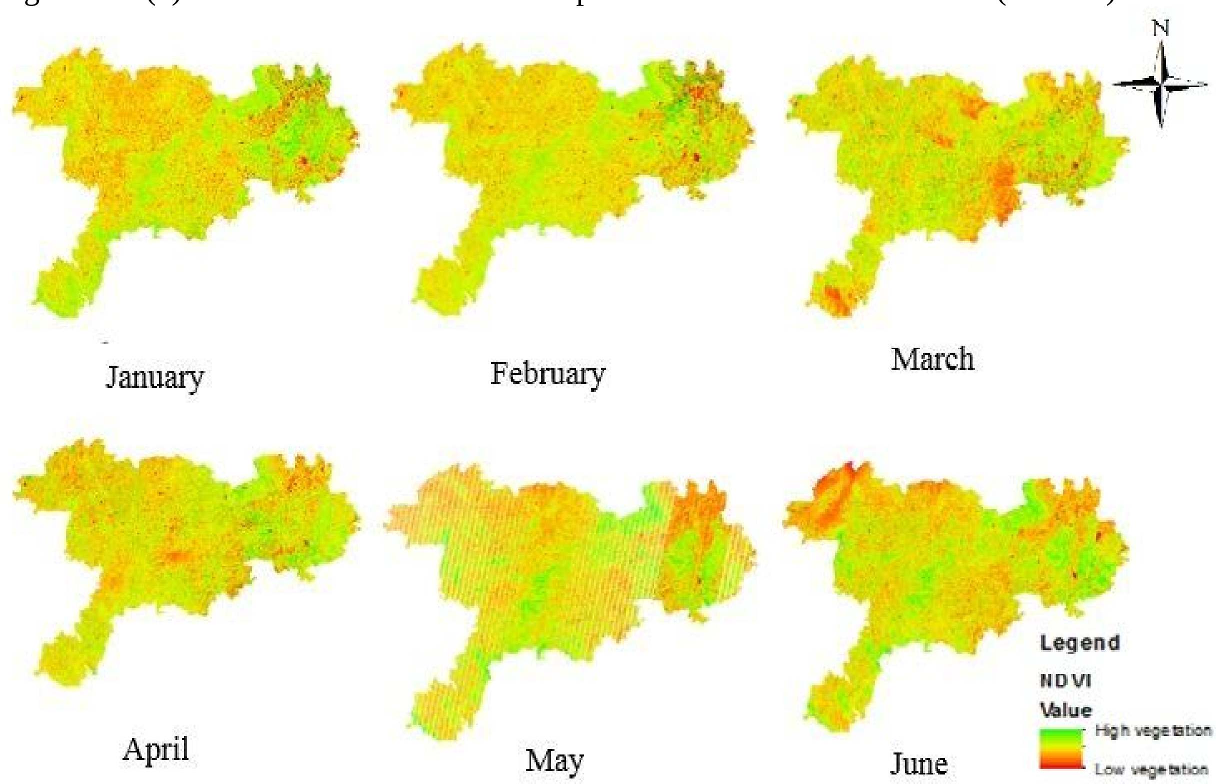

Figure 5.18 (a): Variation of NDVI in Chittoor District for different months (Jan-Jun) in 2016

