PROJECT REPORT

ON

DROUGHT VULNERABILITY ASSESSMENT IN JALNA USING DROUGHT INDICES

Submitted in partial fulfilment of the requirement for the Award of the

BACHELOR'S DEGREE IN CIVIL ENGINEERING

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SUBMITTED

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Declaration

We declare that this written submission represents our ideas in our own words and where other's ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academics honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

Drought is a temporary and recurring hydro-meteorological event, which originates from the lack of precipitation, high temperature, and high evaporation over extended period of time. It is a normal part of any climate and, perhaps the most complex natural hazard, because it develops slowly, it is difficult to detect and has many facets in any single region. Drought preparedness and mitigation depends upon timely information on drought onset, development in time and spatial extent. This information may be obtained through continuous drought monitoring, which is normally performed using drought indices. This project work describes drought assessment, using two different drought indices, SPI (Standardized Precipitation Index) and RAI (Rainfall Anomaly Index). The Marathwada region of Maharashtra was chosen as the study area and this region is characterized as a 'frequently drought prone area', where drought can be expected every 6 to 10 years. A comparison of RAI and SPI values were done for determination of drought severity and temporal extension of drought for planning of mitigation measures for farmers. Using the SPI and RAI as indicators of drought severity from 1901-2002, the characteristics of drought were examined. The monthly rainfall data for the period (2012-2016) was also analyzed and the severity of drought was evaluated as a check with the historical data. The maximum annual SPI was -2.61 in the year 1920, similarly the RAI values also showed the same results which was -4.748 indicating the extreme drought conditions in the study area. The monthly SPI values were also compared with RAI+ and RAI- values for the period under observation. It was observed that the RAI- is highly correlated with SPI for determining the characteristics of droughts in the study area. The overall outcome of this study demonstrates that extreme and severe droughts were experienced in the years 1920, 1972 and 1911, 1912, 1918, 2000, 2001 across the study area leading to unfavourable results on agricultural practices and water resources in the area.

Keywords: Drought, SPI, RAI, Marathwada, Rainfall Analysis.

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Introduction

1.1 General

Drought is a period of time with less-than normal rainfall. Drought is a weather-related natural disaster which affects vast regions for months or years. It has an impact on food production and it reduces life expectancy and the economic performance of large regions or entire country. Drought can also be defined as climatic anomaly, characterized by deficient supply of moisture resulting either from inadequate rainfall, erratic rainfall distribution, higher water need or a combination of all these factors. The escalating impacts of drought includes widespread crop failure, unreplenished ground water resources, depletion of water level in lakes/ reservoirs, leading to shortage of drinking water, reduced food and fodder availability etc. Hence, the occurrence of drought must be understood and appropriate drought indices should be investigated for different goals such as agriculture practices, engineering practices and watershed management.

Drought can be categorized as

1. Meteorological drought.
2. Agricultural drought.
3. Hydrological drought.

Meteorological drought: A meteorological drought occurs when precipitation consistently falls short of average levels for periods of months or years.

Agricultural drought: This type of drought occurs when there isn't enough moisture to support average crop production on farms or average grass production on range land.

Hydrological drought: A hydrological drought occurs when the amount of water needed by crops for growth exceeds the amount available in the soil.

Meteorologists relate drought to deficiencies in rainfall compared to the average mean annual rainfall in an area. There is, however, no consensus on the threshold of deficit that makes a dry spell an official drought. Meteorological drought (India Meteorological Department - IMD) occurs when the seasonal rainfall received over an area is less than 75% of its long-term average value. If the rainfall deficit is between 26-50%, the drought is classified as 'moderate', and 'severe' if the deficit exceeds 50%. To an agricultural scientist, drought occurs when there is insufficient soil moisture to meet the needs of a particular crop at a particular point in time. Deficit rainfall over cropped areas during their growth cycle can destroy crops or lead to poor crop yields. Agricultural drought is typically witnessed after a meteorological drought, but before a hydrological drought. Hydrologists relate drought to a deficiency in surface and sub-surface water availability. It is measured as stream flows and also as lake, reservoir and groundwater levels. A sequence of impacts may be witnessed during the progression of a drought from meteorological, agricultural to hydrological. When drought begins, the agricultural sector is usually the first to be affected because of its heavy dependence on stored soil water. Soil water can deplete rapidly during extended dry periods. If precipitation deficiencies persist, then people dependent on other sources of water begin to feel the effects of the shortage. Those who rely on groundwater, for instance, are usually the last to be affected. When the situation returns to normal, and meteorological drought conditions have abated, the 'recovery cycle' follows the same sequence. Soil water reserves are replenished first, followed by stream flows, reservoirs/lakes and groundwater.

1.2 Impact of Drought in India

India is amongst the most vulnerable drought-prone countries in the world; a drought has been reported at least once in every three years in the last five decades. In India, 68% of the country is subjected to different degrees of water stress and drought conditions. Of the entire area, 35% of the area which receives rainfall between 750 mm – 1125 mm is considered drought prone while another 33%, which receives rainfall between 750 mm – 1125 mm is considered chronically drought prone (Manual for drought management, 2009). Since the mid-nineties, prolonged and widespread droughts have occurred in consecutive years, while the frequency of droughts has also increased in recent times (FAO, 2002; World Bank, 2003). Drought Vulnerability of India may be attributed to the following reasons.

- High average annual rainfall of around 1150 mm; no other country has such an high annual average, however there is considerable annual variation.
- Even though India receives abundant rain as a whole, disparity in its distribution over different parts of the state is so great that some parts suffer from perennial dryness. In other parts, however, the rain is so excessive that only a small fraction can be utilized.
- About 73% of the total annual rainfall is received in less than 100 days during the southwest monsoon and the geographic spread is uneven particularly in tropical wet-dry regions like Mumbai.

1.3 Drought in Jalna (Marathwada Region of Maharashtra)

Jalna District in Marathwada has a semi-arid climate with an average annual rainfall of 729.7 mm, and an average monsoon from June to September with rainfall of 606.4 mm. Marathwada is characterized as a 'frequently drought prone area', where drought can be expected every 6 to 10 years. During the year 1875 – 2014, it has experienced 18 times, including the 2 years of successive drought in 1984 and 1985. The 30- year period from the early 1940's had few droughts including the extreme drought of 1972, during which time the state Employment

Guarantee Scheme - a precursor to the National Rural Employment Guarantee Scheme - was introduced as a drought response measure. In recent years, however, there has been a drastic decline in rainfall, culminating in the extreme drought of 2012.

Rainfall recorded at the Krishi Vigyan Kendra (KVK), Kharpudi, located near Jalna city, also shows a declining trend during the last two to three decades. In 2012, the station recorded barely 200 mm of rainfall. Furthermore, data from the Badnapur Research Station in Jalna shows that during the period of 1984–2010, rainfall in June has tended to decrease while September rainfall has increased over the same period.

1.4 Need of the Study

Even if Jalna and the other parts of the Marathwada region has been reeling under chronic drought conditions since many decades, only socio-economic analysis of drought has been carried out till now. Technical aspects of drought assessment viz. the magnitude, intensity and duration of drought events and drought severity is not given importance in the earlier studies by researchers. A more detailed technical analysis of the severity and duration of drought would give a better picture of drought scenario in this region to plan mitigation measures.

1.5 Aim of the Research Work

This project has been taken up to analyze the rainfall pattern and behavior and also to assess the intensity of drought in the Jalna region using Drought Indices (DI) with the following objectives.

1.6 Objectives of the Research work

1. To examine the influence of rainfall and other meteorological parameters on drought perceptions.
2. To carry out the drought vulnerability assessment using Drought Indices.
3. To compare the drought indices to suggest a suitable index for drought assessment in Jalna.

1.7 Organization of the Report

The following report comprises of five chapters as mentioned below:

- Chapter 1 comprises of introduction to our research work.
- Chapter 2 presents a review of relevant literature where the concepts of rainfall analysis and drought assessment are discussed.
- Chapter 3 deals with the methodology to be adopted for the analysis of rainfall variation and development of SPI and RAI.
- Chapter 4 comprises of the results and discussions on the project work.
- Chapter 5 presents summary and conclusions of the project work.

Chapter 2

Literature Review

The chapter is about the literature survey done for assessing the impacts of various drought events occurred in the history of Jalna, Marathwada region. In order to get a direction for the research work, this chapter discusses the information gathered from various literatures about rainfall analysis, how to assess drought characteristics using various drought indices.

2.1 Background of Study

Rainfall is an important factor that decides the severity of drought or flood in a particular region. Water conservation techniques such as rain water harvesting, rainfall cistern system etc. are all rainfall dependent. Hence, in order to use these techniques, it is necessary to have detailed information on rainfall amount, duration and intensity of drought. Past records of rainfall can be used to predict future trends of rainfall occurrence in rainfed farming areas. This will help in planning various other measures for water conservation. The rainfall runoff relationship will be important for implying techniques like water harvesting.

This chapter presents a review of relevant literature to bring out the background of the study undertaken in this dissertation. The research contributions which have a direct relevance are treated in greater detail. Some of the historical works which have contributed greatly to the understanding of the rainfall analysis and behaviour described. First, a brief review of the historical background is presented. The concepts of rainfall analysis and modelling related to work carried out in this papers, are then discussed. The amount of the literature on the subject has increased rapidly in recent years; particularly on probabilistic modelling. Several of this is available in the proceedings of the conferences and journals which are very helpful to understand the recent work on analysis and behaviour of rainfall and its methods.

2.2 Rainfall Analysis

For this study, only rainfall data of Marathwada region is used to drought analysis thus, drought indices which could be evaluated by only rainfall data are of priority. The various drought indices are estimated till now based on precipitation data are reviewed in this section.

ISRO (2012) researched on the 'National Agricultural Drought Assessment and MonitoringSystem (NADAMS)' project, conceptualized and developed by National Remote Sensing Centre (NRSC), ISRO, Department of Space, provides near real-time information on prevalence, severity level and persistence of agricultural drought at state/ district/sub-district level. Currently, it covers 13 states of India, which are predominantly agriculture based and prone to drought situation.

They have studied agricultural drought assessment with multiple indices:

- Shortwave Angle Slope Index (SASI)
- Normalized Difference Wetness Index
- Normalized Difference Vegetation Index
- Soil Moisture Index (derived from soil water balance approach)
- IMD Rainfall data – rainfall deviation, number of dry weeks

The present report is a summary of agricultural situation during October 2012 for13 states and contains satellite derived vegetation index images, rainfall deviations and assessment of agricultural situation.

Patil (2017) have studied that the development of contract farming helped to change traditional altitude of agricultural producers. Contract farming is encouraged because majority of farmers are marginal and small farmers and they produce mainly for self consumption rather than market. The development of contract farming will definitely help tochange traditional altitude of agricultural producers. It creates ultimately assured market forthe products, which in turn creates an incentive in the mind of agricultural producer to produce more output by using modern technology. Some NGOs with requisite expertise and funding do conduct research activities but these are generally limited to their own projects.

RedR India (2013) have studied that the government had acquired water from near reservoirs or private wells at min rate 400rs per day.The tankers were also filled by existing water treatment plant, pumping from open wells dug in the beds also in some cases from rivers**.** For the purpose of data collection a multi-sectoral drought needs assessment checklist was developed and used for this assessment. This assessment tool was prepared by selecting elements appropriate to a drought situation from the following sources:

- IASC: Multi-Cluster/Sector Initial Rapid Assessment
- OCHA: Rapid Assessment Form
- ICRC & IFRC: Guidelines for assessment in emergencies (March 2008)
- IFRC: How to conduct a food security assessment (Second edition,2006)
- IAG: Joint Assessment Format–Sphere URS

Bhardwaj (2014) has studied to establish the climate profile of the domain area of study the historical assessment of the meteorological parameters viz. Temperature (minimum and maximum) and JJAS precipitation have been carried out. Gridded datasets from IMD at 1 degree resolution for temperature and accumulated rainfall data from the KrishiVigyan Kendra (KVK), Kharpudi located near Jalna city have been utilized. The time periods for both these datasets differ given the different sources used. The 1970-2000 time period has been taken as a reference or the baseline for the regional model simulations for future time slices. The validation of the model dataset has been carried out over the entire Maharashtra domain using six different observational datasets. Data over the Jalna district has been extracted for the baseline and future time slices and spatial and temporal analysis for changes in temperature and precipitation patterns has been carried out. Analysis has been done for computing warm nights using minimum temperatures and heat index considering temperatures and humidity levels, rainfall during peak season in the months of JJAS, total rainfall and extreme rainfall both for historical periods and projections.

2.3 Drought Assessment

A Drought Index (DI) is a prime variable for assessing the effect of drought and defining different drought parameters, which include intensity, duration, severity and spatial extent. It should be noted that a drought variable should be able to quantify the drought for different time scales for which a long time series is essential. The most commonly used time scale for drought analysis is a year, followed by a month. Although the yearly time scale is long, it can also be used to abstract information on the regional behaviour of droughts. The monthly time scale seems to be more appropriate for monitoring the effects of a drought in situations related to agriculture, water supply and ground water abstractions

Hydrological and meteorological indices measure different drought-causative and drought-responsive parameters, and identify and classify drought accordingly. A number of different indices have been developed to quantify a drought based on precipitation, each with its own strengths and weaknesses. They include the Palmer Drought Severity Index (PDSI); Palmer 1965), Rainfall Anomaly Index (RAI); (Van Rooy, 1965), Deciles (Gibbs and Maher,1967), Crop Moisture Index (CMI); (Palmer, 1968) etc. Based on the studies for drought indices, practically all drought indices use precipitation either singly or in combination with other meteorological elements, depending upon the type of requirements, which were also suggested by WMO (1975).

