DROUGHT ANALYSIS USING SPI: A CASE STUDY OF MARATHWADA REGION

A DISSERTATION

Submitted in partial fulfilment of the

requirement for the award of the degree

of

MASTER OF TECHNOLOGY

in

WATER RESOURCES DEVELOPMENT

(WRD- Mechanical)

by

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MAY-2016

CANDIDATE'S DECLARATION

I hereby certify that work presented in the Dissertation titled "**DROUGHT ANALYSIS USING SPI: A CASE STUDY OF MARATHWADA REGION"** in partial fulfilment of the requirement for the award of **Master of Technology in Water Resources Development (Mechanical)** in the Department of Water Resources Development and Management (WRD&M), Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2014 to May 2016 under the supervision and guidance of **Dr. M. L. Kansal**, Professor, WRD&M and **Dr. U. C. Chaube**, Professor, WRD&M, Indian Institute of Technology Roorkee, Uttarakhand, India.

The matter presented in this Dissertation has not been submitted by me for the award of any other degree.

Date:

Place: Roorkee **MEGHA PANDHARINATH SALVE**

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

I have great pleasure in expressing a deep sense of gratitude and indebtedness to my project guide **Dr. M. L. KANSAL, Professor, WRD&M, IIT ROORKEE** and **Dr. U.C. CHAUBE**, **Professor, WRD&M, IIT ROORKEE**, who guided me at every stage of preparation of this Thesis. His support, encouragement, valuable ideas and many excellent comments have been crucial for accomplishing this thesis work. I am truly thankful for their guidance, valuable support, encouragement, inspiration and help rendered to me at both academic and personal level.

I express my deep sense of gratitude to the my colleague Mr. Siddaraj H.P. , Ph. D scholars of WRD&M DEPARTMENT, Mr. Surendra Chandhania and Mr. Santosh Palmate for giving their valuable time for guidance, support and help for completion of this thesis work.

Where emotions are involved, words cease to mean. There are no words to pay regards to my parents whose enduring encouragement paved me for this achievement in life and who know how to pay me up with love and affection at the time of trauma and stress.

I would also like to thanks all of my friends, without their help this project couldn’t be materialized in this form.

In the last but highest of all, I am very grateful to Almighty- The inspiration behind all knowledge, Endeavour and The giver of all ideas.

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ABSTRACT

Marathwada, one of the important regions in central India is infamous for its recurring drought situation. Marathwada is a part of Maharashtra state which plays a major role in country's economy. It covers 8 districts of Maharashtra state in India with a geographical area of about 65,000 Km^2. Climate in the region is dry and moderately extreme in nature. Annual rainfall ranges from 675 to 950 mm. Repeatedly affected by the scanty rainfall, this region is included in Drought Prone Areas (DPA) of India. Keeping this in view, the present study focuses on the time series analysis of historical monthly rainfall in Marathwada so as to analyse historical drought events and to predict the future drought events.

To analyse the drought events, various drought indices are developed by various researchers. As the present study is based on rainfall series analysis of Marathwada, different rainfall based drought indices are evaluated namely Rainfall Departure (RD), Standardized Precipitation Index (SPI), Rainfall Decile based Drought Index (RDDI), Z-Score and China Z-Score (CZI) so as to identify characteristics of the drought events. The characteristics evaluated by these all drought indices are the also compared in this study.

In order to be prepared for droughts, it highly important to get an alert about upcoming drought well in advance. Drought forecasting is the most important thing in this regard. In this study, an attempt is made to predict the drought situations by tracing the trends in rainfall in Marathwada. For this purpose, NCEP Reanalysis data is downscaled by Multiple Linear Regression (MLR) technique which is calibrated and validated against historical rainfall data. Future projection of the rainfall data is done by HadCM3_A2 (Hadley Centre Coupled Model, version 3) scenario. Future drought situations are then predicted and their characteristics are identified on the basis of SPI as SPI is considered as the most relevant drought index for regional climate.

Evaluation of drought characteristics of the future drought events will help the water resources planners and managers to take corrective measures so as to manage the water resources on sustainable basis.

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CHAPTER 1

INTRODUCTION

The chapter gives brief introduction about the drought situation in Marathwada region of Maharashtra state (India). The chapter also introduces the objective of study and organization of thesis work.

1.1 GENERAL

Nowadays, 'Drought' is emerging out as a hazard in several parts of India. The records say that nearly 17% drought years in India during 1901 to 2012 were associated with severe impacts over water resources, agriculture, food security, livestock, economy and social life (Niranjan KK, 2013). In recent history, India has faced three major droughts in 2002, 2009 and 2012 during the period of 2002 to 2012 among which, the 2012 drought caused 0.5% reduction in India's gross domestic product (GDP) (Manipadma J.,2013) (which is equivalent to US $9 billion). Unlike the countries like United States of America and Australia, around 49% of the total labour force in India depends on agriculture and agriculture associated firms for livelihood (this figure is 0.7 and 3.6% in USA and Australia respectively) (The World Factbook, 2013); this shows that in Indian context, even a relatively moderate drought can have a widespread impact causing hardship to enormous number of people.

Maharashtra state of India has experienced recurring severe droughts in past few decades affecting thousands of villages, lakh of cattle and crores of people. The worst drought in Maharashtra has made water supply in the state a scary issue. The agriculture sector is badly affected; people had to migrate from their native places for water, livelihood and fodder for cattle. Not only loss of cattle and other livestock is a major issue but also increase in farmer suicides is a serious concern. From the year 1995 to 2004, farmer suicides in Maharashtra increased from 11,866 to 14,729 (Economic Survey of Maharashtra, 2012-2013). Among the various regions of Maharashtra, Marathwada region is the worst hit area that media has referred as 'Graveyard of Farmers...!'(The Hindu, 2007). Marathwada region is selected as study area for this research work as it is recognised as the region of dire drought impacts.

1.2 OBJECTIVES OF STUDY

Objectives of this research work are as follow

i) To study the characteristics of droughts in Marathwada region on the basis of 42 years of historical rainfall data considered for the period 1961 to 2002. Various drought indices such as Rainfall departure from mean (RD), Standardized Precipitation Index (SPI), Z-Score, China Z-Score (CZI) and Rainfall Deciles based Drought Index (RDDI) are used for this purpose and their consistency in prediction of drought is analyzed.

ii) To predict the future drought events and their characteristics using Standardized Precipitation Index (SPI) by statistically downscaling the Global Circulation Model (GCM) output.

1.3 DISSERTATION ORGANIZATION

The study carried out is organized in this report as below:

Chapter 1: INTRODUCTION

This chapter gives brief introduction about the drought situations in India and particularly in Marathwada region of Maharashtra. It also introduces the research objectives and necessity of study.

Chapter 2: LITERATURE REVIEW

This chapter presents review of literature referred for the study. The chapter includes background of the study focusing on why the study is necessary. Also review of various drought indices for drought analysis and drought forecasting methods are presented in the chapter.

Chapter 3: STUDY AREA AND DATA

This chapter introduces the study area for which the study is carried out. Also the data and software used for the study are included.

Chapter 4: METHODS

The procedures and methods followed for the study are explained in this chapter.

Chapter 5: RESULTS AND DISCUSSION

All results obtained are presented in this chapter and are discussed.

Chapter 6: SUMMARY AND CONCLUSION

Based on the results of study appropriate conclusions are presented in this chapter and dissertation work is summarised.

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 Marathwada. Hardship caused by the severe droughts in various sectors like agriculture, economy, water supply, social life and mental health are briefly discussed. In order to get a direction for the research work, this chapter discusses the information gathered from various literatures about how to assess drought characteristics, what are the different drought indices and how to assess future drought events and their characteristics.

2.1 BACKGROUND OF STUDY

To commence the study, it was important to go through the need of the study. In this session, review of the devastating drought impacts is presented so as to highlight the necessity of drought characteristics analysis. The study is not only important for Marathwada region but also for Drought Prone Areas (DPA) all over the India because though drought impacts vary from region to region, the overall issues are similar and Marathwada region is indicative of the rest of the DPAs in India.

Maharashtra state is an important state of India contributing about 15% of country's gross GDP). About 40% of the Maharashtra State falls under DPA, having annual average rainfall less than 750 mm (29.5 in). Rain fed agriculture; livestock are the major sources of income generation for over 64% of the state's population. Marathwada region of Maharashtra state is probably the most drought affected area. This region has faced recurring severe drought from past few decades. These recurring droughts have had adversely affected many sectors like agriculture, food security, social and economic life etc. One of the major and worst impacts of drought is reduction in agricultural products. Marathwada has very high percentage of non-irrigated land. Out of the total cultivable land in Maharashtra about 53% is under *Kharif* and about 30% is under *Rabi* crops. These mostly comprise of food grains and oilseeds. The rainfall during June to September affects both the *Kharif* and the *Rabi* crops thus, regularity of rainfall during this period important. But it is seen that there is considerable fluctuation in the number of rainy days as well as the amount of rainfall from year to year. Crop management on fields during this period thereby becomes quite difficult. Marathwada's annual rate of growth in irrigated area is far below Vidarbha and the rest of the state. Crop failure, reduction in employment of unskilled agricultural labour and increased commodity prices severely has affected the rural economy. Crop failures due to lack of rainfall forced farmers to borrow money from money lenders and banks with high interest rates and this weaken financial status of farmers and further affected the social life and mental health.

In 2001, drought affected about 20,000 villages in 23 districts of Maharashtra; 28.4 million people and 4.5 million hectares of crops in the State.

In 2012, the state received 82 per cent rainfall; it was less than 75% for 31 talukas in Marathwada. Central Maharashtra and Marathwada division received 546 mm (21.5") and 458 mm (18") rainfall which corresponds to a 25% and 33% rainfall departure from mean, respectively, when compared with the long term average. This year, water level in the major reservoir went down to 52 percent. Overall effect was that, 22 talukas had less than 75 percent sowing. The shortage of water and fodder was a serious concern. The 2012 drought cased a dreadful impact over agricultural production and rural livelihood. Jowar, bajra, cotton and tur crops were completely wiped out in Kharif season followed by failure of wheat, jowar and cotton crops in Rabi season too (Mail online India, 013). Directorate of Economics and Statistics (Economic Survey of Maharashtra,2012-2013) reported about 21%, 5% and 18% reduction in cereals, pulses and total food grains production, 33% and 29% reduction in sugarcane and citrus fruit production respectively and 11% decrease in vegetable production during 2012 compared to the previous year. Inland fishery suffered about 16% production loss as a consequence of drought in year 2012-13 (Economic Survey of Maharashtra,2012-2013; The Crop Sit Market Report 2014; Udmale P.,2014;Kiem AS,2013)

In 2013, 39 out of 76 talukas of Marathwada region faced drought. As 7 of 10 major dams were dried up, 4000 tankers were employed to provide drinking water across the state every day of which 1807 were deployed to Marathwada alone (Hindustan Times, 2013). This drought was declared as most severe drought in drinking water and fodder crisis point of view. 11,000 villages were suffered by intensive water crisis, 533 fodder camps were set up for 45,200 cattle, cost around 750 crores (Srijit Mishra, 2006). This year, all the districts of Marathwada state were declared as drought hit and Marathwada's per capita income fell to 40% lower than the rest of Maharashtra.

2015 was again the year of deficient monsoon, followed by unseasonal rain and showers of hail and destroyed crops across the arid, drought-prone regions of Vidarbha and Marathwada. The untimely rains in December 2014 and February 2015 damaged the yield a lot. In year 2014-15, moong production declined by 61%, tur by 42%, urad by 48%, soybean by 59% and oilseeds by 56% compare to year 2013-14 (Hindustan Times, 2015). In 2015, per capita water availability in Marathwada was 438 cubic meters (cum), as against 985 cum in Vidarbha and 1,346 cum in the rest of Maharashtra. Water availability per hectare of culturable command area (CCA) in Marathwada, Vidarbha and the rest of Maharashtra is 1,383 cum, 3,627 cum and 9,173 cum respectively (GRIST Media, 2015).

Recurring droughts over Marathwada had a threatening impact over water reservoirs as well as groundwater storage. Major dams in Marathwada region like Jaikwadi in Paithan, Kornool in Tuljapur do not reach to their full capacity as there is no enough rainfall, because of this it is priority to release water for drinking purpose and not for irrigation. As a result of this, farmer started digging bore wells to support agricultural activities which in turn resulted in depletion of ground water level. Now a day, in Marathwada, no ground water is available above 400-500 feet. 66 talukas in Marathwada show severe depletion in groundwater level. The intensity of water crisis can be imagined as 55 villages in Aurangabad, 152 villages in Latur, 14 villages in Jalna and 28 villages in Osmanabad has no more water to be pumped out.

The most severe impact of drought is effect on social life. Drought in Marathwada has ruined rural life mainly. Due to inability to bear crop losses and financial predicament; 422 farmers committed suicide in 2014. The situation became worst in 2015 as famer suicide poll reached highest in previous 10 years. In 2015, eight districts of Marathwada collectively recorded 1109 suicides. Beed district alone recorded 299 cases of them.

2.2 DROUGHT CHARACTERISTICS ANALYSIS

Drought severity, drought duration and drought return period are the important drought characteristics. According to (Saravi, M. Mohseni, 2009) droughts are generally characterized by a prolonged and abnormal moisture deficiency. In drought studies it is important to characterize the start and end of a drought as well as its intensity, duration, frequency and magnitude. (Saravi, M. Mohseni, 2009) analysed drought characteristics based on SPI on three time scales including 3-6- and 12- month for Karoon river basin, Iran. There are many other drought indices to calculate drought characteristics and research work is done to find out which drought index gives most accurate results. (Morid, Saeid, 2006), compared seven drought indices for drought monitoring in the Tehran province of Iran. The indices used include deciles index (DI), percent of normal (PN), standard precipitation index (SPI), China-Z index (CZI), modified CZI (MCZI), *Z*-Score and effective drought index (EDI). The comparison of indices is based on drought cases and classes that were detected in the province over the 32 years of data, as well as over the latest 1998–2001 drought spell. The results show that SPI, CZI and *Z*-Score perform similarly with regard to drought identification and respond slowly to drought onset. DI appears to be very responsive to rainfall events of a particular year, but it has inconsistent spatial and temporal variation. The SPI and EDI were found to be able to detect the onset of drought, its spatial and temporal variation consistently, and it may be recommended for operational drought monitoring in the Province.

2.3 RAINFALL BASED DROUGHT INDICES

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.

2.3.1 Rainfall Departure from Mean (RD)

Rainfall departure from mean is a straightforward method to calculate rainfall deficit from long term mean of regional rainfall. It is calculated in terms of percentage departure from mean rainfall. Rainfall departure from mean is easy to understand as negative values indicate rainfall deficiency while positive values indicate excess rainfall over mean value. Earlier a year was defined as drought year by India meteorological Department if annual rainfall deficit is more than 25% of long term mean (Appa Rao, 1986). Recently, India meteorological Department adopted new norm (The Economic Times, Jan 12, 2016) according to which rainfall departure more than -10% spanning over 20-40% of the country's area is defined as 'Deficient Year' and rainfall departure more than-10% spanning over more than 40 % of country's area is defined as 'Large Deficient Year' and the term 'Drought' will not be used by IMD henceforth.

2.3.2 Standardized Precipitation Index (SPI)

To indentify drought events and their severity, Mckee et al. (1993) developed Standardized Precipitation Index (SPI). Standardized Precipitation Index (SPI) of any location is calculated based on long term precipitation values. SPI is a reliable drought index and can be applied to multiple time scales like 1, 3, 6, 12 or 24 months. Continuous long term data of at least 30 years is required to compute SPI; it does not allow missing data. Also, SPI calculation for longer time period is not advisable as it decreases length of dataset. To calculate SPI index, long term precipitation data is fitted to gamma probability distribution which is then transformed to normal distribution; this transformed probability is known as SPI. The mean SPI is zero for the desired period (Mckee,1993). Positive SPI values indicate greater than mean precipitation while negative values indicate less than mean precipitation. The drought event begins when SPI goes down below -1 and ends when SPI becomes positive. SPI range is divided into several categories so as to indentify drought and wet events. Detailed description of SPI categories is given in Table 1.

Table 1: SPI values related to rainfall events

SPI Values	Remark
2.0 and more	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Very Dry
-2 and less	Extremely Dry

2.3.3 Rainfall deciles based drought index (RDDI)

The RDDI was suggested by (Gibbs and Maher, 1967). To calculate deciles, the rainfall data of each year of the given time period is arranged in the ascending order and cumulative frequency distribution is constructed. The total distribution is then spit into 10 deciles. The first decile having the highest rainfall values in the series shows the wettest years of the series and the last decile indicates the driest years during the considered time period.

2.3.4 Z-Score

Z- Score is another simple drought index like RD. Z- score calculation doesn't require the data to be fit for any distribution and because of this it is supposed that it might not represent the shorter time scales (Edwards D.C., 1997). It is calculated by subtracting the long term mean of rainfall from an individual rainfall value and dividing the difference by the standard deviation.

2.3.5 China Z-Index (CZI)

China Z- Index (CZI) is used by National Climate Centre (NCC) of China to monitor drought conditions throughout the country. Precipitation data is assume to follow the Pearson Type III distribution and is calculated from the value of Z-Score. It has been found that SPI, Z-Score and CZI give same results (Wu et al., 2001). Wu et al. (2001) suggested that because of simplicity in calculating drought severity at monthly time step using CZI, it can be preferred over SPI, where rainfall data are often incomplete.

2.4 PREDICTION OF FUTURE DROUGHT EVENTS

Bordi, Isabella, et al, (2005), in her study; 'Methods for Predicting Drought Occurrences' had mentioned that the Standardized Precipitation Index for drought monitoring, based only on monthly precipitation, properly describes the climatic condition of a particular region. By applying an appropriate forecast method to the precipitation time series and then computing the SPI, it is possible to predict future drought occurrences. Projection of rainfall data to future by using downscaling model is a good approach to forecast future rainfall events. Duhan, Darshana, (2015) had developed downscaling model for the projections of monthly maximum and minimum air temperature for three stations, namely, Allahabad, Satna, and Rewa in Tons River basin, India. The three downscaling techniques, namely, multiple linear regression (MLR), artificial neural network (ANN), and least square support vector machine (LS-SVM), were used for the development of models, and best identified model was used for simulations of future predictand (temperature) using third-generation Canadian Coupled Global Climate Model (CGCM3) simulation of A2 emission scenario for the period 2001−2099. To reduce the bias in monthly projected temperature series, bias correction technique is employed.

CHAPTER 3

STUDY AREA, DATA AND SOFTWARE

The chapter gives detailed information about the study area, data and software used. Study area and its climate are described in detail. Further the data and software used for analysis and their brief description is also included.

3.1 MARATHWADA: STUDY AREA

Marathwada or Aurangabad region is one of the six divisions of Maharashtra state. It has geographical area of about 65,000 km^2 and consists of 8 districts comprising of 76 talukas. Marathwada region is located in the main drainage of Godavari River between 70°5′–78°5′E longitude and 17°5′–20°5′N latitude. Figure 1 illustrates location of the study area.

Population of the Marathwada region is 18.7 Million according to 2011 census. Its geographical & cultivable areas are 6.481 & 5.930 M ha respectively. Table 2 highlights geographical area, Culturable Command Area (CCA) and water availability of Marathwada in compare to Vidarbha and rest of Maharashtra.

Table 2: Maharashtra, Distribution of Culturable Command Area (CCA)

Sr. No	Region	Geographic Area (Mha)	Share in Area (%)	CCA (Mha)	Average Annual Water Availability (BCM)
1	Marathwada	14.5	47.4	10.6	34.2
2	Vidarbha	6.5	21.0	4.7	9.7
3	Rest of Maharashtra	9.7	31.7	3.9	103.2
4	Maharashtra	30.7	100.0	24.7	147.1

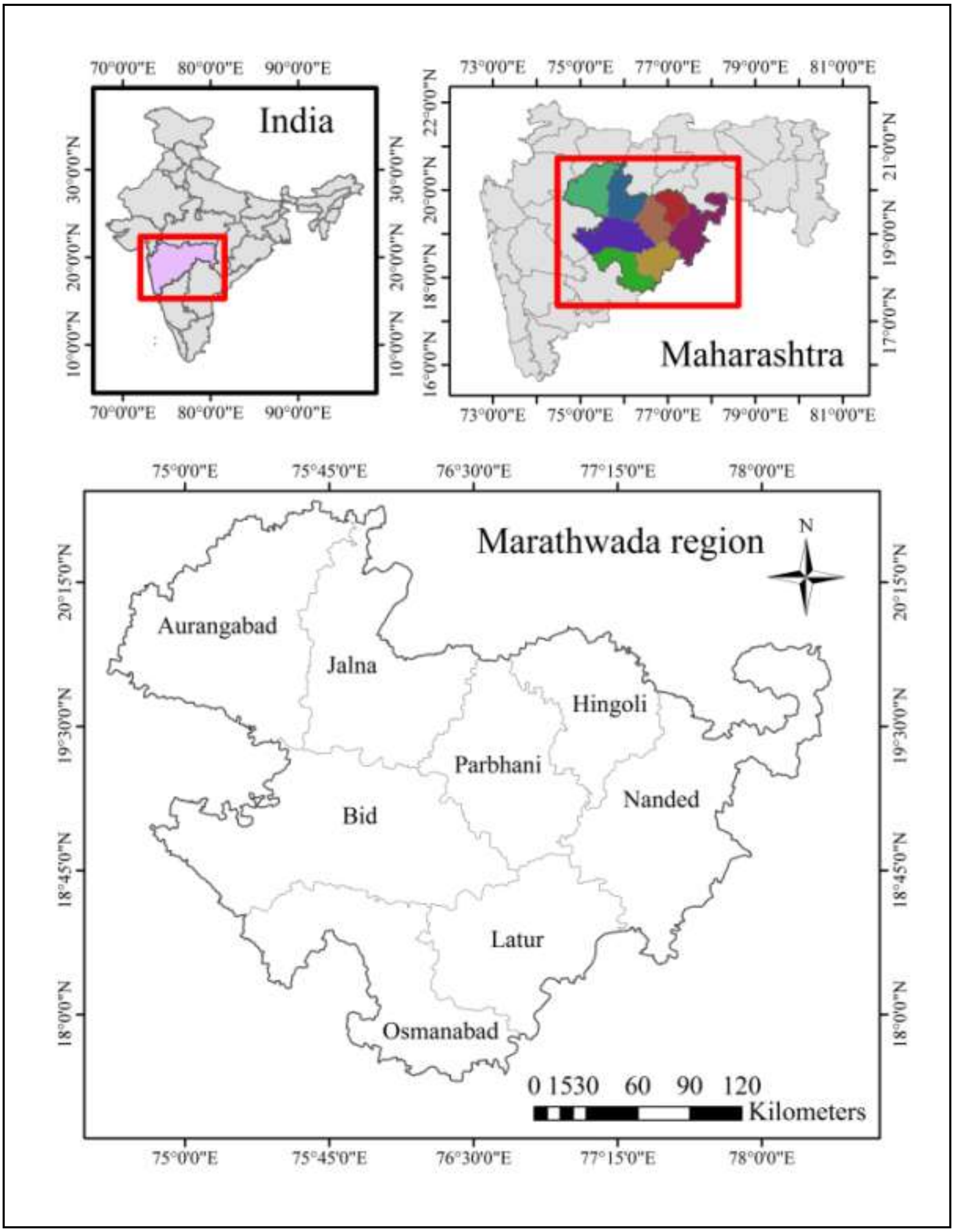

Figure 1: Location of Marathwada region

3.2 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.

3.2.1 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.

3.2.2 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.

3.2.3 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 10^0C to 16^0C.

3.2.4 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 36^0C to 41^0C. Marathwada region receives pre-monsoon rains during this season.

The average rainfall of the Marathwada region is approximately 780 mm which is only 57% of the average rainfall of the entire state (1380 mm). Marathwada receives rain from both south-west and north-east monsoon winds. The proportion of the rainfall derived from the north-east monsoon increases towards east. Aurangabad, Jalna, Beed and Osmanabad districts of Marathwada region fall under the rain shadow of Sahyadri Mountains and therefore the beginning and end of the rainy season is quite uncertain in these parts. The rainfall is also meager. The rainfall increases as we go towards east viz. Parbhani, Nanded, Hingoli and Beed. General climatic features of individual districts of Marathwada are listed in table 3.

Table 3: 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 DATA

3.3.1 Historical Rainfall Data

For the present study, rainfall data of eight districts of Marathwada for the period from 1961 to 2002 is downloaded from the India Water Portal website. Using area weighted average method, rainfall data is evaluated for entire Marathwada region. Yearly rainfall is also calculated by summing up monthly rainfall values. This monthly and annual rainfall data is presented in Appendix – E. Five drought indices namely Rainfall Departure (RD), Standardized Precipitation Index (SPI), Rainfall Decile based Drought Index (RDDI), Z-Score and China Z-Index (CZI) are then calculated using this rainfall data.

Table 4: Details about historical data used for study

Sr. No	Station	Period	No. Of Years	Area (km^2)	Remark
1	Aurangabad	1961-2002	42	10,100	Monthly Rainfall Data
2	Beed	1961-2002	42	10,693	
3	Hingoli	1961-2002	42	4,526	
4	Jalna	1961-2002	42	7,612	
5	Latur	1961-2002	42	7,157	
6	Nanded	1961-2002	42	10,545	
7	Osmanabad	1961-2002	42	7,569	
8	Parbhani	1961-2002	42	6,251	
9	Marathwada	1961-2002	42	64,453	Area weighted average rainfall data

3.3.2 NECP Reanalysis data

Gridded NCEP reanalysis data at spacial resolution of $2.5^{\circ}*3.75^{\circ}$ is downloaded from Canadian Centre for Climate Modelling and Analysis. The potential predictors are then found out by calibrating and validating the data by historical rainfall data for period of 1961-1990 and 1991-2001 respectively. Future rainfall data is the generated using those potential predictors in HadCM3_A2 scenario for the period of 2002 to 2099.