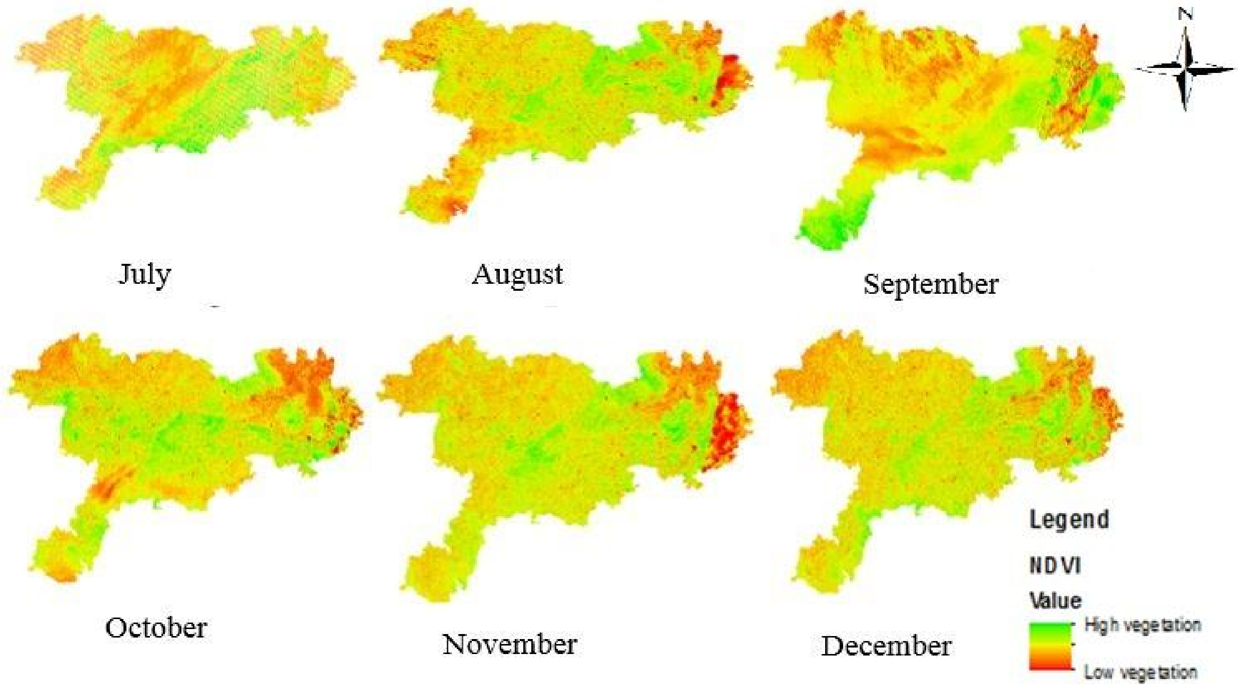

Figure 5.18 (b): Variation of NDVI in Chittoor District for different months (Jul-Dec) in 2016