2.3.1 Standardized Precipitation Index (SPI)

A deficit of precipitation impacts on soil moisture, stream flow, reservoir storage, and ground water level, etc. on different time scales. McKee et al., (1993) developed the SPI to quantify precipitation deficits on multiple scales.

Santos et al. (2010) have assessed the spatio-temporal variability of drought in Portugal using SPI at different time scales (1, 6 and 12 consecutive months and 6 months from April to September and 12 months from October to September), principal component analysis and cluster analysis. By this way three different and spatially well-defined regions with different temporal evolution of droughts were identified (north, central and south regions of Portugal). Gebrehiwot et al., (2011) assessed the spatial and temporal variation of drought in northern highlands of Ethiopia based on the SPI .The results of the SPI analysis reveal that the eastern and southern zones of the study region suffered a recurrent cycle of drought over the last decade.

Vasiliades et al. (2011) calculated the SPI and four other Palmer's indices viz.PDSI, WPLM, PHDI and the Palmer moisture anomaly Z-index and compared them to a water balance derived drought index for assessment of hydrological droughts in 14 sub-watersheds of Pinios river basin. The results showed that the water balance derived drought index is a good indicator of hydrological drought in all sub-watersheds, since it is capable to quantify drought severity and duration. SPI at 3- and 6-month timescales and the WPLM could be used along with the water balance derived drought index in risk and decision analysis at the study area.Further methodology to be adopted is explained in chapter 3.

2.3.2 Rainfall Anomaly Index (RAI)

RAI was developed by Van Rooy (1965). The positive and negative RAI indices are computed by using the mean of ten extremes. RAI uses normalized precipitation values based upon the station history of a particular location.RAI addresses droughts that affect agriculture, water resource and other sectors, as RAI is flexible in that it can be analyzed at various timescales.

Pandey et al. (2014) Comparative study of number of drought years obtained through various drought indices clearly revealed that all the methods yielded similar results, although at places marginal differences were observed in the number of drought years. This indicates suitability of any of these methods in deducing the drought years. Among the three methods employed, Aridity Index (Ia) seems to be the most accurate method for drought severity assessment as it is based on the computation of various parameters of water balance. Comparatively, the Departure Index (DI) is rather simple in computation and sees only the annual rainfall variation to asses' drought severity. Rainfall Anomaly Index (RAI) although doesn't quantify drought severity but only the dry years, still it is similar in approach as DI and therefore yields similar results as DI. Drought indices revealed that overall drought proneness is apparently high in Daltonganj and Chaibasa, although both of them have mild droughts in majority of the years. On the contrary in terms of moderate droughts, Dumka has the highest severity followed by Daltonganj, Jamshedpur and Dhanbad whereas Chaibasa and

Ranchi has the least percentage. Therefore, to combat drought situation supplementary irrigation facilities should be made available in high drought prone regions. The crop selection in these regions should be directed towards adoption of crops which require low moisture conditions.

Rodrigues. (2017) this work aimed at presenting a study of the space-time variation of the rainfall precipitation in the Salgado river basin, in the state of Ceará, utilizing the Rainfall Anomaly Index (RAI) as a tool, as well as accomplishing its spatial distribution in order to identify areas of higher or lower severity of events. The present study was developed for the Salgado River Basin (Figure 1). It is located in the southern region of the state of Ceará and it has the Salgado River, a tributary of the Jaguaribe River, as the main river, with 308km of length. In addition, it drainage area of 12,623.89 km², which is equivalent to 9% of the state territory, encompassing23 municipalities (CEARÁ, 2009).The database used in this study was obtained by means of 7 meteorological stations of the Meteorology Foundation in Ceará - FUNCEME, provided by the National Water Agency (ANA), by means of the Hidroweb platform. Data from the daily precipitation of the period between 1974 and 2015 (42years) at the stations located in Aurora, Crato, Icó, Jardim, Mauriti, Milagres and Várzea Alegre were utilized. From the precipitation data, the Annual Rainfall Anomaly Index (RAI) was calculated to analyse the frequency and intensity of the dry and rainy years in the studied area. In addition, the monthly RAI was calculated for specific years of the historical series aiming to analyse the distribution of rainfall in the years of greatest anomaly.

The above literature survey shows that considerable work has been done on drought assessment using different indices in India and across globe. But very less literature is available on drought assessment in Marathwada region using drought indices. Hence this study has been taken up and the methodology adopted will be explained in Chapter 3.

Chapter 3

Methodology

3.1 General

This chapter deals with the methodology to be adopted for the rainfall analysis as well as drought analysis in Jalna.

3.2 Study Area

Maharashtra state has a geographical area of 3,07,713 sq.km and the State has 35 districts and 353 talukas. Administratively, the State has six divisions with Headquarters at Konkan (New Bombay), Pune, Nasik, Aurangabad, Amravati and Nagpur. The population of the State is 112.3 million as per 2011 Census out of which 41 million is urban and 55.7 million rural. Out of total area of the State, 73 %, i.e., 2.25 lakh, sq. km of area is cultivable and 17.6 % is under forest.

Marathwada Region which is mainly located in the main drainage of Godavari River is facing severe Drought conditions. Actually, the region is facing the recurrent droughts with constant variations of rains and prolonged gaps. However, the water scarcity which year, especially in **Jalna (Bhokardan, Badnapur),** Aurangabad, Beed and Osmanabad districts is altogether different from the femine of 1972.

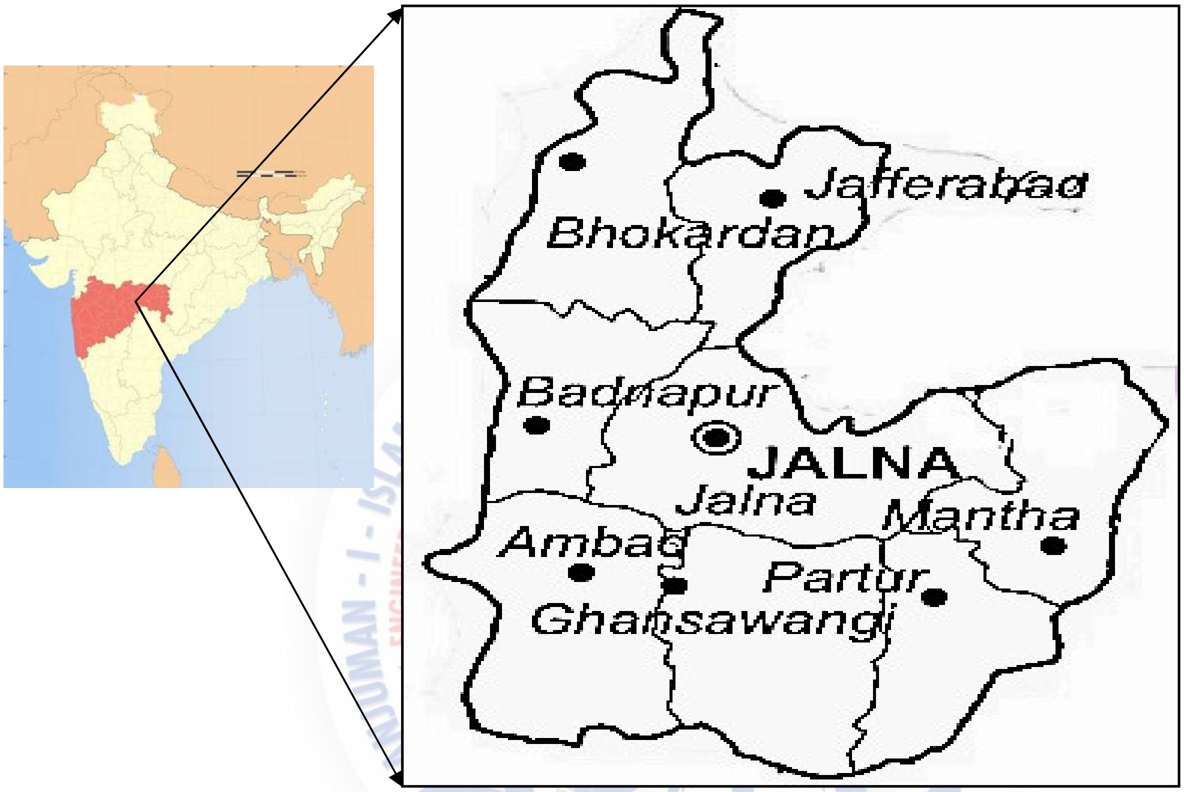

Figure 3.1 Map Layout of Jalna

Local perceptions of recent climate trends among farmers and officials in Jalna are that temperature has increased, rainfall has been decreasing, the onset of the monsoon has become delayed and erratic, and the number of rainy days has decreased. Jalna district in Marathwada has a semi-arid climate with an average annual rainfall of 729.7 mm, and an average monsoon from June to September with rainfall of 606.4 mm.

Table 3.1 General climatic features of each district in Marathwada

Sr. No.	District	Average annual rainfall (mm)	Temperature (C)		Area (Km^2)
			Minimum	Maximum	
1	Aurangabad	676	5	46	10,100
2	Beed	717	7	46	10,693
3	Hingoli	885	11	43	4,526
4	Jalna	719	9	43	7,612
5	Latur	797	14	40	7,157
6	Nanded	912	10	45	10,545
7	Osmanabad	701	9	44	7,569
8	Parbhani	796	14	42	6,251

3.3 Climate and Rainfall

Climate in Marathwada region is dry and moderately extreme in nature. The maximum summer temperature varies between 36°C and 43°C and during winter the temperature oscillates between 10°C and 16°C. Annual rainfall ranges from 675 to 950 mm. Usually Rainfall starts in the first week of June and July is the wettest month. Four distinct seasons are noticeable in a year.

3.3.1 Monsoon

June to September is considered as Monsoon. The rains start with the south - west winds. Nearly 88% of the total average rainfall occurs in this season. The number of average annual rainy days is 46 in Marathwada while the count is 95 in Konkan, 55 in Vidarbha and 51 in Western Maharashtra.

3.3.2 Post Monsoon

The fair weather season with meager rainfall between October to mid-December is a called as post-monsoon season. Nearly 8% of total annual rainfall occurs in this season. Yield of Rabi crops depends upon the weather during these months.

3.3.3 Winter

Winter season is described as a period of two or two and half months from mid-December until end of February. Approximately 4% of annual rainfall occurs in winter. Most of the Rabi crops are harvested during winter. Temperature in winters is in between 100^{o}C to 160^{o}C.

3.3.4 Pre-Monsoon

Also known as summer, this season lasts for three months; March to May. Climate is dry and extreme and temperature is high between 360^{o}C to 410^{o}C. Marathwada region receives pre-monsoon rains during this season.

Jalna District in Marathwada has a semi-arid climate with an average annual rainfall of 729.7 mm, and an average monsoon from June to September with rainfall of 606.4 mm. Marathwada is characterized as a 'frequently drought prone area', where drought can be expected every 6 to 10 years. During the year 1875 – 2014, it has experienced 18 times, including the 2 years of successive drought in 1984 and 1985. The 30- year period from the early 1940's had few droughts including the extreme drought of 1972, during which time the state Employment Guarantee Scheme - a precursor to the National Rural Employment Guarantee Scheme - was introduced as a drought response measure. In recent years, however, there has been a drastic decline in rainfall, culminating in the extreme drought of 2012.

Rainfall recorded at the Krishi Vigyan Kendra (KVK), Kharpudi, located near Jalna city, also shows a declining trend during the last two to three decades. In 2012, the station recorded barely 200 mm of rainfall. Furthermore, data from the Badnapur Research Station in Jalna shows that during the period of 1984–2010, rainfall in June has tended to decrease while September rainfall has increased over the same period.

