METEOROLOGICAL, HYDROLOGICAL AND AGRICULTURAL DROUGHT ASSESSMENT
&
FORECASTING:
A CASE STUDY OF NORTH GUJARAT REGION, INDIA

A Synopsis Submitted to

The Maharaja Sayajirao University of Baroda

in Fulfilment of the Requirement for the Award of Degree of

Doctor of Philosophy

in

Civil Engineering

GUIDED BY
DR. T.M.V. SURYANARAYANA
Ph.D. in Civil Engineering
Fellow I.W.R.S., Fellow I.S.H.,
M.I.A.H.S., M.A.P.H.W., M.A.H.I.,
M.I.S.G., M.A.A.M.

PREPARED BY
PRANAV B. MISTRY
M.E. CIVIL (WRE)

सत्यं शिवं सुन्दरम्

WATER RESOURCES ENGINEERING AND MANAGEMENT INSTITUTE
FACULTY OF TECHNOLOGY AND ENGINEERING
THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA
SAMIALA – 391410

APRIL 2023

CONTENTS

REFERENCES

Publications

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Drought is considered as one of the most dangerous natural hazards in the today's world. Drought represents the effect of water demand unmet by the available resources. Drought as an environmental disaster is associated with a deficit of water resources over a large geographical area, which extends for a significant period of time. It occurs in areas with high and low rainfall and all climate conditions. Drought occurs when precipitation is lower than normal. It is hardly to define by drought as being phenomenon due to inexistence of a start time and an end time. Drought assessment is very important to manage water resources in lean period. It plays vital role in managing water demands especially in agriculture sector. Drought is one of the most common natural events that have a great negative impact on agriculture and water resources. Drought is one of the natural disasters that in comparison with the other disasters are of tremendous importance due to intensity, duration, areal extent, economic damages and long term effects. In the present study, drought years and degree of deficit of annual rainfall are determined in North Gujarat district by use of different meteorological drought indices viz., Percent of Normal Index, Percentage departure from mean (PD), Standardized Precipitation Index (SPI- 3 to 12 Months), Reconnaissance Drought Index (RDI-3 to 12 Months), Rainfall Anomaly, Standardized precipitation evapotranspiration index (SPEI – 3 to 12 Months), China Z index and Modified China Z index using monthly rainfall, maximum temperature , minimum temperature, potential evapotranspiration data. For this study, monthly rainfall data of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 68, 73, 78, 71, 68, 81, 79 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation. From the annual rainfall departure analysis, the drought years have been identified and it is observed that 1901, 1904, 1911,1915,1923,1939,1969,1987,2002 are affected by severe drought and 1974 is affected by extreme drought condition. The study also reveals that 6%, 15% and 15% of Extreme dry years, severe dry years and Moderate dry years occur amongst drought years considered, which means 36% years are categorized into moderate to extreme drought years out of the total drought years. The study also reveals that according to PNI, 17% years, 3% years and 9% years are observed as Moderate drought, Extreme drought and severe drought years respectively. Wherein PD, 29% years, 15% years and 10% years are observed as Mild Drought, Moderate drought and severe drought conditions respectively. Wet and dry periods were compared using trend analysis of SPI-3, SPI-6, SPI-9 & SPI-12 values PN and PD values. This study provides a preliminarily idea about the climate of North Gujarat districts is mostly arid in nature. It is revealed that almost 37% of the area possess semi-arid to 18% as arid zone and 48% as dry sub humid in Sabarkantha district.

The results show that the climate of most part of North Gujarat districts is Arid to Dry Sub humid. In Northern Gujarat, evapotranspiration rate is very high and mostly crops are remained under water stress till reaching to maturity. So, Agricultural activity depends on proper irrigation rather than rainfall. It is conclude that Northern parts are most vulnerable to drought.

The trend analysis and correlation matrix also shows that there is highly correlation when time scale is increased and gives highly correlated between the different metrological drought indices. Also, Mann Kendall trend test and Sen's slope estimator used for non-parametric test for meteorological drought indices. Also, the results of frequency analysis shows that extreme drought conditions occurred 5 times, severe drought conditions occurred 7 times and moderate drought conditions occurred 16 times all over the study period. The results also showed that both indices behave in the same manner in various time scales (3, 6, 9 and 12 months), but RDI due to use of potential evapotranspiration in similar climatic conditions is more sensitive than the SPI. So, it is recommended that the RDI index should be used as the proper drought index in drought monitoring systems for water resources planning and management.

For Hydrological and Agricultural drought analysis is carried out using Satellite-based remote sensing techniques to monitor droughts affected areas. Agriculture drought is mainly dependent on low rainfall which results in agricultural production. In recent years, Remote Sensing (RS) and Geographic Information System (GIS) have played a remarkable role in assessment of various types of hazards either natural or man-made. Various agricultural drought indices have been developed to assess the intensity of agricultural drought and to detect drought affected areas using Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Vegetation Condition Index (VCI), Normalized Difference Built-up Index (NDBI), and land surface temperature (LST). The results shows that NDVI decreased by 4% to 6% and NDWI decreased by 1 to 2% in the study area, while LST shows a significant increase by *1.5ºC –3*.5°C. This relationship revealed that when rainfall increases, NDVI, VCI also tends to decrease. Also there is increase in NDVI As a result, the event of agricultural drought increased. From the VCI analysis as extreme, high and moderate drought areas respectively in the study area. This study suggests that the effect of drought could be reduced through involving the smallholder farmers in a wide range of on and off-farm practices. This study may help to improve the existing agricultural drought monitoring systems carried out in different parts of Gujarat. The results will be useful in future for planning, designing and operating irrigation system and crop planning too.

Certificate

This is to certify that the synopsis entitled **"METEOROLOGICAL, HYDROLOGICAL AND AGRICULTURAL DROUGHT ASSESSMENT & FORECASTING:A CASE STUDY OF NORTH GUJARAT REGION, INDIA"** which is being submitted to The Maharaja Sayajirao University of Baroda in Fulfilment of the Requirement for the Award of Degree of Doctor of Philosophy in Civil Engineering by **Mr. Pranav B. Mistry** written by him under my supervision and guidance. The original work carried out by him independently. The matter presented in this synopsis has not been submitted for the award of any other degree.

Dr. T.M..V. Suryanarayana	**Dr. T.M..V. Suryanarayana**
Supervisor	**Director**
W.R.E.M.I	**W.R.E.M.I**

Dean
Faculty of Technology and Engineering
The Maharaja Sayajirao University of Baroda

ACKNOWLEDGEMENT

Every Dissertation has several minds behind its preparation, implementation and completion. This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable support in the preparation and completion of this study. I am very thankful to them although this is hardly an adequate compensation for the time they have extended.

First, I would like to express my deep and sincere thankfulness to my guide Dr. T.M.V. Suryanarayana, Director and Associate Professor, Water Resources and Engineering Management Institute, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, for his exceptional direction, inspiration, positive criticism, encouragement support and supreme support through out the period of my Ph.D. work. His guidance helped me in throughout the period of my work. I would always hope for such help and sprit from his side in my future career.

I would also be grateful to Dr. F. P. Parekh, Associate Professor, Water Resources and Engineering Management Institute, Faculty of Technology and Engineering, The M. S. University of Baroda for her valuable guidance during the course of my dissertation work.

I warmly thank Sumitra Sonaliya, Inayat shah, Vikas Rana and Mugdha Trivedi and for their co-operation, eternal moral support and constant encouragement in all possible way.

I want to also thank to all members of Water Resources Engineering And Management Institute, The Maharaja Sayajirao University of Baroda for providing an excellent and inspiring working atmosphere.

Finally and most importantly, I am thankful to my family and God. I am highly grateful to my parents for their blessings and inspiration.

Date:

Vadodara **(Pranav B. Mistry)**

ABSTRACT

Climate change has been emerging as one of the challenges in the global environment. Information of predicted climatic changes in basin scale is highly useful to know the future climatic condition in the basin that ultimately becomes helpful to perform planning and management of the water resources available in the basin.

Downscaling, or regionalization, is the term given to the process of deriving finer resolution data from coarser resolution GCM data. Most impacts researchers feel that the horizontal resolution of most GCMs is generally too coarse to be used in impacts models in its original format. Most concerns are related to the fact that regional climate is affected by forcing and circulations which occur at sub- grid scale and hence are not explicitly taken into account at the scales at which GCMs operate. It may be possible to define a relationship, or relationships, between site climate and large-scale climate which can then be used to derive more realistic values of the future climate at the site scale. Downscaling methodologies fall into different categories of statistical downscaling, dynamical downscaling and statistical-dynamical downscaling.

This study is based on the regression methods of statistical downscaling technique which is multiple linear regression, artificial neural network and principal component regression. This study is carried out for the area of Vallabh Vidyanagar is located in the Anand district. Climatological parameters such as maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hours are used for estimation of crop yield for year 1981 to 2006.

The whole dataset has been divided into 70% - 30%. That means 70% data has considered for the training and remaining 30% data has selected for the validation of the model. The models were evaluated using performance indices such as Root Mean Square Error (RMSE), Coefficient of Correlation (r), Coefficient of Determination (R^2) and Discrepancy Ratio (D.R).

Developed the Multiple Linear Regression (MLR), Artificial Neural Network (ANN) and Principal Component Regression (PCR) model using climatological parameters as independent variables and crop yield as dependent variable.

Principal component regression model is developed by incorporating principal components (PCs) as independent variables and crop yield as dependent variables as regressors in the equation of regression developed using curve expert software and results are compared with multiple linear regression and artificial neural network.

From the results obtained, it can be seen that developed model using climatological parameters are maximum temperature, minimum temperature, wind velocity and relative humidity and sunshine hours with principal component regression (PCR) is the best model for present study. Hence, it can be concluded that PCR technique provides the best results of RMSE, r, R^2 and D.R. for this study and one may use this model for the future prediction of yield of cotton.

The model developed using principal component regression for estimation yield of cotton gives RMSE values as 0.1745 kg/ha and 0.2140 kg/ha, r value as 0.9999 and 0.9999 ,R^2 value as 0.9998 and 0.9998 and D.R. value as 1.0000 and 0.9999 respectively for training and validation.

LIST OF TABLES

Table No.	Title	Page No.

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Drought is the most complex but least understood of all natural hazards. It is broadly defined as “severe water shortage”. Low rainfall and fall in agricultural production has mainly caused droughts. A droughts impact constitutes losses of life, human suffering and damage to economy and environment.

1.2 DROUGHT

There is no clear definition of drought; it only depends on the context and regions. Scientist over time tried to define this phenomenon, but still there is no clear definition. The primary cause of any drought is a deficiency in rainfall and, in particular, the timing, distribution, frequency and intensity of this deficiency in relation to the existing water storage, demand, and use. This deficit can result in an unavailability of water essential for the functioning of a natural (eco-) system and/or indispensable for a certain human activities.

The following categories of drought are usually considered:

1. ***Meteorological***
   Meteorological drought is usually defined on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as specific to a region since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

2. ***Hydrological***
   Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale.

3. ***Agricultural***
   Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth.

1.3 DROUGHT ASSESSMENT AND ITS NEED

The quantification of drought severity is called as drought assessment. Drought assessment can be done with the use of a suitable drought index. The drought index selection depends upon the application of drought assessment. It could be meteorological, hydrological or Agricultural drought assessment. Remote sensing derived drought indices could aid a helping hand in this context.

1.4 DROUGHT INDICES

Several drought indices have been used to quantify the drought events, each having its own strengths and weakness. Generally most of this indices are based on the meteorological and hydrological parameters such as rainfall, temperature Evapotranspiration, Potential Evapotranspiration, soil moisture etc. Most commonly used indices are Percent Normal, Palmer Drought Severity Index, Soil Water Supply Index, Standardized Precipitation Index, Crop Moisture Index, and Standardized Precipitation evapotranspiration Index.

A drought index value can be defined as an individual number used for decision-making policies. Typically, drought indices are continuous functions of precipitation, stream discharge, temperature or other quantifiable variables. Rainfall data is extensively used to compute drought indices due to availability of long-term rainfall archives. Although rainfall data alone might not reveal the scale of drought-linked circumstances, it can serve as a logical solution in data-poor areas. Although there are many drought indices that have been developed by researchers, only a reduced number are being used operationally in most countries.

.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter review of investigations on drought analysis. This chapter contains various literature review on different types of drought i.e., meteorological drought, hydrological drought and agricultural drought. Also, literature of development of drought forecasting models and development of drought severity duration frequency curves.

2.2 LITERATURE REVIEW ON METEOROLOGICAL DROUGHT ANALYSIS

In rain-fed agriculture, rainfall has a crucial role to play for suitable crop planning. Twenty eight years (1983-2010) daily rainfall data has been analysed by **Ray et al. (2012)** to find out weekly, monthly, seasonal and yearly meteorological drought occurrence at Barapani station of Ri-Bhoi district, Meghalaya. The average annual rainfall of Barapani worked out to be 2,410.40 mm (coming under high rainfall region). They observed frequency of drought was the highest in 28th week in a tune of 11 times; month of December to a tune of about 14 times. Based on rainfall analysis it was found that during 28 years no scanty drought year was experienced. However, there was one moderate drought year which corresponds to the year 1998. Critical dry spells expected to occur during 26th to 28th week of the year.