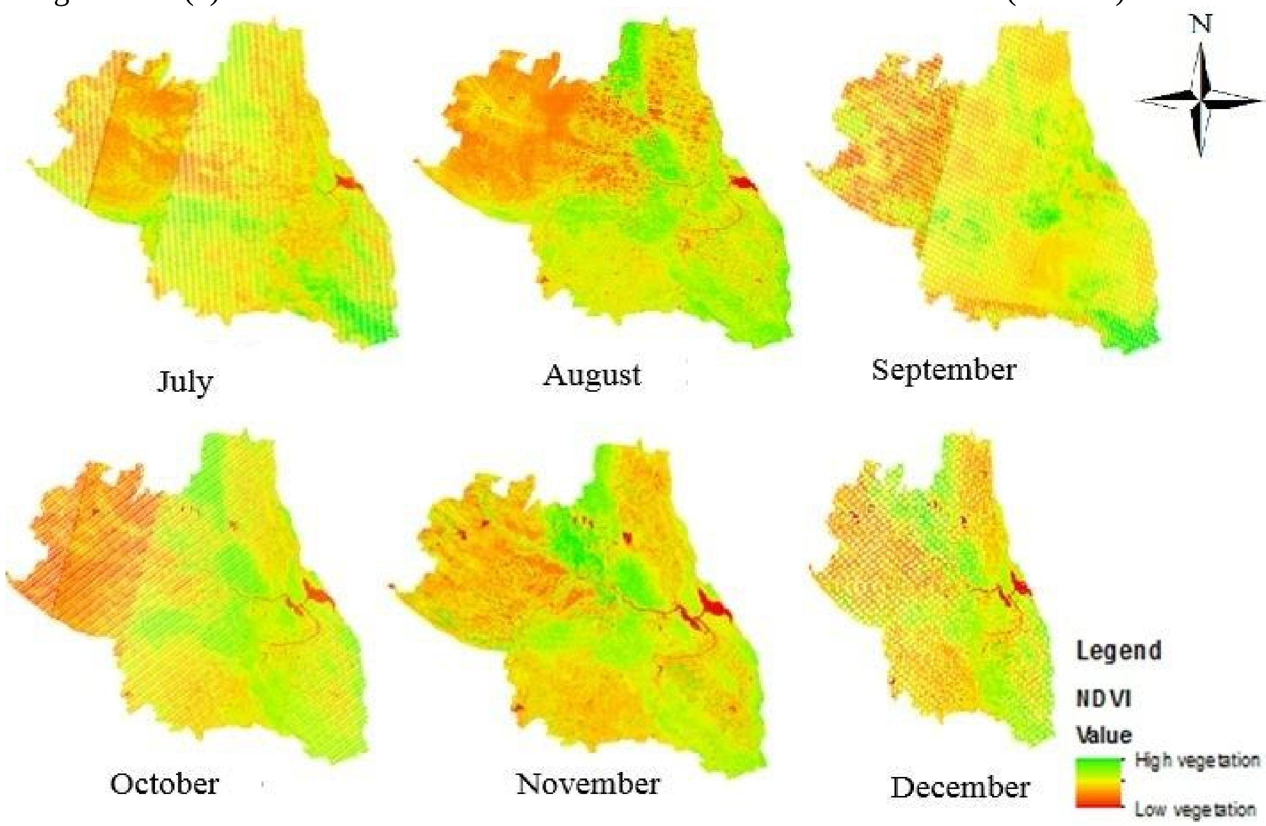

Figure 5.19: Variation of NDVI in YSR Kadapa District for different months (Jul-Dec) in 2016