As described in literature review, a detailed drought assessment using rainfall based drought indices (SPI & RAI) is carried out in this project work to understand the drought severity in Jalna. The methodology adopted is summarized in the flow chart (Fig 3.1)

3.4 Methodology

The flow chart listing detailed steps of methodology to be adopted is mentioned below:

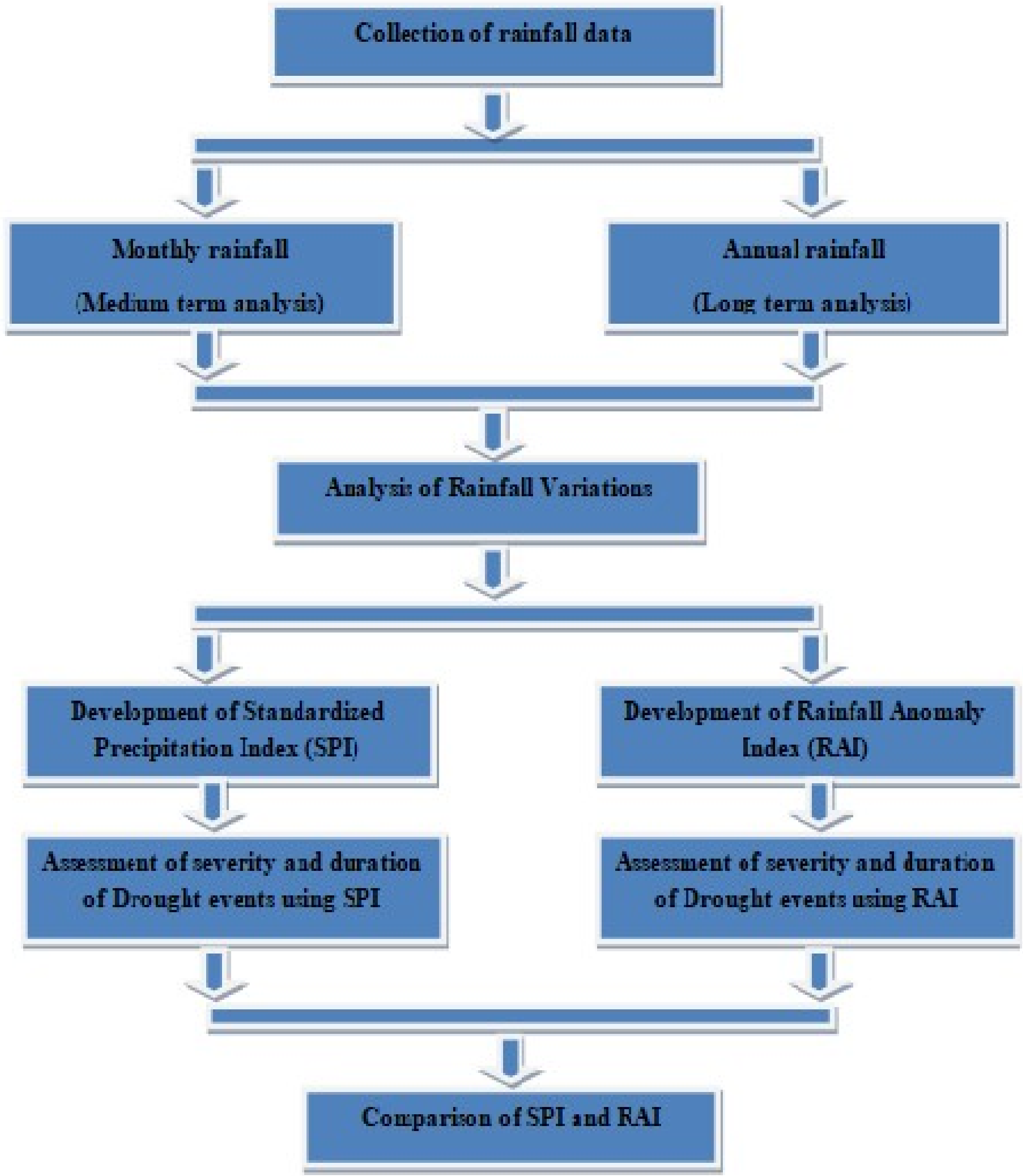

Figure 3.2 Methodology adopted in the work

3.5 Collection of Rainfall Data

In this study, the monthly rainfall data for a period of 1901-2002 was collected from Indian water portal (IMD) Santacruz. Rainfall analysis as well as drought analysis was carried out using the rainfall data. Monthly rainfall data for the period of 2012-2016 was also taken to have a comparative study of the historical data with the present rainfall data.

3.6 Rainfall Analysis

Monthly and annual variation of rainfall in the study area is analyzed using the historical as well as the recent rainfall data. Also the basic statistical parameters were computed and presented in the form of rainfall hyetographs.

3.7 Drought Indices

3.7.1 Standardized Precipitation Index (SPI):

A deficit of precipitation impacts on soil moisture, stream flow, reservoir storage, and ground water level, etc. on different time scales. McKee et al., (1993) developed the SPI to quantify precipitation deficits on multiple scales. The nature of the SPI allows an analyst to determine the rarity of a drought or an anomalously wet event at a particular time scale for any location in the world that has a precipitation record. A drought event occurs at the time when the value of SPI is continuously negative. The event ends when the SPI becomes positive. Table no.3.2 provides a drought classification based on SPI. SPI can be calculated using the following mathematical expression. The SPI is calculated by taking the difference of the precipitation from the mean for a particular time scale, then dividing it by the standard deviation.

SPI = (Xik - Xi)/ói

where,

ói = Standardized deviation for the "i" th station

Xik = Precipitation for the "i" th station and " k" th observation

Xi = Mean precipitation for the "i" th station

Table 3.2 Drought categories using SPI

SPI values	Drought Category
0 to – 0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.0 or more	Extreme drought

Advantages of SPI

- SPI is spatially invariant in its interpretation, and probabilistic, so it can be used in risk and decision analysis.
- SPI is calculated even if other metero-hydrological measurements are not available.
- The SPI has the ability to quantify precipitation deficit for multiple time scales.
- SPI is standardized and can compare dry and wet periods on different locations.

In this study, RAI is also used in addition to SPI to check the correlation of both the indices in investigating drought severity in Jalna.

3.7.2 Rainfall Anomaly Index (RAI):

RAI was developed by Van Rooy (1965). The positive and negative RAI indices are computed by using the mean of ten extremes.

Let,

Ḿ = The mean of the ten highest precipitation records from the period under study.

Ṕ = The mean precipitation of all the records for the period

P = The precipitation for the specific year.

Then the positive RAI (for positive anomalies) for that year is ,

$$RAI = 3((P-\acute{P})/(\acute{M}-\acute{P}))$$

Let,

ḿ = The mean of the ten lowest precipitation records from the period under study.

Then the negative RAI (for negative anomalies) for that year is ,

$$RAI = -3((P-\acute{P})/(\acute{m}-\acute{P}))$$

Table 3.3 Drought categories using RAI

RAI	Class description
≥4.00	Extremely wet
2.00 to 4	Very wet
0 to 2	Wet
-2 to 0	Dry
-4 to -2	Very Dry
Below -4	Extremely Dry

Advantages of RAI

- RAI uses normalized precipitation values based upon the station history of a particular location.
- RAI addresses droughts that affect agriculture, water resource and other sectors, as RAI is flexible in that it can be analyzed at various timescales.
- RAI is easy to calculate, with a single input (precipitation) that can be analyzed on monthly, seasonal and annual time scales.

The above methodology was adopted for drought vulnerability assessment and the results obtained from the analysis is discussed in Chapter 4.

Chapter 4
Results and Discussions

4.1 General

This chapter deals with the results of rainfall analysis and drought assessment using the Standaradized Precipitation Index (SPI) and Rainfall Anomaly Index (RAI). The results are analyzed and discussed in this chapter.

4.2 Rainfall Analysis

The rainfall analysis is carried out using monthly rainfall data for the period 1901-2002, It is also used for annual, seasonal and monthly analysis and are shown in figures 4.1 and 4.2.

The figure 4.1 shows that the average mean rainfall is 719.34 mm which is shown by the red line. It was observed that 50% of the total years was hardly shown above the average annual rainfall and the remaining 50% were below the average mean rainfall and also the rainfall trend is very uncertain, over the decades.

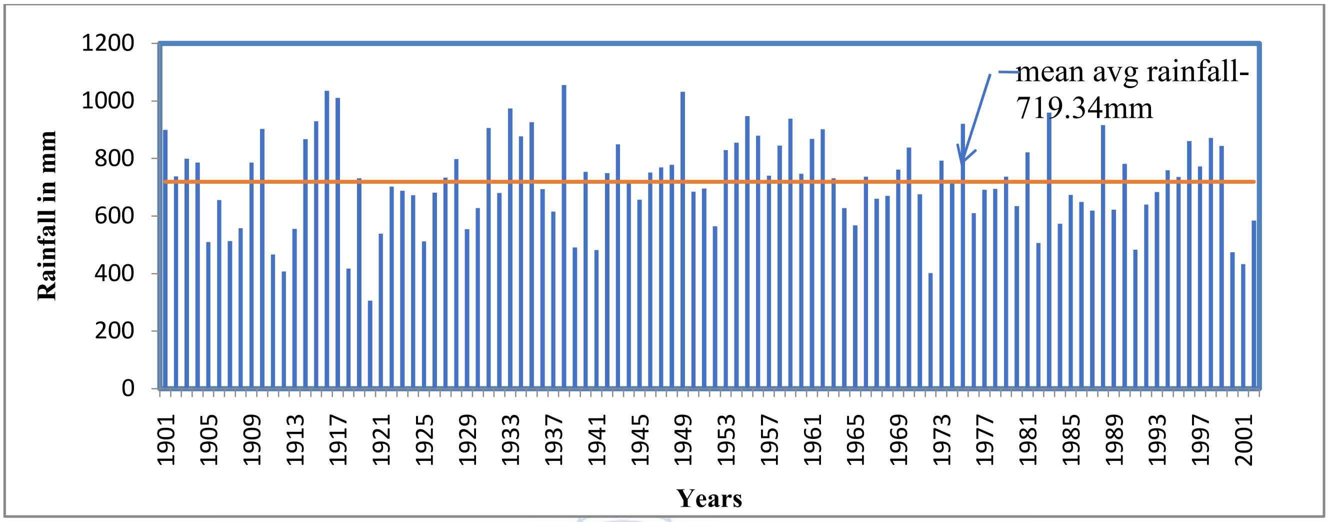

Figure 4.1 Analysis of annual mean rainfall (1901-2002)

Table 4.1 Maximum and minimum annual rainfall over a period (1901-2002)

Maximum rainfall in mm	**1055.284 mm (1938)**
Minimum rainfall in mm	**305.601 mm (1920)**

The maximum average monthly rainfall was observed in the year 1938 which was 1055.284 mm. The minimum average annual rainfall was found in the year 1920 which was 305.601 mm. To understand the monthly variation of rainfall, a more detailed monthly analysis was carried out for the period 1901-2002 (Figure 4.2). The maximum monthly rainfall was found in September which was 196.753 mm and the minimum rainfall was found in February which was 3.706 mm (Table 4.2).

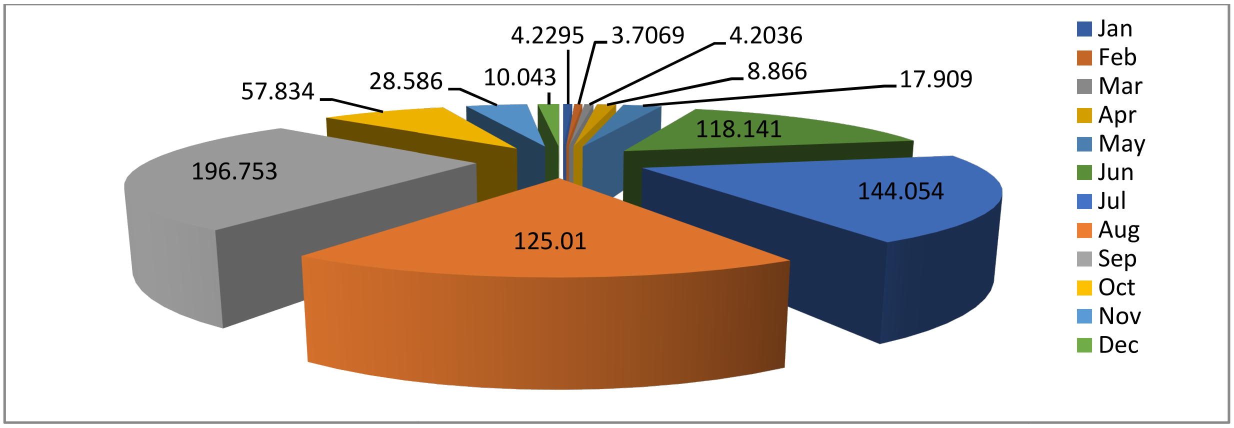

Figure 4.2 Analysis of average monthly rainfall in Jalna (1901-2002)

Table 4.2 Maximum and minimum monthly rainfall over a period (1901-2002)

Maximum rainfall in mm	**196.753 mm (September)**
Minimum rainfall in mm	**3.7069 mm (February)**

4.3 Drought Assessment

The drought analysis was carried out by using different drought indices like Standardized Precipitation Index (SPI) and Rainfall Anomaly Index (RAI), which were later compared together to check the severity of the Drought.

4.4 Drought Analysis using SPI

A more detailed monthly drought analysis was done using SPI to have a clear picture of agricultural drought during crop growth period (June-September).

4.4.1 Development of SPI using historical data (1901-2002)

The annual variation of drought events was analyzed using annual SPI values. The figure 4.3 shows that the most extreme drought was occurred in the year 1920 i.e (SPI index was -2.61) which comes in to the category of extreme drought condition and its standard range is n > -2. Severe Drought Conditions was observed for 7 years in the study area whose SPI range lie between -1.5 to -2. Moderate Drought Conditions for 10 years were observed whose range lie between -1 to -1.5. Whereas Mild Drought Condition was observed for 30 years whose range lie between 0 to -1 in the study area.