3.4 SOFTWARE

3.4.1 Microsoft Excel 2007

Downscaling process is done in Microsoft Excel 2007. Calibration, validation and future scenario generation is all done in Microsoft Excel 2007. For the advanced calculations and functions, Excel add-ins namely Kutool and numXL are used. Further, calculations and analysis of all drought indices are done in Microsoft Excel 2007.

3.4.2 Easyfit 5.6

Easyfit 5.6 standard software is used to check the fitting of precipitation data to gamma distribution for SPI analysis and Pearson Type III distribution for CZI calculation. Distribution graphs and characteristics are also generated.

3.4.3 SPI_SL_6.exe

To indentify drought events in future, SPI is calculated for Marathwada region using downscaled NCEP data after bias correction for the period 1960 to 2099. To calculate SPI, software program developed by national drought mitigation centre i.e. **SPI_SL_6.exe** is used. For this software, downscaled monthly precipitation is given as input file.

CHAPTER 4

METHODS OF HISTORICAL AND FUTURE DROUGHT ANALYSIS

The chapter is about the methods and steps adopted for analysing the drought characteristics of historical drought events and predicting the future drought characteristics. The first step is to calculate various rainfall based drought indices and compare drought characteristics evaluated by them. In second step future rainfall data is predicted by downscaling the Global Circulation Model (GCM) output and projecting the rainfall data using The HadCM3_A2 (Hadley Centre Coupled Model, version 3) scenario. Finally future drought events and their characteristics are predicted using SPI.

4.1 CALCULATION OF DROUGHT INDICES BASED ON HISTORICAL DATA

To calculate drought indices based on Precipitation value, historical annual rainfall data of each of the districts of Marathwada region is used. Historical data of monthly precipitation is obtained from 1961 to 2002 for individual districts. To extend the scope of study for the entire region, area weighted average method is used to generate the precipitation data for entire Marathwada region as a whole. The area weighted average method adopted is explained below:

Let A_1, A_2, A_3……… A_8 are areas of eight districts and P_1, P_2, P_3……… P_8 be the precipitation values of eight stations then weighed average rainfall of the entire region is given as follow.

$$R = \frac{\sum_{i=1}^{8} A_i * P_i}{\sum_{i-1}^{8} A}$$

Where, R = weighted average rainfall

All drought indices are calculated on the annual time scale thus the monthly precipitation data is converted to annual precipitation data by summing up the rainfall values for12 months. After calculating drought index, drought characteristics are estimated. Most of the drought indices itself indicate the drought severity. Drought duration is the period of consecutive drought events and frequency (or return period) of drought is calculated by dividing the number of drought events by total number of study years.

4.1.1 Rainfall Departure from Mean (RD)

Rainfall departure from mean is calculated for each of the districts of Marathwada region for the time period of 42 years (1961-2002) on annual time scale. First of all long term mean rainfall is calculated for each of the districts and For Marathwada as a whole using weighted average area method. RD is calculated as follow:

$$RD = \frac{(X - M)}{M} * 100$$

Where,

X = Annual rainfall (mm)

M = Long term mean of annual rainfall (mm)

4.1.2 Standardized Precipitation Index (SPI)

In this study, SPI index is calculated for eight districts and the whole Marathwada for 12 months time scale. The monthly rainfall data of each of the station for the period 1961 to 2002 is fitted to Gamma distribution. It is observed that the precipitation data fits the gamma distribution well. The Probability Distribution and Cumulative Distribution graphs of the rainfall data are presented in figure 2 respectively.

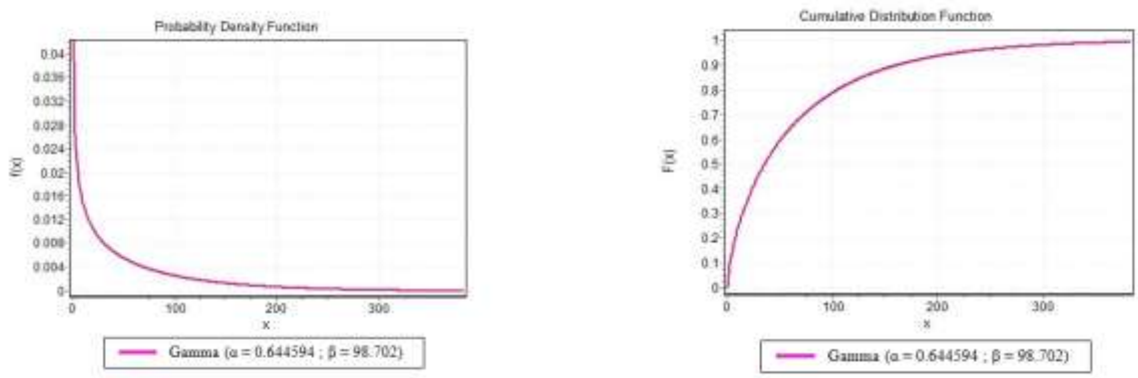

Figure 2: PDF and CDF of Rainfall data fitted to Gamma Distribution

The Gamma probability function is given as

$$\Gamma(y) = \int_0^\infty y^{(\alpha-1)} e^{-y} dy$$

Where,

$\alpha =$ Shape parameter

$\beta =$ Scale parameter

$x =$ Amount of precipitation in particular month (mm)

$\Gamma(\alpha) =$ Gamma function

Integrating the probability density function, cumulative probability function is yielded which is given as follow

$$G(y) = \int_0^y g(y)dy = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^y y^{(\alpha-1)} e^{-y/\beta}$$

Gamma distribution is undefined when y=0, thus to account with zero precipitation values in precipitation series, the distribution is modified as:

$$H(y) = q + (1-q)G(y)$$

The cumulative probability function is then transformed into the standard normal distribution to yield the SPI. Following the approximate conversion:

$$z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 + d_2 + d_3 t^3}\right)$$

$$t = \sqrt{\ln\left(\frac{1}{(H(y))^2}\right)}$$

$$for \quad 0 < H(y) < 0.5 \quad and$$

$$z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 + d_2 t^2 + d_3 t^3}\right)$$

$$t = \sqrt{\ln(\left(\frac{1}{(1 - H(y))^2}\right)}$$

$$for \quad 0.5 < H(y) < 1$$

$$where, \quad c_0 = 2.515517; c_1 = 0.802853; c_2 = 0.010328;$$

$$d_1 = 1.432788; d_2 = 0.189269; d_3 = 0.001308$$

Manually calculating SPI values using above procedure is practically infeasible thus, the software program developed by national drought mitigation centre i.e. **SPI_SL_6.exe** is used to calculate SPI 12. For this software, downscaled monthly precipitation is given as input file. The output then generated is the SPI 12 values of the each month corresponding to the input months. SPI 12 is actually the rainfall anomaly indicator value of a particular month which is generated considering the rainfall behaviour of previous 11 months. Thus, SPI 12 values are evaluated for each month during the period 1961-2002.

Anomalous behaviour of rainfall can be identified from SPI values as extraordinary heavy rainfall indicates more positive SPI while scanty rainfall shows deviation towards more negative SPI. Drought event is considered commencing when SPI goes below -1 and is said offsetting when SPI becomes positive (i.e. rainfall just above the mean rainfall). The region is said to have continuous drought when several consecutive months show negative SPI values. The drought magnitude (DM) of continuous drought intensity corresponds to the cumulative water deficit over the drought period (Thompson, 1999) and the average of this cumulative water deficit over the drought period is mean intensity (MI) which is calculated as follow:

$$MI = \frac{\sum_{i=1}^{N} SPI}{N}$$

Where,

N= Number of months having continuous negative values if SPI

The frequency or return period of the drought event may be defined as the average time lapse between two consecutive drought events which can be calculated simply by dividing the duration considered for the study by number of drought events observed in that time duration. (Dalezios et al., 2000).

4.1.3 Rainfall Decile based Drought Index (RDDI)

To calculate RDDI, the annual rainfall data of all station is arranged in order of decreasing rainfall. Then years are ranked according to decreasing values of rainfall and cumulative frequency distribution is calculated. The data is then divided into 10 deciles in which the lowest decile shows the driest years of the series. The years of lowest rainfall are then analysed for duration and return period.

4.1.4 Z-Score

Z-Score can be calculated on multiple time scales like SPI. In this study as all drought indices are calculated for 12 month time scale, Z- Score also is computed on annual basis. To calculated Z-Score Precipitation data do not need to fit to any distribution. Calculation of Z-Score is done as follow:

$$Z - Score = \frac{(X - M)}{\sigma}$$

Where,

X = Annual rainfall (mm)

M = Long term mean of annual rainfall (mm)

σ = Standard deviation of annual rainfall

4.1.5 China Z Index (CZI)

Calculation of CZI requires the precipitation data to fit the Pearson Type III distribution. The data for annual precipitation is then fitted to Person Type III distribution using Easyfit 5.6.

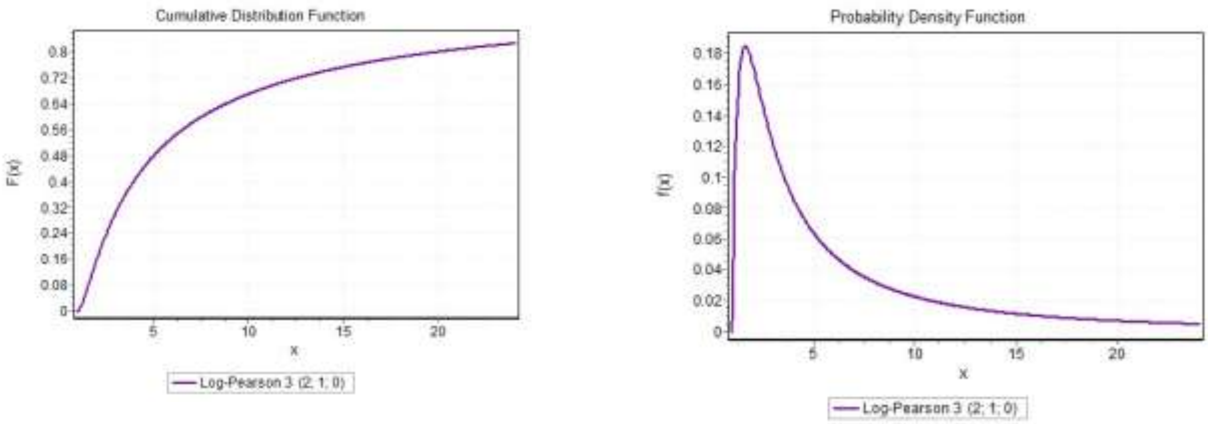

Figure 3: PDF and CDF of Rainfall data fitted to Pearson Type III Distribution

CZI is calculated for each station for the 12 month time scale as follow:

$$CZI = \frac{6}{C_{st}}\left(\frac{C_{st}}{2} Z_{score} + 1\right)^{1/3} - \frac{6}{C_{st}} + \frac{C_{st}}{6}$$

Where,

C_{st} = Coefficient of skewness

Z_{score} = Z-Score for the same time scale for which CZI is to be calculated

4.2 CALCULATIONS OF DROUGHT CHARACTERISTICS

4.2.1 Intensity

Intensity of any drought event is defined according to the drought index used to identify the drought. In this study, five drought indices are used to identify drought events and all indices have their own intensity indications. The following table represents the intensity indication of each drought index.

Table 5: Details about historical data used for study

Sr.No.	Drought index	Drought Intensity		
		Moderate	Severe	Extreme
1	Rainfall Deficit	Rainfall deficit between -25% to -50% of long term mean rainfall		Rainfall deficit less than -50% of the long term mean rainfall
2	SPI	-1 < SPI< -1.49	-1.5 < SPI< -1.99	-2 < SPI
3	RDDI	Seventh and eighth decile		Ninth and tenth decile
4	Z-Score	-1 < Z- Score< -1.49	-1.5 < Z-Score< -1.99	-2 < Z-Score
5	CZI	-1 < CZI< -1.49	-1.5 < CZI < -1.99	-2 < CZI

4.2.2 Duration

Duration of a drought event is an important characteristic. Drought duration is generally considered as the time span between the onsets of the drought till the event of normal rainfall.

4.2.3 Return period or Frequency

Observing the number of drought events in the time period of study, drought return periods are evaluated.

4.3 DOWNSCALING NCEP DATA

The detailed procedure adopted for downscaling and future projection of precipitation data is explained below

i) The gridded NCEP Reanalysis data downloaded for the period 1961 to 2001 for spacial resolution of 2.5° *3.75°. This data consist of data of 26 climate parameters which are called as predictors for the period of 1961 to 2001. The entire data is then extracted to Microsoft Excel 2007. Series of 26 parameter’s data are then extracted and arranged in excel. Details of 26 parameters are given in table 6.

Table 6: Predictor Variables and their codes

Predictor Variable	Parameter Code
Mean sea level pressure	Ncepmslpas
Surface airflow Strength	ncepp__fas
Surface Zonal Velocity	ncepp__uas
Surface Meridional Velocity	ncepp__vas
Surface Vorticity	ncepp__zas
Surface Wind Direction	ncepp_thas
Surface Divergence	ncepp_zhas
850 hPa Airflow Strength	ncepp8_fas
850 hPa Zonal velocity	ncepp8_uas
850 hPa Meridional velocity	ncepp8_vas
850 hPa Vorticity	ncepp8_zas
850 hPa Wind Direction	ncepp8thas
850 hPa Divergence	ncepp8zhas
850 hPa Geopotential Height	ncepp850as
Relative Humidity at 850 hPa	ncepr850as
500 hPa Airflow Strength	ncepp5_fas
500 hPa Zonal velocity	ncepp5_uas
500 hPa Meridional velocity	ncepp5_vas
500 hPa Vorticity	ncepp5_zas
500 hPa Wind Direction	ncepp5thas
500 hPa Divergence	ncepp5zhas
500 hPa Geopotential Height	ncepp500as
Relative Humidity at 500 hPa	ncepr500as
Surface Specific Humidity	Ncepshumas
mean temperature at 2m	Nceptempas
Near Surface relative humidity	Nceprhumas

ii) SPSS Statistics Software is used to calculate Pearson's correlation coefficients of each predictor with the observed rainfall series. Multiple sets of the most correlated predictors are then selected for the actual downscaling procedure. Using Multiple Linear Regression

Method (MLR), precipitation series of rainfall is generated for calibration period from 1961 to 1990. MLR method is used to model linear relationship between predictand and predictors which are in this case, Climate parameters and rainfall series respectively. The model equation of Multiple Regression Method is given as follow:

$$y_i = b_o + b_1 x_{i,1} + ... + b_k x_{i,k} + e_i$$

Where,

b_o = regression constant

b_k = coefficient of k^{th} predictor

e_i = error term

$x_{i.k}$ = value of k^{th} predictor in year *i*

y_i = predictand in year *i*

vi) The generated rainfall series is then again analysed in SPSS Statistics Software for the correlation with the observed historical data. After exercising with multiple sets of predictors, the set of predictor which is observed to have best correlation with the observed rainfall data is then selected as the set of the most potential predictors.

iv) Downscaled rainfall data is validated for the period from 1991 to 2001 using the selected set of the most potential predictors evaluated from calibration period. After checking the consistency of the most potential predictors for validation period, those parameters are selected to generate the future scenario

vi) Calibration and Validation is done against the historical rainfall data. Generated rainfall data for Calibration period (1961-1990) and Validation period (1991-2001) is shown along with the historical rainfall data plotted against the time series in the following figure. For the selected set of predictors, generated rainfall data and observed rainfall data show R^2 value of 0.734.

v) The set of selected potential predictors are listed in Table 7. Figure 4 shows the calibrated data against the historical data for period 1961-1990 and Figure 5 shows the validated data against the historical data for period 1991-2001.

Table 7: Potential predictors selected for downscaling

Coefficient of Predictor	Potential Predictors	Parameter Code	Regression Constant	R^2 Value
.634	Surface Vorticity	ncepp__zas	90.595	0.734
-.001	Surface Wind Direction	ncepp_thas		
-.075	850 hPa Vorticity	ncepp8_zas		
-.507	Relative Humidity at 850 hPa	ncepr850as		
1.288	500 hPa Vorticity	ncepp5_zas		
6.350	Near Surface relative humidity	nceprhumas		
-.002	850 hPa Wind Direction	ncepp8thas		

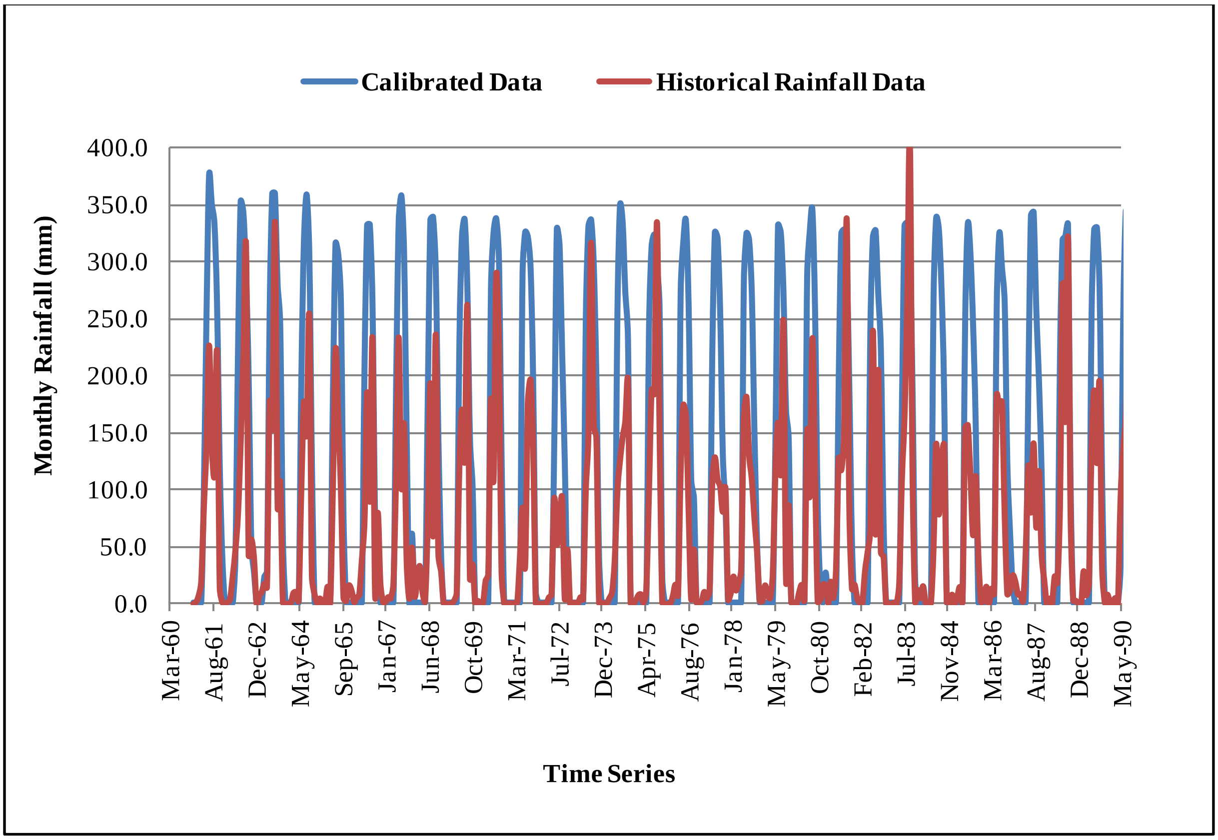

Figure 4: Calibrated rainfall data plotted against historical rainfall data (1961-1990)

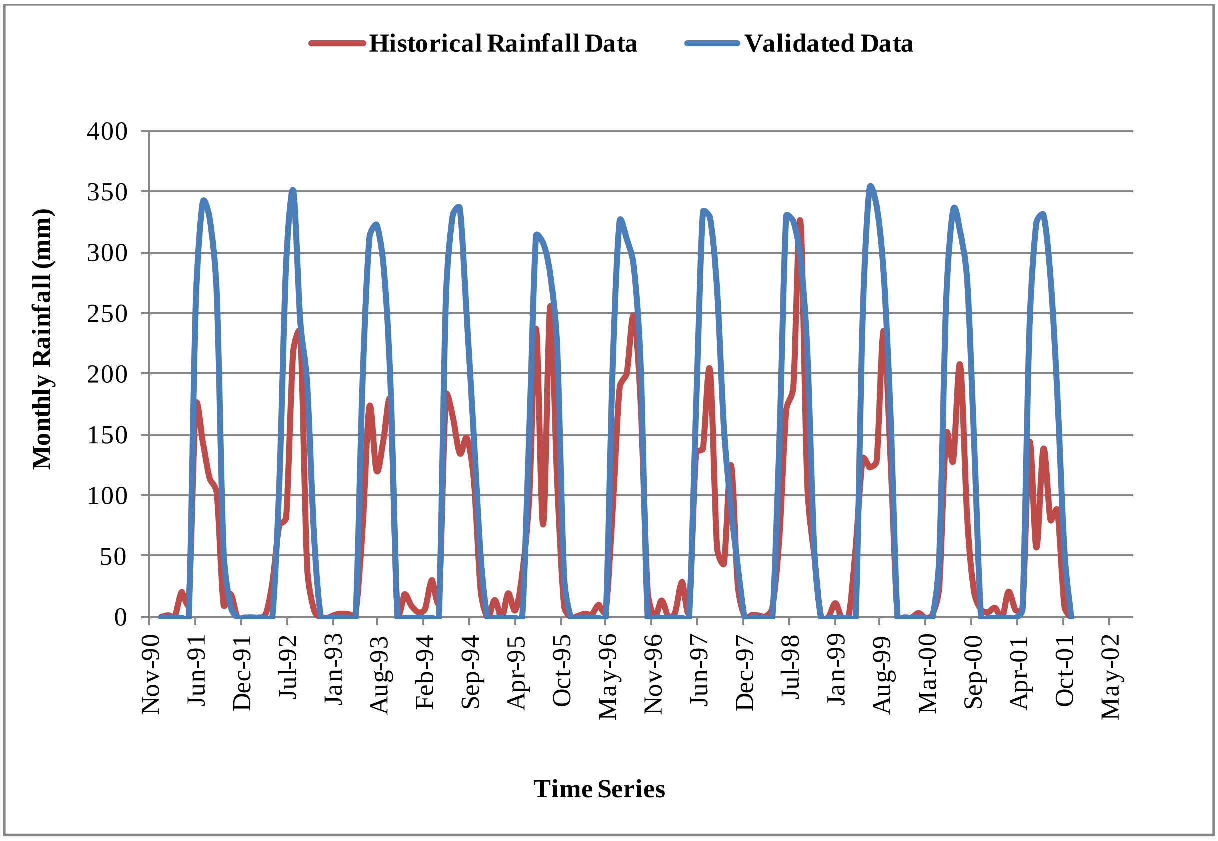

Figure 5: Validated rainfall data plotted against historical rainfall data (1991-2001)

4.4 GENERATION OF FUTURE RAINFALL SCENARIO AND BIAS CORRECTION

The set of most potential predictors found out in calibration and validation of NCEP data is then used for construction of the future monthly rainfall series. The HadCM3_A2 (Hadley Centre Coupled Model, version 3) scenario developed at the Hadley Centre in the United Kingdom is used to construct future precipitation series.

The rainfall series is generated by the HadCM3_A2 scenario using the selected set of predictors for the period 1961 – 2099. The generated rainfall series is plotted against the historical rainfall series from 1961-2002 which is shown in following figure.

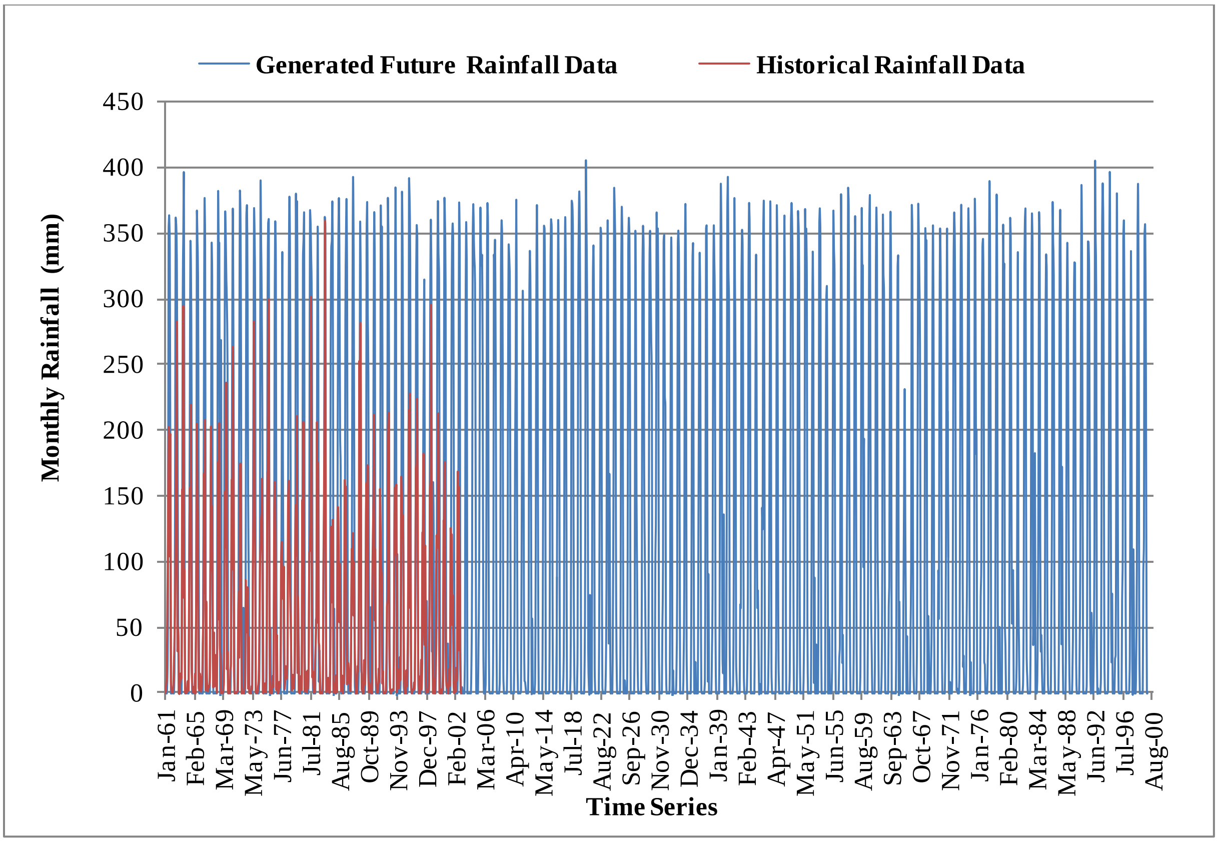

Figure 6: Generated Future Rainfall Data

It can be clearly noticed that the generated rainfall data have higher values than the observed rainfall series. It means that the developed downscaling model is generating over predicted future rainfall data. Bias Correction technique is adopted to correct the bias between over predicted future rainfall data and historical rainfall data.