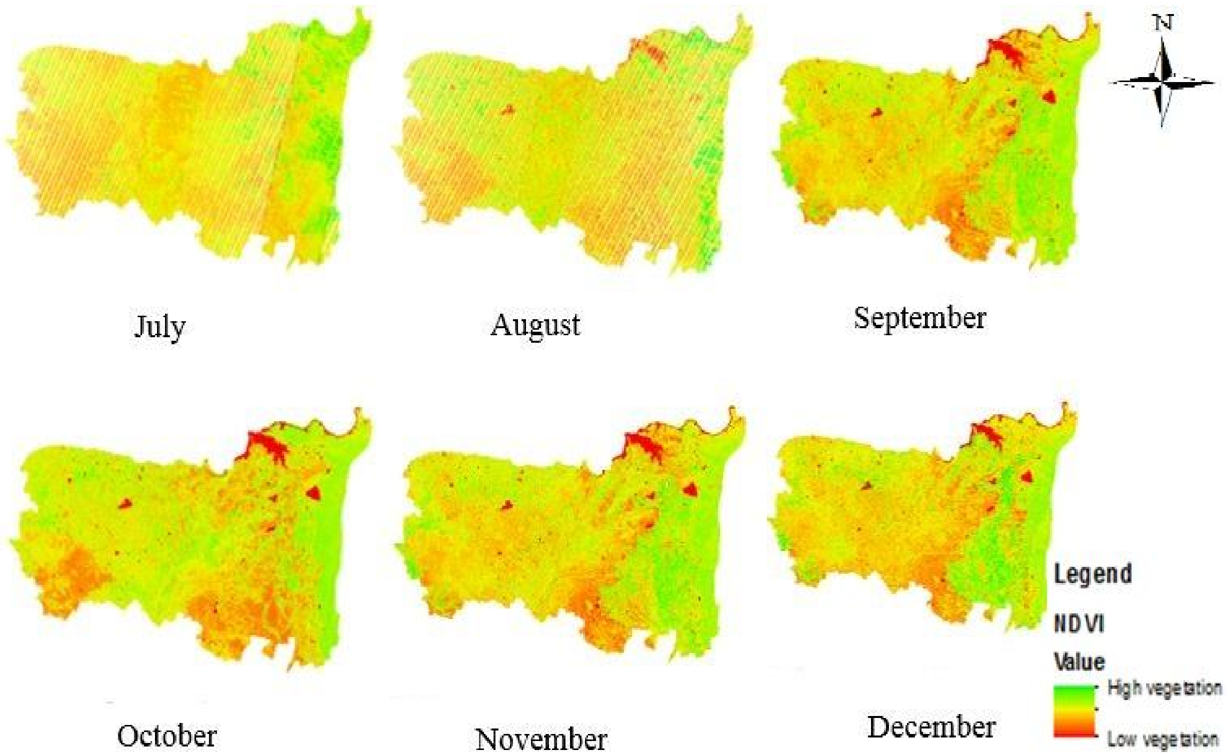

Figure 5.20: Variation of NDVI in Kurnool District for different months (Jul-Dec) in 2016

From the obtained geospatial models NDVI is calculated. Based on this regression analysis was done with the original NDVI values and obtained geospatial model NDVI for Anantapur, Chittoor, Kadapa, and Kurnool districts. From the regression analysis, it was observed that observed NDVI and Predicted NDVI are in good statistical relation with r^2= 0.77 in Anantapur district (Fig. 5.21), r^2 = 0.63 in Chittoor district (Fig. 5.22), r^2 = 0.71 in Kadapa district (Fig. 5.23) and r^2 was 0.97 in Kurnool District (Fig. 5.24).