Drought is a natural phenomenon which differs from other natural hazards by its slow accumulating process and its indefinite commencement and termination. **Das et al. (2012)** addressed water deficiency and drought occurrence over Kutch district, Gujarat, because nearly 45% of the whole Kutch district is severely suffering by deficiency of water. Earth observation data (LANDSAT ETM+) and Standardized Precipitation Index were used to analyze drought severity. Daily rainfall data over the study area were obtained from Indian Meteorological Department (IMD) for the period of study (1990-2014) and geo-referenced for further analyses. Using Remote Sensing and GIS techniques, rainfall variability map over the period of study has been prepared to show rainfall distribution and land use and land cover map is prepared to show the area under different land use classes and impacts of drought over land uses. Standardized Precipitation Index (SPI) was generated for each block wise and scenario of drought development has been analyzed using decadal data set for the study period (1990-2014). The present study suggests method and techniques for continuous drought monitoring by linking temporal earth observation and rainfall data. The methodology will be very useful for the development of a regional drought monitoring system.

Patel et al. (2017) studied floods and droughts requires the knowledge of wet and dry event sequences. They are the two important extreme conditions which directly or indirectly affects every field of environmental science. These extreme conditions are due to the change in one, of the many but most important parameter, rainfall. The standardized precipitation index is designed to quantify the rainfall for multiple time scales. These time scales reflect the impact of drought/floods on the availability of the different water resources. The modified classification by Agnew is referred for the classification of wet and dry events during the 20th Century for Surat district. The monthly rainfall data from 1901 to 2000 is utilized to determine the SPI values. SPI was calculated for 4, 6, 12, 24 and 48 months' time scales. The area experienced more than 20% years of dry and wet events for the 20th Century. It is observed that the years 1942, 1945 and 1959 are identified as severe wet events for all the time scale.

Year 1998 is identified as moderate wet event for all time scale. Years 1936 and 1987 are identified as severe dry events and year 1935 is identified as moderate dry event for all the time scales. No extreme wet event was observed. For extreme dry scenario all the years identified for different time scales are different.

Analysis of drought is very important for the irrigation purpose of a country. **Keka et al. (2012)** analysed drought in the eastern part of Bangladesh has been studied. Yearly meteorological drought has been analyzed by comparing the yearly rainfall deficiency with the mean yearly rainfall. Yearly drought analysis has also been performed by three climatic indexes. The climatic indexes are De Mortone Aridity Index, IdM; Seleaninov Hydrothermic Index, IHS; and Donciu Climate Index, IcD. With the help of annual rainfall assurance (A %) yearly drought analysis has been performed by the climatic indexes. Monthly drought analysis has been done with the rainfall data, considering average rainfall and minimum rainfall for a month. In this study 17 meteorological stations have been chosen for analysis. Distribution of rainfall, annual variation of rainfall, yearly drought and percentage of drought affected areas has been presented with the help of different figures and tables. Monthly drought analysis shows that generally the month of January, February, March, November and December are drought affected. The month of April faces drought almost every year. May and October face drought occasionally. The months June, July, August and September experience heavy rainfall.

Due to rapid growth of population, massive deforestation and anthropogenic activities, noticeable change in climate conditions is being observed in Pakistan. Increased aridity due to climate change is a growing environmental problem of the agricultural country like Pakistan. It is essential to assess and monitor aridity to combat the probable land degradation and drought desertification. Identification of arid and semi-arid regions on climatic basis is the first essential step in any project of land reclamation for agricultural and other purposes. A geographic information system is used by **Haider and Adnan (2014)** for the assessment of aridity in Pakistan from long term climatic data of fifty years (1960-2009) collected from fifty four stations situated in the country. In the delineation of climatic zones and delimitation of their boundaries, five well known aridity models viz. De Martonne Aridity index, Erinc Aridity index, Thornthwaite Precipitation Effectiveness index, UNESCO Aridity index and Thornthwaite Moisture index are utilized for this purpose. The study shows that southern parts of the country are dry and more vulnerable to drought while the northern parts have variable types of climate. Almost 75 to 85% of the total area of the country is arid in which most part lies in the south while less than 10% area is humid lies in the north of the country. This study will be a good predicator for agricultural scientist, agronomist and hydrologist to plan according the climate of the region.

Trend analysis is conducted by **Rahmat et al. (2015)** using nonparametric trend tests (Mann-Kendall and Spearman’s rho) for five selected meteorological stations in Victoria. For the drought analysis, the Standardized Precipitation Index (SPI) was applied to 3 month and 12 month time scales using monthly mean precipitation data for the time series of over 60 years. The computed SPI values for both time scales showed statistically significant downward trend for all stations. To compare one time period to another, the series were then subdivided into two 33 year periods. For the 3 month basis, three out of five stations showed significant decreasing trends. In contrast, for the 12 month time scale, the results showed downward trends for all stations illustrating conditions becoming drier over the last thirty three years (1977-2010). These results could be associated with the consequences of climate change as it is postulated that droughts would become more common in the future.

2.3 LITERATURE REVIEW ON HYDROLOGICAL DROUGHT ANALYSIS

Drought is a natural disaster that occurs when water availability is significantly below the normal levels during a significant period of time and cannot meet the demand. **Soumyashri and Patil (2016)** focused on hydrological drought assessment in Bhima sub basin, which receives rainfall annually, but in dry season some of the areas start to become drought. This also due to the fact of large difference between river flows during the wet and dry seasons, which is significantly influenced by precipitation, resulting in hydrological drought. It consists of more reliable information's and the main factor in the decision making process. Indices for characterizing hydrological drought are, in general, data demanding and computationally intensive. It is based on cumulative streamflow volumes for overlapping periods of 3, 6, 9, and 12 months within each hydrological year at 5 hydrometric stations in Bhima sub basin over the period 1980-2010. Both long and short term drought has very severe impacts on basin. As per SDI methodology the extreme droughts occurred in long term scale (12 month scale) during period of 2008-2009.

The impact of meteorological and hydrological drought on groundwater resources in coastal deserts in the south of Iran was investigated during 1991-2011, using Standardized Precipitation Index (SPI), Standardized Runoff Index (SRI), and Groundwater Resources Index (GRI). **Bazrafshan et al. (2016)** indicated that wet and drought spells governed the area in the first and second decades, respectively, which was similarly reflected by the three indices; GRI had a good correlation with SPI and SRI in 48-month time scale. This correlation was simultaneously in the eastern and western coasts and with a 6 months delay in the central plains.

2.4 LITERATURE REVIEW ON AGRICULTURAL DROUGHT ANALYSIS

Agriculture is an economic activity that is highly dependent upon weather and climate in order to produce the food and fiber necessary to sustain human life. The climate variations have direct and indirect effects on agricultural productivity. If these variations continue on a long term period, an issue of agricultural drought and food scarcity occur making agricultural productivity vulnerable. Especially, the effects of climate variation on agriculture are recurrent meteorological phenomenon affecting several parts of the world, in India too. **Nithya and Rose (2014)** studied to make an attempt to understand the biophysical aspects of agricultural vulnerability using the modern methods of remote sensing and GIS. Agricultural vulnerability is determined based on Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI). SPI values of rain gauge stations are interpolated to determine the spatial pattern and threshold value of drought for agricultural vulnerability. Anomaly of the NDVI and NDWI were classified to determine the agricultural drought vulnerability. SPI, NDVI and NDWI were integrated to classify the agricultural vulnerability of the present study area namely Srivilliputhur Taluk of Virudhunagar district. From the study, it is found out that the north east part is highly vulnerable and the western part of the study area is less vulnerable to agricultural drought. The resultant map shows the spatial distribution of the areas facing agricultural drought conditions. The agricultural vulnerability map will help in the preparation of the area for mitigation measures that will in turn reduce the impacts of climate variation on agriculture.

In recent years, the topic of climate change in effect of greenhouse gases increase has been lionized in scientific studies. **Shamsnia and Boustani (2014)** studied meteorological parameters is highly important in hydrology problems, since the same parameters generally form the climate of a region and is due to variations caused by water, wind, rain, etc. Drought as an environmental disaster is associated with a deficit of water resources. Satellite indices can be used for assessment of different hydrological and climate phenomena. In this research, an index called the Radiant three meteorological satellite indices (NDVI, VCI, SAVI)were used in five regions (Abadeh, Eghlid, Bavanat, Marvdashand Shiraz). The Results showed that the rain effect on vegetation is less for Marvdasht area (9 and 12 months), while it is high for Shiraz (3 months). So it is suggested that in rangelands, 6-month time scale of RDI, in forest areas, long term time scales (9 and 12 months) and in rainfed lands, short term time scales (less than 3 month) can be used for drought Monitoring.

Increasing temperature and altered precipitation patterns, leads to the extreme weather events like Drought which drastically affects the agricultural production. The agricultural drought monitoring, assessment as well as management can be done more accurately with the help of geospatial techniques like Remote Sensing. Raichur District, of Karnataka (India) falls in a plateau region and located between 15º 33’and16º 34’ N latitudes and 76º 14’and 77º 36’ E longitudes. It is a drought prone region and falls within the most arid band of the country. The district relies on the traditional agricultural based economy; hence the impact of drought on the agriculture not only affects the production but also the livelihood of common man. **Sruthi and Aslam (2015)** analyzed the vegetation stress in the Raichur district with the calculation of NDVI values and the land surface temperature (LST). By calculating the correlation between LST and NDVI, it can be clearly noticed that they show a high negative correlation. The correlation between LST and NDVI is -0.635 for the year 2002 and -0.586 for the year 2012. The LST when correlated with the vegetation index it can be used to detect the agricultural drought of a region, as demonstrated in this work.

2.5 LITERATURE REVIEW ON DROUGHT FORECASTING METHODS

In order to have effective agricultural production the impacts of drought must be mitigated. An important aspect of mitigating the impacts of drought is an effective method of forecasting future drought events. **Belayneh and Adamowski (2013)** studied three methods of forecasting short-term drought for short lead times are explored in the Awash River Basin of Ethiopia. The Standardized Precipitation Index (SPI) was the drought index chosen to represent drought in the basin. The following machine learning techniques were explored in this study: artificial neural networks (ANNs), support vector regression (SVR), and coupled wavelet-ANNs, which pre-process input data using wavelet analysis (WA). The forecast results of all three methods were compared using two performance measures (RMSE and R2). The forecast results of this study indicate that the coupled wavelet neural network (WA-ANN)models were the most accurate models for forecasting SPI 3 (3-month SPI) and SPI 6 (6-month SPI) values overload times of 1 and 3 months in the Awash River Basin in Ethiopia.

CHAPTER 3

STUDY AREA AND DATA COLLECTION

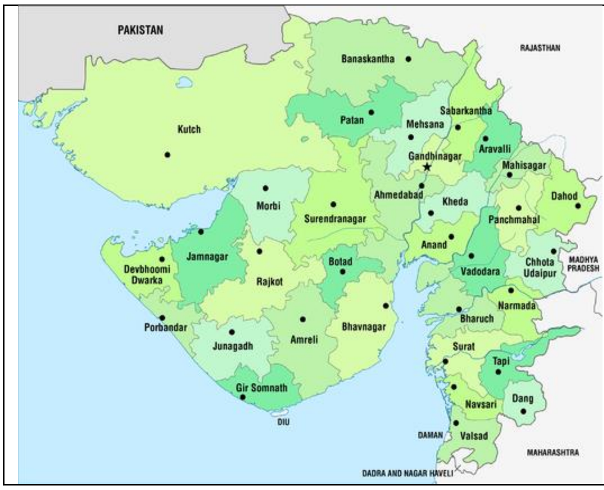
3.1 GENERAL

This chapter contains the brief general idea of climate of Gujarat and study area. Also, discussed various sources from where data will be collected.

3.2 CLIMATE OF GUJARAT

The climate of Gujarat is also varied and can be divided into three seasons: (1) hot and dry season from May to June; (2) warm and rainy season from June to September; and (3) cool and dry post-rainy season from October to April (Agro climatology of Gujarat). The north-western part of the state is dry, with less than 500 mm of rain every year. In the more temperate central part of the state, the annual rainfall is more than 700 mm. In the southern part, rainfall averages 2000 mm a year. Incidence and distribution of rainfall, particularly in Saurashtra and Kutch regions and in the northern part of Gujarat is highly erratic. As a result, these regions are very often subjected to drought. Most of the rain (90-95% of the annual total) falls during the period of June to September, when the southwest monsoon prevails. The north- west monsoon does not occur in Gujarat state. In the winter temperatures averages between 12º and 27º. In the summer temperatures average between 25º and 43º and have been known to reach as high as 48ºC. The highest temperatures have been recorded at Ahmedabad and in regions of Banaskantha while temperatures are relatively low at places located in coastal regions. The district map of Gujarat is shown below in Figure 3.1.