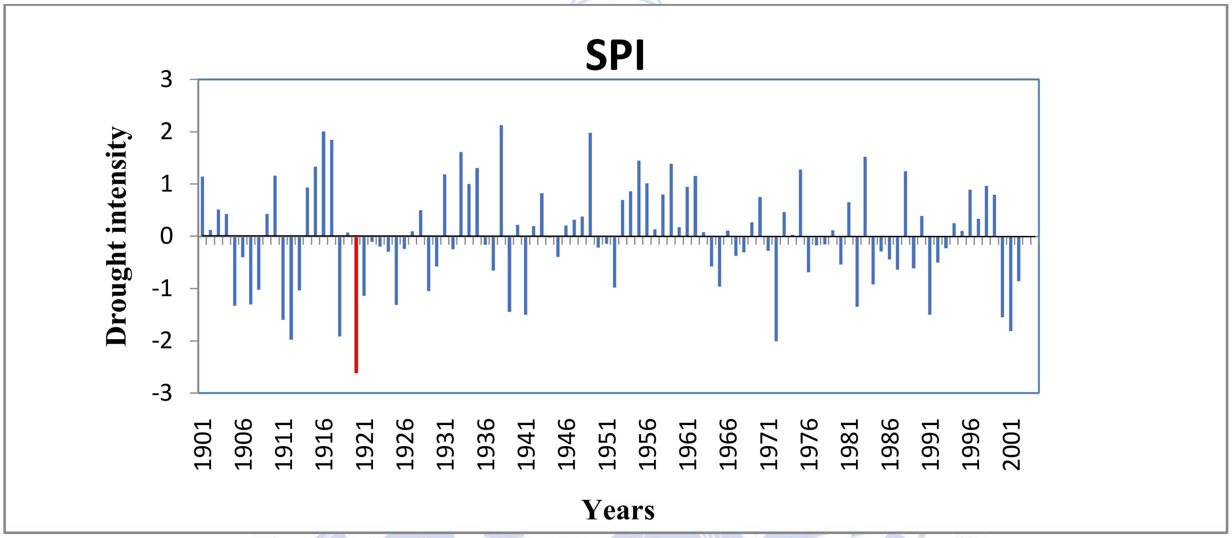

Figure 4.3 Analysis of annual SPI in Jalna (1901-2002)

Table 4.3 Analysis of drought categories over a period (1901-2002)

SPI	Year	Category
-2.61	1920	Extreme
-1.50 to -1.99	8 years	Severe
-1.00 to -1.49	3 years	Moderate
0 to -0.99	32 years	Mild

The monthly drought analysis shows that the most extreme drought was occurred in the year 1941(Figure 4.4) i.e (SPI index was -2.09) which comes in to the category of extreme drought condition and its standard range is n > -2. Severe Drought Condition was observed for 4 years whose SPI range lie between -1.5 to -2. Moderate Drought Condition for 10 years were observed whose range lie between -1 to -1.5.Whereas Mild Drought Condition were observed for 36 years whose range lie between 0 to -1.

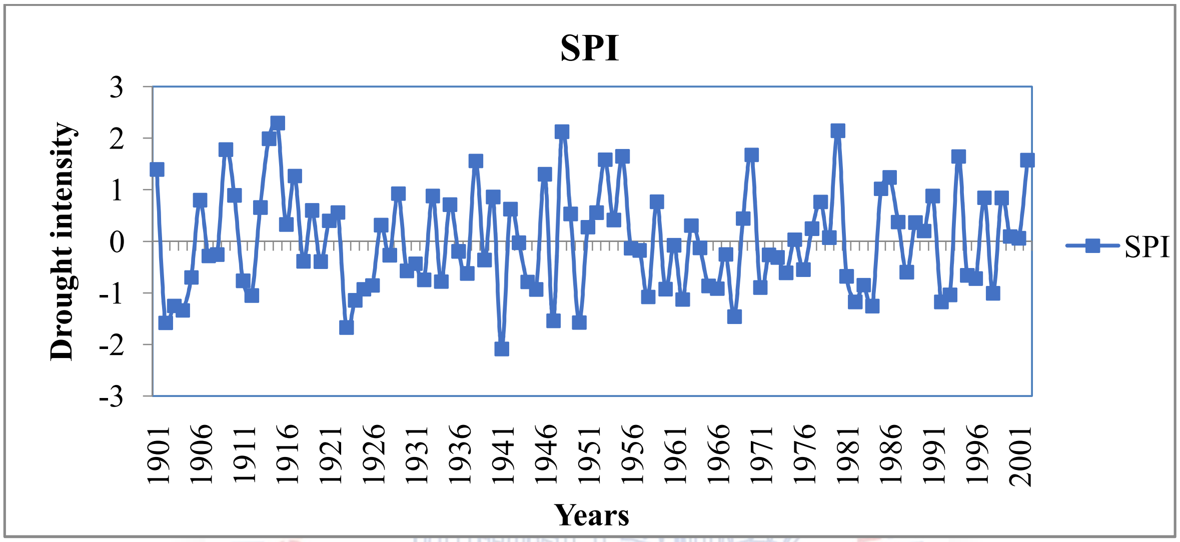

Figure 4.4 Analysis of SPI June (1901-2002)

The figure 4.5 shows that the most extreme drought was occurred in the year 1971 i.e (SPI index was -2.34) which comes in the category of Extreme drought condition and its standard range is n > -2. Severe Drought Condition was observed for 8 years whose SPI range lie between -1.5 to -2. Moderate Drought Condition 3 years were observed whose range lie between -1 to -1.5. Whereas Mild Drought Condition were observed for 32 years whose range lie between 0 to -1.

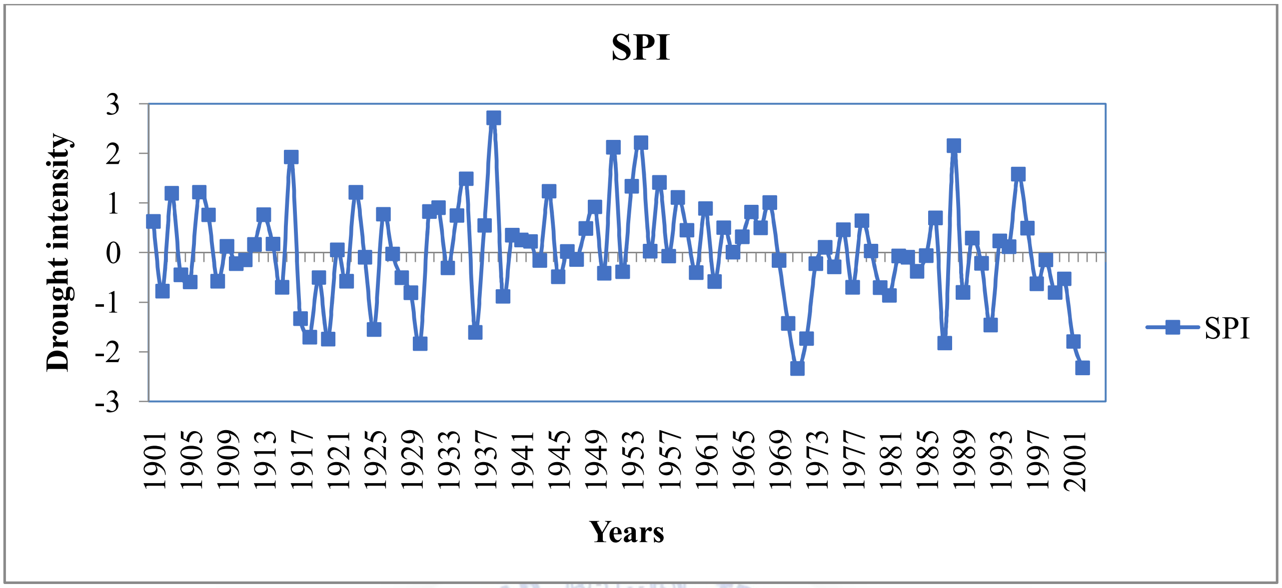

Figure 4.5 Analysis of SPI July (1901-2002)

No extreme drought was found in August month (Figure 4.6). However, severe drought Condition was observed for 2 years with SPI range between -1.5 to -2. For Moderate Drought Condition, 17 years were observed whose range lie between -1 to -1.5.Whereas Mild Drought Condition of 32 years were observed whose range lie between 0 to -1.

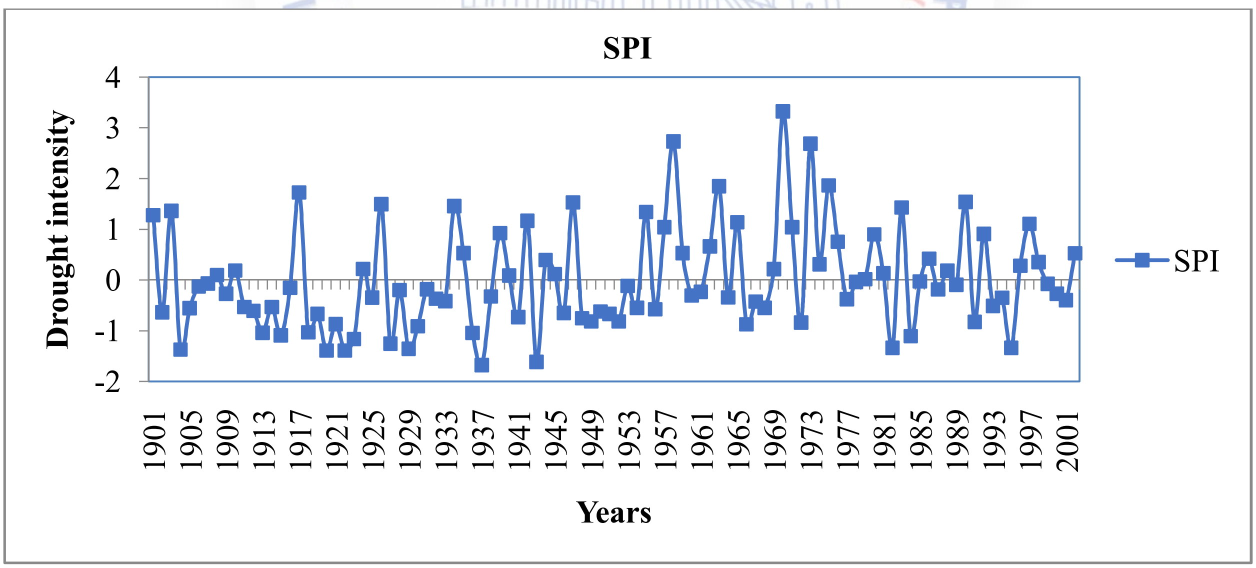

Figure 4.6 Analysis of SPI August (1901-2002)

The figure 4.7 shows that no extreme drought was found in September. Severe Drought Condition was observed for 2 years whose SPI range lie between -1.5 to -2. Moderate Drought Condition of 18 years were observed whose range lie between -1 to -1.5. Whereas Mild Drought Condition of 32 years were observed whose range lie between 0 to -1.

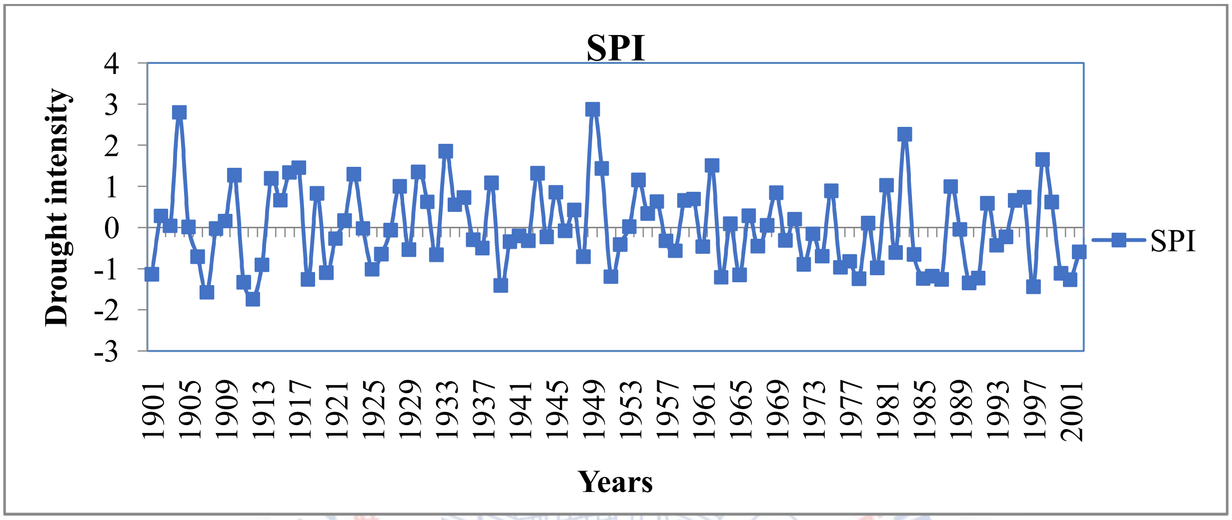

Figure 4.7 Analysis of SPI September (1901-2002)

The figure 4.8 shows that no extreme drought was found for Extreme drought and Severe Drought Condition occurred in October. Moderate Drought Condition 18 years were observed whose range lie between -1 to -1.5. Whereas Mild Drought Condition 35 years were observed whose range lie between 0 to -1.