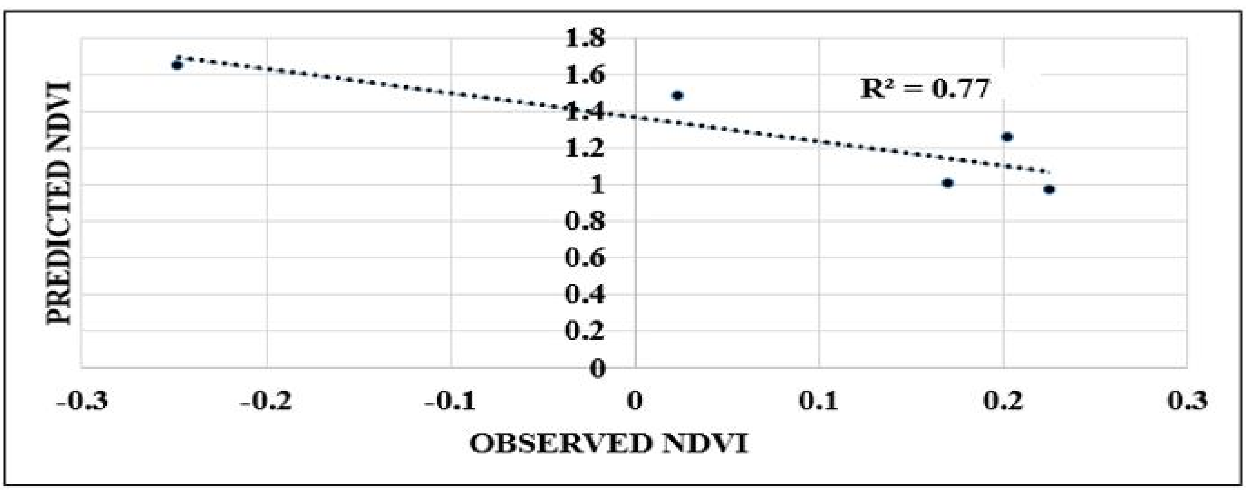

Figure 5.21: Observed and Predicted NDVI in Anantapur District for the year 2016

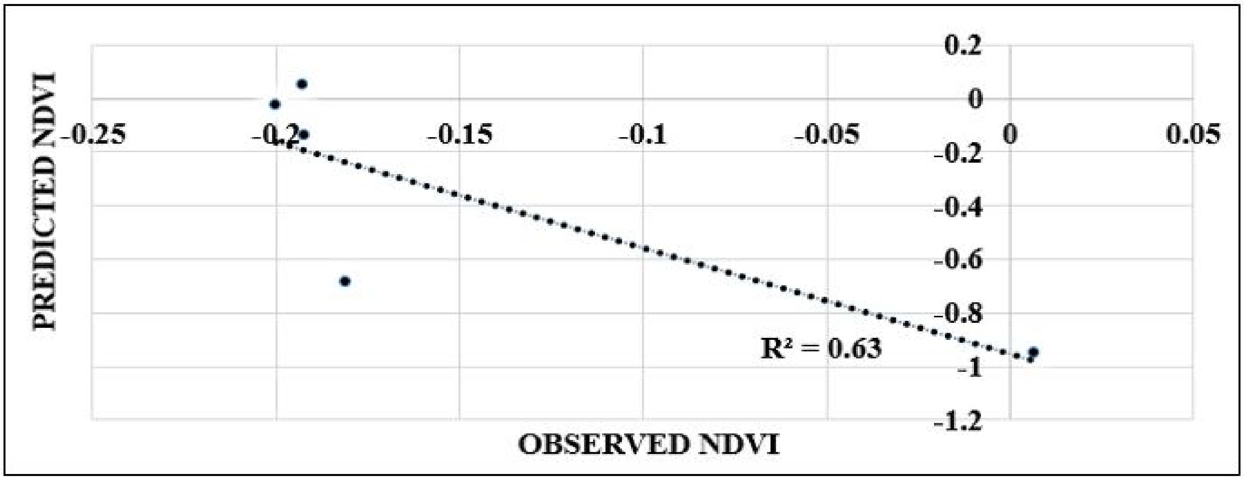

Figure 5.22: Observed and Predicted NDVI in Chittoor District for the year 2016

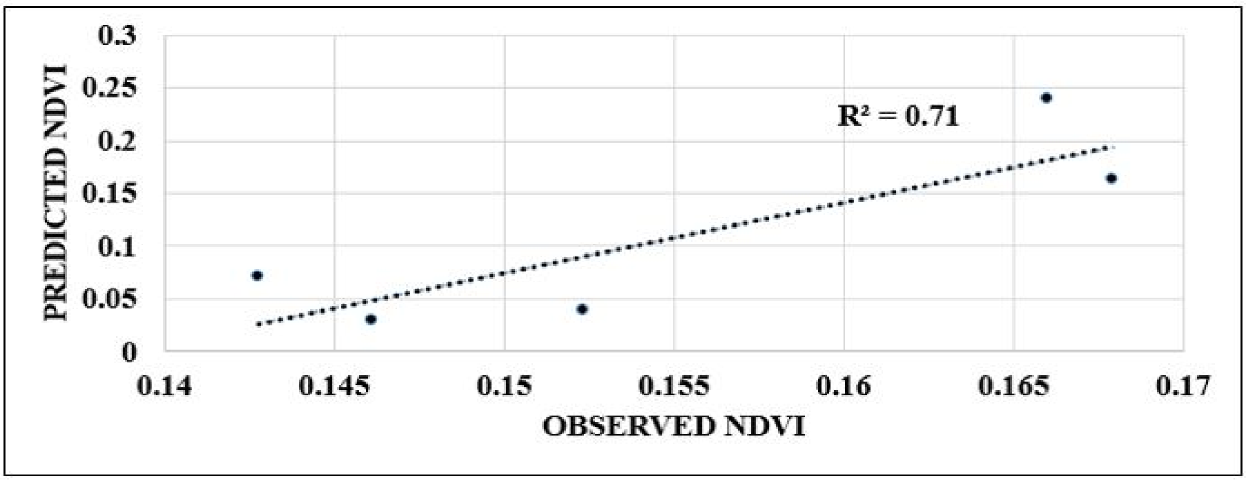

Figure 5.23: Observed and Predicted NDVI in YSR Kadapa District for the year 2016