To apply the bias correction, probability of exceedance of monthly projected rainfall values is matched with probability of exceedance of monthly historical rainfall values (Wood et al. 2007). For this purpose, the probability exceedance curve for the historical rainfall data is plotted for the time period 1961 to 2001. The probability exceedance curve for the projected rainfall data from 2002 to 2099 is also obtained. It is assumed that the rainfall data follows the same curve of probability exceedance for any time period. Based on this assumption the projected data is bias corrected matching the values of probability exceedance of it to the values of probability exceedance of historical rainfall data.

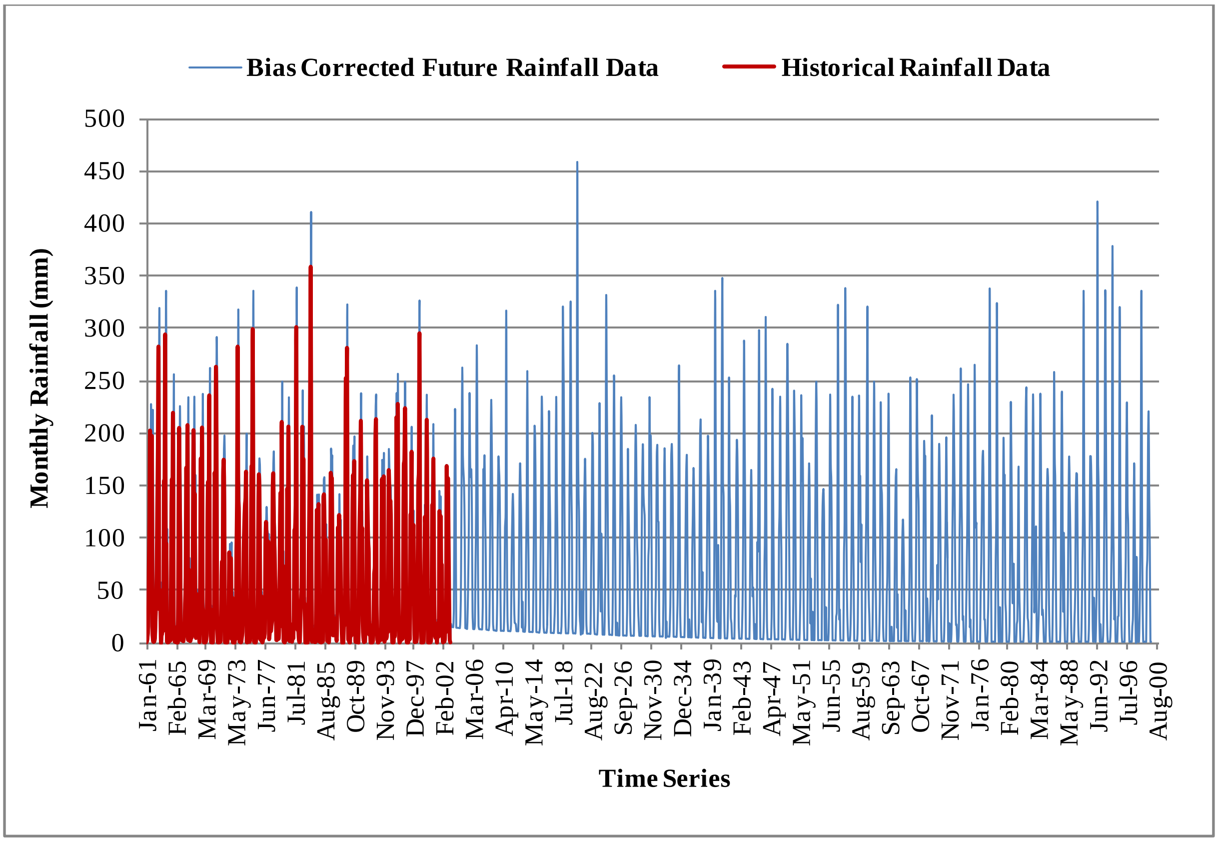

Figure 7: Bias Corrected Future Rainfall Data

4.5 PREDICTION OF FUTURE DROUGHT EVENTS AND THEIR CHARACTERISTICS USING SPI

The projected precipitation data is then used as the input data for the **SPI_SL_6.exe** program so as to calculate SPI values for future on 12 month time scale. As the grid size of downscaled data is not so fine that individual district's data could be projected thus drought events are identified and analysed for the integrated Marathwada region. Drought severity, drought duration and drought return period for the future are calculated based on SPI values for future.

CHAPTER 5

RESULTS AND DISCUSSIONS

All results achieved by evaluating various drought indices and drought characteristics are presented in this chapter. Drought characteristics of historical drought events evaluated by various drought indices are discussed so as to identify the drought index which gives the best results about severity, duration and return period of drought. The best identified drought index is then applied to projected rainfall data to predict drought characteristics of probable future drought events.

5.1 GENERAL

The main objective of the study is to assess drought characteristics based on standardized precipitation Index (SPI) as it is the most reliable drought index but drought characteristics are also evaluated based on other rainfall based drought indices viz. Rainfall Deficit (RD), Z-Score, China Z-Score (CZI) and Rainfall deciles based Drought Index (RDDI) so that better conclusions can be drawn. Further, an attempt is made to predict future drought events based on SPI values of the generated future rainfall data which is achieved by downscaling technique.

In this chapter all the results are briefly presented and discussed.

5.2 RAINFALL DEFICIT (RD)

Annual rainfall data of eight districts Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad and Parbhani for the time period from 1961 to 2002 is plotted against the time series with reference to the respective long range mean value of annual rainfall. Rainfall values below mean indicates deficit rainfall while rainfall values above mean indicates excess rainfall. It is analysed for the concerned time period, maximum rainfall deficiency over the eight districts ranges from -44% to -56%. Overall rainfall trend show declination over the passage of time. Besides the eight districts, Annual rainfall trend for overall Marathwada region is also presented based on area weighted average method. All the plots are presented in Appendix-A.

Rainfall Deficit is the lag of rainfall below long term average rainfall. Based on rainfall deficit of eight districts of Marathwada and weighted area average of Marathwada for the period 1961 to 2002, drought events are identified. The results based on Rainfall deficit are presented in Table 7 respective deficit.

Table 8: Rainfall Deficit based Drought Events and their Characteristics

<table>
<tr><th>Station</th><th>Year</th><th>Rainfall Deficit (% from mean)</th><th>Drought Severity</th><th>Duration (Years)</th><th>Return period (Years)</th></tr>
<tr><td rowspan="5">Aurangabad</td><td>1967</td><td>-44</td><td>Moderate</td><td>1</td><td rowspan="5">8</td></tr>
<tr><td>1978</td><td>-26</td><td>Moderate</td><td>1</td></tr>
<tr><td>1988</td><td>-25</td><td>Moderate</td><td>1</td></tr>
<tr><td>1998</td><td>-32</td><td>Moderate</td><td rowspan="2">2</td></tr>
<tr><td>1999</td><td>-33</td><td>Moderate</td></tr>
<tr><td rowspan="2">Beed</td><td>1972</td><td>-53.1</td><td>Severe</td><td>1</td><td rowspan="2">21</td></tr>
<tr><td>2001</td><td>-25.4</td><td>Moderate</td><td>1</td></tr>
<tr><td rowspan="5">Hingoli</td><td>1972</td><td>-55.7</td><td>Severe</td><td>1</td><td rowspan="5">8</td></tr>
<tr><td>1976</td><td>-25.7</td><td>Moderate</td><td>1</td></tr>
<tr><td>1984</td><td>-40.4</td><td>Moderate</td><td>1</td></tr>
<tr><td>1991</td><td>-33.2</td><td>Moderate</td><td>1</td></tr>
<tr><td>2001</td><td>-36.8</td><td>Moderate</td><td>1</td></tr>
<tr><td rowspan="5">Jalna</td><td>1972</td><td>-42.7</td><td>Moderate</td><td>1</td><td rowspan="5">8</td></tr>
<tr><td>1982</td><td>-27.9</td><td>Moderate</td><td>1</td></tr>
<tr><td>1991</td><td>-31.3</td><td>Moderate</td><td>1</td></tr>
<tr><td>2000</td><td>-32.5</td><td>Moderate</td><td rowspan="2">2</td></tr>
<tr><td>2001</td><td>-38.3</td><td>Moderate</td></tr>
<tr><td rowspan="5">Latur</td><td>1965</td><td>-29.1</td><td>Moderate</td><td>1</td><td rowspan="5">8</td></tr>
<tr><td>1972</td><td>-50.8</td><td>Severe</td><td>1</td></tr>
<tr><td>1976</td><td>-24.4</td><td>Moderate</td><td>1</td></tr>
<tr><td>1980</td><td>-26.5</td><td>Moderate</td><td>1</td></tr>
<tr><td>1984</td><td>-33.6</td><td>Moderate</td><td>1</td></tr>
</table>

Station	Year	Rainfall Deficit (% from mean)	Drought Severity	Duration (Years)	Return period (Years)
Nanded	1972	-52.5	Severe	1	14
	1984	-41.9	Moderate	1	
	2001	-25.4	Moderate	1	
Osmanabad	1965	-30.1	Moderate	1	11
	1972	-54.7	Severe	1	
	1980	-30.9	Moderate	1	
	2002	-26.8	Moderate	1	
Parbhani	1972	-50.9	Severe	1	11
	1984	-34.5	Moderate	1	
	1991	-27.3	Moderate	1	
	2001	-31.6	Moderate	1	
Marathwada	1972	-50.5	Severe	1	14
	1984	-27.0	Moderate	1	
	2001	-27.0	Moderate	1	

5.3 STANDARDIZED PRECIPITATION INDEX (SPI)

Based on the monthly rainfall data of eight districts and derived rainfall data for Marathwada by weighted average area method, SPI values for 12 months time scale are calculated for the period 1961 to 2002. According to pre-specified drought categories based on SPI values, drought events, their respective intensity, duration and return period is identified. All results are presented in the Table 9.

Table 9: SPI based Drought Events and their Characteristics

Station	Year	Drought Magnitude	Mean Intensity	Duration (Months)	Drought	Return Period (Years)
Aurangabad	1973	-14.8	-2.1	7	Extreme	8
	1982	-13.6	-1.4	10	Moderate	
	1992	-12.6	-1.6	8	Severe	
	2001	-19.8	-1.7	12	Severe	
	2002	-12	-1.5	8	Severe	
Beed	1973	-7.8	-1.1	7	Moderate	14
	1977	-9.7	-1.1	9	Moderate	
	2001	-7.2	-1.0	7	Moderate	
Hingoli	1972-73	-16.6	-1.3	13	Moderate	6
	1977	-12.2	-1.2	10	Moderate	
	1985	-6	-1.0	6	Moderate	
	1987	-6.8	-1.1	6	Moderate	
	1988	-6.8	-1.1	6	Moderate	
	1992	-9	-1.1	8	Moderate	
	2001	-6.5	-1.1	6	Moderate	
Jalna	1973	-9.5	-1.4	7	Moderate	8
	1983	-8.6	-1.2	7	Moderate	
	1992	-9.2	-1.2	8	Moderate	
	2001	-12.1	-1.0	12	Moderate	
	2002	-8.1	-1.0	8	Moderate	
Latur	1966	-10.7	-1.3	8	Moderate	8
	1973	-18.3	-2.6	7	Extreme	
	1977	-13.4	-1.3	10	Moderate	
	1985	-16	-1.5	11	Moderate	
	1973	-29	-2.9	10	Extreme	
Nanded	1985	-11.4	-1.9	6	Severe	14
	1992	-10.8	-1.4	8	Moderate	
	2002	-9.6	-1.2	8	Moderate	

Station	Year	Drought Magnitude	Mean Intensity	Duration (Months)	Drought	Return Period (Years)
Osmanabad	1973	-19.9	-2.8	7	Extreme	21
	1981	-8.7	-1.1	8	Moderate	
Parbhani	1973	-17.7	-2.5	7	Extreme	8
	1977	-8.8	-1.5	6	Moderate	
	1992	-12.1	-1.5	8	Severe	
	2001	-8.9	-1.5	6	Moderate	
	2002	-9.7	-1.4	7	Moderate	
Marathwada	1973	-19.5	-2.8	7	Extreme	10
	1992	-11.4	-1.4	8	Moderate	
	2001	-9	-1.5	6	Severe	
	2002	-8.8	-1.3	7	Moderate	

Analysis is also done to find out the longest duration of drought and the most intense duration of drought duration during the period for each individual district and Marathwada as a whole. Their respective Drought Magnitude and Mean Intensity of drought are also calculated and results are arranged in Table 9 and Table 10 respectively. The most intense drought events for all stations are listed in Table 11. For the duration 1961 to 2002, graphs for SPI 12 versus time series are plotted for each station. All graphs are presented in Appendix-B.

Table 10: Peak Intensity drought events based on SPI

Station	Peak Intensity		
	Year	Month	SPI
Aurangabad	1992	July	-2.83
Beed	1966	August	-1.17
Hingoli	1966	July	-1.36
Jalna	1964	August	-1.45
Latur	1972	October	-3.09
Nanded	1973	June	-3.44
Osmanabad	1972	October	-3.35
Parbhani	1973	June	-2.85
Marathwada	1972	October	-3.14

Table 11: Longest Duration of drought events based on SPI

Station	Longest Duration			
	Duration in Months	Time Period	Drought Magnitude	Mean Intensity of Drought
Aurangabad	29	Nov-91 to Mar-94	-20.67	-0.71
Beed	31	Apr-66 to Oct-68	-12.95	-0.42
Hingoli	30	Oct-91 to Mar-94	-19.34	-0.64
Jalna	27	Oct-00 to Dec-02	-27.04	-1.0
Latur	25	Sep-71 to Sep-73	-39.9	-1.6
Nanded	25	Aug-71 to Aug-73	-44.5	-1.8
Osmanabad	25	Sep-71 to Sep-73	-41.63	-1.7
Parbhani	25	Aug-71 to Aug-73	-39.85	-1.6
Marathwada	25	Aug-71 to Aug-74	-40.27	-1.6

Table 12: The Most Intense Drought durations based on SPI

Station	Most Intense Duration			
	Duration in Months	Time Period	Drought Magnitude	Mean Intensity
Aurangabad	11	Sep-72 to July-73	-24.38	-2.2
Beed	13	Aug-72 to Aug-73	-13.65	-1
Hingoli	25	Aug-71 to Aug-73	-26.89	-1.1
Jalna	3	Jun-81 to Aug-81	-3.92	-1.3
Latur	25	Sep-71 to Sep-73	-39.9	-1.6
Nanded	25	Aug-71 to Aug-73	-44.53	-1.8
Osmanabad	25	Sep-71 to Sep-73	-41.63	-1.7
Parbhani	25	Aug-71 to Aug-73	-39.85	-1.6
Marathwada	25	Aug-71 to Aug-74	-40.27	-1.6

5.4 RAINFALL DECILES BASED DROUGHT INDEX (RDDI)

RDDI does not gives the exact severity of the drought event but it comparatively identifies extreme dry year during the given time period. The duration of 42 years is considered in this study. Based on RDDI calculations, the driest years during the period 1961 to 2002 are found for each station and are presented in Table 12 along with duration and return period.

Table 13: Results for the driest years based on RDDI

Station	Year	Rainfall	Mean Rainfall	Duration	Return Period
Aurangabad	1972	369	657	1	8
	1982	489		1	
	1991	495		1	
	2000	447		2	
	2001	440			
Beed	1972	333	711	1	8
	1976	541		1	
	1984	566		1	
	2001	531		2	
	2002	552			
Hingoli	1972	389	878	1	8
	1976	652		1	
	1984	524		1	
	1991	587		1	
	2001	555		1	
Jalna	1972	402	703	1	8
	1982	507		1	
	1991	483		1	
	2000	474		2	
	2001	433			
Latur	1965	569	803	1	8
	1972	395		1	
	1976	607		1	
	1980	590		1	

Station	Year	Rainfall	Mean Rainfall	Duration	Return Period
Nanded	1972	439	923	1	8
	1984	536		1	
	1987	734		1	
	2001	689		1	
Osmanabad	1965	498	713	1	8
	1976	575		1	
	1980	493		1	
	2002	522		1	
Parbhani	1976	610	802	1	8
	1984	525		1	
	1991	583		1	
	2001	549		1	
Marathwada	1972	379	767	1	8
	1984	559		1	
	1991	601		1	
	2001	560		1	
	2002	617		1	

5.5 Z-SCORE

Z-Score follows the same category distribution of drought as that of SPI but it is comparatively easy to calculate. Z-score of all stations is calculated for 12 month time scale for the period 1961 to 2002. The results for drought intensity, drought duration and drought return period are tabulated below in Table 13. Graphs are plotted between annual Z-score and considered time series. All Z-Score plots are shown in Appendix-C.

Table 14: Drought Events and their Characteristics based on Z-Score

Station	Year	Z- Score	Drought Severity	Duration (Years)	Return Period (years)
Aurangabad	1972	-2.5	Severe	1	6
	1965	-1.0	Moderate	1	
	1982	-1.4	Moderate	1	
	1991	-1.4	Moderate	1	
	2000	-1.8	Extreme	3	
	2001	-1.9	Extreme		
	2002	-1.3	Moderate		
Beed	1972	-2.8	Severe	1	6
	1965	-1.1	Moderate	1	
	1976	-1.3	Moderate	1	
	1984	-1.1	Moderate	1	
	2000	-1.1	Moderate	3	
	2001	-1.4	Moderate		
	2002	-1.2	Moderate		
Hingoli	1972	-2.3	Severe		8
	1976	-1.0	Moderate	1	
	1984	-1.6	Extreme	1	
	1991	-1.3	Moderate	1	
	2001	-1.5	Moderate	1	
Jalna	1972	-2.2	Severe	1	11
	1982	-1.4	Moderate	1	
	1991	-1.6	Extreme	1	
	2000	-1.7	Extreme	1	

Station	Year	Z- Score	Drought Severity	Duration (Years)	Return Period (years)
Latur	1972	-2.5	Severe	1	5
	1965	-1.4	Moderate	1	
	1976	-1.2	Moderate	2	
	1977	-1.0	Moderate		
	1980	-1.3	Moderate	1	
	1984	-1.6	Extreme	2	
	1985	-1.1	Moderate		
	2002	-1.1	Moderate	1	
Nanded	1972	-2.4	Severe	1	14
	1991	-1.1	Moderate	1	
	2001	-1.2	Moderate	1	
	1972	-2.9	Severe	1	
Osmanabad	1965	-1.6	Extreme	1	8
	1976	-1.0	Moderate	1	
	1980	-1.6	Extreme	1	
	2002	-1.4	Moderate	1	
Parbhani	1972	-2.2	Severe	1	8
	1976	-1.0	Moderate	1	
	1984	-1.5	Extreme	1	
	1991	-1.2	Moderate	1	
	2001	-1.4	Moderate	1	
Marathwada	1972	-2.7	Severe	1	7
	1976	-1.0	Moderate	1	
	1984	-1.4	Moderate	1	
	1991	-1.1	Moderate	1	
	2001	-1.4	Moderate	2	
	2002	-1.0	Moderate		

5.6 CHINA Z INDEX (CZI)

CZI of all stations is evaluated for 12 month time scale for the period 1961 to 2002. The results for drought intensity, drought duration and drought return period are tabulated below in Table 14.Graphs are plotted between CZI and considered time series. All plots are shown in Appendix-D.

Table 15: Drought Events and their Characteristics based on CZI

Station	Year	CZI	Duration (Years)	Drought Severity	Return Period (Years)
Aurangabad	1972	-2.4	1	Severe	6
	1965	-1.0	1	Moderate	
	1982	-1.4	1	Moderate	
	1991	-1.4	1	Moderate	
	2000	-1.8	1	Extreme	
	2001	-1.8	1	Extreme	
	2002	-1.3	1	Moderate	
Beed	1972	-5.4	1	Severe	6
	1965	-1.1	1	Moderate	
	1976	-1.4	1	Moderate	
	1984	-1.1	1	Moderate	
	2000	-1.1	1	Moderate	
	2001	-1.5	1	Extreme	
	2002	-1.3	1	Moderate	
Hingoli	1972	-2.7	1	Severe	8
	1976	-1.1	1	Moderate	
	1984	-1.8	1	Extreme	
	1991	-1.4	1	Moderate	
	2001	-1.6	1	Extreme	
Jalna	1972	-2.4	1	Severe	8
	1982	-1.5	1	Moderate	
	1991	-1.7	1	Extreme	
	2000	-1.8	1	Extreme	
	2001	-2.1	1	Severe	

Station	Year	CZI	Duration (Years)	Drought Severity	Return Period (Years)
Latur	1972	-2.7	1	Severe	5
	1965	-1.5	1	Moderate	
	1976	-1.2	1	Moderate	
	1977	-1.0	1	Moderate	
	1980	-1.3	1	Moderate	
	1984	-1.7	1	Extreme	
	1985	-1.1	1	Moderate	
	2002	-1.1	1	Moderate	
Nanded	1972	-3.0	1	Severe	11
	1984	-2.2	1	Severe	
	1991	-1.1	1	Moderate	
	2001	-1.2	1	Moderate	
Osmanabad	1972	-2.9	1	Severe	8
	1965	-1.6	1	Extreme	
	1976	-1.0	1	Moderate	
	1980	-1.6	1	Extreme	
	2002	-1.4	1	Moderate	
Parbhani	1972	-3.4	1	Severe	8
	1976	-1.1	1	Moderate	
	1984	-1.8	1	Extreme	
	1991	-1.3	1	Moderate	
	2001	-1.6	1	Extreme	
Marathwada	1972	-3.5	1	Severe	7
	1976	-1.0	1	Moderate	
	1984	-1.6	1	Extreme	
	1991	-1.2	1	Moderate	
	2001	-1.6	1	Extreme	
	2002	-1.1	1	Moderate	

5.7 FUTURE DROUGHT EVENTS

Future rainfall series is generated by downscaling NCEP Reanalysis data using HadCM3_A2 scenario for the period of 97 years from 2003 to 2099. SPI values are calculated for this duration on the times scale of 12 months. Future drought events and their characteristics are the identified using SPI 12 values.

Table 16: Future Drought Events and their Characteristics based on SPI

Year	Drought Magnitude	Mean Intensity	Duration (Months)	Drought Severity	Return Period (years)
2011-12	-15.4	-1.3	12	Moderate	11
2022	-5.3	-1.3	4	Moderate	11
2027-28	-14.5	-1.3	11	Moderate	11
2032-2033	-18.0	-1.6	11	Severe	33
2035	-8.0	-1.3	6	Moderate	11
2044-45	-14.0	-1.3	11	Moderate	11
2047-48	-19.3	-1.4	14	Moderate	11
2052-53	-7.2	-1.2	6	Moderate	11
2054-55	-17.0	-1.5	11	Severe	33
2064-2066	-59.8	-2.1	29	Extreme	49
2070	-12.1	-1.2	10	Moderate	11
2081-82	-36.2	-2.6	14	Extreme	49
2086-87	-9.7	-1.2	8	Moderate	11
2097-98	-16.0	-1.6	10	Severe	33

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

An exercise has been carried out to assess the drought characteristics of Marathwada region which is suffering from consecutive scanty rainfalls and drought situations over the past several years. Different drought indices are used in this study to identify drought characteristics. Drought characteristics for eight districts of Marathwada region are identified and summarised in this study. Apart from identifying drought characteristics, an attempt is made to predict future drought events and their probable characteristics in Marathwada region. Detailed summary of this study is given below;

i) Historical precipitation data of the Marathwada region from year 1960 to 2002 is used to calculate drought indices namely Rainfall Departure (RD), Standardized precipitation Index (SPI), Rainfall Decile based Drought Index (RDDI), Z-Score and China Z-Score (CZI) for each of the individual districts and the whole Marathwada area to calculate drought characteristics. All drought indices are calculated on 12-month time scale so that they can be compared. Their results for drought characteristics are verified against the past drought events.

ii) The NCEP reanalysis data is downscaled using Multiple Linear Regression (MLR) technique and is calibrated and validated against the historical data for the period 1961-1990 and 1991-2001 respectively. The Hadley Centre Coupled Model, version 3 (HadCM3) is used for projecting future predictand (rainfall) using A2 scenario for the period 2003−2099. Bias correction is done to remove bias from projected data.

iii) To identify the future drought events, SPI is used as prediction tool. SPI is calculated for projected future rainfall data. Assuming that SPI represents the regional climatic condition better than other indices, future drought events and their characteristics are predicted.