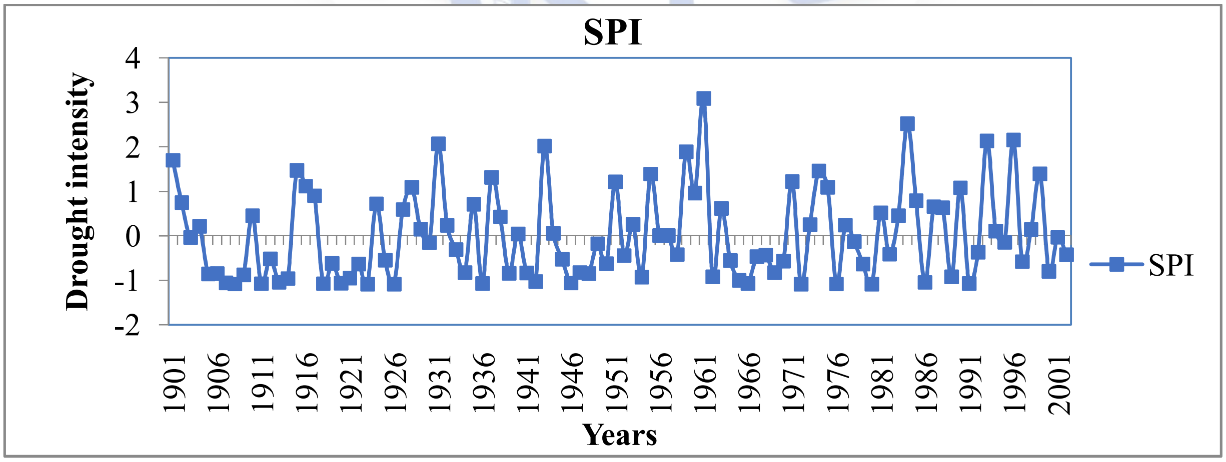

Figure 4.8 Analysis of SPI October (1901-2002)

4.4.2 Recent data (2012-2016)

An analysis of recent rainfall data from the last five years (2012-2016) indicated that the average maximum rainfall of monsoon period from June to October was 566.56mm. This shows that the average annual rainfall in Jalna does not vary and is not affected by climate change so much.

The figure 4.9 shows that the graphical data had found that the no drought was found for Extreme drought condition and Severe Drought Condition. For Moderate Drought Condition 1 year was observed whose range lies between -1 to -1.5. Whereas Mild Drought Condition 2 years were observed whose range lies between 0 to -1.

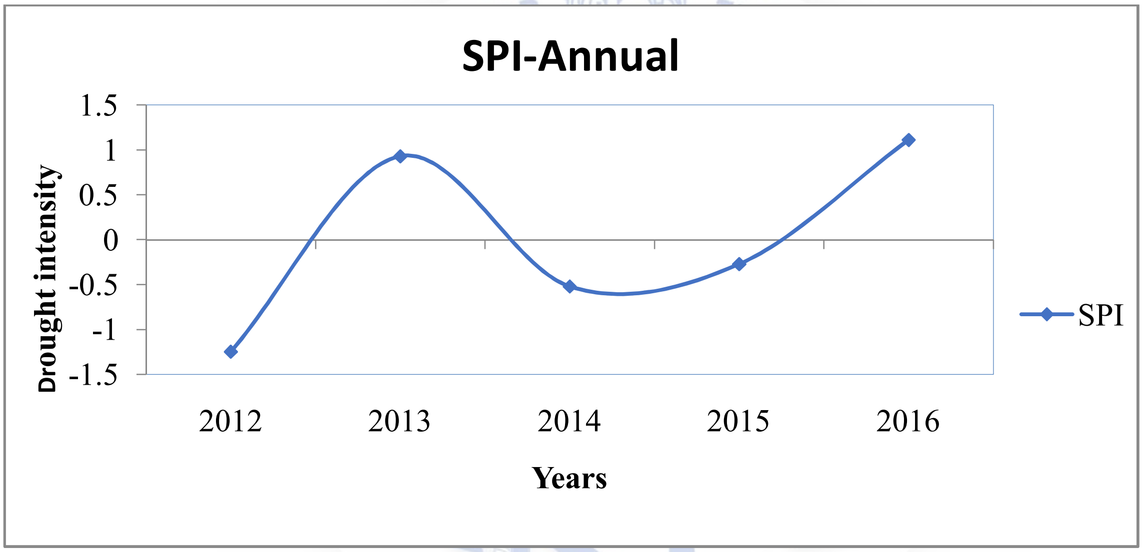

Figure 4.9 Analysis of Annual SPI (2012-2016)

4.5 Drought Analysis using RAI

Drought assessment for the monsoon months was also carried out using RAI and results are shown below.

The figure 4.10 shows extreme drought in the year 1920 i.e (RAI index was -4.748) which comes in to the category of Extremely dry condition and its standard range is n > -4. Very dry Drought Conditions was observed for 14 years in the study area whose RAI range lie between -2 to -4. Whereas dry drought condition were observed for 34 years whose range lie between 0 to -2.

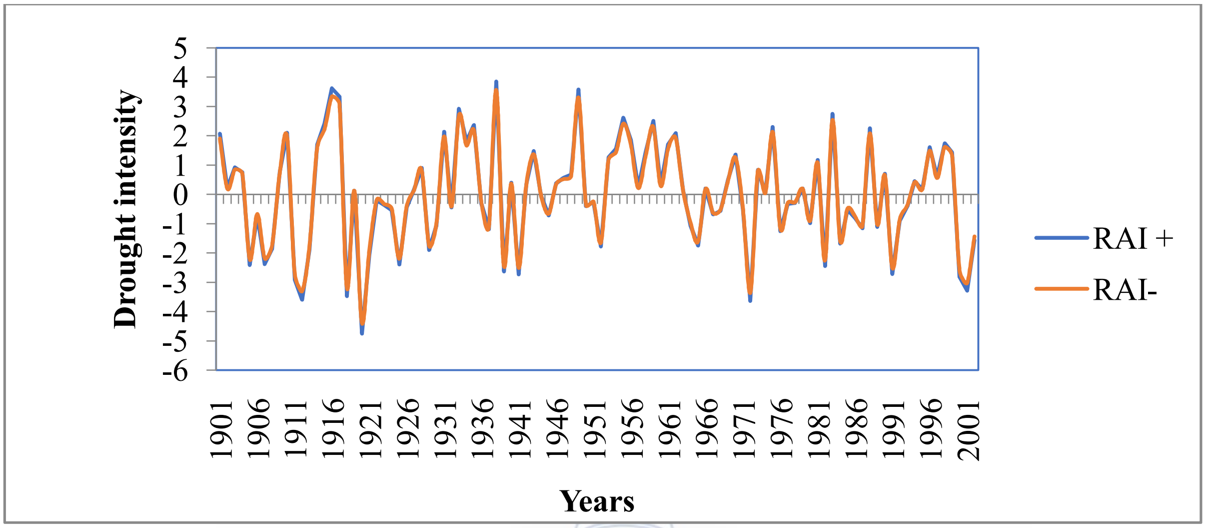

Figure 4.10 Analysis of Annual RAI (1901-2002)

The figure 4.11 shows that the most extreme drought had occured in the year 1941 i.e (RAI index was -4.19) which comes in the category of Extremely dry drought condition and its standard range is n > -4. Very dry drought condition were observed for 16 years whose RAI range lie between -2 to -4. Whereas dry drought condition were observed for 36 years whose range lie between 0 to -2.

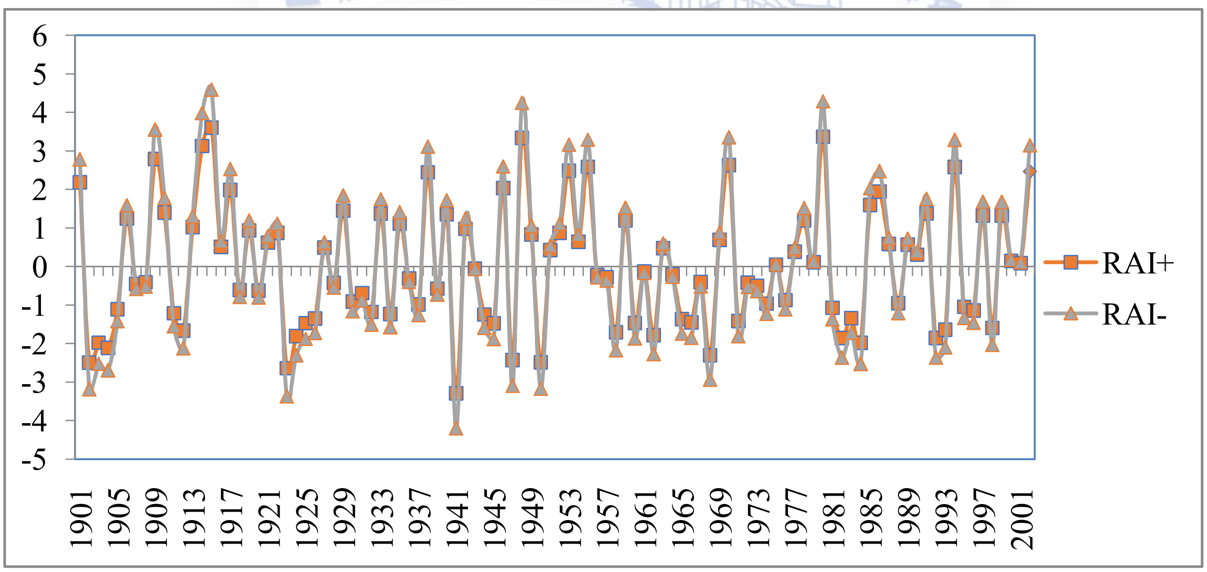

Figure 4.11 Analysis of RAI June (1901-2002)

The Figure 4.12 shows that the most extreme drought was occured in the year 1971 i.e (RAI index was -3.800) which comes in the category of Extremely dry drought condition and its standard range is n > -4. Very dry drought condition was observed for 13 years whose RAI range lie between -2 to -4. Whereas dry drought condition were observed for 39 years whose range lie between 0 to -2.

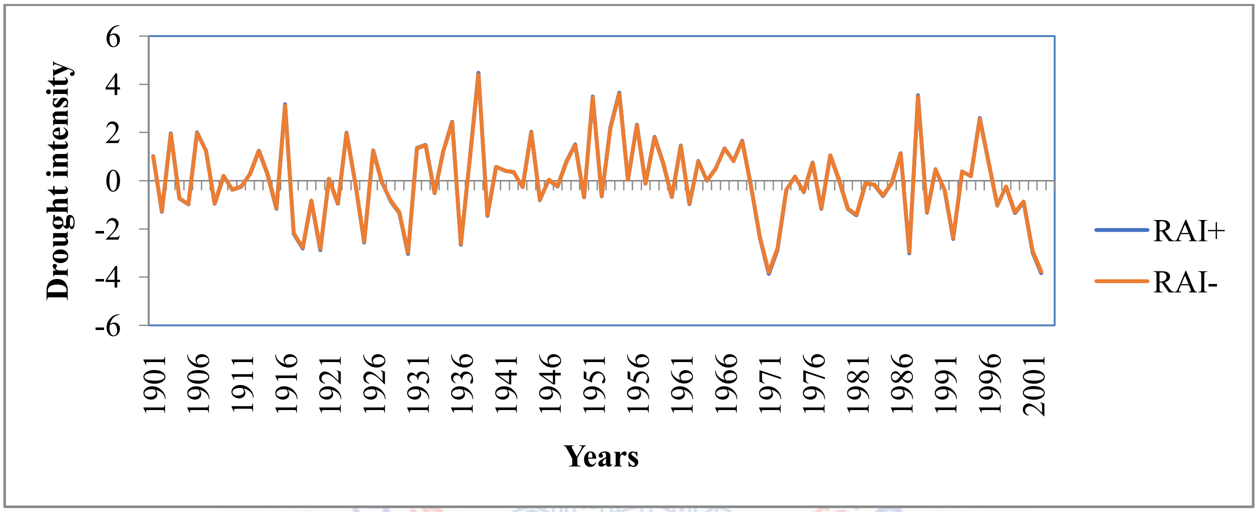

Figure 4.12 Analysis of RAI July (1901-2002)

No extreme drought was found in August month (Figure 4.13). However, very drought Condition was observed for 15 years with RAI range between -2 to -4. Whereas dry Drought Condition were observed for 45 years whose range lie between 0 to -2.