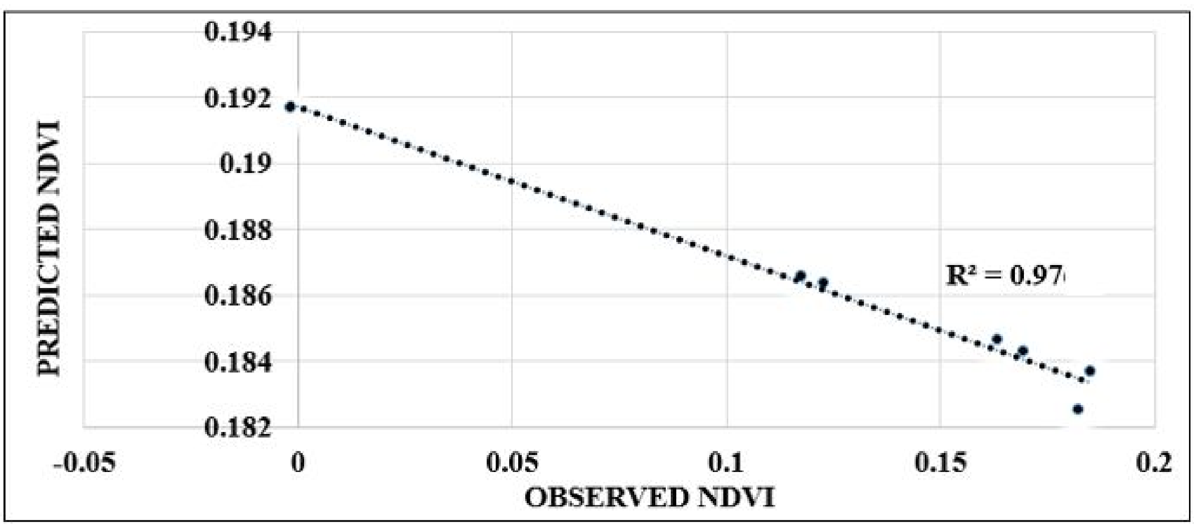

Figure 5.24: Observed and Predicted NDVI in Kurnool District for the year 2016

Now from the collected crop yield data, multiple correlations were done between different crop yields and NDVI. The obtained correlations and their models are shown in table 5.2. The Pearson Correlation coefficient (r) of Sugarcane in Anantapur, Jowar in Chittoor, Horse Gram in Kadapa and Sesamum in Kurnool which is tabulated in table 5.2 shows good correlation with NDVI in the year 2016. The Pearson Correlation coefficients (r) for Sugarcane was found to be 0.57 which was a moderate positive linear relationship, for Jowar it was found to be 0.85 which was a strong positive linear relationship, for Horse Gram it was found to be -0.53 which was a moderate negative linear relationship and for Sesamum it was found to be 0.79 which was a strong positive linear relationship.

Table 5.2: Crop Yield Predicted models

District	**Crop**	**Crop Yield model (t/ha.)**	**Correlation coefficient (r)**
Anantapur	Sugarcane	0.0359× NDVI - 3.15073	0.57
Chittoor	Jowar	0.231258×NDVI - 0.17078	0.85
YSR Kadapa	Horse Gram	0.581128 - 0.96375×NDVI	-0.53
Kurnool	Sesamum	1.297 × NDVI - 0.16327	0.79

5.6 Observed and Predicted Crop Yield

Based on the above correlation coefficients, regression analysis was done between the corresponding crop yields and NDVI values. From this regression analysis, different crop yield models were developed and are shown in table 5.2. From the analysis, the coefficient of determination r^2 was found to be 0.60 for Sugarcane crop in Anantapur district, 0.72 for Jowar crop in Chittoor district, 0.61 for horse gram crop in YSR Kadapa district and 0.63 for Sesamum crop in Kurnool district. For the rest of the crops, correlation coefficient and statistical relation are not in good agreement with NDVI. These regression models are able to predicted crop yield before harvesting.