3.3 CLIMATE OF NORTH GUJARAT REGION



Districts of North Gujarat

1. Gandhinagar
2. Aravalli
3. Banaskantha
4. Mehsana
5. Patan
6. Sabarkantha

Figure 3.1: Gujarat District Map

3.4 DATA COLLECTION AND SOURCES

For the present study various data will be collected from the various websites and organizations is shown below.

1. **Meteorological Data**

a. http://www.indiawaterportal.org/
b. http://www.imd.gov.in/

2. Hydrological Data

a. http://www.cwc.nic.in/
b. http://cgwb.gov.in/
c. http://www.india-wris.nrsc.gov.in/wrpinfo/index.php?title=Gujarat

3. Agricultural Data

Data used for agricultural drought monitoring will be acquired from the satellite sources. Also Landsat images of various bands will be collected from different online sources.

a. www.earthexplorer.usgs.gov
b. www.landviewer.org

CHAPTER 4

METHODOLOGY

4.1 METEOROLOGICAL DROUGHT INDICES

Percent Normal Index

This index is computed by dividing the actual precipitation by the "normal" precipitation (typically considered to be a 30-year mean) and multiplying by 100. This index can be calculated for a variety of time scales. Usually these time scales range from a single month to a group of months. The equation and classification is given below Table 4.1 for this index is:

$$I = \frac{P}{P_{30}} \times 100$$

Table 4.1: Percent of Normal Index Classification

Drought Classes	PNI (%)
Extremely Wet	---
Very Wet	---
Moderately Wet	≥110
Near Normal	80 to 110
Moderately Drought	55 to 80
Severely Drought	40 to 55
Extremely Drought	≤40

Percentage Departure from Mean

This index is estimated using the following equation. If the departure of annual rainfall from normal (%) is 0 or above then there is no drought, 0 to -25 mild drought,-26 to -50 moderate droughts,-50 or more it's a severe drought situation. The classification is given below Table 4.2

- $P_d = \left[\frac{P_i - \bar{P}}{\bar{p}}\right] \times 100$

Here, Pd is the percentage departure; Pi is the rainfall at any time and $p^{-}$is the mean rainfall. This clearly indicates the departure of any precipitation events from its mean

Table 4.2: Percentage of Departure from Mean Classification

Class Range	Drought Class
> 0.0	No Drought
0 to -25	Mild Drought
-25 to -50	Moderate Drought
> -50	Severe Drought

Rainfall anomaly index

Rainfall anomaly index calculates the annual rainfall variability. It is used for the purpose of assessing the degree of droughts and their management. This technique incorporates the rainfall measurements for a given area during a particular time period.
The rainfall data were arranged in descending order of intensity in which higher rainfall values are ranked first and the lowest rainfall values are ranked last.
Further the average value of the ten highest rainfall measurements comprising the maximal average of ten extrema and the ten lowest rainfall measurement comprising the minimal average of ten extrema was computed for the period under consideration. These values represent the positive and negative anomalies respectively based on average rainfall values of ten extrema.

RAI is calculated for positive anomalies and negative anomalies as given in below equation.

$$\mathrm{RAI} = +3\left[\frac{\mathrm{RF} - \mathrm{M_{RF}}}{\mathrm{M_{H\,10}} - \mathrm{M_{RF}}}\right]$$

$$\mathrm{RAI} = -3\left[\frac{\mathrm{RF} - \mathrm{M_{RF}}}{\mathrm{M_{L\,10}} - \mathrm{M_{RF}}}\right]$$

Standardized Precipitation Index
The Standardized Precipitation Index (SPI) was developed by McKee et al (1993). The SPI is based only on precipitation. The SPI assigns a single numeric value to the precipitation, which can be compared across regions and time scales with markedly different climates.

Jain et al. (2010) reported that there are a number of indices to quantify drought using meteorological data; however, the SPI is most widely used index. SPI can be computed at different time scales and hence can quantify water deficit so different duration. The classification is given below Table 4.3

Table 4.3: Standardised Precipitation Classification

SPI Values	Drought condition
2.0 +	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderate wet
-0.99 to +0.99	Near normal
-1.0 to -1.49	Moderate dry
-1.5 to -1.99	Severe dry
-2.0 to less	Extreme dry

4.2 HYDROLOGICAL DROUGHT INDICES

Normalised Difference Water Index (NDWI)

Based on the fact that water has strongest absorption while vegetation has strongest reflectivity at near infra-red, McfeetersS.K. (1996) proposed the method of NDWI to highlight water body. NDWI proved to work well in separating water body and vegetation but has limitations when it comes to soil and built up area. The following equation was used to calculate:

$$\text{NDWI} = \frac{(\text{NIR} - \text{SWIR})}{(\text{NIR} + \text{SWIR})}$$

Water Ratio Index (WRI)

Due to dominating spectral reflectance of water in green (Band 2) and red (Band 3) bands as compared to Near Infra-red (Band 4) and Medium Infra-red(Band 5). WRI shows values, in general, greater than 1 for water (Shen L. et al(2010), Fang-fang Z. et al (2011)).

Modified Normalised Difference Water Index (MNDWI)

Due to the limitations of NDWI, Xu (2006) proposed MNDWI which was found to be efficient in distinguishing water and urban areas.

4.3 AGRICULTURAL DROUGHT INDICES

Normalised Difference Vegetation Index (NDVI)

NDVI is a widely used slope based vegetation index using red and near infrared band. It is one of the most widely used vegetation indexes. Furthermore, the measurement scale has the desirable property of ranging from -1 to 1, with 0 representing the approximate value of no vegetation, and negative values non-vegetated surfaces. Here, NDVI is calculated for mapping vulnerability of drought. The following equation was used to calculate:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}$$

Normalized Difference Built-up Index (NDBI)

NDBI stands for Normalized Difference Built-up Index, In comparison to the other land use / land cover Surfaces, built-up lands have higher reflectance in MIR Wavelength range (1.55~ 1.75µm) than in NIR Wavelength range (0.76~ 0.90µm). NDBI is very useful for mapping the urban built-up areas and has been computed using the equation expressed as follows:

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}$$

Vegetation Condition Index (VCI)

VCI is a widely used algorithm for estimating vegetation condition based on NDVI min and max value. The VCI is expressed in percentage (%) and gives an idea where the observed value is situated between the extreme values (minimum and maximum) in the previous years. The below equation was used to calculate VCI: The classification is given below Table 4.3

$$VCI_{ij} = \left(\frac{NDVI_j - NDVI_{min}}{NDVI_{max} + NDVI_{min}}\right) * 100$$

Table 2: Classification Schemes for Drought Monitoring using TCI, VCI and VHI

Drought Classes	TCI / VCI / VHI
Extreme Drought	<10
Severe Drought	<20
Moderate Drought	<30
Mild Drought	<40
No Drought	>40

Source: Kogan, 2002

Soil Adjusted Vegetation Index

The SAVI index was developed as a modification of the NDVI. The SAVI is used to correct the influence of soil brightness.

$$SAVI = ((NIR-RED))/((NIR+RED+L))*(1+L)$$

Where, NIR is the near Infrared band, RED is the red band, and L is the soil brightness correction factor. Generally, L=0.5 works well in most situations and it is the default value used for calculation.

CHAPTER 5
RESULTS AND ANALYSIS

5.1 GENERAL

This chapter illustrates the results and analysis of the meteorological drought, hydrological and agricultural drought analysis. Also, development of different drought forecasting model for the present study region. The different meteorological drought indices were analyzed. Also, the percentage of drought proneness under different categories of the area were computed.

5.2 RESULTS OF METEOROLOGICAL DROUGHT INDICES

The monthly rainfall data of hundred and two years (1901 to 2002) was analysed using percent of normal method. The average annual rainfall of Sabarkantha district is 812.83 mm. The classification is given below Table 5.1

Table 5.1: Drought Years Obtained Using Percentage of Normal Method

Classification	Range	Year
Extremely Drought	≤ 40	1915
Severe Drought	40 to 55	1904,1911,1918,1923,1974,1987,2002
Moderate Drought	55 to 80	1901,1902,1905,1925,1936,1939,1940,1948,1951, 1965,1968,1969,1972,1985,1986,1991,1995
Near Normal	80 to 110	1903,1907,1909,1912,1914,1916,1920,1922,1924, 1928,1929,1930,1931,1932,1935,1938,1943,1946, 1947,1949,1952,1953,1957,1958,1960,1962,1964, 1966,1967,1971,1976,1978,1979,1982,1988,1989, 1992,1993,1997,1999,2000,2001
Moderate Wet	≥ 110	1906,1908,1910,1913,1917,1919,1921,1926,1927, 1933,1934,1937,1941,1942,1944,1945,1950,1954, 1955,1956,1959,1961,1963,1970,1973,1975,1977, 1980,1981,1983,1984,1990,1994,1996,1998

PERCENTAGE OF DEPARTURE FROM MEAN FOR ANNUAL RAINFALL

Annual Rainfall Departure for identification of drought years and the extent of deficit of annual rainfall, the annual rainfall departure analysis has been carried out. A year is considered as drought year if the total amount of annual rainfall over an area is deficient by more than 25% of its normal value. From the analysis it was observed that years 1904,1911,1915,1923,1974,1987,2002 as a severe drought & 1901, 1918, 1936, 1939, 1940, 1948, 1951, 1960, 1965, 1968, 1969, 1972, 1985, 1986, 1991, 1995 as a moderate drought occurred in Sabarkantha district. The classification is given below Table 5.2

Table 5.2: Drought Years Obtained Using Percentage of Departure Method for Annual Rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1904,1911,1915,1923,1974,1987,2002
Moderate Drought	-25 to -50	1901,1918,1936,1939,1940,1948,1951,1960,1965,1968,1969, 1972,1985,1986,1991,1995
Mild Drought	0.0 to -25	1902,1903,1905,1907,1925,1928,1929,1930,1931,1932,1935, 1938,1949,1952,1957,1958,1962,1964,1966,1971,1978,1979, 1982,1988,1989,1992,1993,1999,2000,2001
No Drought	0.0 or Above	1906,1908,1909,1910,1912,1913,1914,1916,1917,1919,1920, 1921,1922,1924,1926,1927,1933,1934,1937,1941,1942,1943, 1944,1945,1946,1947,1950,1953,1954,1955,1956,1959,1961, 1963,1967,1970,1973,1975,1976,1977,1980,1981,1983,1984, 1990,1994,1996,1997,1998

From the annual and seasonal rainfall departure analysis, the drought years have been identified and its average frequency of drought is presented The classification is given below Table 5.3 and 5.4

Table 5.3: Total Percentage of drought severity with number of years for PD using Annual Rainfall

Classification	Range	No of Year	%
Severe Drought	-50 to -75	7	6.86
Moderate Drought	-25 to -50	16	168
Mild Drought	0.0 to -25	30	29.41
No Drought	0.0 or Above	49	48.03

Table 5.4: Total Percentage of drought severity with number of years for PD using Seasonal Rainfall

Classification	Range	No of Year	%
Severe Drought	-50 to -75	7	6.86
Moderate Drought	-25 to -50	17	16.66
Mild Drought	0.0 to -25	27	26.47
No Drought	0.0 or Above	51	50

Rainfall anomaly index is obtained during a particular year by calculating maximum rainfall and mean annual rainfall. The mean value of the 10 highest and 10 lowest rainfall values is calculated. The classification is given below Table 5.5

Table 5.5: Drought years obtained using Rainfall Anomaly Index

Classification	Range	Year
Extremely dry	≤ -3.0	1904,1911,1915,1923,1974,1987

Very dry	-2.0 to -2.99	1918,1948,1951,1968,1969,1972,2002
Moderate dry	-1.0 to -1.99	1901,1902,1905,1925,1936,1939,1940,1957,1960,1962 1964,1965,1966,1979,1985,1986,1991,1992,1995,1999 2000
Normal	0.5 to -0.99	1903,1907,1909,1910,1912,1914,1916,1920,1922,1924 1928,1929,1930,1931,1932,1935,1938,1943,1946,1947 1949,1952,1953,1958,1961,1967,1971,1976,1978,1980 1981,1982,1983,1984,1988,1989,1993,1997,2001
Moderate wet	1 to 1.99	1906,1908,1913,1921,1934,1937,1941,1942,1950,1955 1963,1970,1990,1996,1998
Very wet	2 to 2.99	1917,1919,1945,1973,1975,1977
Extremely wet	≥ 3.0	1926,1927,1933,1944,1954,1956,1959,1994

From the analysis, the highest DI is concerned with value of 10 percent in 1906 – 1907,1908 – 1909,1917 – 1918,1919 – 1920, 1921 – 1922,1926 – 1927,1927 – 1928,1933 – 1934,1934 – 1935,1937 – 1938,1941 – 1942,1944 – 1945,1945 – 1946,1954 – 1955,1956 – 1957,1959 – 1960,1963 – 1964,1973 – 1974,1975 – 1976,1977 – 1978,1994 - 1995 respectively.