6.2 CONCLUSIONS

Conclusions drawn from the study are presented below;

i) All drought indices show consistency in identifying the extreme drought which occurred in year 1972. The duration identified for this drought by all drought indices is nearly one year. So it can be concluded that all drought indices are consistent in identifying the most severe drought. But for less severe droughts and droughts with less spatial extents, drought indices show inconsistency. Extreme and severe drought indices identified by these drought indices are listed in the table below:

Table 17: Extreme and severe droughts identified by various drought indices

			(red)	Extreme Drought Year					
			(purple)	Severe Drought Year					
	Aurangabad	Beed	Hingoli	Jalna	Latur	Nanded	Osmanabad	Parbhani	Marathwada
RD	1972 1967	1972	1972 1984 2001	1972 2001	1972	1972 1984	1972	1972	1972
RDDI	1972, 1984, 1991, 2001, 2002 (Driest years of the time duration 1960-2001) 1965, 1976, 1977, 1980, 2000 (Moderate dry years of the time duration 1960-2001)								
SPI	1972 1981 1992	1972	1972	1972 1965	1972 1984	1972 1984	1972 1993	1972 1991	1972 2001
Z-Score	1972 2001	1972	1972 1984	1972 1991 2001	1972 1984	1972	1972 1965 1980	1972 1984	1972
CZI	1972 2001	1972 2001	1972 1984 2001	1972 2000	1972 1984	1972	1972 1965 1980	1972 1984 2001	1972 1984 2001

ii) The Rainfall Decile based Drought Index is not so reliable that it only shows the years of less rainfall in its tenth decile but doesn't actually defines drought years. Also, return period calculated by RDDI depends upon the time duration of study as it divides the study period in ten deciles and return period of driest years would be always one tenth of study duration.

iii) SPI, Z-Score and CZI follow the same severity categories for drought events thus these are found easier to compare. SPI, Z-Score and CZI show much more consistent results about drought occurrence, drought severity and drought durations. For example, Osmanabad district faced severe drought in 1965 which is not indicated by RD and RDDI.

iv) Though SPI and CZI are found to be more consistent, advantage with SPI is that it shows onset and offset of the drought event on a monthly scale. Knowing the SPI index, it is easy to say in which month the drought began to emerge and in which month it began to offset.

v) SPI should be preferred over other indices for its ability to specify drought duration on monthly scale. For example, all drought indices show that 1972 drought was extreme and of one year duration but SPI specifies that the one year duration was distributed among last 4 months of 1971 and first 7 to 8 months of 1972.

vi) Return period results of the drought calculated by the various drought indices show great inconsistency about the drought return period. Return periods calculated for moderate, severe and extreme drought events by considered drought indices are shown in the table below.

Table 18: Return periods of drought calculated by considered drought indices

Drought Index	Drought Return Period (Years)		
	Moderate	Severe	Extreme
Rainfall Departure from Mean	21	42	Not Defined
Rainfall Decile based Drought Index	8	8	8
Standardized Precipitation Index	21	42	42
Z-Score	8	42	Not Identified
China Z-Index	14	42	21

vii) Overall conclusions for the comparison study of drought indices is that they are highly consistent for indication of an extraordinary drought but when it is needed to specify the extent of severity, they show deviations. RD and RDDI can be used to identify extreme drought events where it is of not much importance to know about detailed drought characteristics. When more accuracy is required for drought severity and duration, SPI, Z-Score or CZI should be preferred. Sometimes Z-Score or CZI can be preferred over SPI because of the comparatively simple calculation than SPI but SPI gives advanced information about onset and offset of the drought.

viii) Drought events are predicted by evaluating SPI of the projected rainfall data for the period 2003 to 2099. In year 2011 and 2012, predicted SPI shows moderate drought situation which goes well with real time drought situations.

ix) Future SPI shows severe drought in 2032-2033 for the duration of 11 months. Other severe droughts are expected in 2044 for 4 months and for short spans in 2053 to 2056 which are not continuous. One severe drought extending for 5 months is also expected in 2097.

x) The extreme droughts of the future are expected in 2064-2066 with the time span of about 21 months which could be the longest and intense drought in future. 2081-2082 is also identified as drought event having temporal extension of 14 months within which 2082 could be the most intense drought year of the century.

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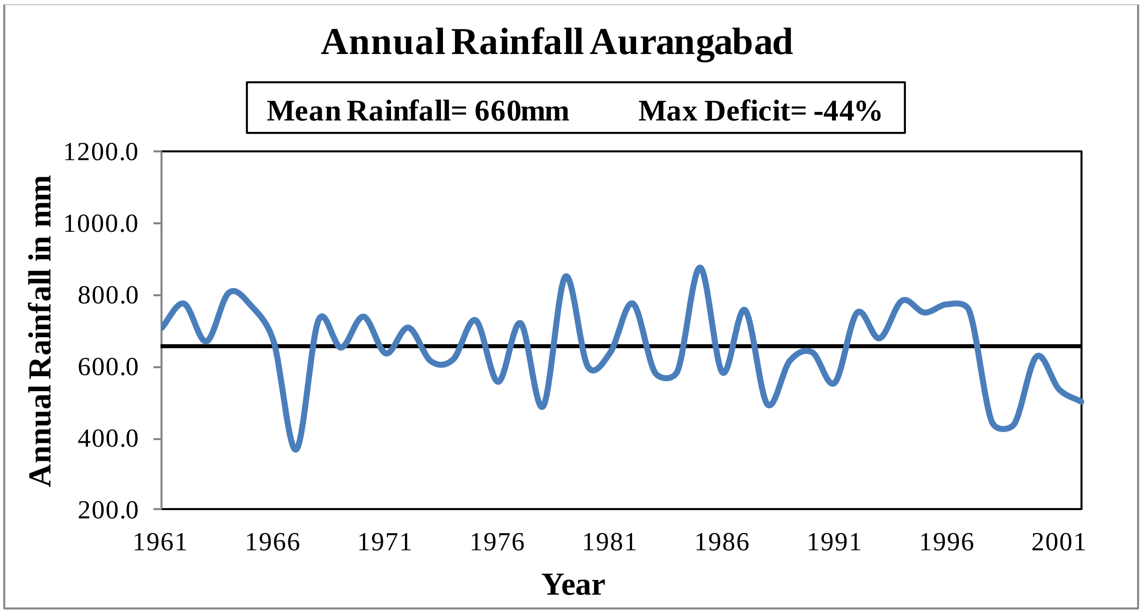
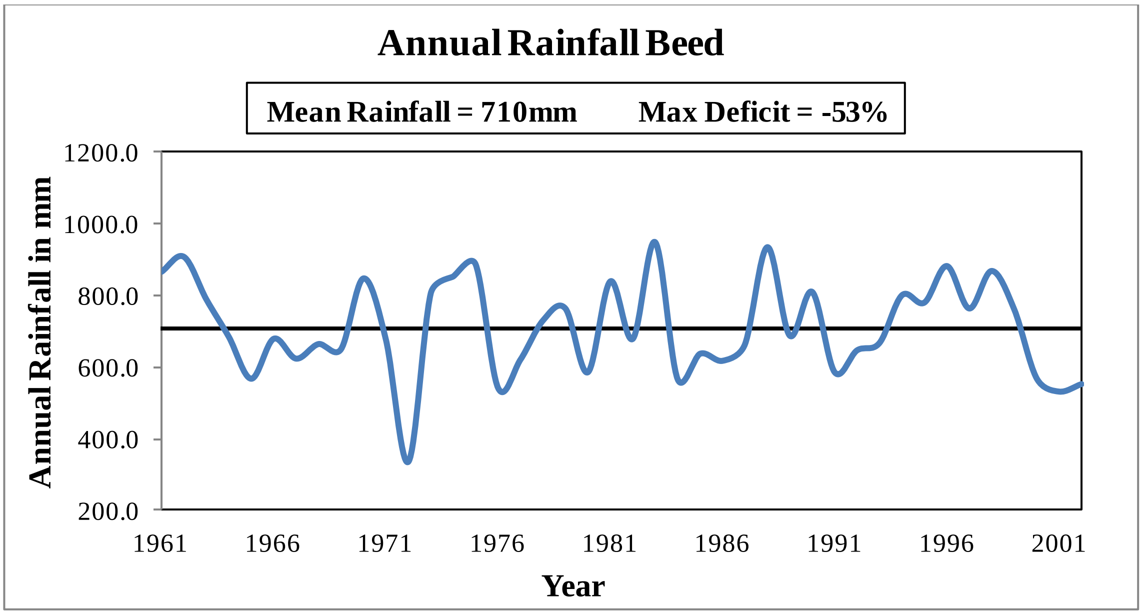
APPENDIX A

Plots for Annual Rainfall Fluctuations about Long Term Average Mean Rainfall





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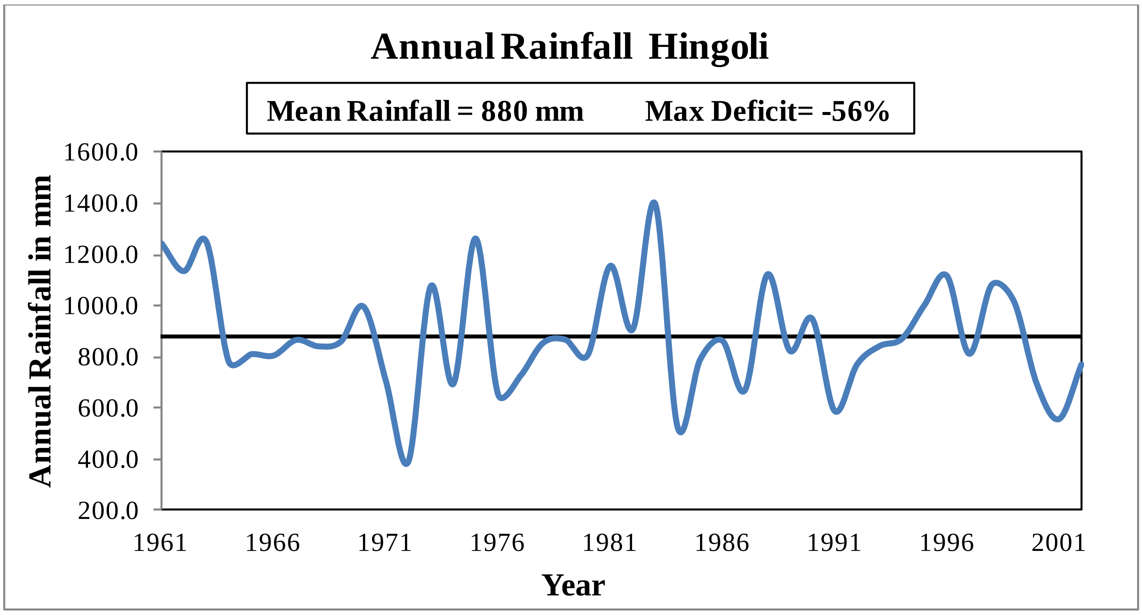
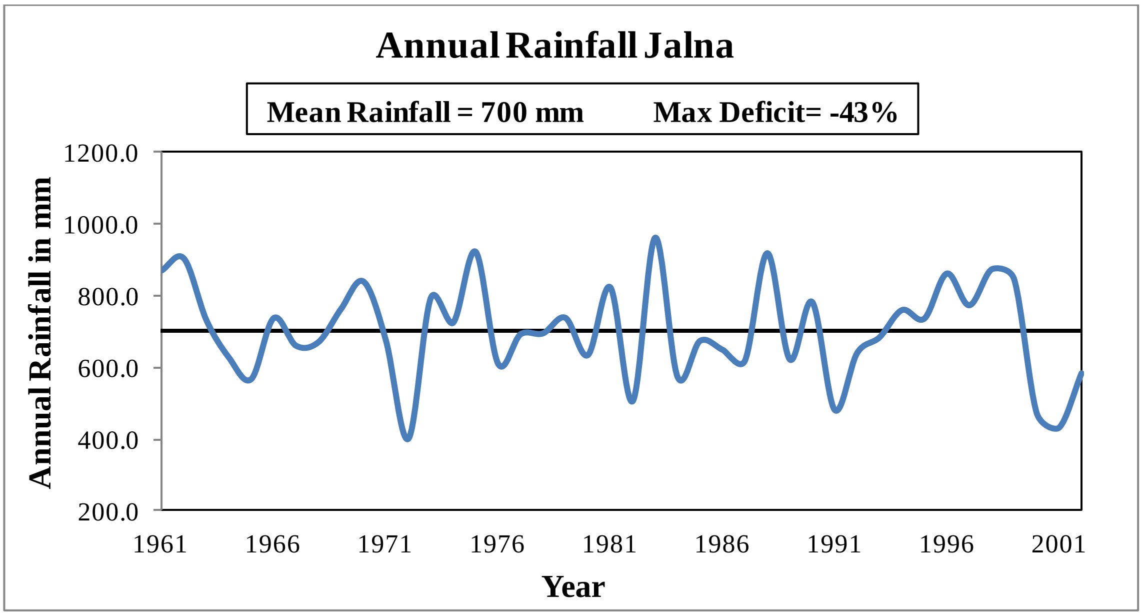
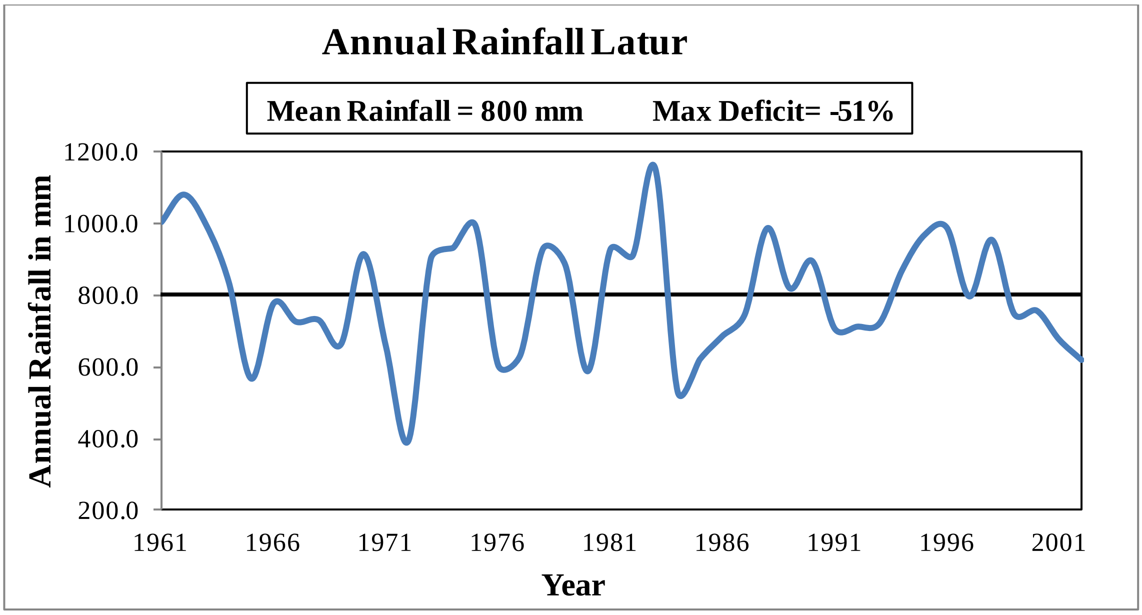
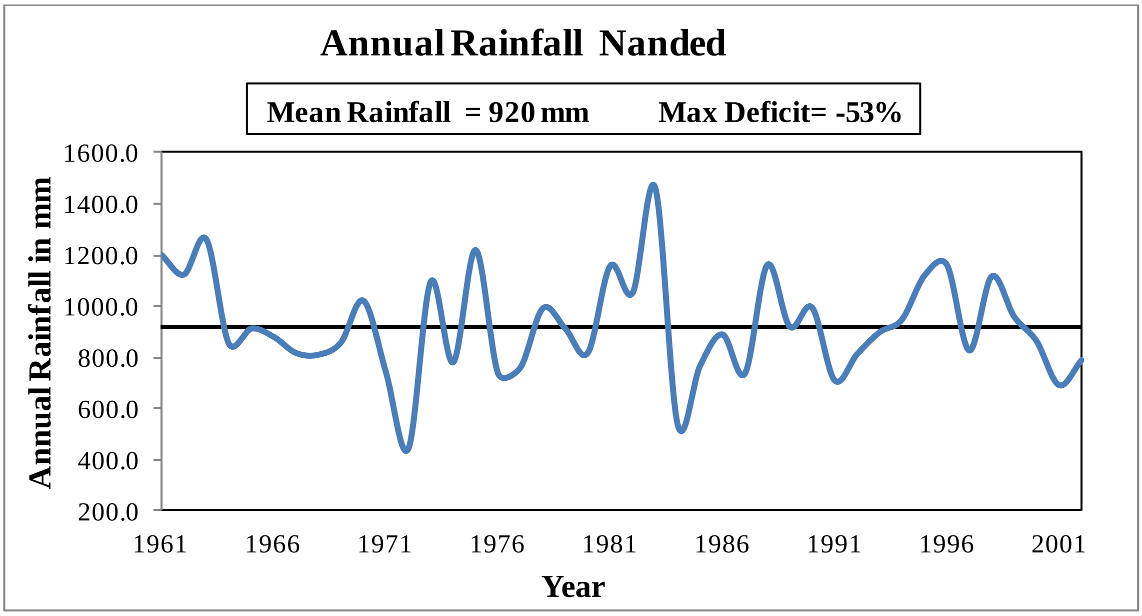




Plots for Annual Rainfall Fluctuations about Long Term Average Mean Rainfall





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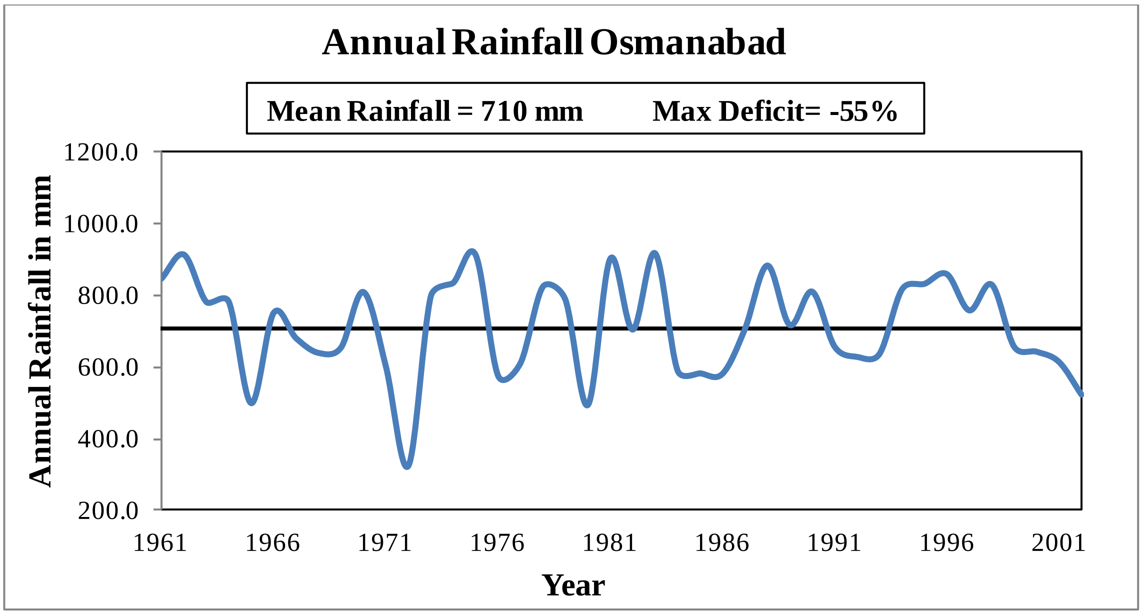

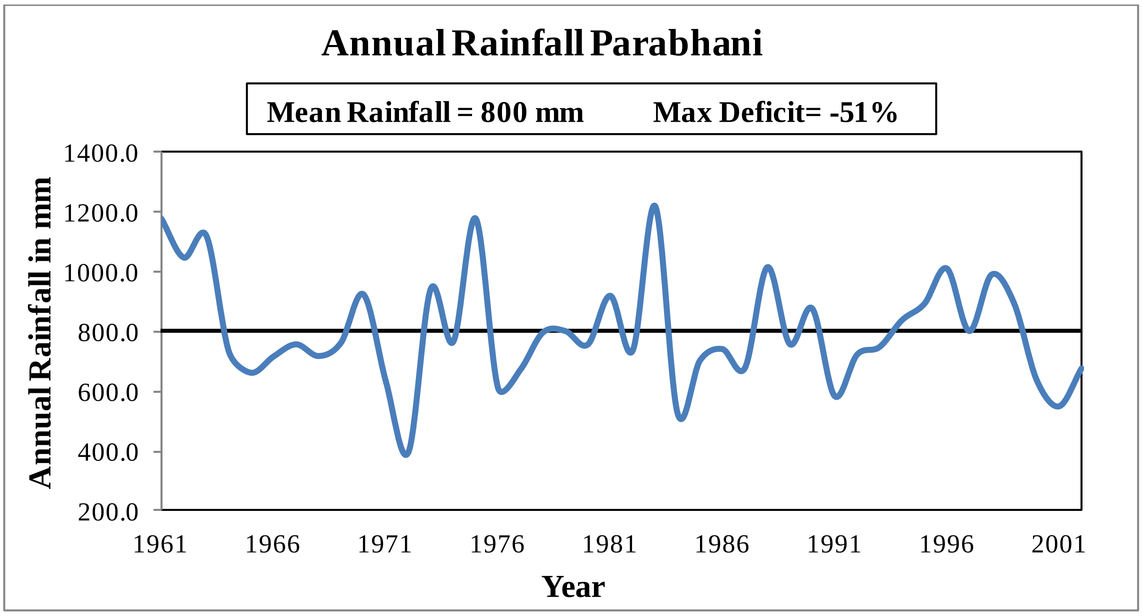

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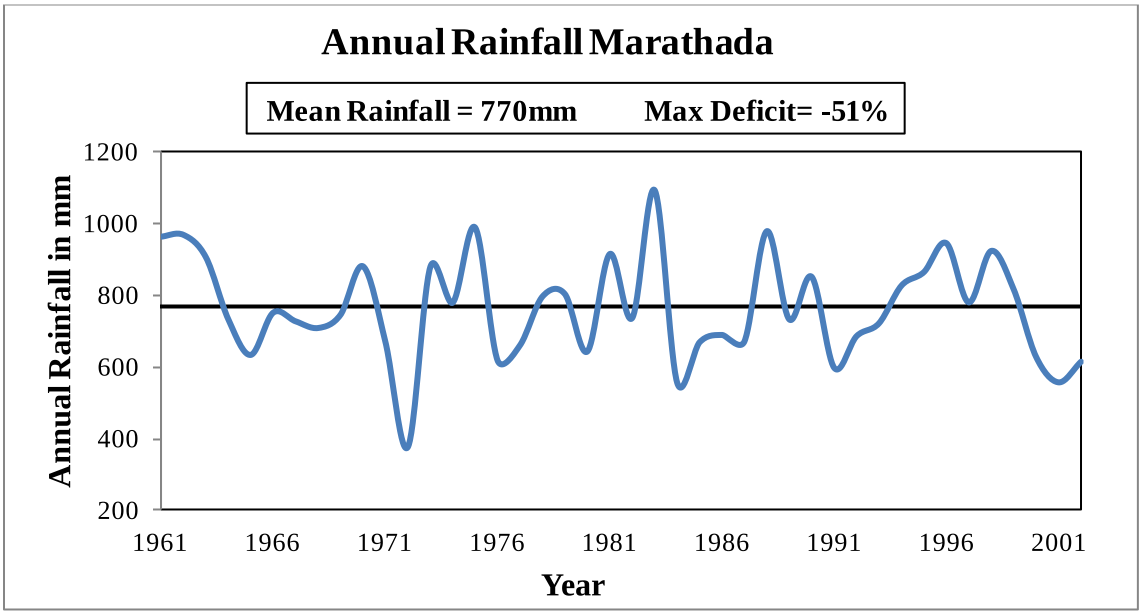
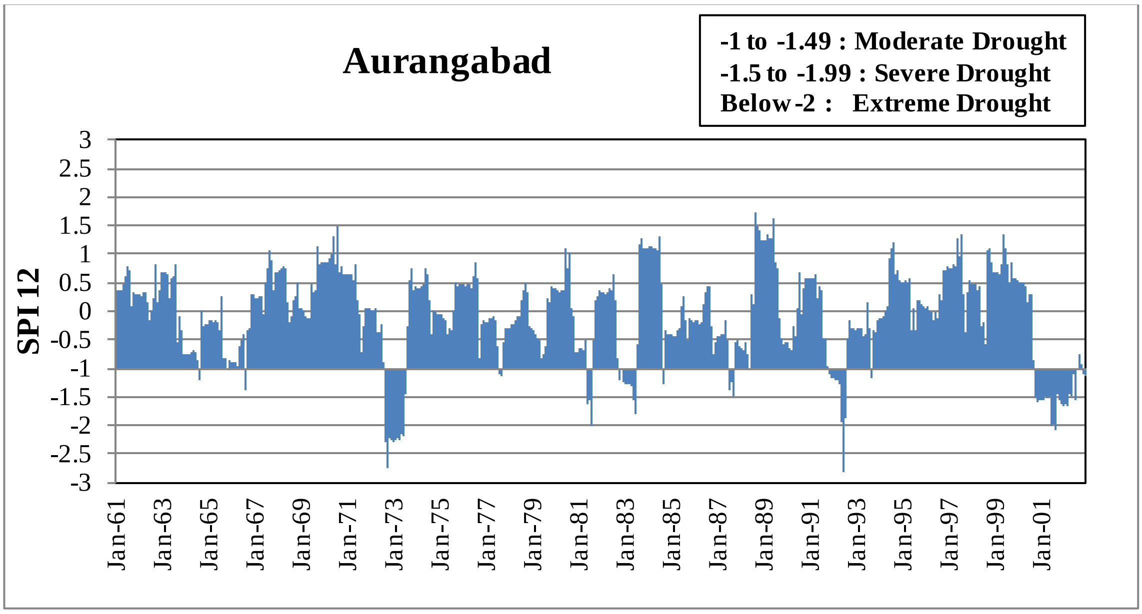
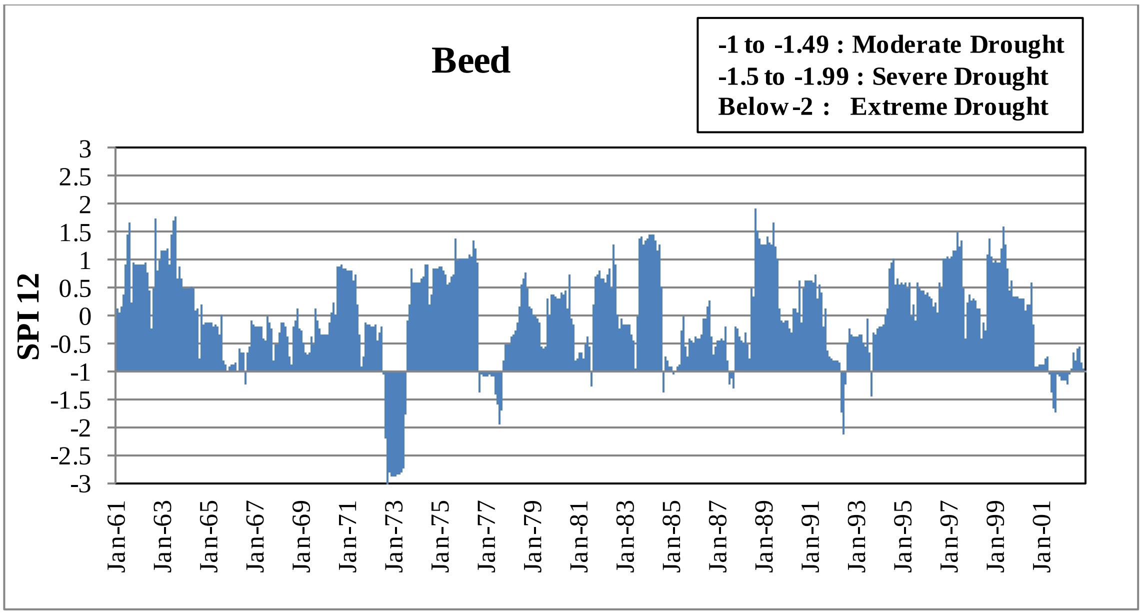