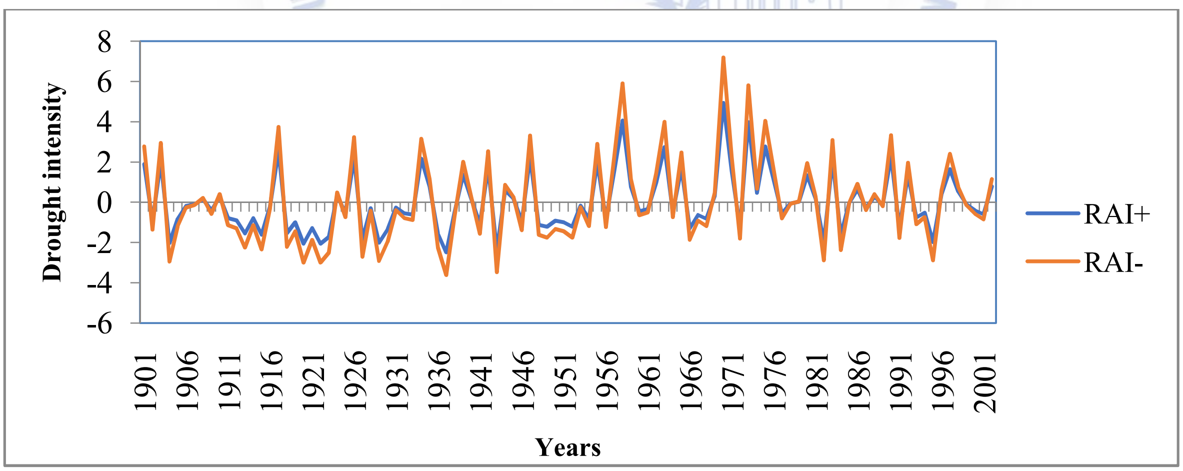

Figure 4.13 Analysis of RAI August (1901-2002)

No extreme drought was found in August month (Figure 4.14). However, very dry drought Condition was observed for 23 years with RAI range between -2 to -4. Whereas dry Drought Condition were observed for 23 years whose range lie between 0 to -2.

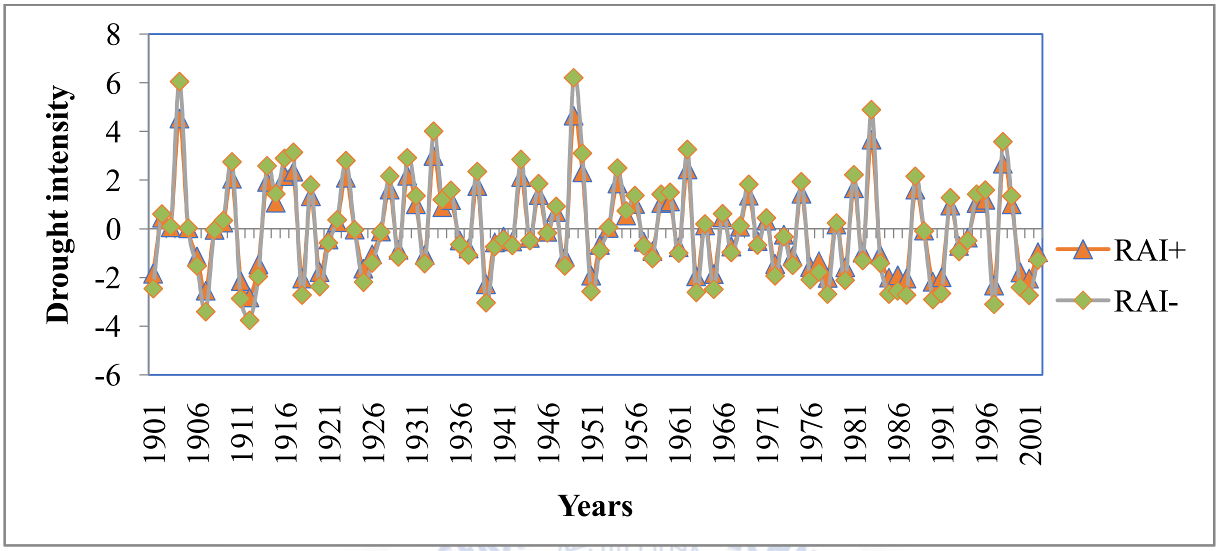

Figure 4.14 Analysis of RAI September (1901-2002)

No extreme drought was found in August month (Figure 4.15). However, very dry drought condition was observed for 32 years with RAI range between -2 to -4. Whereas dry drought condition were observed for 23 years whose range lie between 0 to -2.

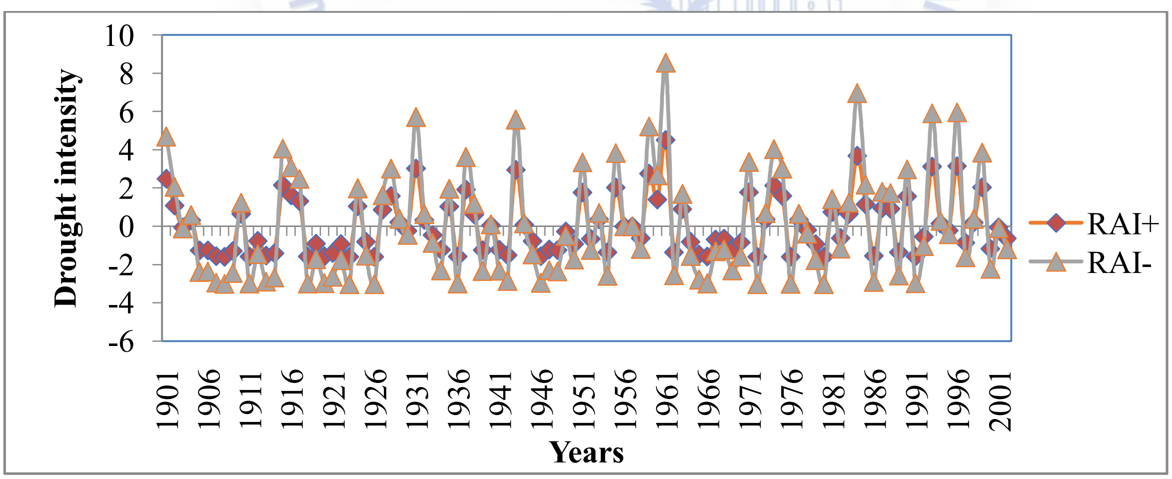

Figure 4.15 Analysis of RAI October (1901-2002)

4.6 Comparative Study using SPI and RAI

4.6.1 Historical Data (1901-2002)

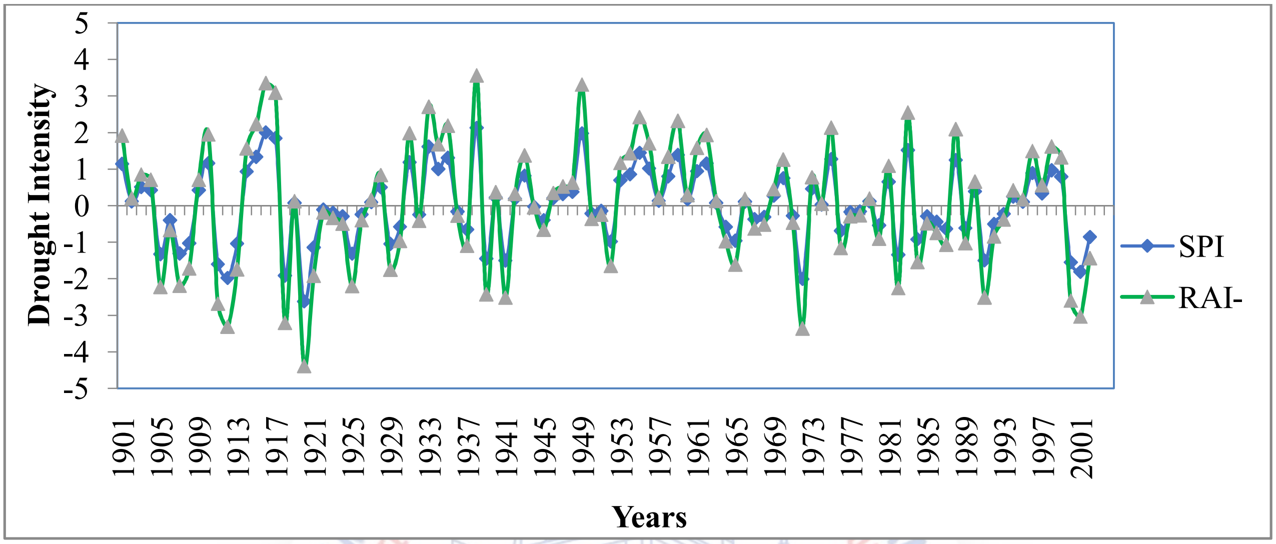

Figure 4.16 Comparative Annual study of SPI and RAI (1901-2002)

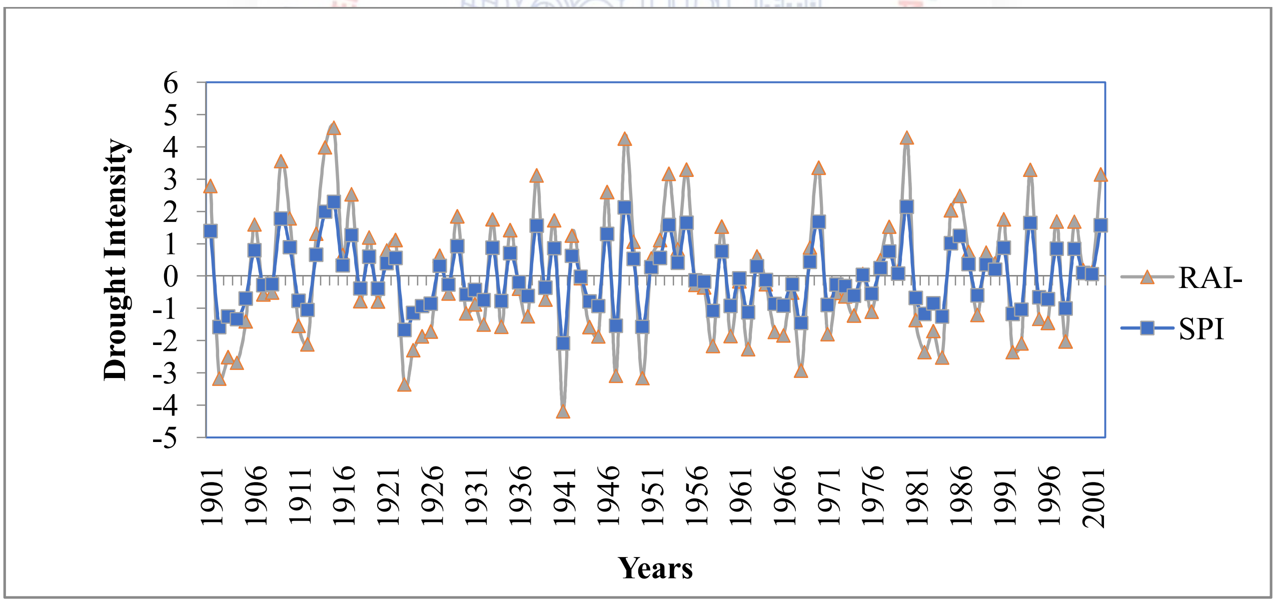

Figure 4.17 Comparative study of June SPI and RAI (1901-2002)

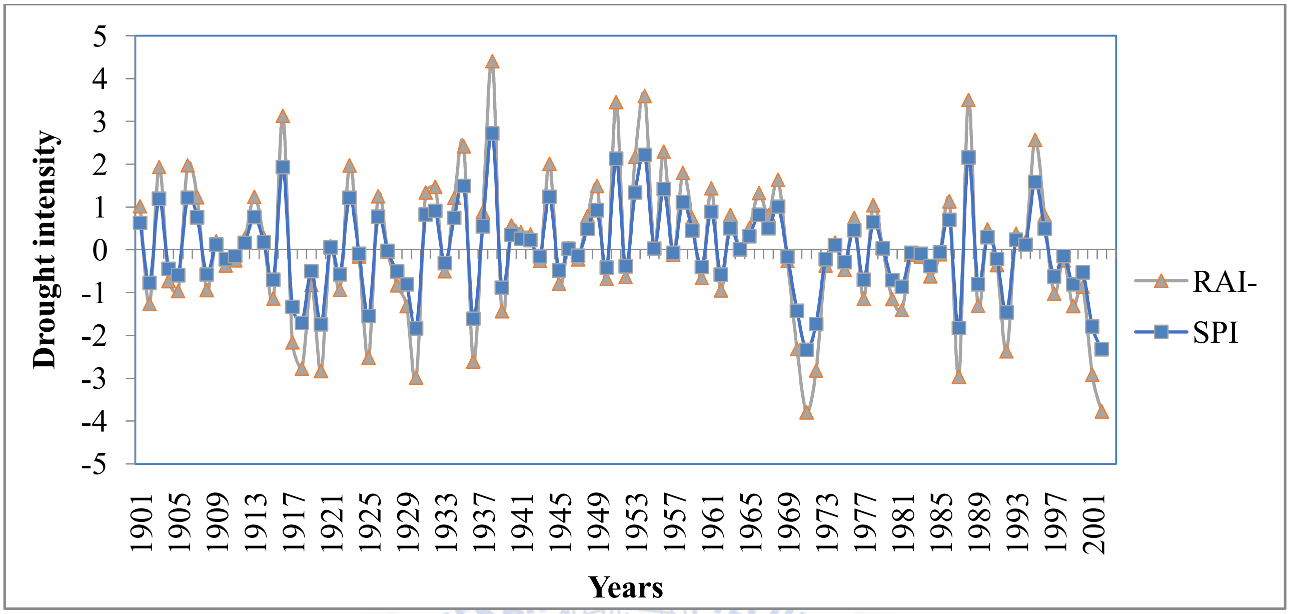

Figure 4.18 Comparative study of July SPI and RAI (1901-2002)