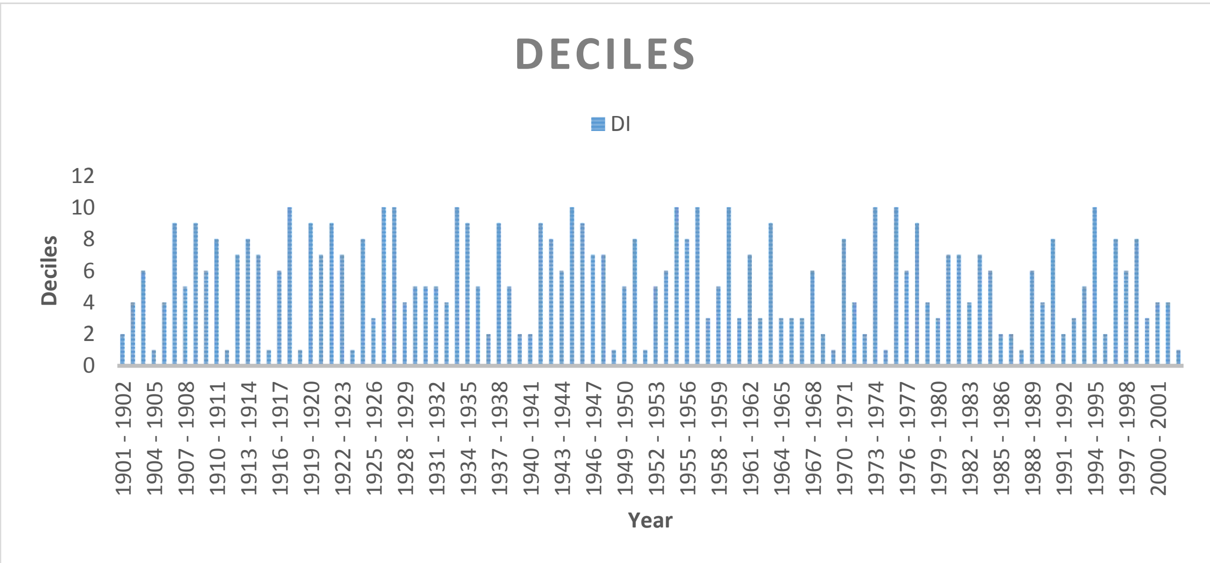


Figure 5.1: Values of DI for the year (1901-2002)

From Deciles analysis, the drought years have been identified and percentage value of drought and number of drought year in each class has been identified which is shown in below.

Table 5.6 Total Percentage of Drought Severity with Number of Years Using Deciles

Classification	Range	No of Year	%
Much Below Normal	1-2	21	20.58

Below Normal	3-4	20	19.60
Near Normal	5-6	20	19.60
Above Normal	7-8	20	19.60
Much Above Normal	9-10	21	20.58

STANDARDIZED PRECIPITATION INDEX

The SPI has been applied in the study area to quantify annual precipitation deficits anomalies on annual scale for the period during 1901 to 2002.The estimation of SPI values for the time scale of 3, 6, 9 and 12 months has been estimated in this section. The estimated value of SPI demarcates precipitation events over a specified time period into surplus (heavy Precipitation), medium/normal, and low/deficits precipitation. The Standardized Precipitation Index is calculated using DrinC software. The classification is given below Table 5.7

Table 5.7: Drought years obtained using SPI for time steps 12 month

Classification	Range	Year
Extremely Dry	-2 to less	1911 – 1912,1915 – 1916,1923 – 1924,1974 – 1975, 1987 – 1988
Severe Dry	-1.5 to -1.99	1904 – 1905,1969 – 1970,2002 – 2003
Moderate Dry	-1.0 to -1.49	1918 – 1919,1936 – 1937,1939 – 1940,1948 – 1949, 1951 – 1952,1968 – 1969,1972 – 1973,1985 – 1986, 1986 – 1987
Near Normal	-0.99 to 0.99	1901 – 1902,1902 – 1903,1903 – 1904,1905 – 1906, 1906 – 1907,1907 – 1908,1909 – 1910,1910 – 1911, 1912 – 1913,1913 – 1914,1914 – 1915,1916 – 1917, 1920 – 1921,1921 – 1922,1922 – 1923,1924 – 1925, 1925 – 1926,1928 – 1929,1929 – 1930,1930 – 1931, 1931 – 1932,1932 – 1933,1935 – 1936,1938 – 1939, 1940 – 1941,1941 – 1942,1942 – 1943,1943 – 1944, 1946 – 1947,1947 – 1948,1949 – 1950,1950 – 1951, 1952 – 1953,1953 – 1954,1955 – 1956,1957 – 1958, 1958 – 1959,1960 – 1961,1961 – 1962,1962 – 1963, 1964 – 1965,1965 – 1966,1966 – 1967,1967 – 1968, 1970 – 1971,1971 – 1972,1976 – 1977,1978 – 1979, 1979 – 1980,1980 – 1981,1981 – 1982,1982 – 1983, 1983 – 1984,1984 – 1985,1988 – 1989,1989 – 1990, 1990 – 1991,1991 – 1992,1992 – 1993,1993 – 1994, 1995 – 1996,1996 – 1997,1997 – 1998,1998 – 1999, 1999 – 2000,2000 – 2001,2001 – 2002
Moderate Wet	1.0 to 1.49	1908 – 1909,1917 – 1918,1919 – 1920,1933 – 1934, 1934 – 1935,1937 – 1938,1945 – 1946,1954 – 1955,

		1963 – 1964,1973 – 1974,1975 – 1976,1977 – 1978
Very Wet	1.5 to 1.49	1926 – 1927,1927 – 1928,1956 – 1957,1959 – 1960, 1994 – 1995
Extremely Wet	2.0 +	1944 – 1945

Table 5.8: Total Number of drought years using SPI (3, 6, 9 and 12)

Classification	Range	SPI 3	SPI 6	SPI 9	SPI 12
Extremely Dry	-2 to less	1	3	3	5
Severe Dry	-1.5 to -1.99	7	5	2	3
Moderate Dry	-1.0 to -1.49	14	7	16	9
Near Normal	-0.99 to 0.99	60	69	64	67
Moderate Wet	1.0 to 1.49	14	12	10	12
Very Wet	1.5 to 1.49	6	5	7	5
Extremely Wet	2.0 +	--	1	--	1

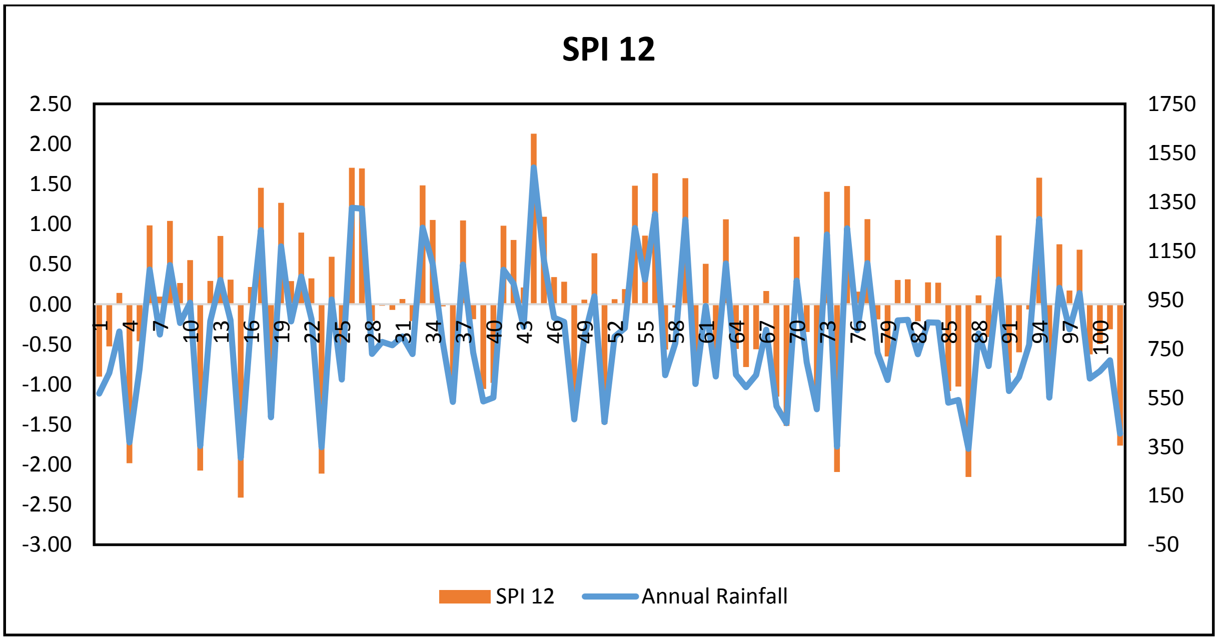


Figure 5.2: SPI 12 Plot for Sabarkantha District and Annual Rainfall

From the results obtain using SPI (3, 6, 9 and 12) method is analyze. SPI 12 gives better results while comparing it with SPI values and Annual Rainfall graph. Also, it is observed that Extreme dry condition occurs 5 times, severe dry, Moderate Dry, Near Normal, Moderate Wet, Very Wet and Extremely Wet situations occurs 3, 9, 67, and 12, 5 and 1 time respectively.

RECONNAISSANCE DROUGHT INDEX

The computation for RDI was carried out for drought assessment in district using Drin C Software. Its range is similar to that of SPI. Its value -1 or less indicates dry condition.-1 to -

1.49 moderately dry,-1.5 to -1.99 severely dry,-2 or less extremely dry. The RDI values for Sabarkantha districts is computed for different time scale. Below 16 shows the drought affected years for RDI 3. The study produced the drought severity at 3, 6, 9 and 12 months' time steps, in this section. After computing different values RDI latter the comparison of RDI time measure from this best time scale is selected for analysis. The classification is given below Table 5.9

Table 5.9: Drought years obtained using RDI for time steps 12 month

Classification	Range	Year
Extreme Drought	-2 or less	1904 – 1905,1911 – 1912,1915 – 1916,1923 – 1924, 1974 – 1975,1987 – 1988
Severe Drought	-1.5 to -1.99	1951 – 1952,1969 – 1970,2002 – 2003
Moderate Drought	-1 to -1.49	1918 – 1919,1936 – 1937,1939 – 1940,1948 – 1949, 1968 – 1969,1972 – 1973,1985 – 1986,1986 – 1987
Normal Conditions- Wet	0 to 0.99	1901 – 1902,1902 – 1903,1905 – 1906,1925 – 1926, 1928 – 1929,1932 – 1933,1938 – 1939,1940 – 1941, 1957 – 1958,1960 – 1961,1962 – 1963,1964 – 1965, 1965 – 1966,1966 – 1967,1971 – 1972,1978 – 1979, 1979 – 1980,1982 – 1983,1989 – 1990,1991 – 1992, 1992 – 1993,1993 – 1994,1995 – 1996,1999 – 2000, 2000 – 2001,2001 – 2002
Normal Conditions-Dry	0 to -0.99	1903 – 1904,1906 – 1907,1907 – 1908,1909 – 1910, 1910 – 1911,1912 – 1913,1913 – 1914,1914 – 1915, 1916 – 1917,1920 – 1921,1921 – 1922,1922 – 1923, 1924 – 1925,1929 – 1930,1930 – 1931,1931 – 1932, 1935 – 1936,1941 – 1942,1942 – 1943,1943 – 1944, 1946 – 1947,1947 – 1948,1949 – 1950,1950 – 1951, 1952 – 1953,1953 – 1954,1955 – 1956,1958 – 1959, 1961 – 1962,1967 – 1968,1970 – 1971,1976 – 1977, 1980 – 1981,1981 – 1982,1983 – 1984,1984 – 1985, 1988 – 1989,1990 – 1991,1996 – 1997,1997 – 1998, 1998 – 1999
Moderately Wet	1.00 to 1.49	1908 – 1909,1917 – 1918,1919 – 1920,1933 – 1934, 1934 – 1935,1937 – 1938,1945 – 1946,1954 – 1955, 1959 – 1960,1963 – 1964,1973 – 1974,1975 – 1976, 1977 – 1978,1994 – 1995
Severely Wet	1.5 to 1.99	1926 – 1927,1927 – 1928,1944 – 1945,1956 – 1957