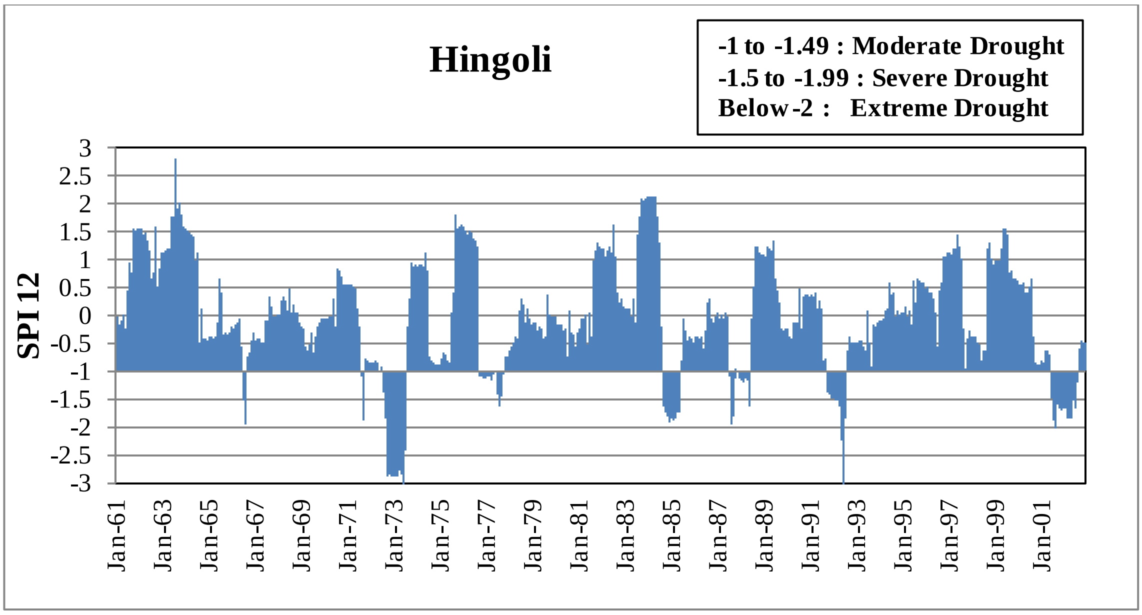
Plots for Annual Rainfall Fluctuations about Long Term Average Mean Rainfall

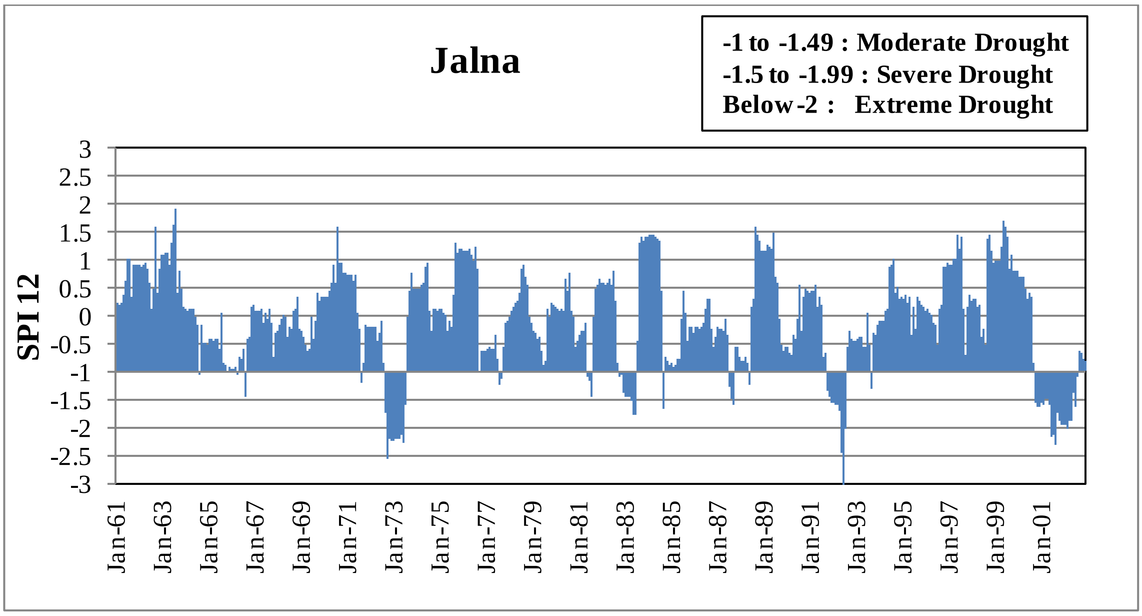
Plots of SPI 12 versus time series for Marathwada region





Plots for SPI 12 versus time series for each district of Marathwada region





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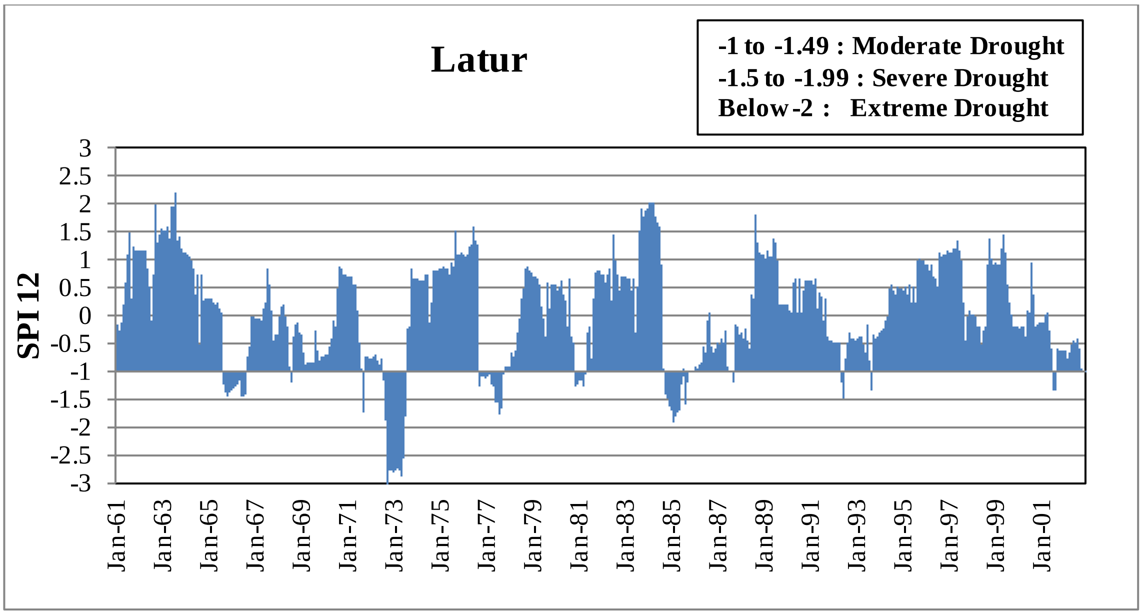

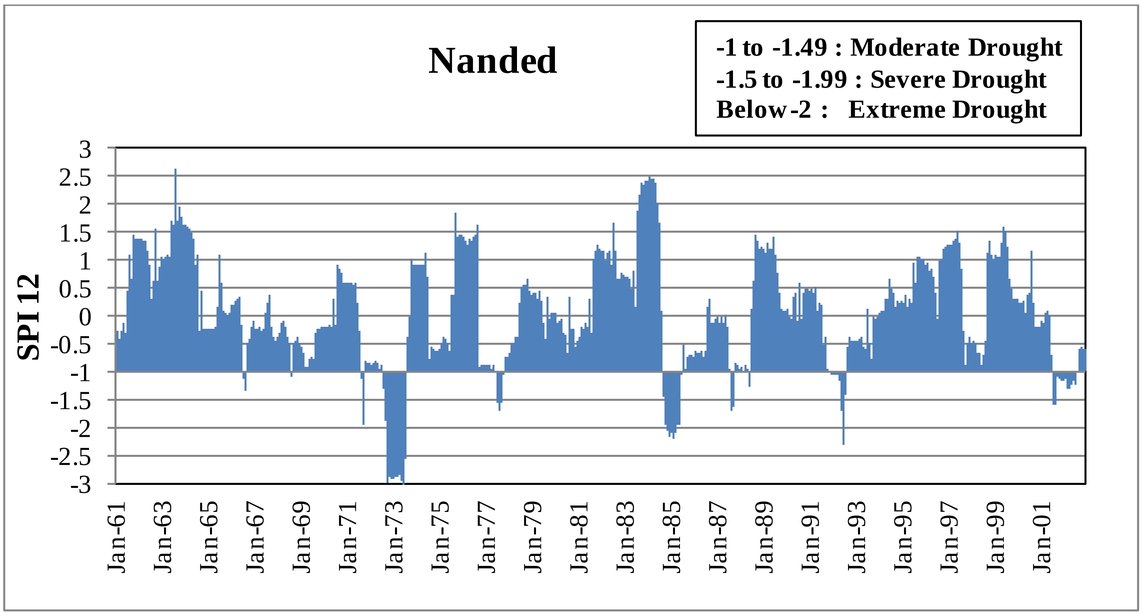

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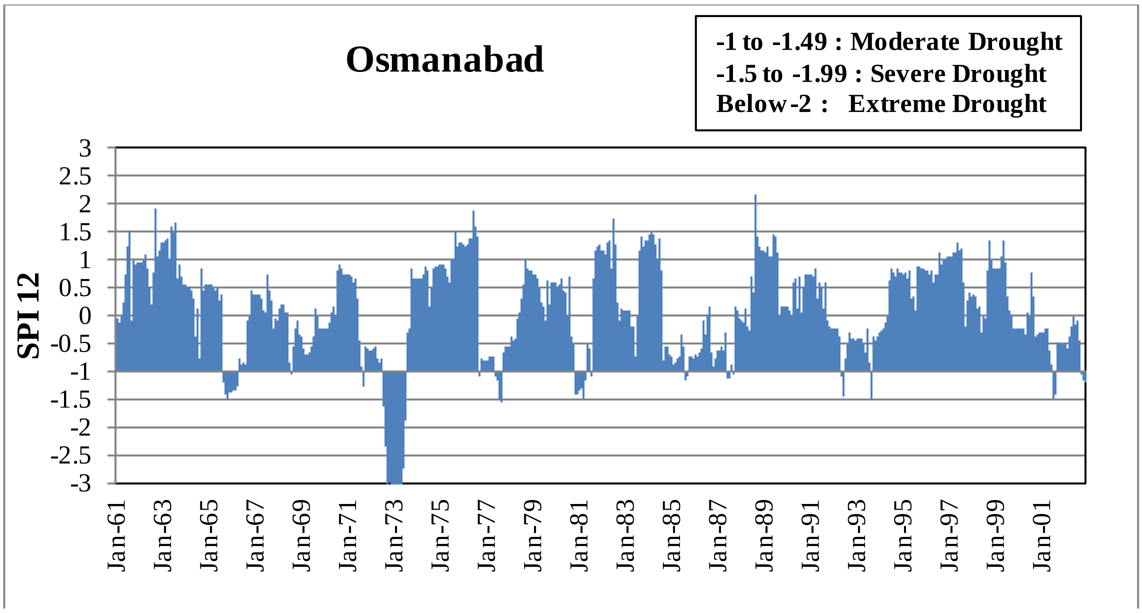
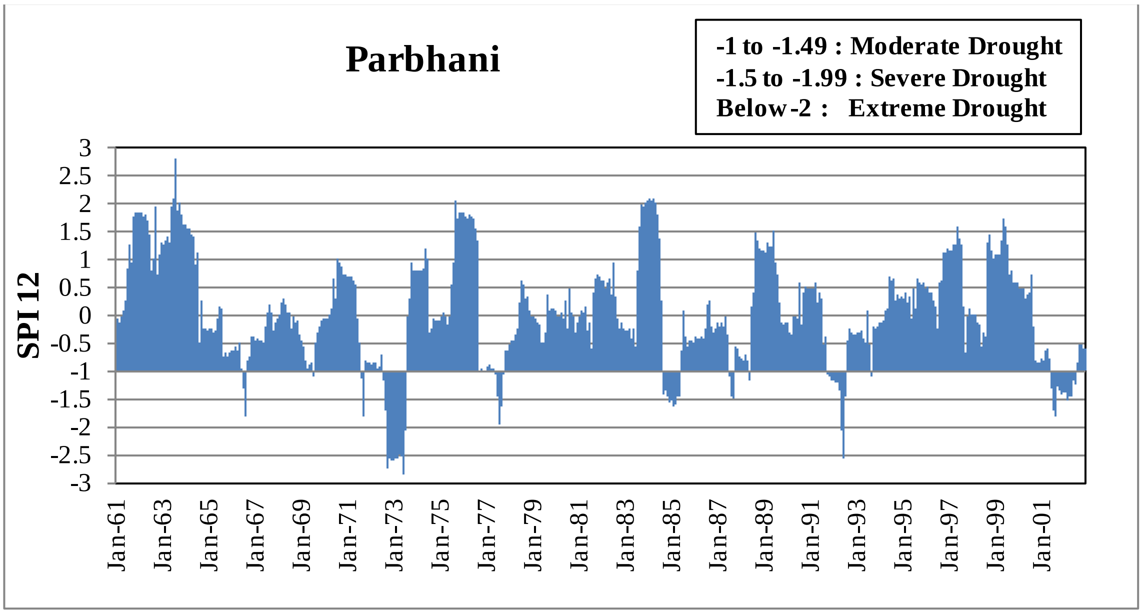
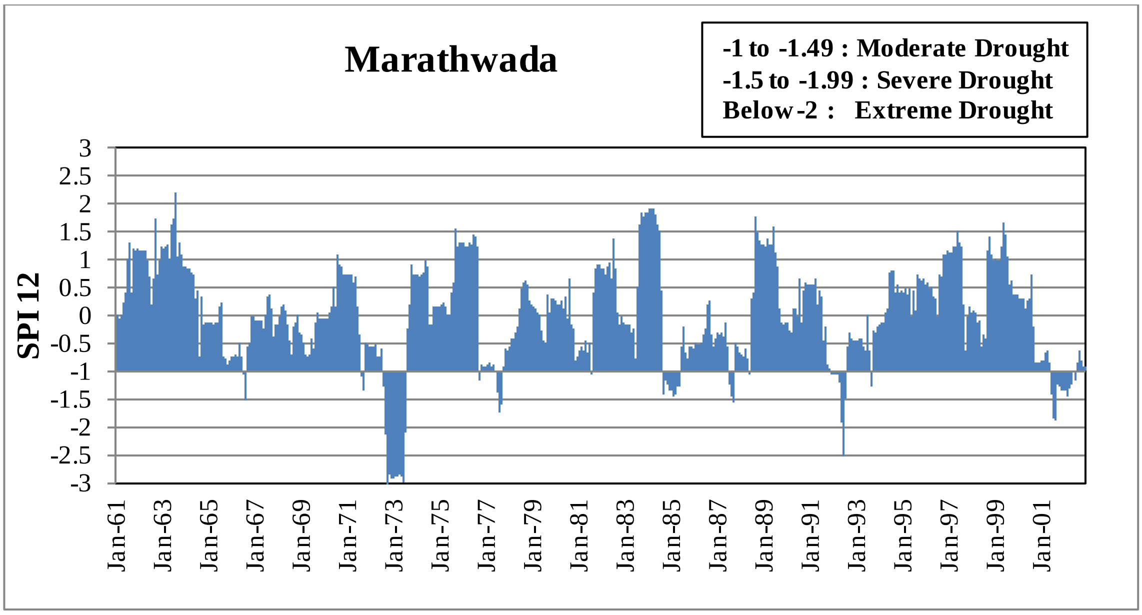


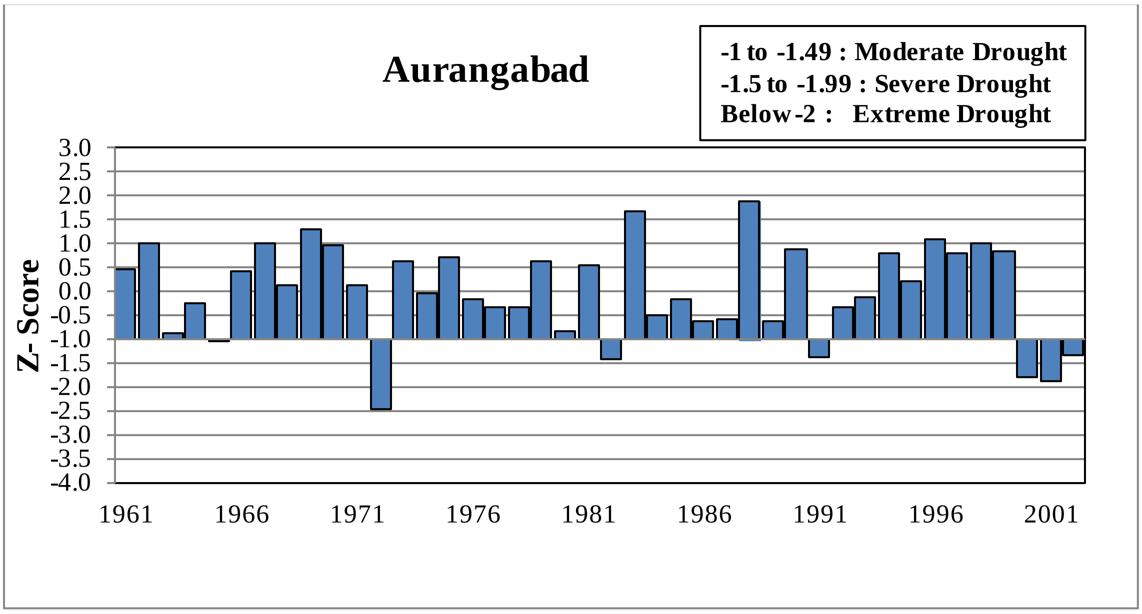


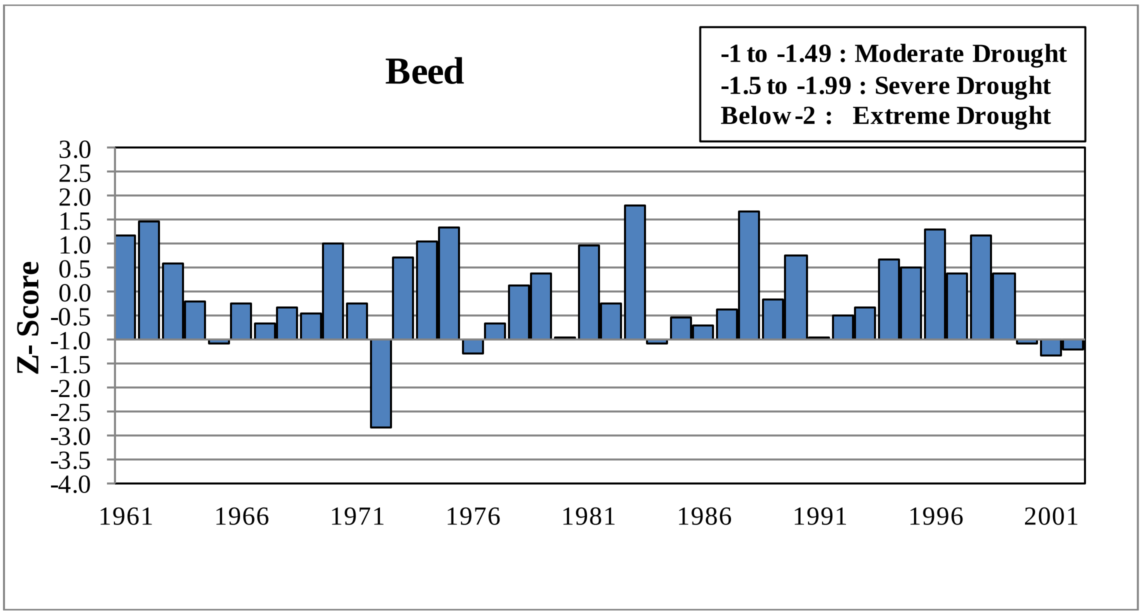
Plots for SPI 12 versus time series for each district of Marathwada region

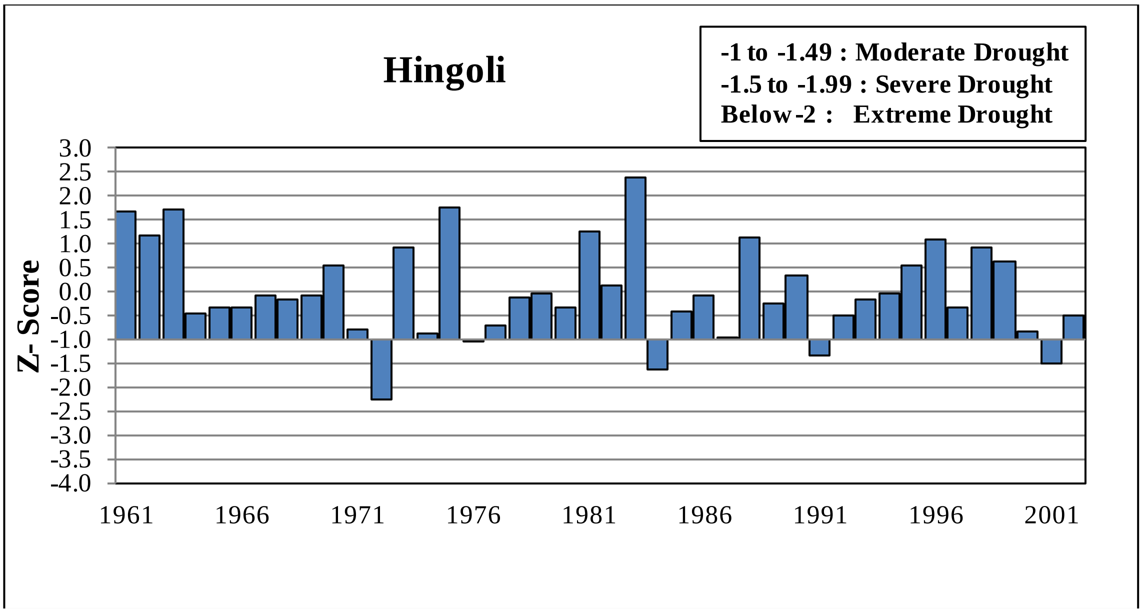


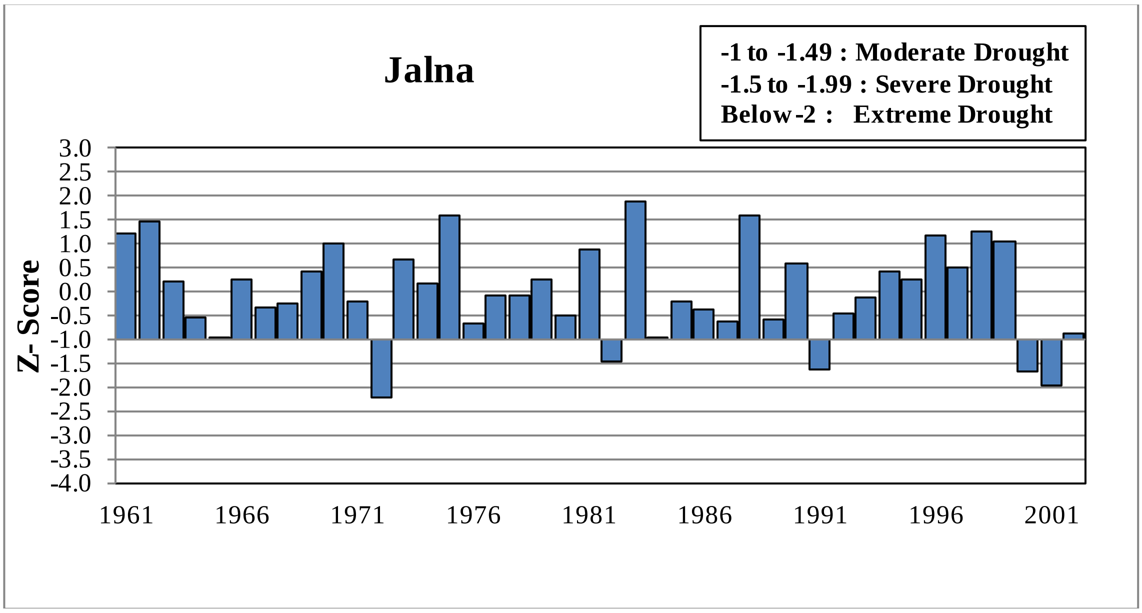
Plots for SPI 12 versus time series for each district of Marathwada region