From the regression models, the observed and predicted crop yield for different crops in different districts was plotted in figures 5.25 and 5.26. RMSE for sugarcane was found to be 5.05%, for Jowar it was 13.33%, for Horse Gram it was 9.04% and for Sesamum, it was 6%.

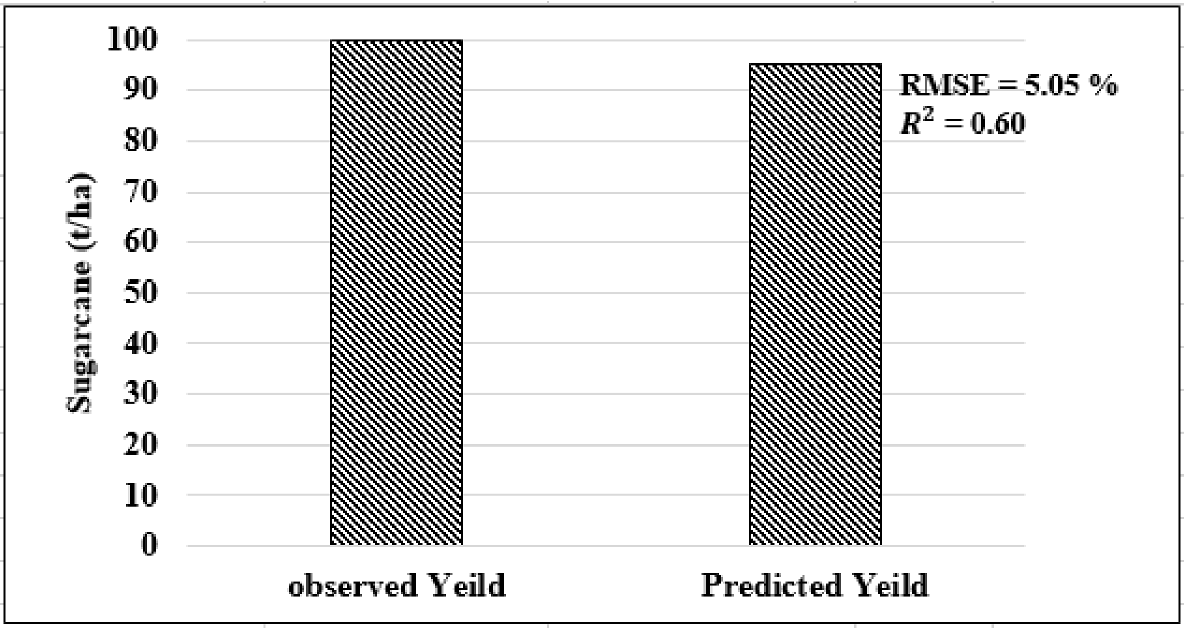

Figure 5.25: Observed and Predicted Sugarcane Crop in Anantapur District using NDVI Models