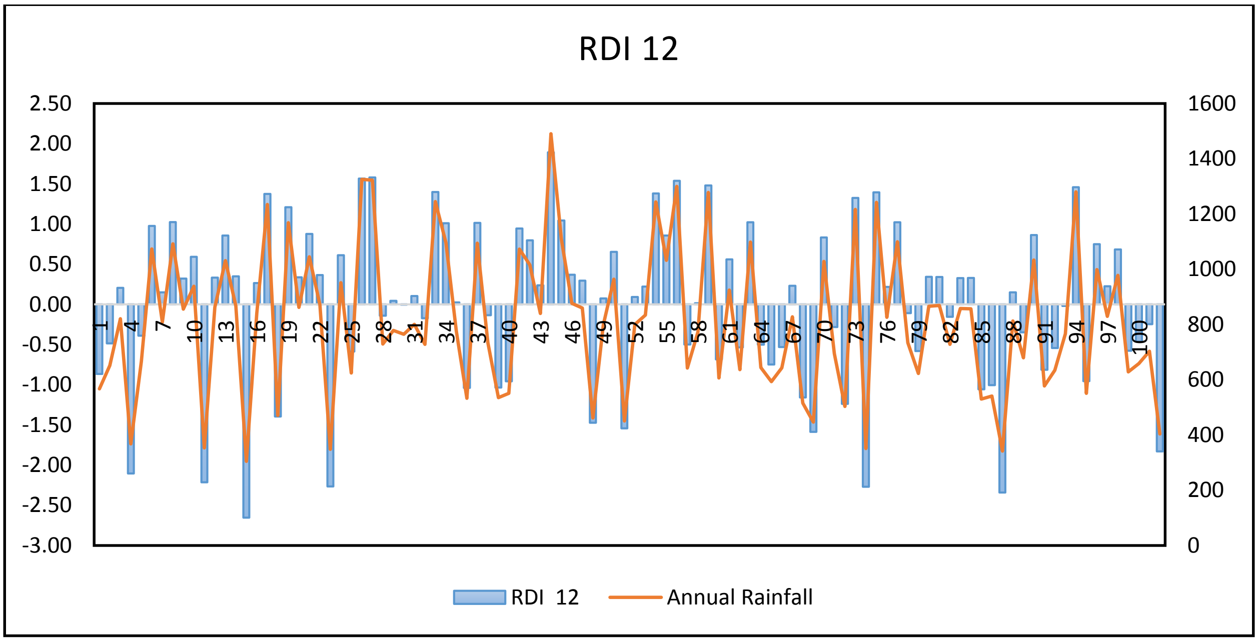


Figure 5.3: RDI 12 Plot for Sabarkantha District and Annual Rainfall

Table 5.10: Total Number of drought years using RDI (3, 6, 9 and 12)

	RDI 3	RDI 6	RDI 9	RDI 12
Extreme drought	4	7	3	6
Severe drought	9	1	2	3
Moderate drought	9	6	12	8
Normal Conditions-Dry	19	29	72	41
Normal Conditions-Wet	48	45	22	26
Moderate wet	13	14	11	14
Severe wet	--	--	--	4

Below figure 5.4 shows the number of years affected by drought conditions (Moderate, Severe and Extreme) by means of SPI and RDI for various time scales.

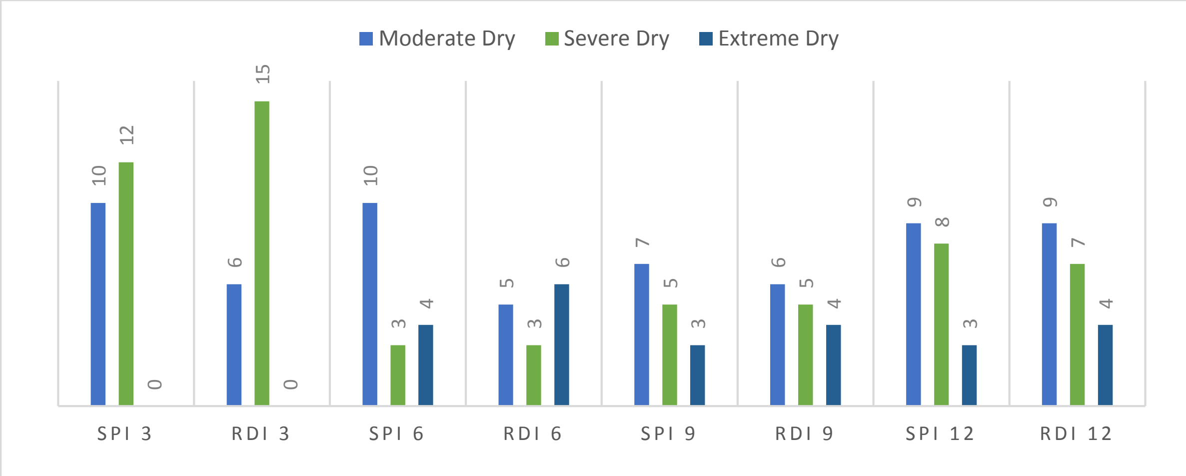


Figure 5.4: Comparisons of Various Time Scales of SPI and RDI

China Z Index and Modified China Z Index

The classification of year obtain using CZI and MCZI is given below Table 5.11 and 5.12

Table 5.11: Drought Years obtain using China Z index

Effective Drought	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995, 2002
Severe Drought	1901, 1939
Moderate Drought	1986, 1936, 1940
Moderate Wet	1906, 1908, 1913, 1917, 1919, 1921, 1933, 1934, 1937, 1941, 1945, 1954, 1963, 1973, 1975, 1977, 1990,
Very Wet	1926, 1927, 1944, 1956, 1959, 1994

Table 5.12: Drought Years obtain using Modified China Z index

Effective Drought	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995, 2002,
Severe Drought	1901, 1939
Moderate Drought	1936, 1940, 1986
Moderate Wet	1906, 1908, 1913, 1917, 1919, 1921, 1933, 1934, 1937, 1941, 1942, 1945, 1954, 1955, 1963, 1973, 1975, 1977, 1990
Very Wet	1926, 1927, 1944, 1956, 1959, 1994

Table 5.13: Standardised Precipitation Evapotranspiration Index

Condition	**Range**	**Years**
Extreme Drought	SPEI <-2	NIL
Extreme Wet	SPEI >2	

Moderate Drought	-1.5 <SPEI< -1.0	1918, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1985, 1986, 1995
Moderate Wet	1 <SPEI< 1.5	1906, 1908, 1919, 1934, 1937, 1941, 1945, 1963, 1973, 1977
Near Normal	-1 <SPEI< 1	1901, 1902, 1903, 1905, 1907, 1909, 1910, 1912, 1913, 1914, 1916, 1920, 1921, 1922, 1924, 1925, 1928, 1929, 1930, 1931, 1932, 1935, 1938, 1942, 1943, 1946, 1947, 1949, 1950, 1952, 1953, 1955, 1957, 1958, 1960, 1961, 1962, 1964, 1965, 1966, 1967, 1970, 1971, 1976, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1988, 1989, 1990, 1991, 1992, 1993, 1996, 1997, 1998, 1999, 2000, 2001
Severe Drought	-2 <SPEI< -1.5	1904, 1911, 1915, 1923, 1974, 1987, 2002
Severe Wet	1.5 <SPEI< 2	1917, 1926, 1927, 1933, 1954, 1956, 1959, 1975, 1994

5.3 Results of Climatic indices

2. Estimation of drought by different climatic index over the study area.

Three climatic indexes such as: de Mortone aridity index, (IbM); Seleaninoy hydrothermic index, (IhS); and Donciu climatic index, (IcD) were used.

The correlation established between the assured rainfall (A%) for years and climatic indexes provide the polynomial expression, statistically very significant. It has quantified very significant Correlation between annual rainfall assurance (A%) and climatic indexes using logarithmic Expression which is shown in below Table.5.14 and The classification is given below Table 5.15

Percentage of rainfall for every years of average rainfall has been determined. Deducting percentage value from 150 the annual rainfall assurance (A %) has been found. By putting the value of A in each climatic index equation the value of each climatic index has been determined.

Table 5.14: Mathematical function of Climatic index

Climatic index	Symbol	Mathematical function
Mortone aridity index	IdM	IdM = – 7.3566 lnA + 58.037
Seleaninov hydrotheremic index	His	IhS = – 0.4006 lnA + 3.1001
Donciu climate index	IcD	IcD = – 24.269 lnA + 191.17

Table 5.15: Drought years obtain using Mortone Aridity Index

Classification	Range	Year
Very Droughty	23-24	1904,1911,1915,1923,1974,1987
Droughty	24-25	1918,1948,1951,1969,2002

Medium	25-29	1901,1902,1905,1925,1928,1929,1930,1932,1935, 1936,1938,1939,1940,1949,1957,1958,1960,1962, 1964,1965,1966,1968,1971,1972,1978,1979,1982, 1985,1986,1989,1991,1992,1993,1995,1999,2000, 2001
Rainy	29-33	1903,1907,1909,1910,1912,1914,1916,1920,1922 1924,1931,1943,1944,1946,1947,1950,1952,1953 1961,1967,1976,1980,1981,1983,1984,1988,1997
Very Rainy	33-40	1906,1908,1913,1921,1926,1927,1934,1937,1941 1942,1945,1955,1963,1970,1977,1990,1996,1998
Excessively Rainy	>40	1917,1919,1933,1954,1956,1959,1973,1975,1994

Table 5.16: Drought years obtain using Donciu Climate Index

Classification	Range	Year
Droughty	70-80	1904,1911,1915,1923,1974,1987,2002
Medium	80-95	1901,1902,1905,1918,1925,1928,1929,1930,1932 1935,1936,1938,1939,1940,1948,1951,1957,1958 1960,1962,1964,1965,1966,1968,1969,1971,1972 1978,1979,1982,1985,1986,1989,1991,1992,1993 1995,1999,2000,2001
Rainy	95-100	1903,1907,1909,1912,1914,1916,1920,1931,1943 1947,1949,1952,1953,1967,1976,1980,1981,1983 1984,1988,1997
Very Rainy	100-110	1910,1922,1924,1944,1946,1950,1961,1998
Excessively Rainy	>110	1906,1908,1913,1917,1919,1921,1926,1927,1933 1934,1937,1941,1942,1945,1954,1955,1956,1959 1963,1970,1973,1975,1977,1990,1994,1996

In this Section of attempts were taken to reveal the distribution of precipitation and erosion all over North Gujarat region by means of two climate change related precipitation indices named Precipitation Concentration Index (PCI) and Modified Fournier Index (MFI). Now for Annual and Seasonal PCI showed mixed rainfall distribution in different seasons with PCI values varying from 8 to 45. This shows highly irregular and unpredictable nature of rainfall in present study region. This results in uncertainly of rainfall affects the different irrigation management and crop sowing practices. The classification is given below Table 5.17

Table 5.17: Number of Years for PCI

	PCI (ANNUAL)	PCI (SEASONAL)	WINTER (D-J-F)	SPRING (M-A-M)	SUMMER (J-J-A)	AUTUM (S-O-N)	SUPRA-WET (OCT-MAR)	SUPRA-DRY (APR-SEP)
uniform precipitation	0	41	0	3	27	3	0	0
moderate distribution	0	54	10	12	70	25	1	28
irregular	1	6	13	15	3	29	11	49
strong irregular distribution	101	1	79	72	2	45	90	25
	102	102	102	102	102	102	102	102

Precipitation concentration index (PCI) was computed on Annual and Seasonal Scales and percentage of distribution of years in each ranges which was shown in above Tables. The

Annual PCI values vary from 20 to 45 which was representing in above figure.

Now, If PCI value is less or equal to 10 means low precipitation concentration, which indicates uniform monthly rainfall distribution for that particular year. The values of PCI between 11 and 15 define a moderate concentration of precipitation, which implies seasonality in rainfall distribution.

The PCI values exceeding 20 indicate that the rainfall distribution is having strong irregularity and higher concentration. On an annual scale, lower and higher PCI values are 22.6 (1974) and 45.01 (1991) respectively. As per the calculation of annual PCI, all the years have values greater than 20, which indicates the higher concentration of southwest monsoon.

5.4 Results of Aridity Indices

3. Estimation of various aridity index over the study area.

Aridity index (AI) is a numerical indicator of the degree of dryness of the climate at a given location. These indicators serve to identify and delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of agricultural land and water resources development. The focus of this objective is to determine the aridity of the drought prone areas. The classification of AI is given below Table 5.19, 5.20 and 5.21

Table 5.18 Aridity Indices

AI Values (UNESCO AI)	Climate Class
≤0.03	Hyper Arid
0.03-0.2	Arid
0.2-0.5	Semi-Arid
0.5-0.65	Dry Sub Humid
>0.65	Humid

Im Values (ERIC AI)	Climate Class
<8	Hyper Arid
8-15	Arid
15-23	Semi-arid
23-40	Dry sub humid
40-55	Humid
>55	Very Humid

AI Values (De Martonne AI)	Climate Class
≤5	Arid
5-12	Semi-arid
12-20	Dry Sub humid
20-30	Wet Sub humid
30-60	Humid
≥60	Very Humid

Table 5.19: Drought years obtain using Erinc Aridity Index

Classification	Range	Year
Arid	8-15	1904,1911,1915,1918,1923,1936,1939,1948,1951,1968 1969,1972,1974,1985,1986,1987,1995,2002
Semi-arid	15-23	1901,1902,1905,1907,1925,1928,1929,1930,1931,1932 1935,1938,1940,1949,1952,1957,1958,1960,1962,1964 1965,1966,1971,1978,1979,1982,1988,1989,1991,1992 1993,1999,2000,2001
Dry sub humid	23-40	1903,1906,1908,1909,1910,1912,1913,1914,1916,1917 1919,1920,1921,1922,1924,1926,1927,1933,1934,1937 1941,1942,1943,1945,1946,1947,1950,1953,1954,1955 1956,1959,1961,1963,1967,1970,1973,1975,1976,1977 1980,1981,1983,1984,1990,1994,1996,1997,1998
Humid	40-55	1944

Table 5.20: Drought years obtain using Thornthwaite's Precipitation Effectiveness Index