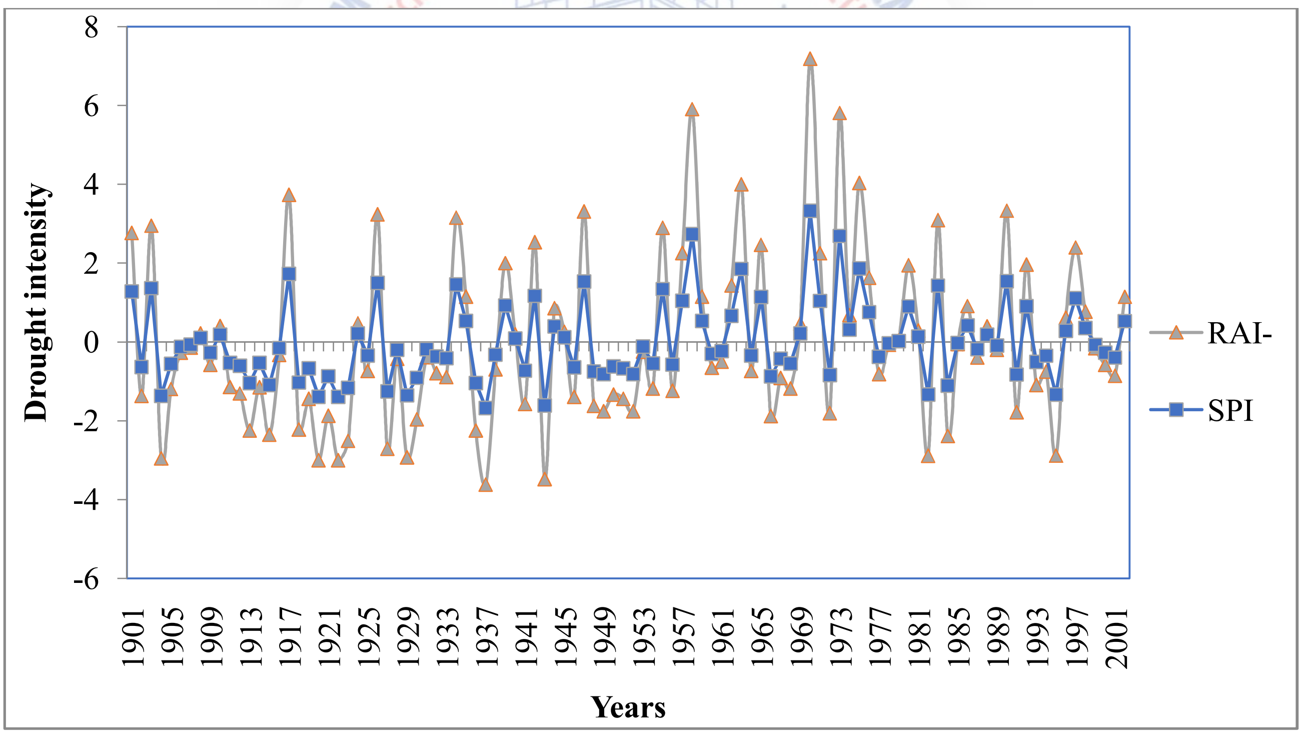

Figure 4.19 Comparative study of August SPI and RAI (1901-2002)

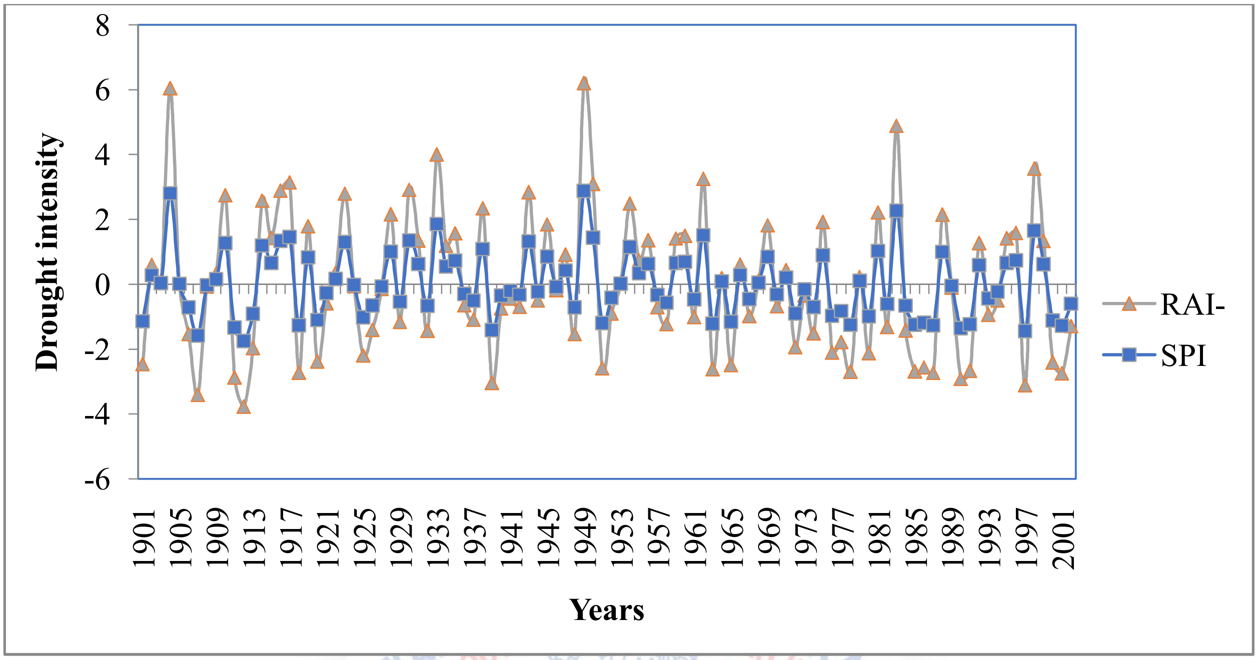

Figure 4.20 Comparative study of September SPI and RAI (1901-2002)

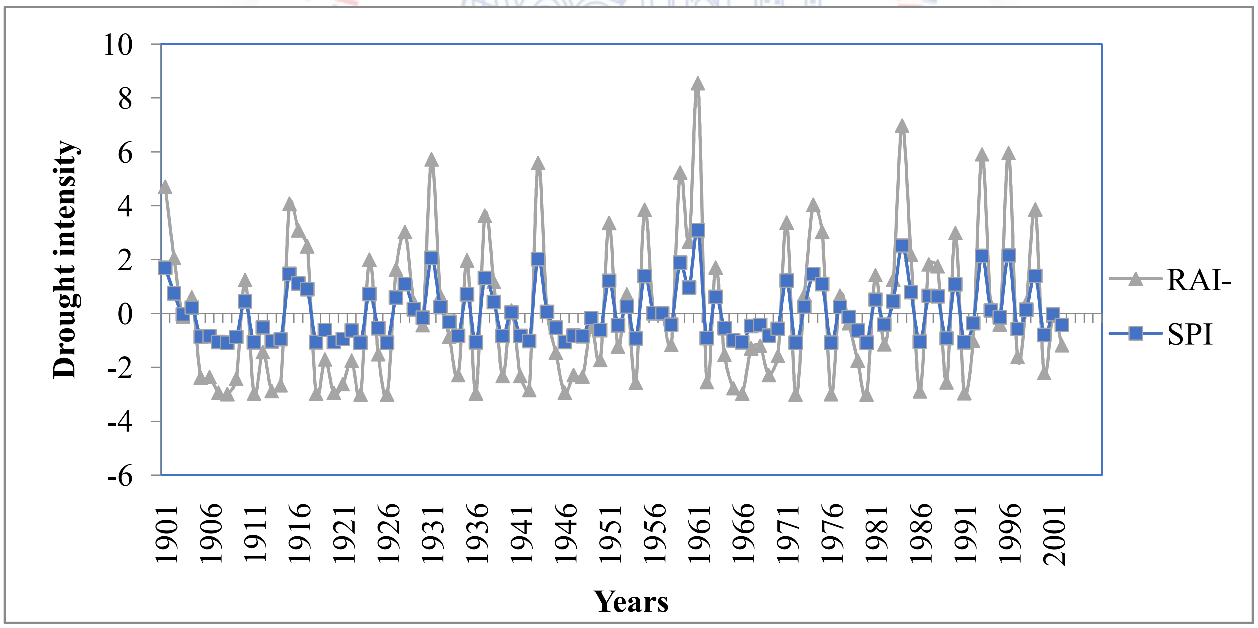

Figure 4.21 Comparative study of October SPI and RAI (1901-2002)

The Comparison of SPI and RAI was carried out to validate both the SPI and RAI- values and to evaluate the drought conditions in the study area. Both the maximum value of SPI for extreme and severe is -2.61 and -1.67 respectively. Similarly the maximum value of RAI- for extreme and severe is -4.38 and -3.35 respectively which shows the same type of Drought in the study area. From the study it is clear that the RAI- is highly correlated with the SPI values. The coefficient of correlation is nearing 1. Hence wherever SPI cannot be used, RAI- can be used for drought assessment with greater efficiency. SPI and RAI indices were calculated for Annual as well as for the Monsoon season. As per the figure 4.16 and figure it is observed that

4.6.2 Recent Data (2012-2016)

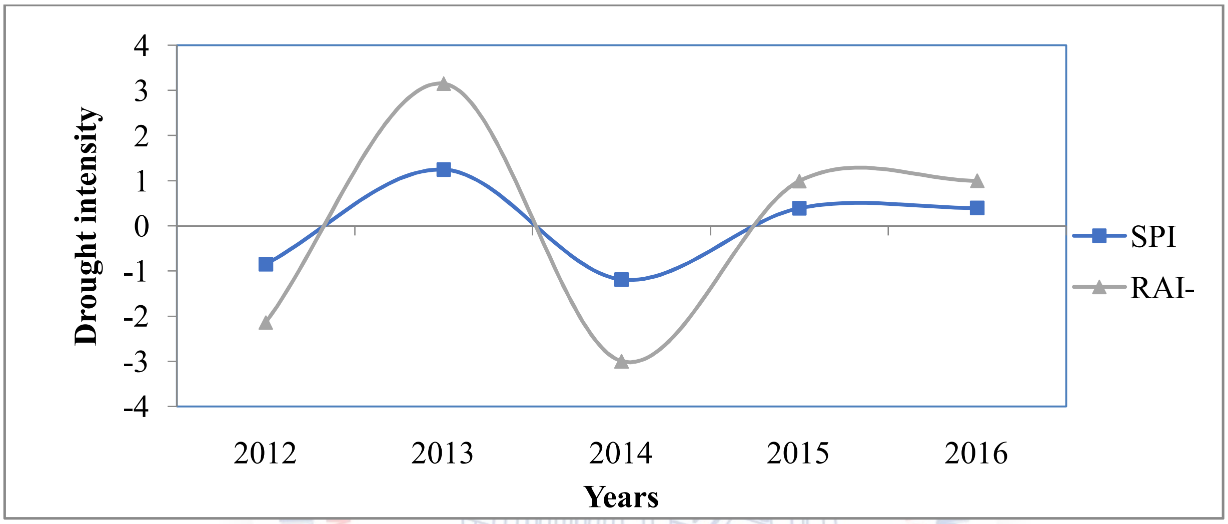

Figure 4.22 Comparative study of June SPI and RAI (2012-2016)

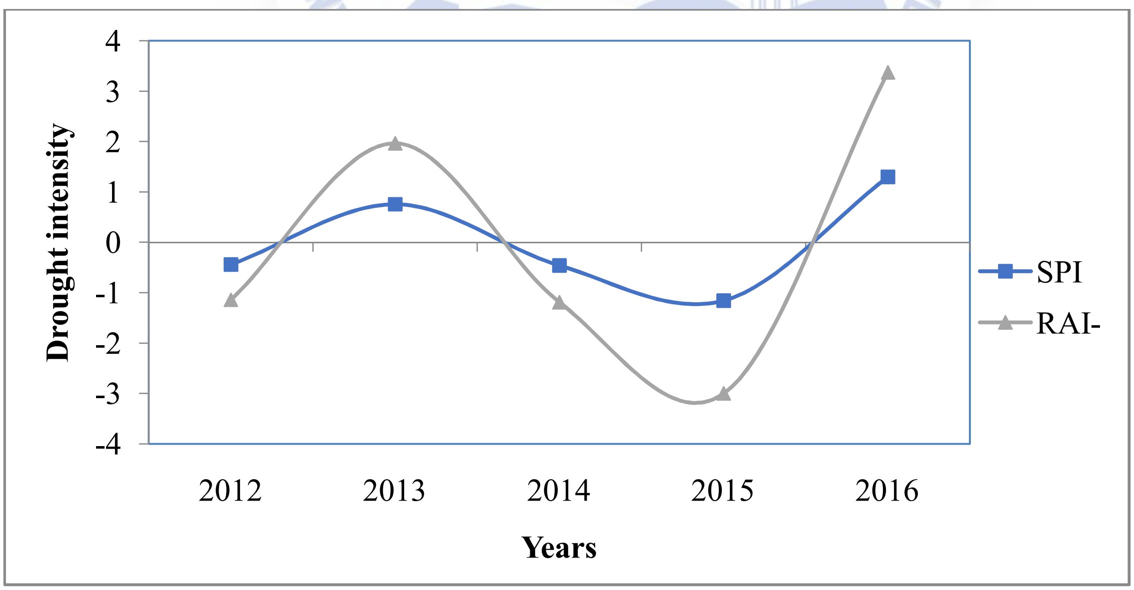

Figure 4.23 Comparative study of July SPI and RAI (2012-2016)