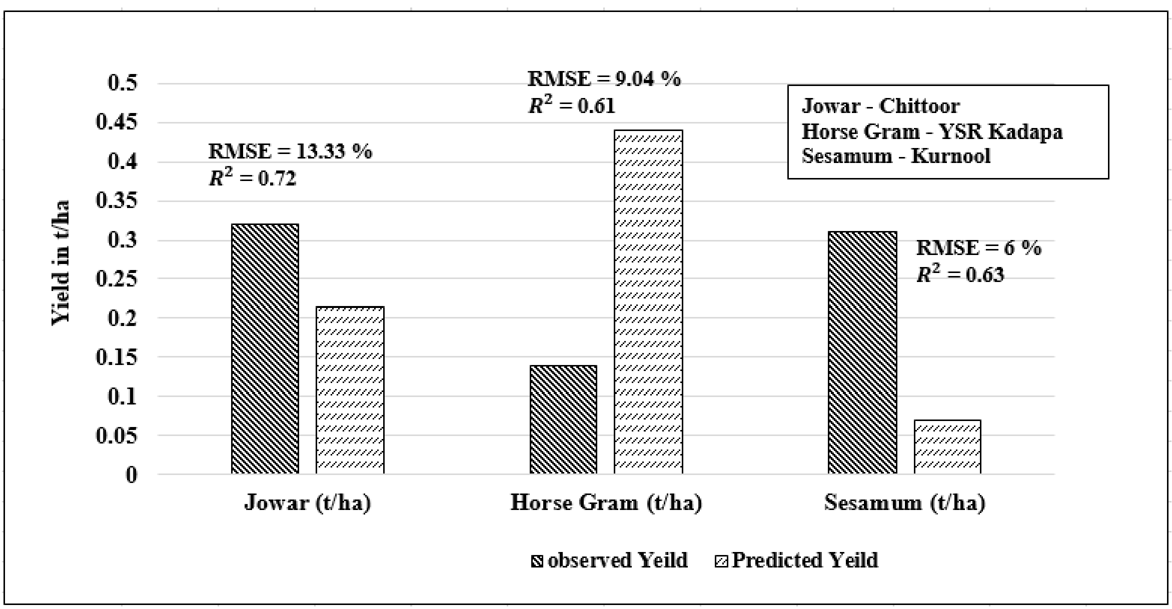

Figure 5.26: Observed and Predicted Crop Yield in different districts.

CHAPTER-6

Conclusions and Future Scope

6.1 Conclusions

The most innovative technique was proposed and applied in this study with the final objective to identify drought and development of a crop yield model for the Rayalaseema region in Andhra Pradesh. The reduced accuracy of agricultural practice, specifically in the rain-fed farming areas, was of great importance. For this reason, precipitation data and satellite data was successfully applied for the drought identification and development of crop yield model in the selected study area in India. This crop yield model was developed by interlinking NDVI values, obtained by Landsat ETM+ and OLI images, precipitation data, and previous crop yield data. The purpose of NDVI is to check the crop growth during dry and normal years. Even though some limitations in the image availability in certain months in a year, crop yield model was developed and analyzed in the year 2016.

It was found that the correlation between NDVI and SPI are in good agreement as they are directly and indirectly related to each other. Regression models obtained by using NDVI and SPI give a better result for the drought year 2016. This model gives a good statistical relation in all districts and the standard estimation error is also within the acceptable limit in all districts. Observed NDVI and Predicted NDVI is also acceptable as the coefficient of determination is satisfactory. NDVI and crop yield have a good correlation with sugarcane in Anantapur district, Jowar in Chittoor district, Horse Gram in Kadapa district and Sesamum in Kurnool district. Further with this correlation, regression analysis was done between Crop yield and NDVI. This analysis gives a satisfactory model with different crop yields in different districts. From this models crop yield was estimated and then RMSE is calculated. RMSE obtained for Sugarcane, Jowar, Horse Gram and Sesamum are within acceptable limits. Further, these Crop Yield models are applicable for future years but on condition that precipitation values obtained in a year must be very near or equal to long-term mean precipitation for the consideration period (minimum 30 years). Based on this study, crop yield was estimated for a particular period before harvesting.

6.2 Future Scope of study

This study can be extended by including some other Meteorological indices like Effective Drought Index (EDI), Surface water Supply Index (SWSI), Crop Moisture Index (CMI), Crop Water Stress Index (CWSI) and Geospatial Indices like Vegetation Index (VI), Vegetation Health Index (VHI), Normalized Difference Water Index (NDWI) etc. so that accuracy of the crop model will be increased but some preventive measures should be taken to avoid complexity of the model equations. In this study crop model was developed based on the precipitation data available for the corresponding water year 2016 i.e. (June 1^{st}, 2016 to May 31^{st}, 2017). Crop yield model developed can be extended for other years by satisfying the condition that the mean precipitation of that year is equal or very nearer to its long-term average precipitation for the period of consideration

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