Classification	Range	Year
Arid	<16	1915
Semi-arid	16-31	1901,1904,1911,1918,1923,1936,1939,1940,1948,1951 1968,1969,1972,1974,1985,1986,1987,1995,2002
Dry sub humid	32-63	1902,1903,1905,1907,1909,1910,1912,1913,1914,1916 1920,1921,1922,1924,1925,1928,1929,1930,1931,1932 1935,1938,1942,1943,1946,1947,1949,1950,1952,1953 1955,1957,1958,1960,1961,1962,1964,1965,1966,1967 1970,1971,1976,1978,1979,1980,1981,1982,1983,1984 1988,1989,1990,1991,1992,1993,1996,1997,1998,1999 2000,2001
Wet sub humid	64-99	1906,1908,1917,1919,1926,1927,1933,1934,1937,1941 1944,1945,1954,1956,1959,1963,1973,1975,1977,1994

Table 5.21: Drought years obtain using Thornthwaite's Moisture Index

Classification	Range	Year
Wet semi-arid	-55 to -26	1915
Dry sub humid	-25 to 0	1904,1911,1923,1974,1987,2002
Wet sub humid	1 to 20	1918,1948,1951,1969
Humid	21 to 50	1901,1936,1939,1940,1960,1965,1968,1972,1979,1985 1986,1991,1995
Very humid	>50	1902,1903,1905,1906,1907,1908,1909,1910,1912,1913 1914,1916,1917,1919,1920,1921,1922,1924,1925,1926 1927,1928,1929,1930,1931,1932,1933,1934,1935,1937 1938,1941,1942,1943,1944,1945,1946,1947,1949,1950 1952,1953,1954,1955,1956,1957,1958,1959,1961,1962 1963,1964,1966,1967,1970,1971,1973,1975,1976,1977 1978,1980,1981,1982,1983,1984,1988,1989,1990,1992 1993,1994,1996,1997,1998,1999,2000,2001

This study provides a preliminarily idea about the climate of North Gujarat districts is mostly arid in nature. It is revealed that almost 37% of the area possess semi-arid to 18% as arid zone and 48% as dry sub humid in Sabarkantha district. The results show that the climate of whole North Gujarat districts is Arid to Dry Sub humid. In Northern Gujarat, evapotranspiration rate is very high and mostly crops are remained under water stress till reaching to maturity. So, Agricultural activity depends on proper irrigation rather than rainfall. It is conclude that Northern parts are most vulnerable to drought. The results will be useful in future for planning, designing and operating irrigation system and crop planning too.

5.5 Results of Frequency Analysis

4. To determine frequency of meteorological drought indices.

Table 5.22: Occurrences and Frequency of Meteorological Drought Indices

PN	Occurrence	Frequency
Extreme Dry	1	0.98
Severe Dry	7	6.86
Moderate Dry	17	16.67
Near Normal	42	41.18
Moderate Wet	35	34.31
Extreme Wet	0	0.00
Very Wet	0	0.00
Total	102	100

PD	Occurrence	Frequency
Extreme Dry	0	0.00
Severe Dry	7	6.86
Moderate Dry	16	15.69
Mild Dry	29	28.43
No Drought	50	49.02
Total	102	100.00

SPI 12	Occurrence	Frequency
Extreme dry	5	4.90
Severe dry	3	2.94
Moderate dry	9	8.82
Near normal	67	65.69
Moderate wet	12	11.76
Extreme wet	1	0.98
Very wet	5	4.90
Total	102	100

RDI 12	Occurrence	Frequency
Extreme dry	6	5.88
Severe dry	3	2.94
Moderate dry	8	7.84
NN-dry	26	25.49
NN-wet	41	40.20
Moderate wet	14	13.73
Extreme wet	0	0.00
Very wet	4	3.92
Total	102	100

SPEI 12	Occurrence	Frequency
Extreme dry	0	0.00
Severe dry	7	6.86
Moderate dry	12	11.76
NN	63	61.76
Moderate wet	10	9.80
Extreme wet	9	8.82
Very wet	1	0.98
Total	102	100

Figure 5.5: Percentage of Dry Period

From the Fig. it is shown that only 1% year is obtained as the extreme wet conditions in the last 102 years, because the average annual rainfall of district is only 520 mm. From the Fig., it reveals that out of the drought years, 36% years are categorized into moderate to extreme drought years, which includes 6% Extreme dry, 15% Severe dry and 15% Moderate dry years.

5.6 Results of Hydrological Drought Indices

5. Estimation of various hydrological drought indices.

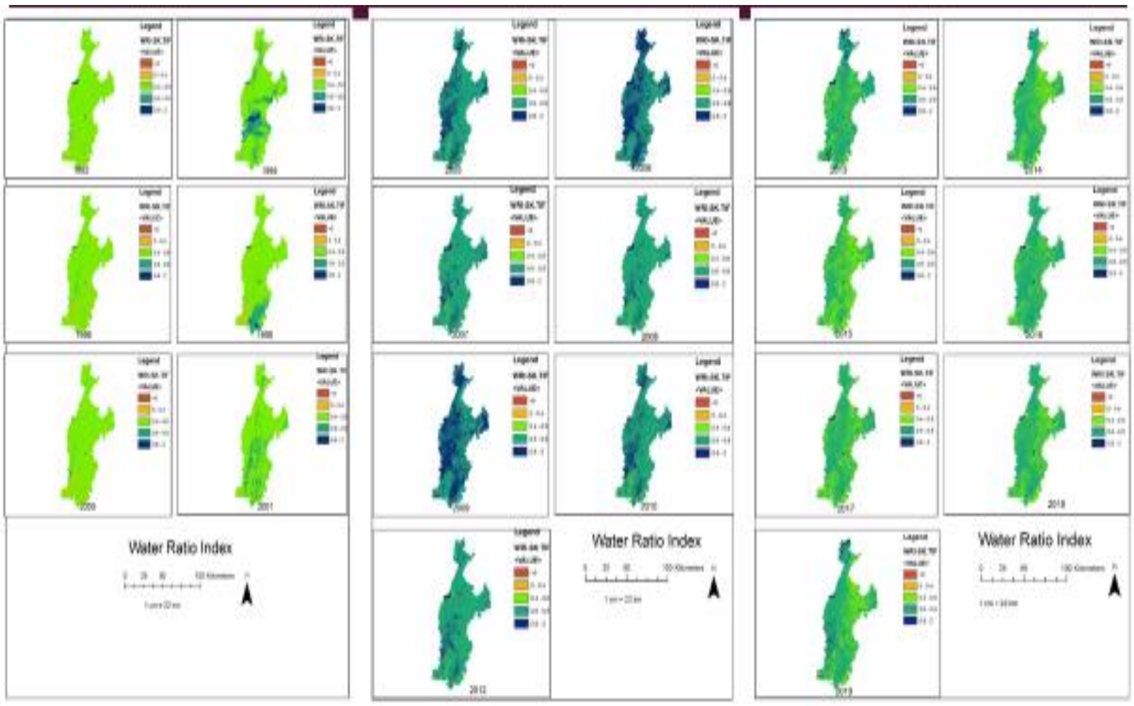


Figure 5.6: Water Ratio Index Map of Sabarkantha District

Table 5.23: Classification of Water Ratio Index

Sr. No	Classification	Range	WRI	WRI	WRI	WRI	WRI	WRI
			1992	**1994**	**1996**	**1998**	**2000**	**2001**
1	Extreme Dry	<0.00	0.0	0.0	0.0	0.0	0.0	0.0
2	Moderate Dry	0.00 to 0.40	98.5	9.1	178.3	163.8	170.5	41.9

3	Medium Dry	0.40 to 0.60	3967.6	3080.0	3882.4	3499.2	3909.5	3498.0
4	Moderate Water	0.60 to 0.80	94.6	982.1	113.7	478.8	98.2	588.2
5	High Water	> 0.80	27.8	117.4	14.1	46.7	10.3	60.4
	Total		4188.5	4188.5	4188.5	4188.5	4188.5	4188.5

Table 5.24: Classification of Normalised Difference Water Index

Sr. No	Classification	Range	NDWI	NDWI	NDWI	NDWI	NDWI	NDWI
			1992	**1994**	**1996**	**1998**	**2000**	**2001**
1	Very Low	< 0.00	4163.3	4170.9	4176.0	4168.0	4178.6	4177.5
2	Low Moisture	0.00 to 0.15	16.7	12.8	2.9	9.6	4.8	6.5
3	Moderate Moisture	0.15 to 0.30	8.3	4.8	8.5	10.2	3.9	4.0
4	High Moisture	0.30 to 0.45	0.1	0.0	1.2	0.6	1.0	0.5
5	Very High Moisture	> 0.45	0.0	0.0	0.0	0.0	0.2	0.0
	Total		4188.5	4188.5	4188.5	4188.5	4188.5	4188.5

Table 5.25: Classification of Normalised Difference Salinity Index

Sr. No	Classification	Range	NDSI	NDSI	NDSI	NDSI	NDSI	NDSI
			1992	**1994**	**1996**	**1998**	**2000**	**2001**
1	Low Saline	< 0.00	4150.6	3963.1	4131.6	4147.2	4122.7	3856.8
2	Medium Saline	0.00 to 0.25	37.2	225.3	54.8	36.6	64.5	329.9
3	High Saline	0.25 to 0.50	0.6	0.1	2.1	4.7	1.3	1.7
4	Very High Saline	> 0.50	0.0	0.0	0.0	0.0	0.1	0.0
	Total		4188.5	4188.5	4188.5	4188.5	4188.5	4188.5

This study indicates a considerable variation in water surface area of the district over a span of 1992 to 2019 years. The classification is given above Table 5.23, 5.24 and 5.25

Remote sensing based indices like WRI, NDWI and NDSI were employed to extract spatial information on Water and soil salinity of the study area respectively. The soil salinity in terms of NDSI increased in the study area. As high water ratio observed at that time the salinity level is reduced due to high ground water table.

5.7 Results of Frequency analysis

6. To determine frequency of hydrological drought indices over the study area.

Table 5.26: Frequency of Water Ratio Index

Classification	WRI	WRI	WRI	WRI	WRI	WRI	WRI
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Extreme Dry	0	0	0	0	0	0	0
Moderate Dry	0	0	0	0	0	0	0
Medium Dry	21	32	45	22	32	30	28

Moderate Water	75	67	54	77	68	69	68
High Water	4	1	1	1	1	1	4
Total	100	100	100	100	100	100	100

Table 5.27: Frequency of Normalised Difference Water Index

Classification	**NDWI 2013**	**NDWI 2014**	**NDWI 2015**	**NDWI 2016**	**NDWI 2017**	**NDWI 2018**	**NDWI 2019**
Very Low	63	72	76	74	76	71	78
Low Moisture	33	24	20	23	19	24	19
Moderate Moisture	4	4	4	3	4	5	2
High Moisture	0	0	0	0	0	0	0
Very High Moisture	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100

5.8 Results of Agricultural Drought Indices

7. To estimate different agricultural drought indices.

Long term sequence of Landsat data were used in the present study to monitor drought extent in North Gujarat district from 1992 to 2019. NDVI has become the main tool to describe vegetation phenology, which high NDVI values show healthy and dense vegetation.

In generally the value of NDVI is divided into non-vegetated land and vegetated land is classified as No vegetation (Less than 0.1), Very small vegetation (between 0.1 to 0.2), Small vegetation (between 0.2 to 0.3), Medium vegetation (between 0.3 to 0.4) and High vegetation (greater than 0.4). The classification is given below Table 5.28

The values of NDVI were difficult to obtain because of fluctuations of vegetation responses each month. Generally, high values of NDVI were recorded in wet seasons, while lowest values were in dry seasons. The diversity in NDVI indicates spatial variation in vegetation health within the study areas are presented in below tables and maps.

In year 2018, average rainfall in Sabarkantha district is only 427.15 mm due to which vegetation in the study area decreased drastically compare with the previous years. Also, the Land Surface Temperature in 2018 year lowest compare to other years. Similarly, in the year 2017, average rainfall in district is 912.30 mm where vegetation area is increases and LST is showing same trend as LST and NDVI is highly correlated with each other and with rainfall.

The comprehensive results suggested that North Gujarat districts remained moderately dry to severe dry. Analysed rainfall data also showed least or minimum rainfall for most of the region.