Plots of Z- Score versus time series for Marathwada region

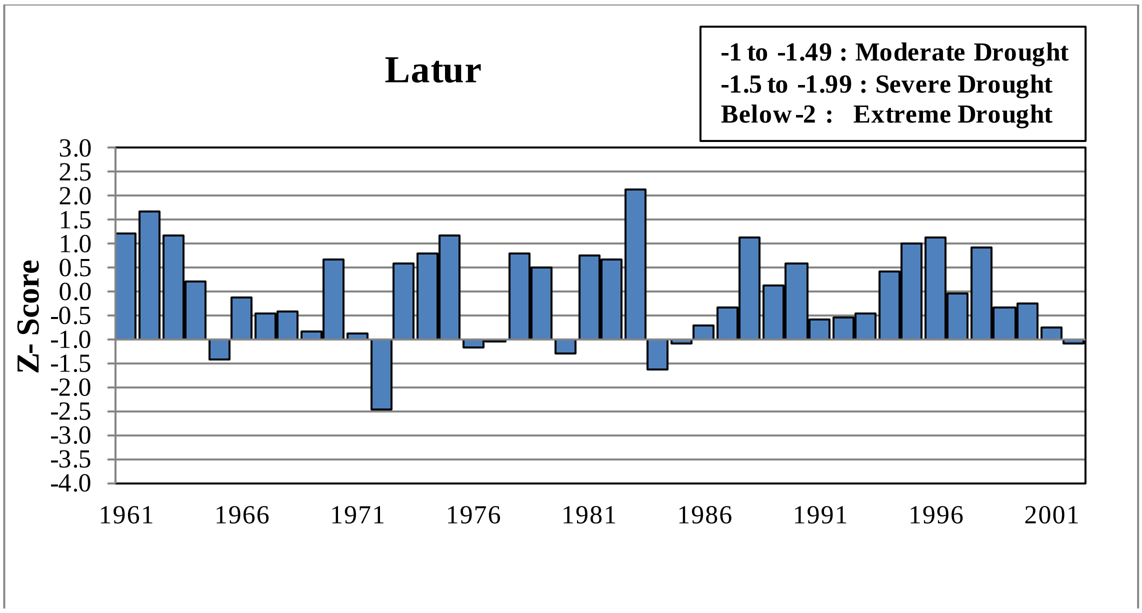


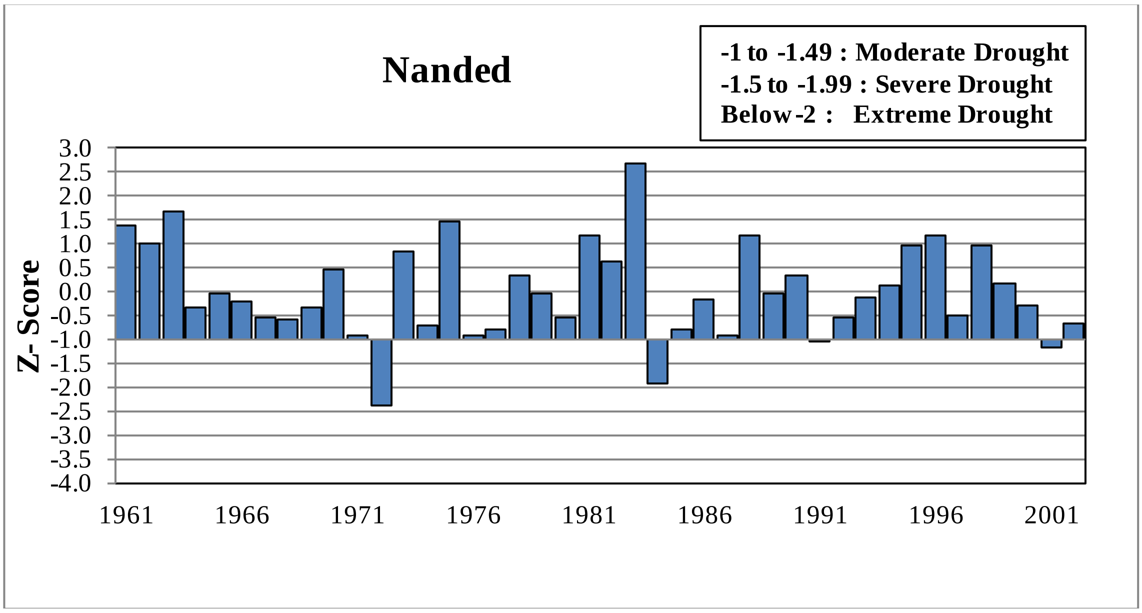




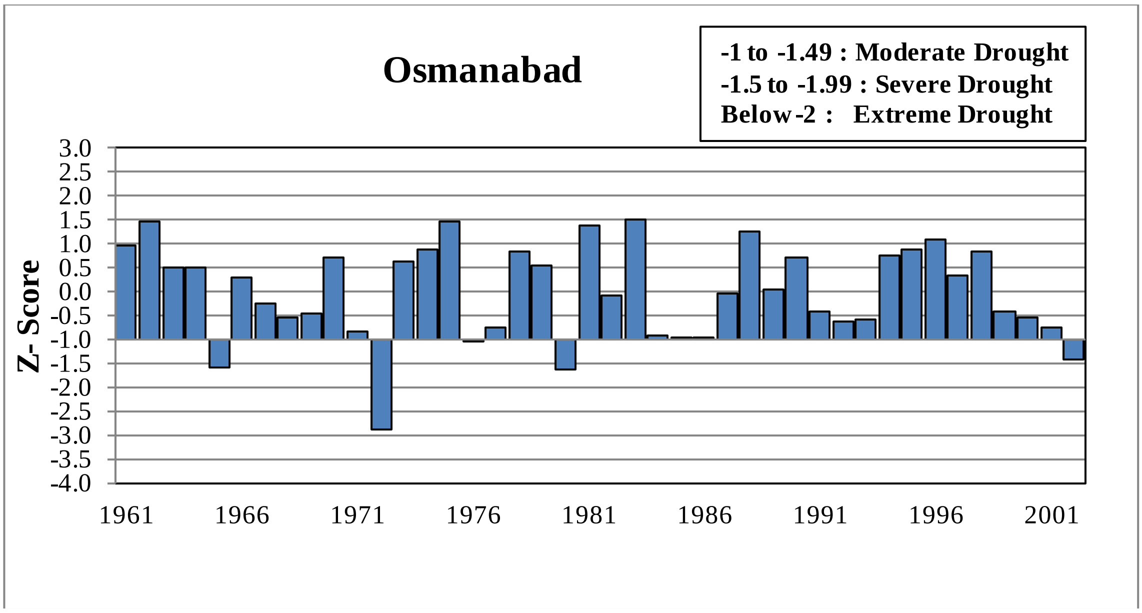


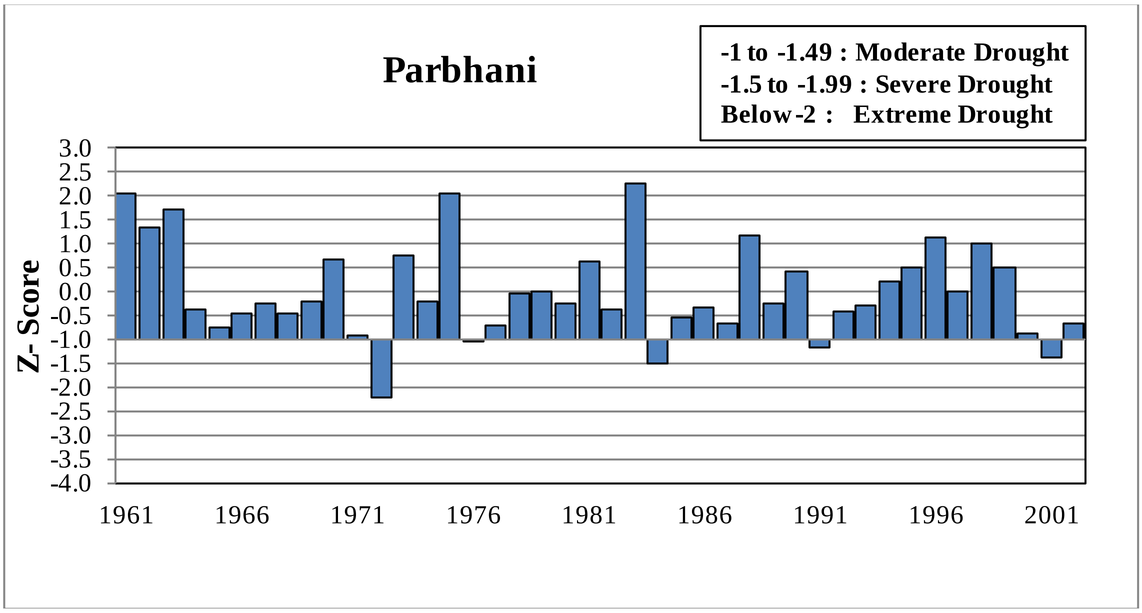
Plots of Z- Score versus time series for Marathwada region



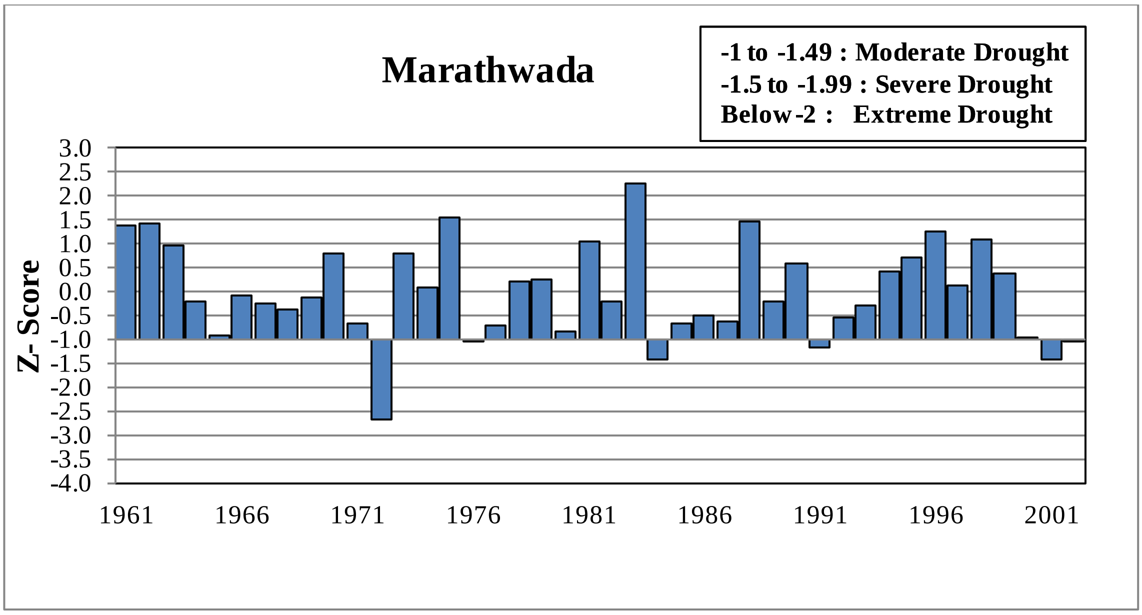


Plots of Z- Score versus time series for Marathwada region



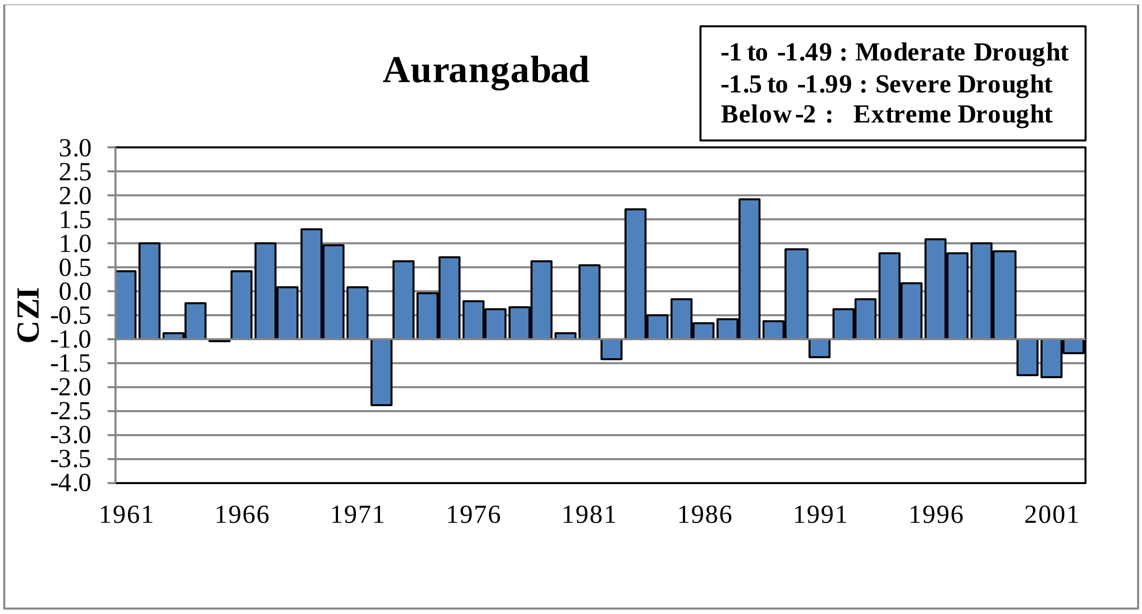


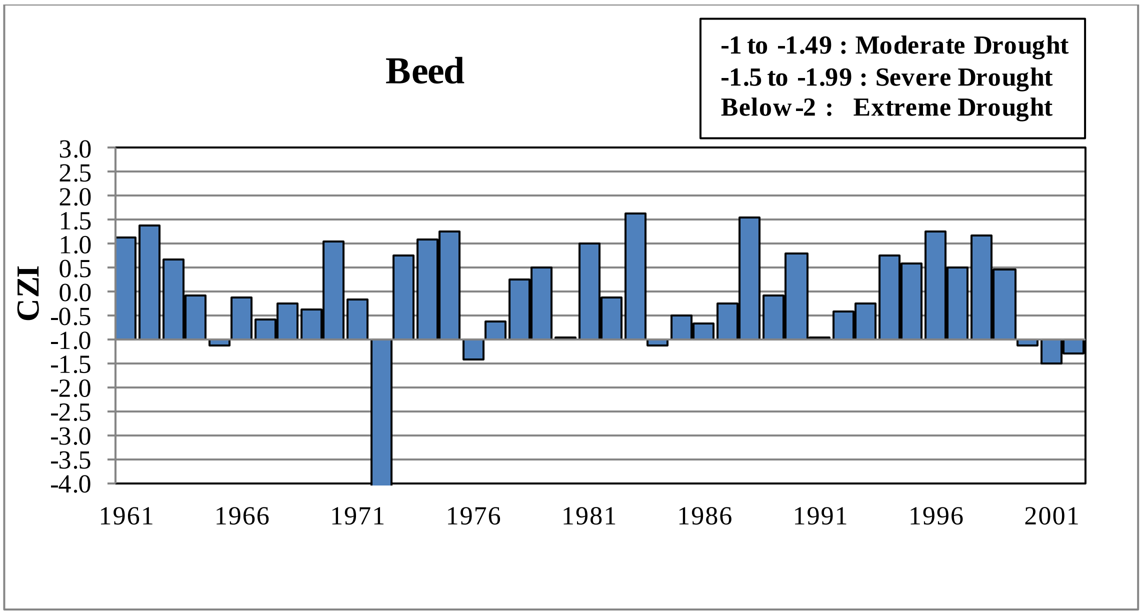
Plots of Z- Score versus time series for Marathwada region



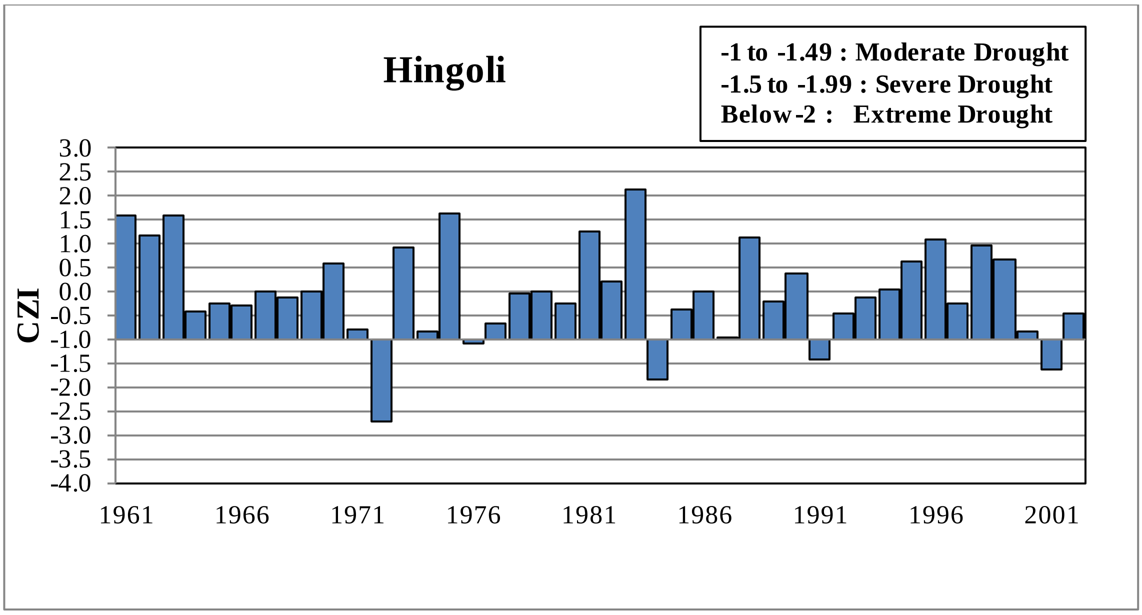
Plots of Z- Score versus time series for Marathwada region

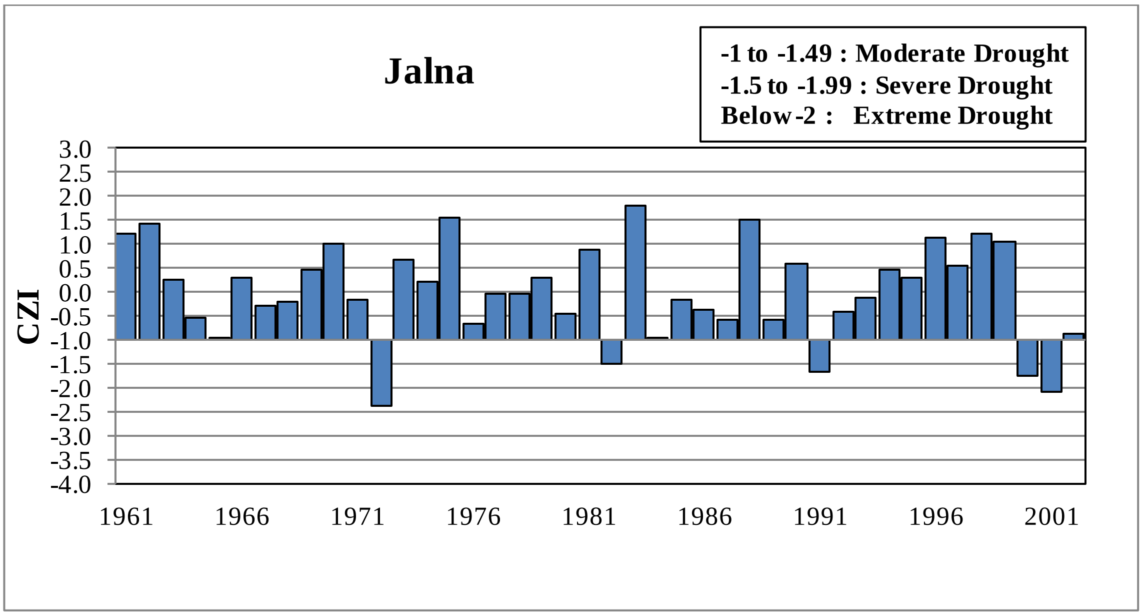
Plots of CZI versus time series for Marathwada region



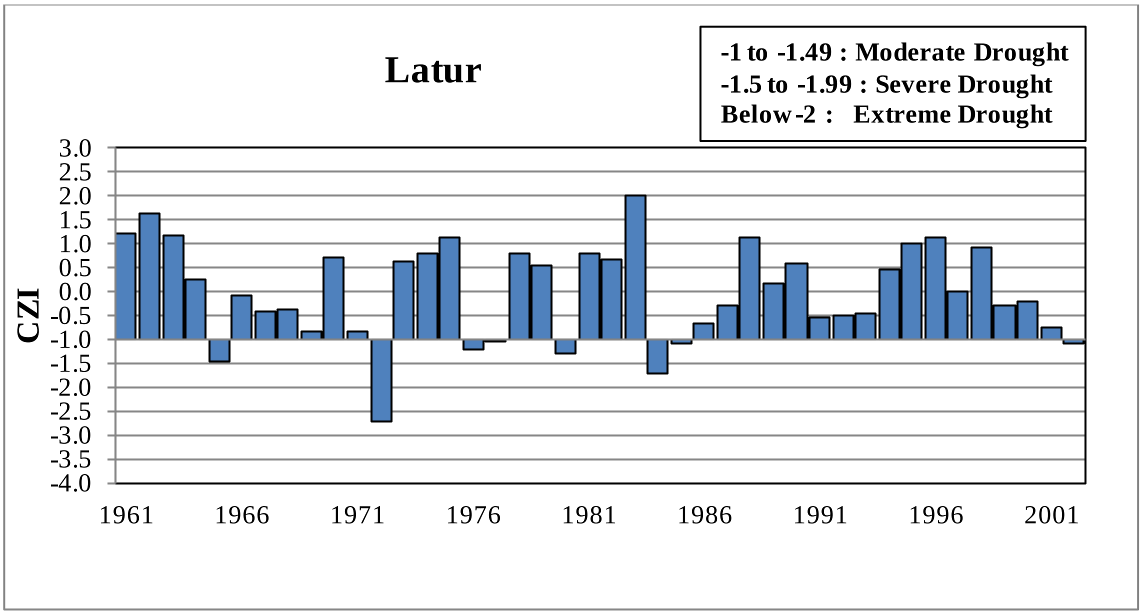


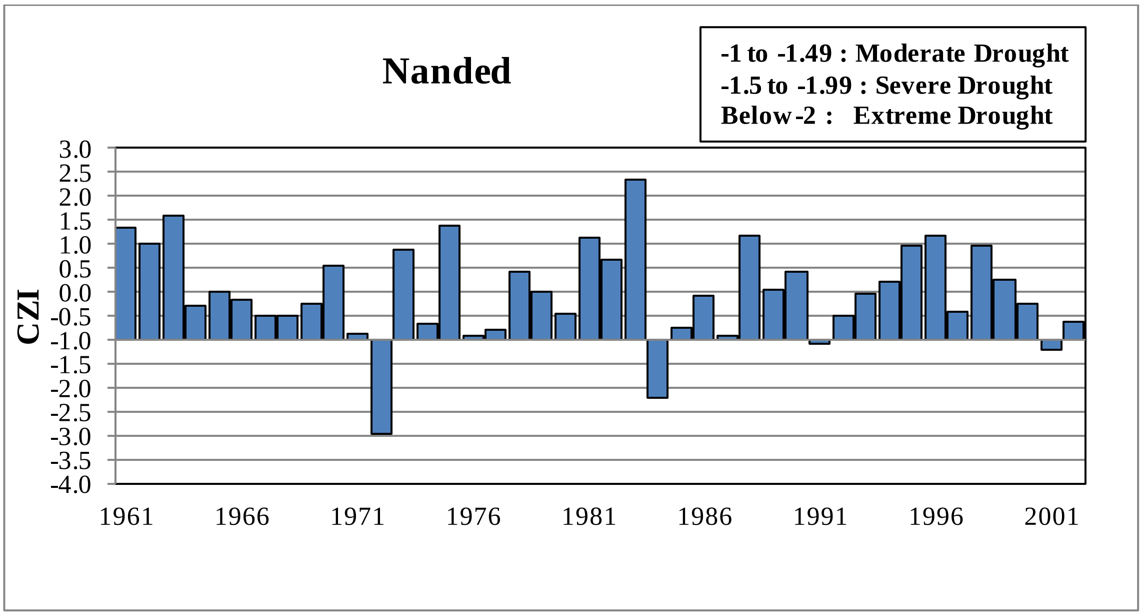
Plots for CZI versus time series for each district of Marathwada region