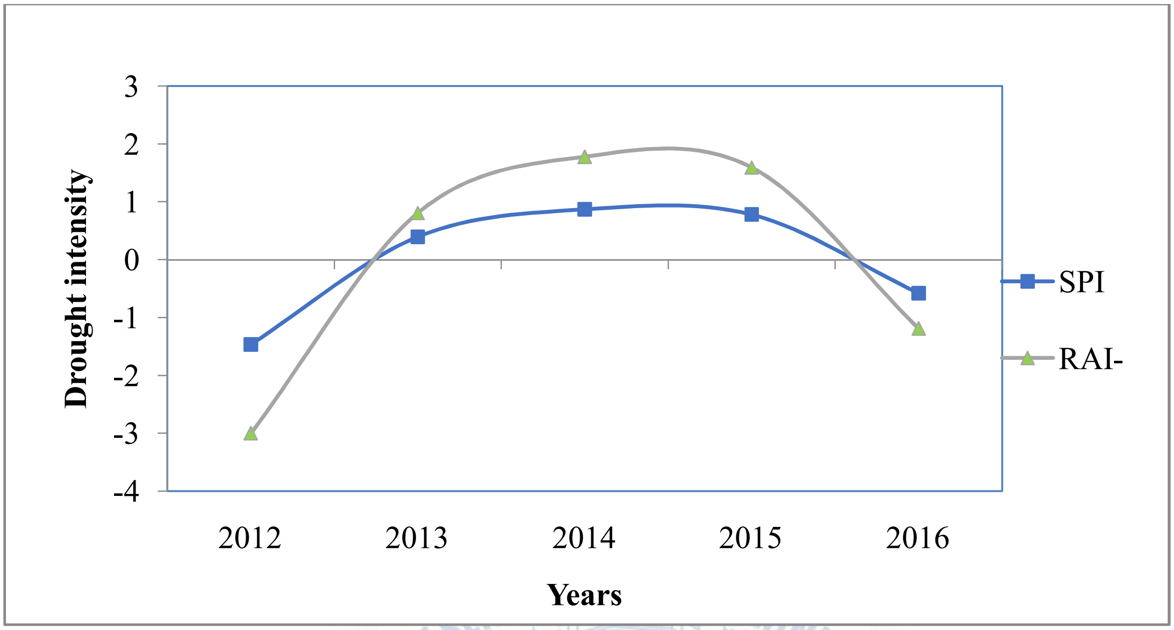

Figure 4.24 Comparative study of August SPI and RAI (2012-2016)

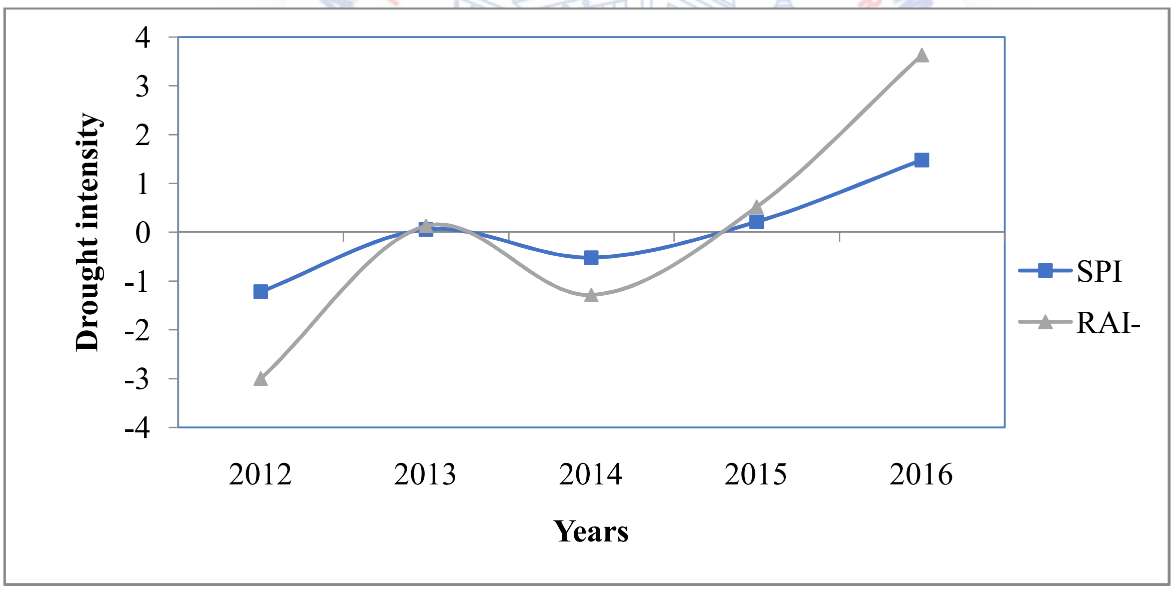

Figure 4.25 Comparative study of September SPI and RAI (2012-2016)

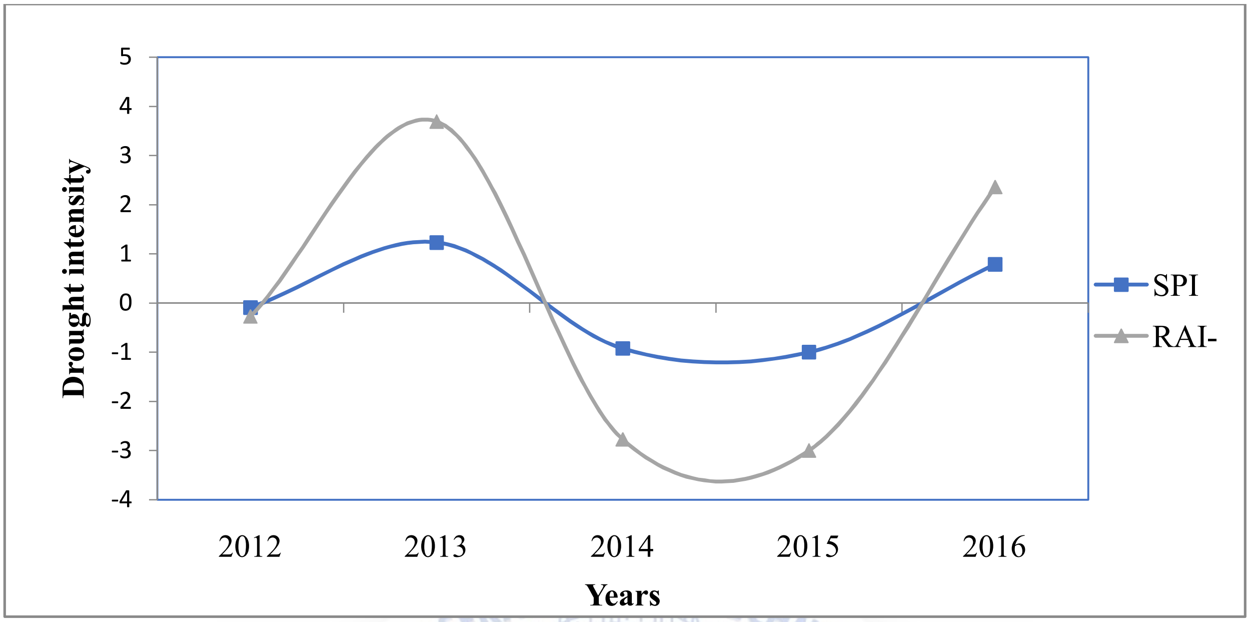

Figure 4.26 Comparative study of October SPI and RAI (2012-2016)

The Comparison of SPI and RAI was carried out to validate both the SPI and RAI values and to evaluate the drought conditions in the study area. Both SPI and RAI indices were calculated for Annual as well as for the Monsoon season. As per the figure 4.5 and figure 4.6 it is observed that the maximum value of SPI for extreme and severe is -2.61 and -1.67 respectively. Similarly the maximum value of RAI- for extreme and severe is -4.748 and -3.6236 respectively which shows the same type of Drought in the study area. From the study it is clear that the RAI- is highly correlated with the SPI values. The coefficient of correlation is nearing 1. Hence wherever SPI cannot be used RAI- can be used for drought assessment with greater efficiency.

Chapter 5
Summary and Conclusion

5.1 Summary

Jalna (region of Marathwada) has been experiencing wide variation in spatio-temporal distribution of rainfall water-level and subsequent water scarcity conditions. The escalating impacts of drought includes widespread crop failure, unreplenished ground water resources, depletion of water level in lakes/ reservoirs, leading to shortage of drinking water, reduced food and fodder availability etc. Marathwada Region of Maharashtra, is facing severe drought every year. It has become the graveyard of farmers. Total number of suicides in January 2016 crossed 1,000 every week 25 to 30 farmers are committing suicide. Hence this study has been taken for carrying out drought assessment in Jalna. Hence, rainfall analysis was carried out in Jalna region using Monthly and yearly data of 105years at Jalna station. It was observed that aberrant variation in rainfall event in monsoon months causing less rainfall, result in drought. An analysis of monthly and yearly rainfall of Jalna, raingauge stations showed that the study area was facing huge variations in rainfall pattern which often causes drought conditions. The average annual rainfall was 719.34 mm which was very less which leads to subsequent drought conditions. Hence a detailed drought vulnerability assessment is carried out using the Standardized Precipitation Index (SPI) and Rainfall Anomaly Index (RAI) as indicators of drought severity from 1901-2002, the characteristics of drought were examined. From the historical data it is observed that the average annual rainfall varies from a minimum of 600-800 mm. Hence even now there are drought conditions occurring in Jalna. A more detailed drought vulnerability assessment was done using 2 drought indices. The SPI analysis showed that the study area had been suffering from mild to extreme droughts almost every year for the period under observation. Similarly the RAI- analysis shows the same years as drought affected with more and less severity of drought. The overall study shows that RAI- is highly correlated with SPI for determining the characteristics of droughts in the study area. The overall outcome of this study demonstrates that extreme and severe droughts were experienced in the year 1920, 1972 and 1911, 1912, 1918, 2000, 2001 across the study area leading to unfavourable results on agricultural practices and water resources in the area.

5.2 Conclusions

- From the rainfall analysis, it is concluded that Jalna is experiencing average maximum rainfall of 719.34 mm which comes in category of semiarid region.
- The Drought condition varies with different intensity i.e from extreme, severe, moderate and mild.
- As a suggestion from this study it was observed that the SPI and RAI- is highly correlated hence both can be successfully used as a Drought indicator to carry out drought vulnerability assessment in Jalna or similar other regions which is experiencing same kind of climatic condition.

REFERENCES

[1] Bhardwaj. (2014), "Extreme risks, vulnerability and community based adaption in India",

[2] ISRO (Indian Space Research Organisation) (Remote sensing technique is used to delineate the drought prone regions of Maharashtra)

[3] Kulkarni et al (http:/www.terrin.org/project/eva)

[4] Mckee et al. (1993), "The Relationship of Drought Frequency and Duration to Time Scales, In Proceedings of 8th Conference on Applied Climatology. American Meteorological Society, Anaheim, CA",

[5] M.P.Van Rooy. (1965), "A rainfall anomaly index independent of time and space", Notes 14, 43,

[6] Pandey et al. (2014), "Assessment of Drought Severity in Various Regions of Jharkhand State of India" Jharkhand, India.

[7] Patil. (2017), (https://www.researchgate.net/publication/232711322)

[8] Rathore et al. (2014), "They made financial credit available to the farmers on easy terms",

[9] RedR India. (2013), "Multi-sector, rapid Needs Assessment of the Drought Situation in Maharashtra,",

[10] Rodrigues. (2017), "Space-time distribution of rainfall anomaly index (RAI) for the Salgado Basin" Ceará State – Brazil.

[11] Santos et al. (2010), "Spatio-Temporal variability using SPI"

[12] Vasiliades et al. (2011), "Assessment of Hydrological drought using SPI"

[13] W.C.Palmer. (1965), "Meteorologic Drought. US Department of Commerce, Weather Bureau, Research Paper No. 45, 58,"

[14] W.C. Palmer. (1968), "Keeping track of crop moisture conditions, nationwide: the new crop moisture index. *Weatherwise"*, 21, 156-161,

[15] W. J. Gibbs and J. V. Maher. (1967), "Rainfall Deciles as Drought Indicators," *Bureau of Meteorology Bul*l vol. 48, Commonwealth of Australia, Melbourne, Australia,

[16] https://www.researchgate.net/figure/Comparison-of-SPI-1-and-RAI-1-time-series-and-related-linear-trends-for-September-and_fig3_272639391.

LIST OF PUBLICATIONS

International Journal

1. "Drought Vulnerability Assessment in Jalna using Drought Indices", International Journal of Engineering Research in Mechanical and Civil Engineering, volume 3, Issue 1, January 2018.

International Conference

1. "Comparison of SPI and RAI for drought assessment in Jalna", In proceedings of "International Conference on Advances in Science, Technology and Engineering, 20th -21st April 2018.

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