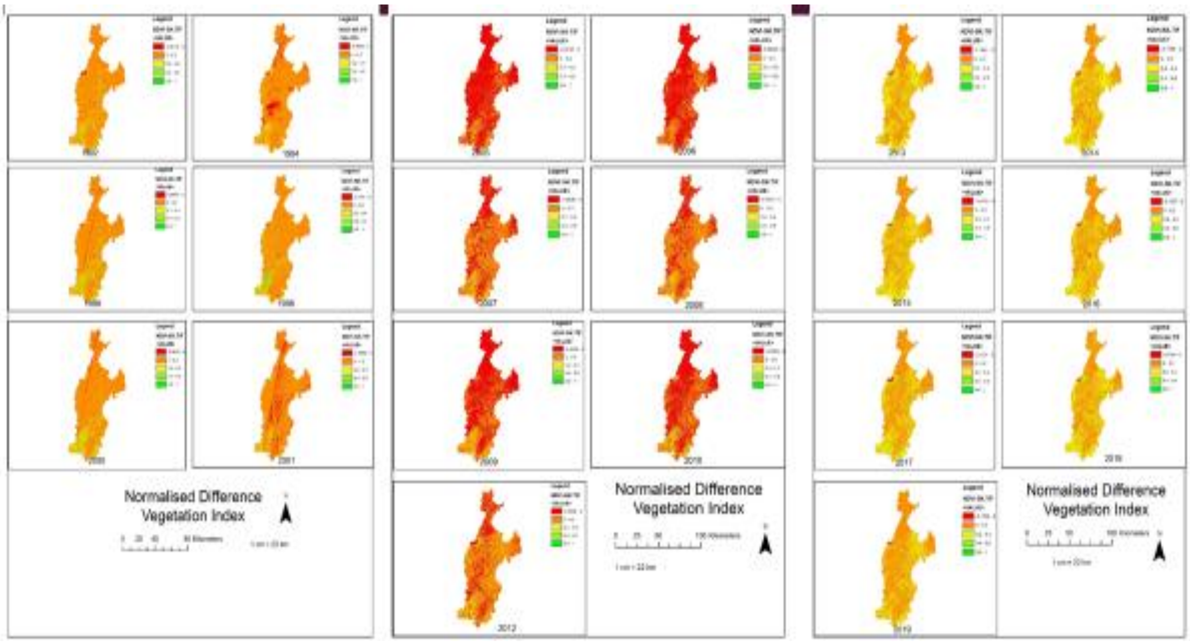


Figure 5.7: Normalised Difference Vegetation Index Map of Sabarkantha District

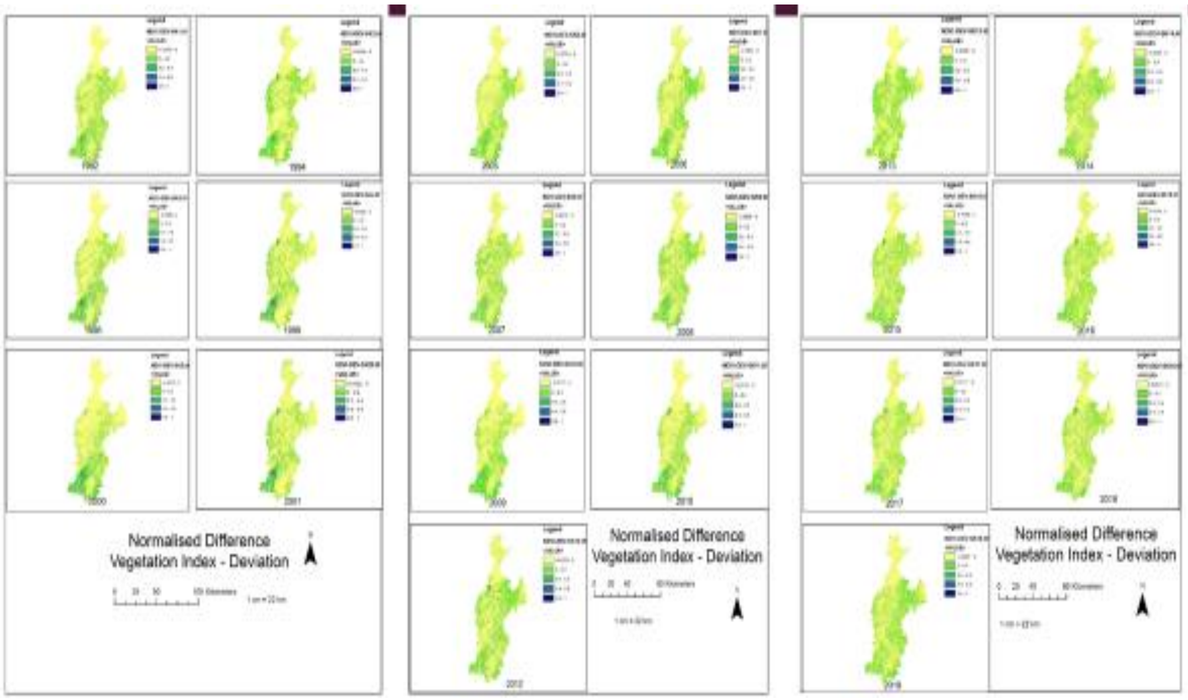


Figure 5.8: Normalised Difference Vegetation Index-Deviation Map of Sabarkantha District

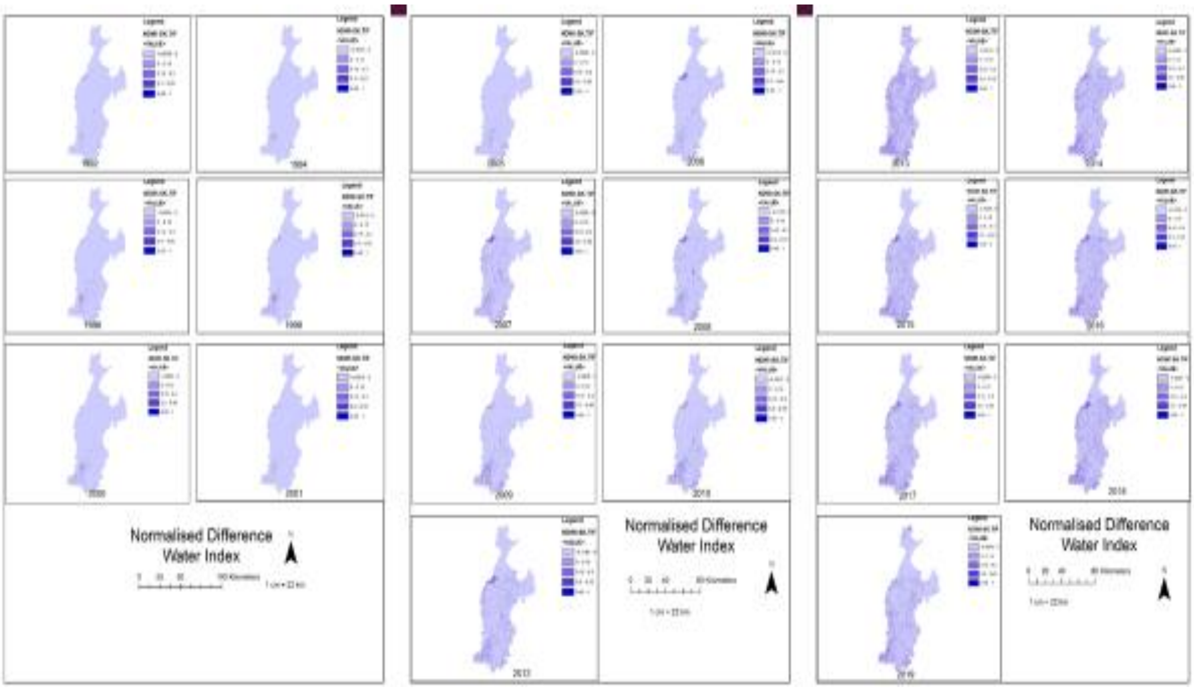


Figure 5.9: Normalised Difference Water Index Map of Sabarkantha District

Table 5.28: Classification of Normalised Difference Vegetation Index

Sr. No	Classification	Range	NDVI 1992	NDVI 1994	NDVI 1996	NDVI 1998	NDVI 2000	NDVI 2001
1	**Extreme Dry**	< 0	45.61	309.86	74.86	48.37	91.74	440.22
2	**Severe Dry**	0.0 to 0.2	3660.08	3578.79	3514.17	3594.25	3568.88	3466.02
3	**Moderate Dry**	0.2 to 0.4	403.71	272.54	433.24	395.54	369.77	228.35
4	**Moderate Wet**	0.4 to 0.6	78.92	27.29	158.80	121.63	155.90	52.11
5	**Extreme Wet**	> 0.6	0.18	0.01	7.44	28.69	2.21	1.79
	Total		4188.50	4188.50	4188.51	4188.49	4188.50	4188.48

Classification	Range	NDVI 2013	NDVI 2014	NDVI 2015	NDVI 2016	NDVI 2017	NDVI 2018	NDVI 2019
Extreme Dry	< 0	13.87	18.52	23.83	21.43	25.52	20.63	15.10
Severe Dry	0.0 to 0.2	2518.0	2358.7	2297.1	2648.8	2652.5	2486.7	2890.5
Moderate Dry	0.2 to 0.4	1597.5	1726.1	1726.9	1457.5	1381.7	1545.2	1217.1
Moderate Wet	0.4 to 0.6	59.03	85.13	140.62	60.74	128.71	136.15	65.74
Extreme Wet	> 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		4188.4	4188.5	4188.5	4188.5	4188.5	4188.5	4188.5

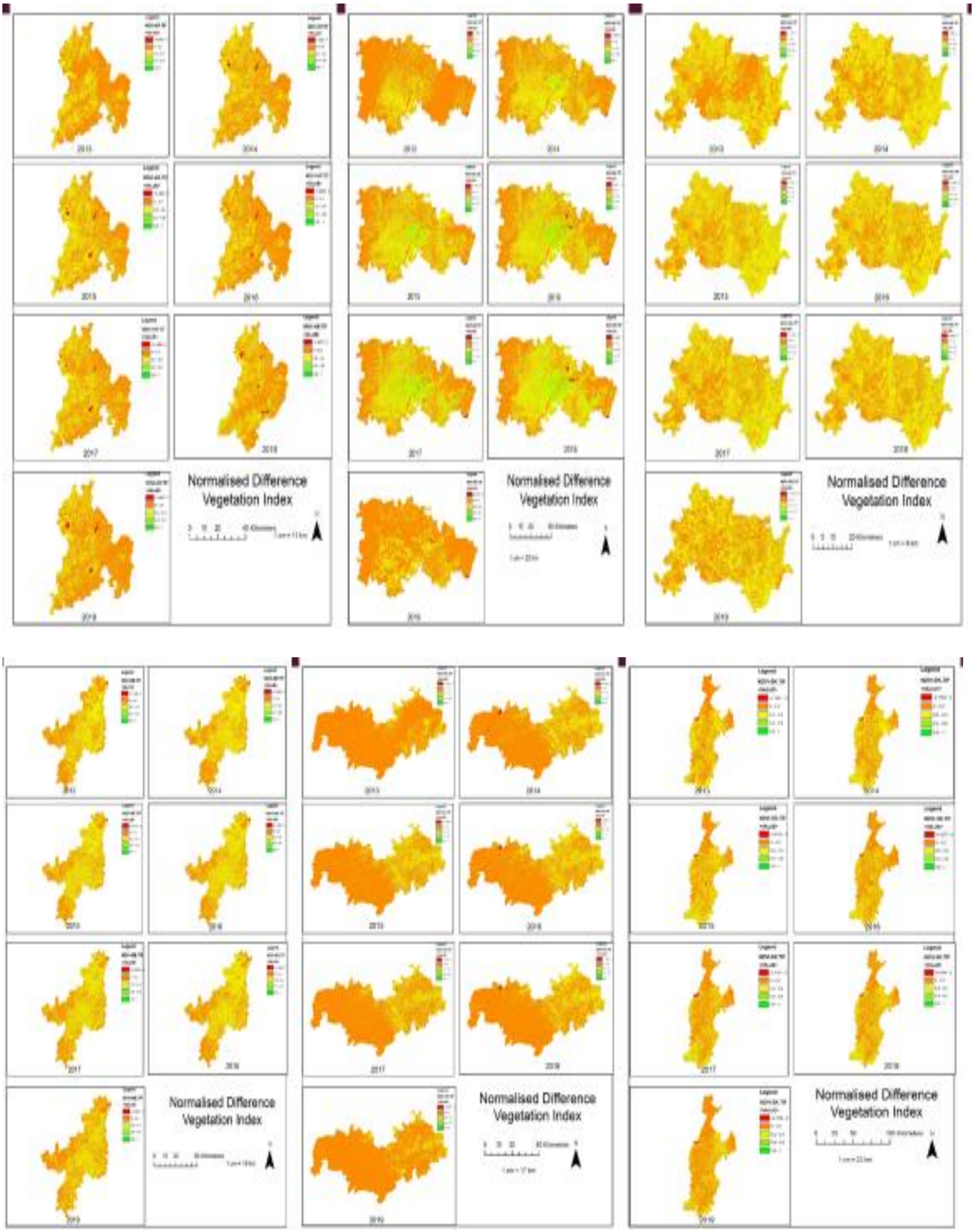


Figure 5.10: Normalised Difference Vegetation Index Map of North Gujarat District

5.9 Results of Vegetation Stress by Remote sensing techniques

8. Computation of vegetation stress by remote sensing techniques.

Table 5.29: Classification of Vegetation Stress using NDVI

Sr. No	Classification	RANGE	NDVI	NDVI	NDVI	NDVI	NDVI	NDVI
			1992	**1994**	**1996**	**1998**	**2000**	**2001**
1	**No Vegetation**	-1 to 0	45.6	309.9	74.9	48.4	91.7	440.2
2	**Slight Vegetation**	0.01 to 0.30	3934.9	3772.7	3784.5	3871.4	3800.0	3614.2
3	**Moderate Vegetation**	0.31 to 0.60	207.8	105.9	321.7	240.0	294.6	132.3
4	**High Vegetation**	0.61 to 1.0	0.2	0.0	7.4	28.7	2.2	1.8
	Total		4188.5	4188.5	4188.5	4188.5	4188.5	4188.5