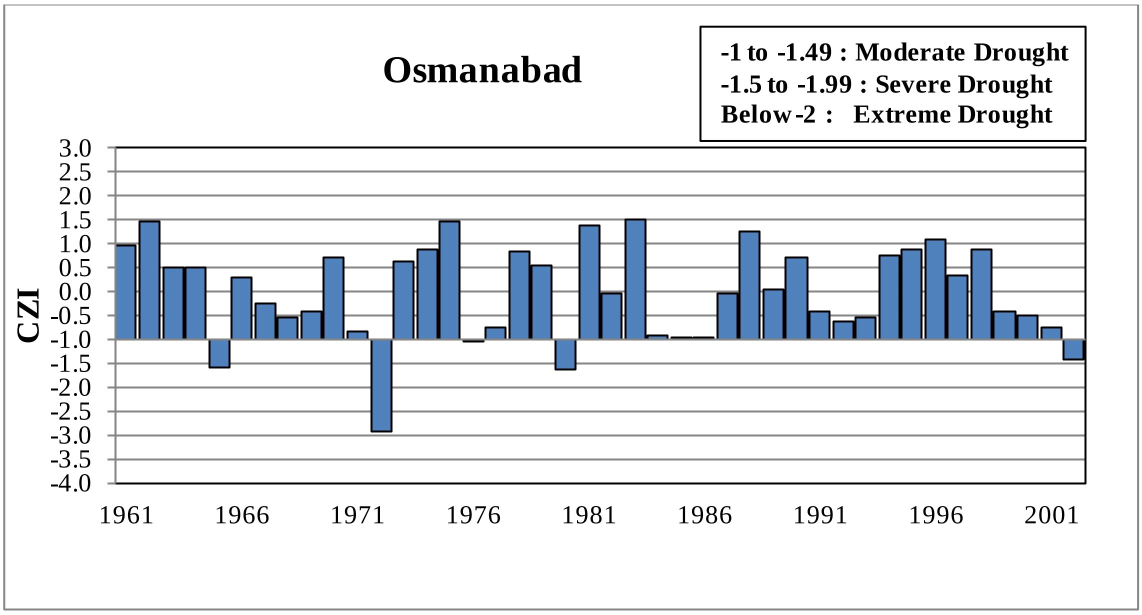


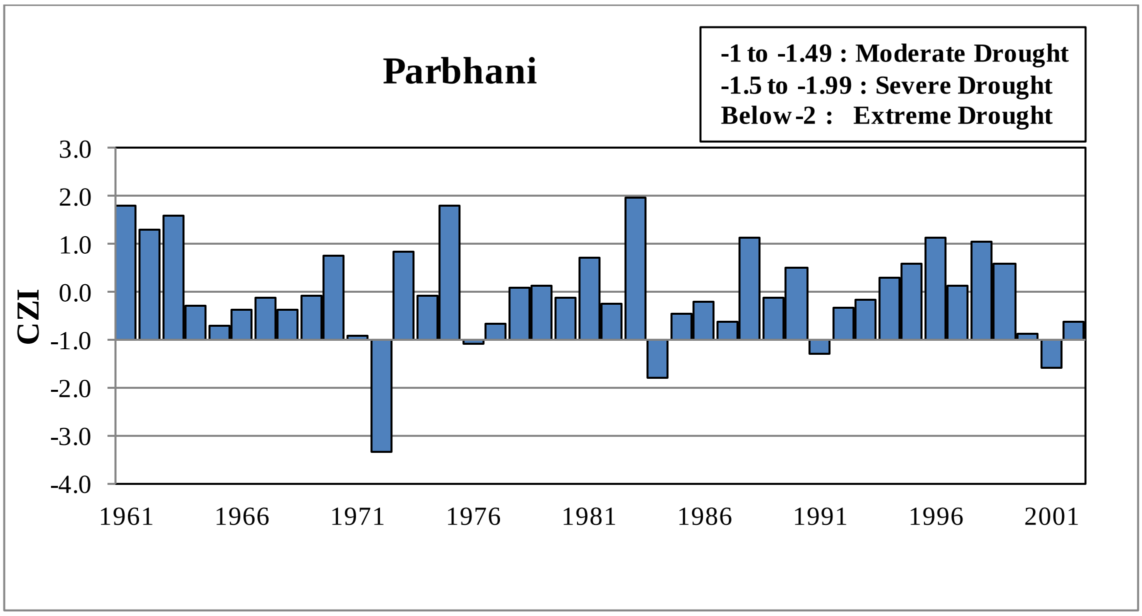
Plots for CZI versus time series for each district of Marathwada region



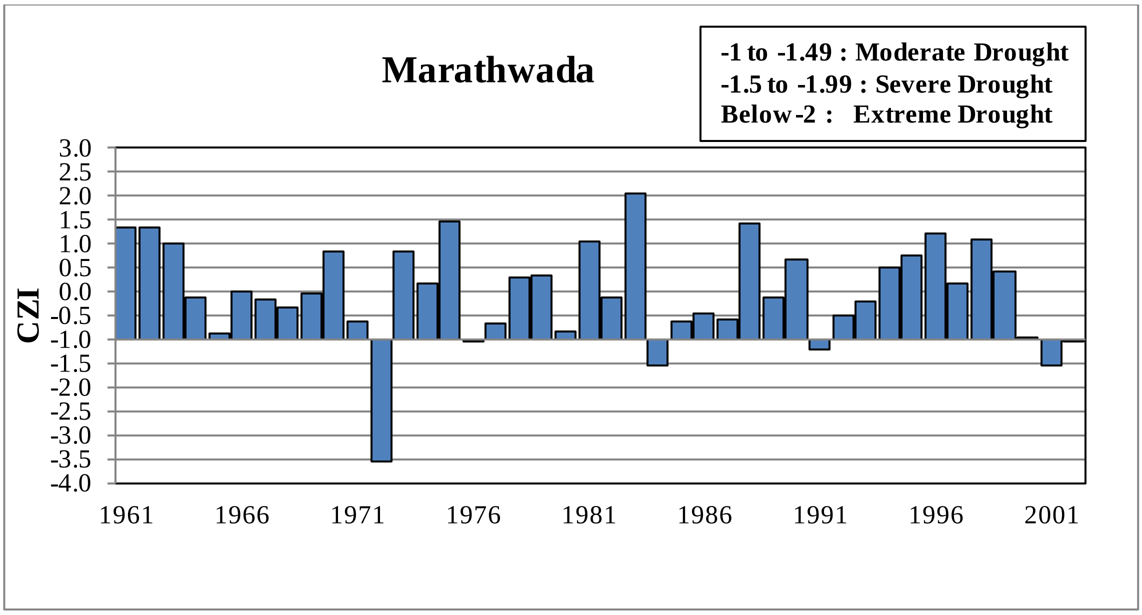


Plots for CZI versus time series for each district of Marathwada region





Plots for CZI versus time series for each district of Marathwada region



Plots for CZI versus time series for each district of Marathwada region

APPENDIX-E

Monthly rainfall data of each district of Marathwada region and area weighted average rainfall for overall Marathwada.

Aurangabad	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	4	0	3	100	99	134	85	159	118	4	1
1962	0	0	12	7	69	52	158	118	255	9	38	58
1963	0	2	5	3	1	110	161	153	47	69	4	0
1964	0	0	5	9	5	108	149	100	217	22	15	0
1965	10	0	0	14	0	49	188	189	57	3	3	24
1966	6	0	2	0	51	67	208	51	198	1	104	21
1967	0	0	5	2	0	154	244	113	151	33	0	73
1968	0	4	14	7	0	50	190	125	195	47	38	0
1969	0	0	0	0	1	145	161	131	331	5	33	0
1970	0	0	0	15	18	199	63	257	185	32	0	0
1971	0	0	0	0	68	90	25	161	246	80	0	0
1972	0	0	0	2	2	92	47	65	86	1	76	0
1973	0	2	0	0	6	97	143	212	214	49	1	6
1974	0	1	7	6	55	73	144	138	128	103	0	0
1975	1	0	0	0	12	94	140	185	206	101	0	0
1976	0	0	3	2	1	127	170	147	79	1	99	8
1977	0	0	14	0	4	120	109	75	77	67	142	8

Monthly rainfall data of each district of Marathwada (mm)

Aurangabad	January	February	March	April	May	June	July	August	September	October	November	December
1978	4	11	13	11	13	122	148	107	98	39	49	5
1979	3	4	6	0	5	80	166	119	221	31	92	2
1980	0	0	1	4	4	210	98	168	63	1	4	5
1981	9	1	2	0	25	68	116	106	254	106	13	22
1982	5	0	1	5	38	58	155	35	108	34	50	0
1983	1	0	0	0	1	65	141	181	386	75	0	1
1984	2	3	0	0	0	57	171	42	135	188	1	0
1985	5	0	0	15	3	117	131	110	72	122	65	0
1986	0	5	0	3	10	163	164	126	75	5	1	31
1987	18	5	2	1	50	111	60	134	45	89	38	37
1988	0	0	0	16	18	83	247	109	329	71	4	0
1989	0	0	20	6	23	141	101	92	188	7	0	8
1990	0	1	0	0	82	120	174	190	74	83	24	9
1991	0	1	1	12	9	160	156	63	74	1	18	0
1992	0	0	0	1	28	66	81	148	252	39	2	0
1993	0	1	3	0	3	74	169	77	136	139	4	34
1994	8	1	4	15	16	214	173	100	156	51	13	0
1995	7	0	9	9	30	69	t	44	236	49	1	0
1996	2	2	2	2	7	92	211	102	224	135	3	0
1997	11	0	2	17	3	173	144	178	41	26	123	33
1998	1	1	2	0	11	66	152	123	301	52	64	0
1999	0	6	0	0	41	157	97	77	248	128	0	1
2000	0	1	0	0	26	111	118	79	77	20	9	7
2001	3	0	7	2	13	124	70	73	69	66	14	0

Monthly rainfall data of each district of Marathwada (mm)

Aurangabad	January	February	March	April	May	June	July	August	September	October	November	December
2002	3	2	3	24	6	181	24	125	112	20	3	0

Beed	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	0	2	18	81	149	217	103	60	216	20	1
1962	0	0	1	25	49	87	106	223	295	45	45	32
1963	0	4	11	14	11	171	159	260	65	93	0	0
1964	0	0	13	20	5	103	166	115	223	28	11	1
1965	0	1	0	25	1	83	163	172	95	5	4	18
1966	6	0	1	4	58	81	162	79	185	8	86	9
1967	0	1	1	5	19	86	224	60	134	37	1	57
1968	2	33	30	6	1	64	168	30	241	50	38	0
1969	0	0	0	2	2	117	144	129	206	22	26	1
1970	2	0	0	34	32	150	105	281	201	43	0	0
1971	0	0	0	1	52	51	21	186	238	127	0	0
1972	0	0	0	2	7	78	37	48	105	3	53	0
1973	0	0	0	2	4	108	136	277	150	127	1	0
1974	0	0	11	13	43	98	142	150	178	219	0	0
1975	2	3	1	0	12	95	158	165	297	154	1	0
1976	0	0	8	12	7	132	133	129	62	4	53	0
1977	0	2	11	3	8	102	103	72	103	111	104	1
1978	5	24	15	13	31	151	164	103	115	64	46	1
1979	1	8	11	5	14	91	155	99	259	18	102	2
1980	0	0	14	21	6	104	100	213	113	1	6	8
1981	18	1	11	5	41	136	66	101	340	97	12	12

Monthly rainfall data of each district of Marathwada (mm)

Beed	January	February	March	April	May	June	July	August	September	October	November	December
1982	0	0	0	29	59	66	208	45	178	49	44	0
1983	0	0	1	0	21	90	137	178	430	78	0	14
1984	4	18	2	0	1	38	160	47	140	155	0	1
1985	5	0	5	15	3	137	134	105	60	115	57	2
1986	0	13	0	11	11	189	130	141	77	6	11	28
1987	20	10	6	3	51	105	68	145	59	130	42	24
1988	0	1	0	28	20	77	255	126	359	66	3	2
1989	0	0	26	11	20	132	174	99	189	29	1	6
1990	0	0	4	0	89	134	159	201	57	134	28	4
1991	0	2	1	25	14	173	134	97	112	8	20	0
1992	0	0	0	2	25	73	82	193	226	41	5	0
1993	0	2	2	2	2	70	151	94	126	194	3	21
1994	7	4	6	31	17	190	169	110	128	118	21	0
1995	10	0	15	10	34	88	200	61	249	105	9	0
1996	1	4	2	8	3	103	167	157	227	191	21	0
1997	11	0	5	29	6	151	124	193	53	40	127	24
1998	0	3	1	1	8	67	166	166	294	111	54	0
1999	0	10	0	1	58	125	107	95	217	149	0	0
2000	0	2	0	2	22	143	106	165	90	25	8	5
2001	4	0	17	5	6	121	60	114	92	101	12	0
2002	6	0	2	30	13	178	33	141	100	45	3	0

Hingoli	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	2	24	16	51	135	319	228	162	298	3	2
1962	2	0	5	19	16	78	194	251	368	51	79	70
1963	0	12	14	21	10	217	173	553	119	131	0	0
1964	0	0	7	3	0	101	198	217	236	16	0	0
1965	11	1	0	12	1	149	365	162	86	9	0	12
1966	26	0	15	15	20	50	210	88	285	2	55	38
1967	3	5	9	7	13	138	210	174	207	43	17	38
1968	14	5	64	19	0	99	291	82	235	15	15	0
1969	0	0	1	1	21	152	223	133	268	21	40	0
1970	3	0	0	7	22	216	123	349	265	10	0	0
1971	2	0	0	0	13	136	53	188	137	175	0	0
1972	0	0	0	2	12	115	72	106	63	1	18	0
1973	0	2	0	13	2	89	185	461	159	164	0	0
1974	0	1	1	9	35	109	99	153	143	142	0	0
1975	3	21	21	0	13	113	267	232	479	112	0	0
1976	0	0	5	13	2	78	241	212	87	1	13	0
1977	0	5	3	3	15	100	178	173	111	49	82	5
1978	17	21	13	26	10	202	219	151	52	98	41	2
1979	2	30	5	1	25	197	189	155	204	17	38	2
1980	0	0	4	6	1	204	100	311	122	1	0	57
1981	18	1	38	1	16	102	212	229	413	69	21	33
1982	13	1	1	27	39	67	320	93	273	35	37	0
1983	0	0	2	0	4	168	235	447	359	172	0	10
1984	7	9	0	0	0	54	94	129	102	128	1	0

Monthly rainfall data of each district of Marathwada (mm)

Hingoli	January	February	March	April	May	June	July	August	September	October	November	December
1985	17	0	6	16	1	223	218	147	58	84	14	2
1986	2	23	0	12	5	190	279	247	71	5	7	20
1987	19	7	8	1	30	169	86	110	88	91	45	14
1988	0	4	0	12	21	107	371	228	249	122	4	3
1989	0	0	41	3	18	141	195	186	202	20	1	16
1990	1	1	5	0	73	143	195	315	57	139	11	8
1991	1	3	1	19	4	174	166	132	65	7	15	0
1992	0	0	0	1	27	72	84	277	263	41	4	0
1993	0	4	4	2	1	71	219	165	184	176	1	14
1994	8	5	10	36	7	172	170	161	197	86	18	0
1995	21	0	34	1	29	122	330	81	292	83	6	0
1996	2	3	6	6	2	68	214	279	326	195	14	0
1997	19	0	3	26	4	120	146	239	56	38	128	30
1998	0	1	3	0	2	71	183	232	444	94	48	0
1999	0	20	0	1	56	155	162	217	285	118	0	0
2000	0	4	0	1	14	159	175	255	71	10	2	3
2001	13	0	35	7	5	160	50	186	52	46	3	0
2002	16	1	6	10	6	217	43	251	158	59	4	0

Monthly rainfall data of each district of Marathwada (mm)

Jalna	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	5	3	8	62	114	190	111	147	220	5	3
1962	0	0	6	14	44	64	114	166	356	9	73	55
1963	0	8	6	14	2	133	170	239	69	90	1	0
1964	0	0	9	13	4	112	144	104	206	29	7	0
1965	13	1	0	21	1	77	160	195	75	5	1	17
1966	12	0	5	1	45	74	186	71	227	1	93	21
1967	0	0	4	4	3	106	170	99	149	33	0	91
1968	6	16	23	14	0	48	196	91	202	35	39	0
1969	0	0	0	0	1	139	136	138	286	14	47	0
1970	3	0	0	21	23	198	71	330	164	28	0	0
1971	0	0	0	0	47	75	24	189	218	122	0	0
1972	0	0	0	3	1	105	55	73	102	1	62	0
1973	0	2	0	2	7	103	133	291	181	71	1	2
1974	0	2	9	9	64	89	150	144	123	134	0	0
1975	2	3	2	0	18	120	129	240	291	115	0	0
1976	0	0	4	7	1	92	168	172	94	1	72	2
1977	0	6	7	0	3	130	108	102	110	70	145	12
1978	11	28	17	14	8	155	177	123	65	51	40	6
1979	5	5	8	1	9	121	146	126	208	25	82	3
1980	0	0	1	4	4	221	108	181	93	1	4	18
1981	22	2	9	1	26	85	100	133	305	85	14	40

Monthly rainfall data of each district of Marathwada (mm)

Jalna	January	February	March	April	May	June	July	August	September	October	November	December
1982	10	1	1	11	39	62	141	42	133	36	32	0
1983	0	0	2	0	3	77	139	213	436	81	0	7
1984	5	10	0	0	0	58	125	57	127	190	2	0
1985	11	0	1	15	2	167	141	123	65	99	49	0
1986	0	17	0	6	8	177	180	151	71	3	2	33
1987	27	10	1	1	42	136	50	114	63	92	49	34
1988	0	0	0	15	23	89	255	136	302	91	5	0
1989	0	0	22	6	22	135	103	119	192	9	0	14
1990	0	1	1	0	76	128	159	220	54	114	19	9
1991	0	3	1	18	7	160	133	74	66	1	20	0
1992	0	0	0	1	27	62	69	181	259	38	2	0
1993	0	3	3	0	1	68	156	94	151	170	3	35
1994	8	3	5	27	12	197	150	104	173	63	17	0
1995	14	0	13	8	29	86	225	42	266	50	2	0
1996	3	4	3	2	4	83	169	142	274	171	5	0
1997	19	0	3	21	4	158	112	194	44	27	152	39
1998	1	2	2	0	5	70	136	147	372	65	72	0
1999	0	16	0	0	52	158	103	120	262	131	0	0
2000	0	2	0	0	17	122	117	108	79	16	7	6
2001	7	0	12	4	8	121	52	100	63	56	10	0
2002	8	2	2	19	4	193	25	158	134	35	4	0

Monthly rainfall data of each district of Marathwada (mm)

Latur	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	0	2	35	126	175	220	131	66	217	34	1
1962	0	2	1	38	58	109	113	286	317	87	57	15
1963	0	5	16	23	27	210	133	368	96	120	0	0
1964	0	1	12	8	2	113	199	142	323	32	8	0
1965	0	0	0	2	1	117	180	133	119	3	2	12
1966	5	2	4	6	11	91	170	126	233	26	92	13
1967	1	1	4	2	45	112	282	79	143	28	2	30
1968	3	54	36	3	9	85	162	29	283	59	10	0
1969	0	0	1	4	9	95	154	120	228	25	28	1
1970	3	0	0	26	31	156	134	247	291	29	0	0
1971	0	0	1	2	32	67	36	157	202	164	0	0
1972	0	1	0	10	14	64	47	85	124	6	44	0
1973	0	0	0	4	2	121	126	311	140	199	0	0
1974	0	0	0	5	11	122	133	148	206	310	0	0
1975	5	3	8	1	10	91	178	143	321	234	1	0
1976	0	0	12	34	22	142	131	141	80	13	32	0
1977	0	0	17	6	16	116	122	101	111	86	61	1
1978	5	31	9	21	65	164	182	139	172	104	39	0
1979	0	19	11	13	45	86	146	81	341	23	119	0
1980	0	0	26	31	3	63	63	245	147	2	2	8
1981	12	0	20	14	34	187	78	145	333	99	6	1

Latur	January	February	March	April	May	June	July	August	September	October	November	December
1982	1	0	0	42	49	76	306	65	273	49	50	0
1983	0	0	0	1	52	110	136	215	463	158	3	21
1984	8	34	0	1	0	61	126	86	131	84	1	1
1985	4	0	11	11	2	139	140	95	56	125	37	3
1986	4	15	0	20	9	195	118	183	87	14	23	20
1987	20	10	16	4	47	103	96	174	72	149	46	12
1988	0	11	0	32	14	84	256	163	366	57	1	4
1989	0	0	32	9	15	139	247	110	205	59	2	4
1990	1	0	10	0	118	145	141	229	84	136	32	3
1991	1	1	1	22	17	192	131	146	155	22	23	0
1992	0	0	0	4	31	93	83	241	209	44	10	0
1993	0	2	2	5	5	80	156	133	140	189	2	8
1994	12	6	8	29	14	173	152	154	115	178	30	0
1995	14	0	23	3	47	112	200	105	252	196	19	0
1996	0	4	1	20	6	103	174	236	221	183	44	0
1997	12	0	6	35	9	116	142	206	73	64	118	17
1998	0	3	1	2	11	63	179	220	274	170	36	0
1999	0	8	0	3	68	101	120	113	208	129	0	0
2000	0	6	0	4	35	183	111	291	90	29	7	3
2001	7	0	28	7	4	167	54	163	109	131	8	0
2002	11	0	5	23	27	184	43	169	89	67	3	0

Monthly rainfall data of each district of Marathwada (mm)

Nanded	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	0	16	31	63	143	323	224	139	253	10	0
1962	1	3	3	32	21	81	188	290	349	54	63	39
1963	0	6	12	21	29	215	161	535	132	151	0	0
1964	1	0	6	3	0	98	195	263	267	14	4	0
1965	3	1	0	12	2	169	386	155	169	6	0	8
1966	26	8	9	19	14	67	223	122	308	9	47	27
1967	3	5	15	7	19	128	256	147	175	29	13	19
1968	16	17	50	10	1	96	238	45	277	25	33	0
1969	0	0	1	7	26	112	234	125	290	20	41	0
1970	3	0	0	15	18	211	148	338	277	11	0	0
1971	2	0	4	5	23	134	57	191	147	177	0	0
1972	0	0	0	16	14	128	74	116	60	4	26	0
1973	0	1	0	16	0	90	191	441	129	226	1	0
1974	0	1	0	14	23	113	90	167	164	206	1	0
1975	6	18	25	3	11	93	272	171	485	133	0	0
1976	0	0	5	31	6	95	269	215	94	3	16	0
1977	0	0	5	10	26	78	194	191	110	65	80	0
1978	19	28	8	29	21	207	242	201	111	91	34	1
1979	5	36	4	9	52	168	167	146	253	12	57	3
1980	1	0	11	19	3	162	115	330	144	4	1	26
1981	16	0	41	9	28	148	211	220	404	57	16	10
1982	8	0	1	43	41	74	371	111	297	70	35	0
1983	0	0	0	0	15	168	233	478	376	176	8	11

Monthly rainfall data of each district of Marathwada (mm)

Nanded	January	February	March	April	May	June	July	August	September	October	November	December
1984	6	13	0	2	1	49	128	147	110	79	0	1
1985	14	0	12	18	1	200	226	127	54	100	10	3
1986	9	22	0	22	5	188	250	268	79	15	16	14
1987	15	5	17	3	32	149	124	147	88	103	46	6
1988	0	16	0	23	19	105	369	246	269	104	4	6
1989	0	0	39	3	17	141	286	182	201	40	2	8
1990	1	1	10	0	98	153	185	315	77	132	17	4
1991	2	3	0	24	6	184	175	180	99	16	18	0
1992	0	0	0	3	32	87	96	308	236	41	7	0
1993	0	4	6	5	4	83	231	192	186	178	1	7
1994	15	7	9	47	7	153	181	201	175	129	24	0
1995	24	0	36	1	37	134	326	128	276	142	14	0
1996	2	2	4	17	3	70	230	336	291	176	31	0
1997	17	0	5	41	7	90	175	233	74	56	109	19
1998	1	1	3	2	5	65	210	273	386	130	40	0
1999	0	17	0	3	66	121	179	213	258	101	0	0
2000	0	9	0	4	25	186	185	367	70	13	2	1
2001	18	0	37	11	6	190	57	224	69	74	3	0
2002	19	1	8	10	15	211	58	257	136	69	3	0

Monthly rainfall data of each district of Marathwada (mm)

Osmanabad	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	0	0	21	110	158	190	87	38	218	23	1
1962	0	4	3	42	68	98	139	183	251	62	39	25
1963	0	11	10	24	25	187	121	232	65	107	0	0
1964	0	4	9	12	3	84	191	100	320	40	14	3
1965	0	0	0	10	2	87	155	118	94	3	7	22
1966	6	0	2	15	68	81	157	104	212	15	83	8
1967	5	1	3	6	30	76	261	61	157	45	0	35
1968	2	31	16	8	8	77	132	23	233	85	24	0
1969	0	0	1	6	10	101	152	98	213	46	26	1
1970	1	0	0	25	35	119	132	229	227	41	0	0
1971	0	0	0	3	47	56	26	154	187	128	0	0
1972	0	3	0	8	12	59	32	33	115	18	42	1
1973	0	0	0	2	7	109	123	224	130	201	1	0
1974	0	0	5	14	32	95	116	120	180	273	0	0
1975	6	5	0	1	15	67	178	137	263	235	5	0
1976	0	0	7	21	20	149	116	122	81	6	54	0
1977	0	0	16	17	18	114	106	65	83	115	75	2
1978	2	24	7	18	73	130	145	110	157	97	60	2
1979	1	12	6	8	44	88	129	70	273	29	127	0
1980	0	0	9	32	4	77	65	186	104	3	8	3
1981	14	0	13	7	41	173	55	112	367	104	13	3
1982	0	0	0	46	59	65	212	39	186	50	47	0
1983	0	0	0	0	33	98	133	137	384	112	0	19

Monthly rainfall data of each district of Marathwada (mm)

Osmanabad	January	February	March	April	May	June	July	August	September	October	November	December
1984	4	23	3	1	1	39	192	48	130	142	5	1
1985	2	0	6	10	4	105	118	82	54	141	57	3
1986	2	8	0	19	13	181	85	130	78	14	22	29
1987	21	10	8	5	57	79	84	154	57	167	41	22
1988	0	4	0	43	11	71	230	115	374	32	1	4
1989	0	0	19	15	14	127	221	77	180	58	2	3
1990	1	0	5	1	113	132	140	173	70	135	37	3
1991	1	0	1	26	23	176	127	109	149	22	21	0
1992	0	0	0	5	25	85	84	184	187	47	11	0
1993	0	1	2	6	6	73	141	93	104	194	3	15
1994	10	4	5	25	20	174	163	115	85	188	27	0
1995	11	0	10	8	43	89	169	76	215	194	17	0
1996	0	3	0	21	6	109	162	159	171	188	40	0
1997	11	0	4	35	9	129	134	175	61	63	114	23
1998	0	3	0	2	14	62	173	167	203	169	37	0
1999	0	3	0	3	59	94	105	70	167	155	0	0
2000	0	3	0	5	37	157	94	200	94	38	9	5
2001	4	0	13	6	4	133	60	115	110	154	13	0
2002	7	0	2	37	30	161	38	121	63	61	2	0

Monthly rainfall data of each district of Marathwada (mm)

Parbhani	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	1	15	23	61	153	261	195	157	298	12	2
1962	1	0	2	24	40	76	128	245	363	41	80	48
1963	0	15	10	32	9	207	155	471	107	115	0	0
1964	0	0	15	8	1	83	192	171	246	14	2	0
1965	3	2	0	19	3	124	224	169	94	11	0	11
1966	14	0	11	7	26	63	167	85	249	7	70	17
1967	1	3	8	7	19	117	210	109	179	53	7	46
1968	16	18	46	22	0	87	208	53	225	25	17	1
1969	0	0	0	1	10	105	171	137	264	33	42	0
1970	8	0	0	15	34	199	104	292	242	31	0	0
1971	1	0	0	0	20	83	29	185	150	165	0	0
1972	0	0	0	1	7	98	62	97	84	1	44	0
1973	0	1	0	11	1	84	154	396	148	147	1	0
1974	0	1	3	11	42	107	119	149	162	171	0	0
1975	1	15	12	0	14	139	215	237	409	135	1	0
1976	0	0	7	16	4	101	178	209	76	3	16	0
1977	0	16	9	2	8	97	121	121	133	65	99	2
1978	16	27	13	21	22	190	190	115	80	76	47	1
1979	1	23	8	4	16	139	188	136	213	18	53	1
1980	0	0	13	11	1	197	99	265	134	1	1	34
1981	21	1	32	4	20	123	128	176	316	64	10	24
1982	5	0	0	30	34	60	235	67	243	24	37	0

Monthly rainfall data of each district of Marathwada (mm)

Parbhani	January	February	March	April	May	June	July	August	September	October	November	December
1983	0	0	5	0	14	120	181	315	414	156	0	15
1984	6	16	0	0	0	42	85	96	138	141	0	1
1985	11	0	6	17	1	183	164	132	60	98	29	2
1986	1	23	0	14	6	187	191	205	76	6	9	22
1987	22	10	9	2	35	139	73	137	77	109	48	17
1988	0	1	0	20	20	93	290	187	298	100	4	2
1989	0	0	37	6	18	135	174	150	201	25	1	10
1990	1	1	6	0	79	136	162	272	59	138	18	6
1991	0	3	1	23	7	172	138	123	89	8	18	0
1992	0	0	0	2	27	72	76	250	250	42	5	0
1993	0	4	3	2	2	69	172	138	162	180	2	14
1994	9	6	9	38	9	176	154	145	169	103	20	0
1995	17	0	27	3	32	107	247	77	278	97	8	0
1996	1	4	4	8	3	82	176	233	288	195	18	0
1997	16	0	4	31	5	129	125	228	57	41	139	25
1998	0	2	2	1	4	68	161	213	384	105	52	0
1999	0	19	0	1	57	138	126	164	259	130	0	0
2000	0	3	0	2	17	152	131	227	80	16	5	4
2001	8	0	29	7	5	143	49	160	71	70	6	0
2002	12	1	4	18	9	197	36	206	134	55	3	0

Marathwada	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	2	7	15	69	120	203	125	106	198	11	1
1962	1	1	4	21	41	68	129	186	279	34	50	40
1963	0	7	9	15	12	154	140	295	74	95	1	0
1964	0	1	8	9	3	89	155	133	217	21	8	1
1965	5	1	0	15	1	91	204	149	88	5	2	15
1966	12	1	5	8	37	63	167	76	208	6	70	17
1967	1	2	6	5	13	102	203	93	142	34	4	46
1968	7	17	29	10	1	64	176	56	206	38	28	0
1969	0	0	0	2	9	110	154	113	236	20	32	0
1970	2	0	0	18	23	162	94	261	196	26	0	0
1971	1	0	1	1	37	77	29	159	175	121	0	0
1972	0	0	0	5	7	85	47	67	79	4	43	0
1973	0	1	0	5	4	87	134	283	142	124	1	1
1974	0	1	5	10	37	86	111	130	138	161	0	0
1975	3	8	7	1	12	89	169	169	300	126	1	0
1976	0	0	5	13	5	101	160	149	72	3	44	2
1977	0	3	9	5	11	94	115	98	91	71	94	4
1978	9	21	11	16	23	144	162	116	90	63	40	2
1979	2	14	6	4	21	107	143	106	211	19	73	2
1980	0	0	7	13	3	145	88	206	97	2	3	16
1981	15	1	17	4	26	107	109	131	302	76	12	17
1982	5	0	1	24	40	58	206	54	176	40	36	0
1983	0	0	1	0	12	97	149	239	356	103	2	10

Monthly rainfall data of each district of Marathwada (mm)

Marathwada	January	February	March	April	May	June	July	August	September	October	November	December
1984	4	12	1	1	1	43	127	69	114	130	1	1
1985	8	0	5	14	2	139	142	103	54	98	38	2
1986	2	14	0	11	8	162	157	157	67	7	9	23
1987	18	7	7	2	39	110	70	122	59	100	39	20
1988	0	4	0	21	17	78	253	142	282	72	3	2
1989	0	0	25	7	17	121	160	111	171	24	1	8
1990	1	1	4	0	79	120	149	210	58	110	20	6
1991	1	2	1	19	9	153	131	98	85	8	17	0
1992	0	0	0	2	25	66	73	193	211	37	5	0
1993	0	2	3	2	3	65	157	106	131	156	2	18
1994	8	4	6	28	12	163	149	118	135	94	18	0
1995	13	0	18	6	30	87	216	65	228	92	7	0
1996	1	3	3	8	4	79	170	175	224	157	17	0
1997	13	0	4	26	5	122	123	181	49	37	112	24
1998	1	2	2	1	7	59	151	166	296	92	47	0
1999	0	11	0	1	50	119	110	116	213	116	0	0
2000	0	3	0	2	21	131	116	176	72	18	6	4
2001	7	0	18	5	6	126	52	121	68	74	8	0
2002	9	1	3	19	11	169	33	155	104	43	3	0

Monthly rainfall data of each district of Marathwada (mm)

Annual rainfall data of each district of Marathwada region and area weighted average rainfall for overall Marathwada

Year	Aurangabad	Beed	Hingoli	Jalna	Latur	Nanded	Osmanabad	Parbhani	Marathwada
1961	709	867	1242	868	1007	1201	847	1178	966
1962	777	909	1133	902	1084	1123	914	1048	971
1963	555	790	1248	731	998	1262	781	1122	909
1964	629	685	779	628	839	852	782	733	736
1965	537	567	809	568	569	911	498	661	636
1966	708	679	804	737	780	879	751	716	754
1967	776	623	864	660	728	815	680	757	730
1968	671	664	839	670	733	808	639	718	711
1969	807	650	858	762	665	857	654	762	748
1970	770	849	995	838	917	1021	809	925	884
1971	670	677	704	675	660	740	601	632	673
1972	369	333	389	402	395	439	323	394	379
1973	731	807	1074	792	904	1095	796	943	881
1974	653	854	692	724	935	779	834	765	782
1975	740	888	1261	920	996	1220	913	1179	992
1976	637	541	652	611	607	735	575	610	621
1977	616	621	724	692	636	758	610	672	663
1978	621	730	852	694	932	991	824	797	799
1979	730	764	865	738	886	911	788	802	806
1980	558	585	806	634	590	816	493	756	646

Annual rainfall data of each district of Marathwada (mm)

Year	Aurangabad	Beed	Hingoli	Jalna	Latur	Nanded	Osmanabad	Parbhani	Marathwada
1981	722	840	1154	822	930	1158	902	920	918
1982	489	679	905	507	913	1052	704	736	739
1983	852	950	1396	959	1158	1465	917	1221	1096
1984	601	566	524	574	533	536	589	525	560
1985	640	637	787	674	623	764	582	703	671
1986	583	617	861	649	688	888	580	741	692
1987	589	663	668	619	750	734	706	677	674
1988	877	936	1120	916	990	1161	883	1016	981
1989	584	688	822	622	822	919	717	758	736
1990	758	811	947	781	898	993	810	877	854
1991	496	585	587	483	709	707	656	583	601
1992	617	647	769	640	714	810	628	722	689
1993	640	667	840	684	724	897	636	748	725
1994	751	801	869	759	872	946	816	838	830
1995	680	781	1000	736	971	1119	832	893	867
1996	784	883	1115	860	991	1162	859	1011	948
1997	751	764	810	772	799	825	758	802	783
1998	774	870	1080	872	958	1116	830	991	927
1999	756	762	1013	844	750	958	656	894	819
2000	447	568	695	474	759	861	642	638	631
2001	440	531	555	433	679	689	613	549	560
2002	502	552	769	584	621	787	522	676	617

Annual rainfall data of each district of Marathwada (mm)

Calibrated NECP reanalysis data (1961-1990) for Marathwada

Year	January	February	March	April	May	June	July	August	September	October	November	December
1961	0	0	0	0	96	252	376	351	334	263	121	40
1962	0	0	0	0	39	225	353	344	289	200	52	27
1963	0	0	0	23	28	256	360	360	279	244	55	0
1964	0	0	0	0	0	196	318	359	308	124	0	0
1965	0	0	0	0	0	183	316	307	265	76	0	0
1966	0	0	0	0	0	209	332	333	264	76	39	0
1967	0	0	0	0	0	191	336	358	308	148	0	61
1968	0	0	0	0	0	180	337	340	293	147	44	0
1969	0	0	0	0	0	227	322	337	278	145	101	0
1970	0	0	0	0	0	276	326	338	303	132	0	0
1971	0	0	0	0	0	289	326	322	296	198	9	0
1972	0	0	0	0	0	138	328	315	218	123	7	0
1973	0	0	0	0	0	250	331	337	297	197	40	0
1974	0	0	0	0	0	254	349	334	272	232	0	0
1975	0	0	0	0	0	240	313	324	295	260	22	0
1976	0	0	0	0	0	273	317	336	261	108	93	0
1977	0	0	0	0	0	217	326	321	254	131	84	0
1978	0	0	0	0	0	282	325	319	272	151	52	0
1979	0	0	0	0	0	145	332	326	276	170	144	0

Calibrated NCEP Reanalysis rainfall data (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December
1980	0	0	0	0	0	286	326	345	255	85	13	0
1981	26	0	0	0	0	196	325	328	302	192	53	0
1982	0	0	0	0	0	236	322	328	271	223	70	0
1983	0	0	0	0	0	169	332	335	314	193	20	0
1984	0	0	0	0	0	268	338	329	276	185	0	0
1985	0	0	0	0	0	248	333	307	244	156	0	0
1986	0	0	0	0	0	262	325	294	264	124	63	16
1987	0	0	0	0	0	190	341	344	258	197	115	0
1988	0	0	0	0	0	217	319	322	333	106	0	0
1989	0	0	0	0	0	255	329	330	277	106	0	0
1990	0	0	0	0	31	249	345	345	267	193	20	0

Calibrated NCEP Reanalysis rainfall data (mm)

Validated NECP reanalysis data (1991-2001) for Marathwada

Year	January	February	March	April	May	June	July	August	September	October	November	December
1991	0	0	0	0	0	259	342	329	267	55	10	0
1992	0	0	0	0	0	111	292	352	244	192	65	0
1993	0	0	0	0	0	196	313	324	289	193	0	0
1994	0	0	0	0	0	264	331	337	246	150	49	0
1995	0	0	0	0	0	153	314	309	283	225	34	0
1996	0	0	0	0	0	209	326	312	289	209	0	0
1997	0	0	0	0	0	172	334	330	270	157	91	42
1998	0	0	0	0	0	146	331	327	296	221	56	0
1999	0	0	0	0	0	248	353	339	283	167	0	0
2000	0	0	0	0	48	262	335	318	278	147	0	0
2001	0	0	0	0	7	239	325	332	280	184	55	0

Validated NCEP Reanalysis rainfall data (mm)

Projected rainfall data by HadCM3_A2 scenario (2002-2099) with bias correction

Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	9	1	3	18	8	156	17	138	83	33	0	0
2003	17	14	13	13	11	16	119	205	127	3	11	13
2004	13	13	12	12	21	55	159	244	158	151	144	102
2005	13	13	12	11	27	53	102	219	152	147	162	120
2006	29	12	11	11	14	62	115	264	183	70	13	12
2007	12	11	11	10	9	21	149	143	157	114	77	11
2008	11	11	10	10	16	67	139	213	165	110	17	11
2009	11	10	10	9	8	26	101	158	144	137	82	10
2010	10	10	10	9	8	27	93	106	296	104	22	10
2011	10	10	9	9	13	67	100	124	96	34	16	17
2012	16	10	9	9	7	31	121	153	123	92	13	38
2013	10	9	9	8	16	70	124	241	119	68	7	9
2014	9	9	9	8	6	35	98	187	173	115	7	9
2015	9	8	8	7	12	63	134	216	180	99	13	8
2016	8	8	8	7	13	52	103	203	126	102	6	8
2017	8	8	8	7	16	30	115	216	127	90	6	8
2018	8	8	7	7	16	69	299	256	182	90	27	8
2019	8	8	7	7	25	125	190	307	142	104	12	8
2020	8	8	7	7	19	72	442	207	124	106	23	17
2021	8	48	7	6	12	90	133	157	105	11	5	7
2022	8	7	7	6	5	54	101	181	167	89	14	7
2023	7	7	6	6	17	45	112	210	108	18	101	51
2024	7	6	6	5	40	92	312	220	145	79	23	6

Projected rainfall data by HadCM3_A2 scenario (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December
2025	7	6	6	5	4	31	130	237	156	82	4	6
2026	18	6	5	5	3	69	155	216	157	103	3	6
2027	6	5	5	5	3	29	165	121	79	60	17	5
2028	6	5	5	4	3	45	133	189	153	93	78	36
2029	18	5	5	4	3	86	141	171	121	118	114	5
2030	5	5	5	4	76	84	218	138	176	128	26	5
2031	5	5	4	4	33	64	161	170	95	104	20	5
2032	5	5	4	4	2	25	111	167	102	0	17	5
2033	5	4	4	4	18	44	158	171	139	92	2	4
2034	5	4	4	3	21	44	129	246	116	16	2	4
2035	4	4	4	3	2	32	98	146	156	76	2	4
2036	21	4	3	3	1	73	105	148	119	70	13	4
2037	4	4	3	3	16	79	178	193	93	8	64	3
2038	4	3	3	2	22	37	113	179	142	126	30	3
2039	3	3	3	2	1	29	108	318	166	83	20	19
2040	92	3	3	2	1	74	218	328	134	128	27	3
2041	3	3	2	2	15	62	235	131	101	14	15	3
2042	3	3	2	2	42	30	124	175	156	103	17	3
2043	3	3	2	2	18	46	131	270	174	103	0	2
2044	3	2	2	1	0	47	110	146	88	33	49	26
2045	3	16	2	1	0	82	71	165	276	103	0	2
2046	2	2	2	1	20	65	101	293	108	10	0	2
2047	2	2	2	1	0	22	221	151	72	11	0	2
2048	2	2	2	1	0	86	113	217	104	77	0	2

Projected rainfall data by HadCM3_A2 scenario (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December
2049	2	2	1	1	16	70	186	267	201	135	85	14
2050	2	2	1	1	0	45	220	190	133	31	0	1
2051	2	1	1	1	22	61	218	137	174	136	33	1
2052	2	1	1	0	0	67	107	153	111	9	58	1
2053	1	28	1	0	0	73	173	231	163	69	0	1
2054	1	1	1	0	0	98	124	128	93	0	0	33
2055	1	1	1	0	22	96	219	153	131	63	0	1
2056	1	1	1	0	21	16	91	304	120	12	28	1
2057	1	1	1	0	0	72	98	316	232	103	40	15
2058	1	1	0	0	13	44	120	217	108	56	0	1
2059	1	1	0	0	18	95	219	142	137	65	108	1
2060	1	1	0	0	0	67	104	201	297	101	43	26
2061	1	0	0	0	0	32	124	231	143	72	42	1
2062	1	0	0	0	16	63	211	134	119	80	12	0
2063	1	0	0	0	41	49	123	219	121	0	0	0
2064	14	0	0	0	0	36	98	140	143	6	43	0
2065	0	0	0	0	0	41	85	99	69	33	0	30
2066	0	0	0	0	0	20	61	231	169	80	19	0
2067	0	0	0	0	28	96	233	169	127	117	44	0
2068	0	0	0	0	0	71	174	156	157	47	0	40
2069	26	0	0	0	19	32	112	199	108	22	0	0
2070	0	0	0	0	70	29	105	171	137	104	33	0
2071	0	0	0	0	22	65	110	178	94	70	0	0
2072	17	0	0	0	20	87	139	218	161	113	47	16

Projected rainfall data by HadCM3_A2 scenario (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December
2073	16	0	0	0	17	88	139	244	130	96	19	24
2074	0	0	0	0	30	64	109	228	149	65	12	21
2075	0	0	0	0	0	67	246	159	88	103	0	0
2076	0	0	0	0	45	63	110	156	161	124	19	21
2077	0	0	0	0	19	38	125	320	136	93	0	0
2078	0	0	0	0	0	65	105	306	126	34	0	0
2079	33	0	0	0	0	89	178	131	138	31	25	0
2080	0	0	0	0	12	80	210	162	89	28	58	73
2081	0	0	0	0	14	8	76	150	36	18	0	0
2082	0	0	0	0	15	34	125	206	220	90	22	19
2083	0	0	0	0	0	45	115	218	150	19	39	60
2084	108	0	0	0	15	29	85	217	163	77	23	30
2085	19	0	0	0	0	32	114	148	132	56	16	0
2086	0	0	0	0	41	86	240	159	130	49	0	0
2087	0	0	0	0	0	35	149	221	114	18	101	38
2088	0	0	0	0	0	38	118	159	116	91	28	0
2089	0	0	0	0	21	33	115	143	139	90	19	0
2090	0	0	0	0	26	64	105	318	137	89	0	0
2091	0	0	0	0	14	76	161	160	131	90	17	0
2092	41	19	0	0	26	69	404	165	124	21	0	16
2093	0	0	0	0	16	75	167	318	197	97	18	0
2094	0	0	0	0	12	61	110	360	118	70	19	49
2095	0	0	0	0	21	12	85	302	108	56	12	0
2096	0	0	0	0	45	68	162	210	110	102	39	0

Projected rainfall data by HadCM3_A2 scenario (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December
2097	0	0	0	0	12	12	88	153	89	20	0	81
2098	34	0	0	0	22	61	143	318	118	31	0	0
2099	0	0	0	0	64	71	168	202	119	79	0	0

Projected rainfall data by HadCM3_A2 scenario (mm)

Statistics of monthly rainfall data of each district of Marathwada Region and Marathwada as a whole

1. Aurangabad (1961-2002)

Aurangabad	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	2	1	3	5	20	110	139	119	162	55	28	9
Standard Deviation	3.9	2.3	4.8	6.2	24.8	45.1	52.1	49.1	89.9	46.7	37.9	16.7
Median (mm)	0	0	2	2	10	103	148	115	153	48	7	0
Coefficient of Skewness	2.1	2.5	1.8	1.3	1.6	0.7	-0.4	0.5	0.5	0.8	1.6	2.3

2. Beed (1961-2002)

Beed	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	3	4	6	9	18	32	39	50	78	54	25	8
Standard Deviation	4.7	7.0	7.4	10.7	22.7	38.2	51.1	61.9	93.7	62.7	32.1	11.8
Median (mm)	0	0	2	7	14	104	143	127	145	65	12	1
Coefficient of Skewness	2.5	2.9	1.6	0.7	1.3	0.3	-0.3	0.6	0.8	0.6	1.6	2.5

3. Hingoli (1961-2002)

Hingoli	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	6	5	9	9	15	133	192	214	192	76	19	9
Standard Deviation	7.7	7.5	14.1	9.2	16.4	50.1	82.9	101.3	116.1	68.2	27.4	16.4
Median (mm)	2	1	5	6	12	135	195	200	173	55	7	0
Coefficient of Skewness	1.1	2.1	2.2	1.0	1.7	0.2	0.2	1.4	0.7	1.1	2.2	2.3

4. Jalna (1961-2002)

Jalna	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	4	4	4	7	18	116	133	142	173	64	27	11
Standard Deviation	6.7	6.0	5.7	7.7	20.5	43.8	49.9	62.5	99.5	56.9	38.5	18.9
Median (mm)	0	2	2	4	8	113	138	130	150	50	6	0
Coefficient of Skewness	1.7	2.5	1.9	0.8	1.3	0.6	-0.2	0.9	0.7	1.0	1.8	2.5

5. Latur (1961-2002)

Latur	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	3	5	8	13	27	122	145	163	189	98	25	4
Standard Deviation	5.0	11.0	9.8	12.7	28.6	41.9	60.3	72.0	99.8	75.5	30.3	7.2
Median (mm)	0	0	3	7	16	112	138	146	164	85	10	0
Coefficient of Skewness	1.8	3.1	1.4	0.8	1.9	0.5	0.5	0.8	0.7	0.7	1.7	1.9

6. Nanded (1961-2002)

Nanded	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	6	5	10	14	20	132	203	228	197	83	20	5
Standard Deviation	7.8	8.6	13.0	12.2	20.3	47.3	82.9	102.5	109.1	68.9	24.4	8.9
Median (mm)	2	1	5	11	16	131	195	207	172	70	11	0
Coefficient of Skewness	1.1	2.0	1.8	1.0	1.9	0.2	0.2	1.1	0.7	0.7	1.8	2.2

Statistics of rainfall data of each district of Marathwada Region

7. Osmanabad (1961-2002)

Osmanabad	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	3	4	4	15	30	108	133	122	164	100	26	6
Standard Deviation	4.6	7.0	5.3	12.7	27.4	39.1	53.2	53.0	90.8	73.2	30.5	9.5
Median (mm)	0	0	2	10	22	98	132	115	157	91	16	1
Coefficient of Skewness	2.3	2.6	1.2	1.0	1.4	0.5	0.1	0.3	0.8	0.5	1.7	1.8

8. Parbhani (1961-2002)

Parbhani	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	4	5	8	11	18	121	156	184	187	79	23	7
Standard Deviation	6.6	7.9	11.0	10.7	18.2	43.4	57.5	85.4	102.5	67.9	30.9	12.7
Median (mm)	1	1	5	7	14	120	162	169	162	65	9	1
Coefficient of Skewness	1.4	1.4	1.9	0.9	1.5	0.3	-0.1	1.3	0.6	1.0	2.0	2.0

9. Marathwada (1961-2002)

Marathwada	January	February	March	April	May	June	July	August	September	October	November	December
Mean Rainfall in mm	4	3	6	9	19	105	138	142	157	68	22	7
Standard Deviation	4.8	5.1	6.8	7.8	18.2	33.5	49.4	58.0	83.1	52.2	27.1	11.0
Median (mm)	1	1	4	7	12	102	146	131	140	67	9	1
Coefficient of Skewness	1.4	1.9	1.9	0.7	1.5	0.3	-0.3	0.8	0.6	0.5	1.7	2.1

Statistics for annual rainfall data of each district of Marathwada Region and Marathwada as a whole

Statistics	**Aurangabad**	**Beed**	**Hingoli**	**Jalna**	**Latur**	**Nanded**	**Osmanabad**	**Parbhani**	**Marathwada**
Mean Rainfall (mm)	676	717	885	719	797	912	701	796	769
Standard Deviation	153	162	212	158	176	199	154	185	161
Coefficient of Skewness	-0.0294	0.1958	0.2372	-0.1501	0.3837	0.3283	0.2363	0.1960	0.0805
Median	677	693	850	731	758	883	681	757	743

Statistics of projected monthly rainfall data for Marathwada (2002-2099)

Marathwada	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Mean Rainfall (mm)	7	4	4	5	16	71	144	184	144	71	24	11	683
Standard Deviation	13.7	6.5	5.4	6.5	17.2	36.2	61.4	66.5	62.6	46.6	31.6	19.2	145.9
Median (mm)	2	1	2	2	14	67	129	171	133	77	15	3	666
Coefficient of Skewness	5.1	3.2	2.4	1.8	1.8	0.8	1.7	0.4	1.2	0.2	2	3.1	0.3