Table 5.30: Classification of Vegetation Stress using SAVI

SR NO	Classification	RANGE	SAVI	SAVI	SAVI	SAVI	SAVI	SAVI
			1992	**1994**	**1996**	**1998**	**2000**	**2001**
1.0	**No Vegetation**	< 0.00	45.6	309.9	74.9	48.4	91.7	440.2
2.0	**Slight Dense**	0.00 to 0.30	3670.7	3586.6	3524.9	3606.2	3577.0	3471.2
3.0	**Moderate Dense**	0.30 to 0.60	394.2	265.3	424.5	384.8	363.0	223.8
4.0	**Highly Dense**	> 0.60	77.9	26.7	164.3	149.2	156.7	53.2
	TOTAL		4188.5	4188.5	4188.5	4188.5	4188.5	4188.5

Table 5.31: Classification of Drought using VCI

Sr No	Classification	Range	VCI	VCI	VCI	VCI	VCI	VCI
			1992	**1994**	**1996**	**1998**	**2000**	**2001**
1.0	**Extreme Drought**	< 10	0.0	0.0	0.0	0.0	0.0	0.0
2.0	**Severe Drought**	10 to 20	0.0	0.0	0.0	7.7	0.0	0.4
3.0	**Moderate Drought**	20 to 30	2.5	3.1	5.3	7.9	0.4	1.2
4.0	**Light Drought**	30 to 40	18.8	20.1	7.3	375.2	1.8	4.3
5.0	**No Drought**	> 40	4132.6	4165.3	4175.8	3797.6	4186.3	4182.6
	TOTAL		4188.5	4188.5	4188.5	4188.5	4188.5	4188.5

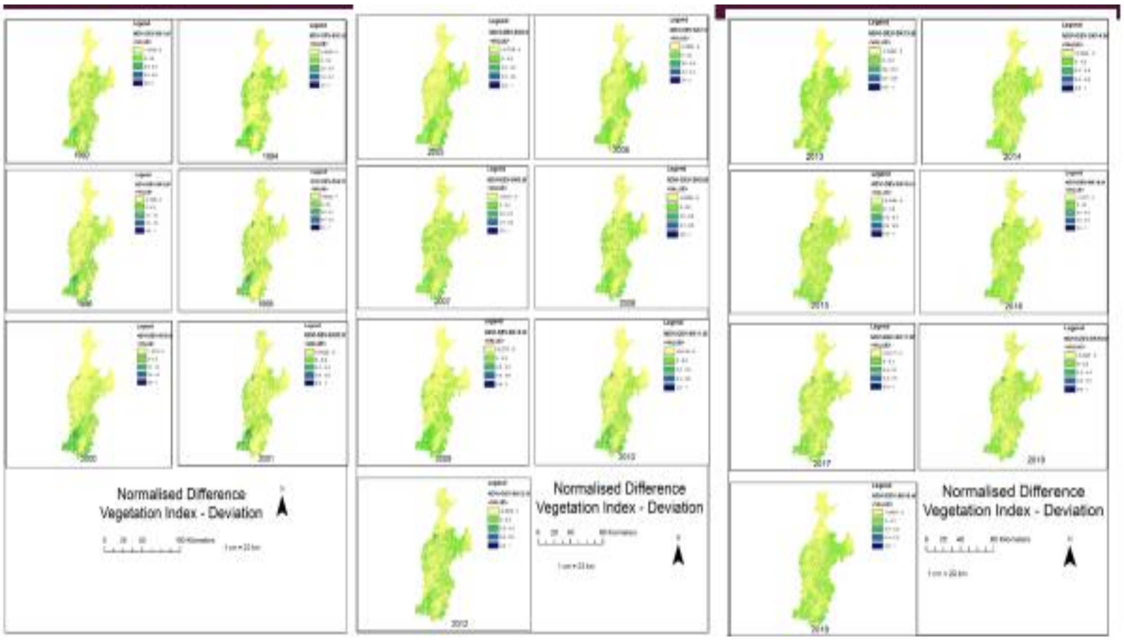


Figure 5.11: Vegetation Index Map of Sabarkantha District

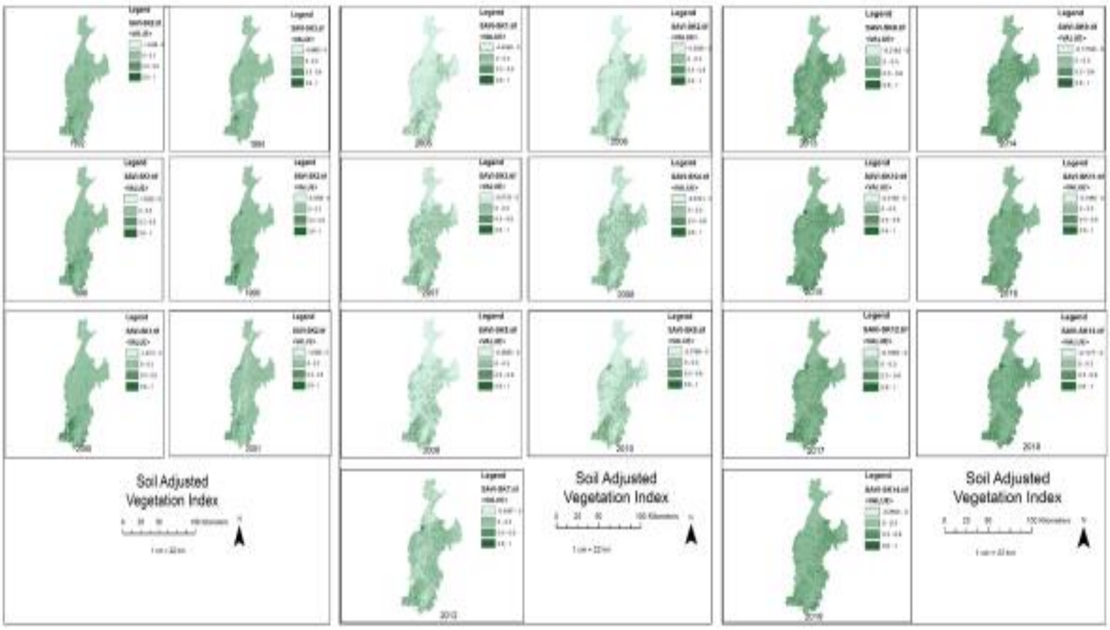


Figure 5.12: Soil Adjusted Vegetation Index Map of Sabarkantha District

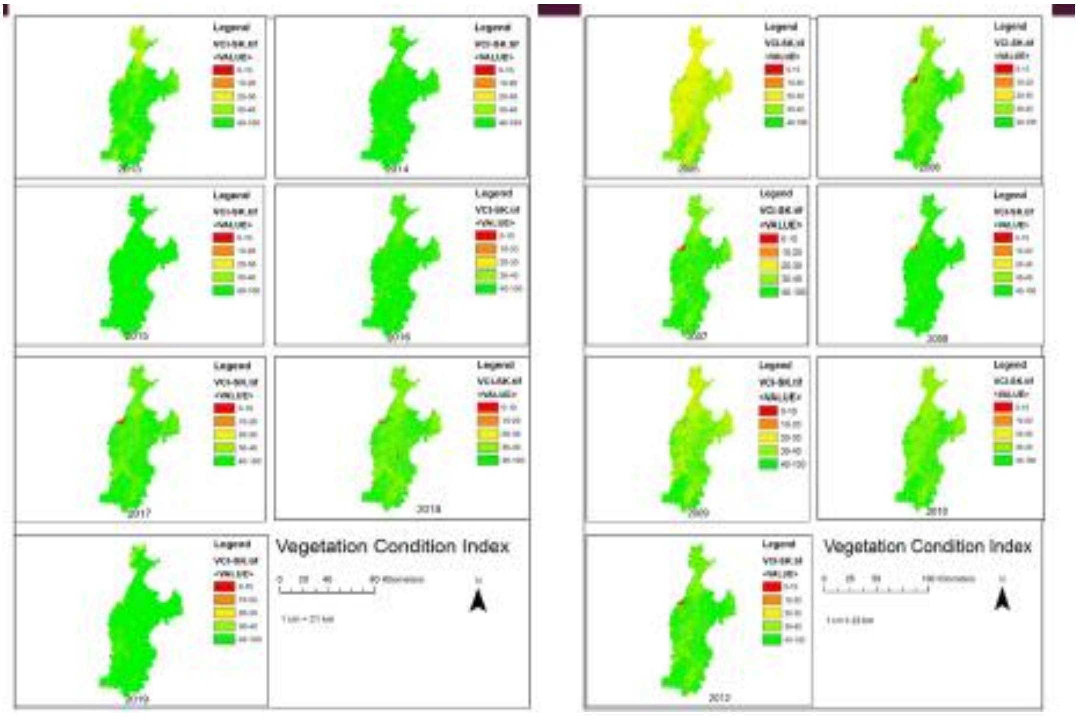


Figure 5.13: Vegetation Condition Index Map of Sabarkantha District

The data analysed here result is focused on April-May month because southwest monsoon mainly starts from July to September is the main time period for agriculture and at the end of season if the area is suffering from drought it means the entire area will be affected by dry condition.

In the above computations of NDVI it was observed that the satellite image of the year 2001 shows the maximum area (440.2 sq.km) fall in the no vegetation category; whereas the year 1992 and 1998 have less percentage of vegetation (about 45.6 sq.km and 48.4 sq.km). The SAVI index was used to study soil moisture, which is the most important factor to maintain crop health. The value of SAVI index is positive, then the area is less affected by drought, if difference value is less than zero then the area is highly affected by drought.

It is also found that in the year 2013 and 2018 more than 60% of area is under dry condition. The results shows that NDVI decreased by 4% to 6% and NDWI decreased by 1% to 2% in the study area, while LST shows a significant increase by 0.35ºC–2.5°C. The maximum LST observed in each year was increasing in all districts. The strong positive correlation found between LST and NDBI means more be the built-up area high is the surface temperature. This study suggests that the effect of drought could be reduced through involving the smallholder farmers in a wide range of on and off-farm practices. This study may help to improve the existing agricultural drought monitoring systems carried out in North Gujarat in general and Sabarkantha in particular.

5.10 Results of Trend analysis of Drought Indices

9. Trend and correlation analysis of drought indices.

In the present study monthly rainfall variability and percentage contribution of rainfall is studied and Non parametric trend test i.e., Mann-Kendall (MK) Test have been used together with the Sen's Slope Estimator for the determination of determine whether there is any positive or negative trend in the rainfall data with their statistical significance.

The objective of this study is to detect drought trends, annual rainfall pattern at statistical significance at multiple time scales as per Mann-Kendall and Sen's slope estimator over the North Gujarat Agro climatic zones. In this study, Meteorological drought is considered and SPI, RDI, SPEI. From the results and analysis it was observed that Rainfall during July is the highest 369.32 mm which contributes to 37.76% of annual rainfall (978.07 mm), followed by August 230.63 mm contributes (23.58%). Rainfall in June and September contributes to 16.07% and 17.87% of the annual rainfall respectively. For temperature January, February, March, April, May, June, September, October, November, December there is an evidence of rising trend while Zc value is showing negative trend in July, August. The results is given below Table 5.32

This study provides the information on rainfall trend on long-term basis and the impact of climate change on different parts of the basin which will be very useful for water resource management, agriculture and economic development of the region.

Table 5.32: Mann Kendall Trend Test and Sen's Slope Estimator of SPI, RDI and SPEI

Time series	Test Z	B
SPI 3	1.61	-0.25
SPI 4	1.46	-0.22
SPI 5	1.02	-0.14
SPI 6	0.93	-0.17
SPI 7	0.73	-0.18
SPI 8	-0.07	0.19
SPI 9	-0.29	0.13
SPI 10	-1.37	0.39
SPI 11	-0.91	0.27
SPI 12	-0.94	0.23

Time series	Test Z	B
RDI 3	1.60	0.0630
RDI 4	1.44	0.0408
RDI 5	1.00	0.0817
RDI 6	0.93	0.0345
RDI 7	0.68	0.0276
RDI 8	-0.10	0.2948
RDI 9	-0.32	0.2092
RDI 10	-1.41	0.4417
RDI 11	-0.94	0.3158
RDI 12	-0.96	0.2683

Time series	Test Z	B
SPEI 3	-1.03	0.094
SPEI 4	-0.85	0.053
SPEI 5	-1.83	0.204
SPEI 6	-0.74	0.071
SPEI 7	-1.55	0.356
SPEI 8	-1.10	0.263
SPEI 9	-1.09	0.223
SPEI 10	-1.06	0.205
SPEI 11	-1.00	0.188
SPEI 12	-0.94	0.178

Figure 5.14: Trend Analysis of Meteorological Drought Indices

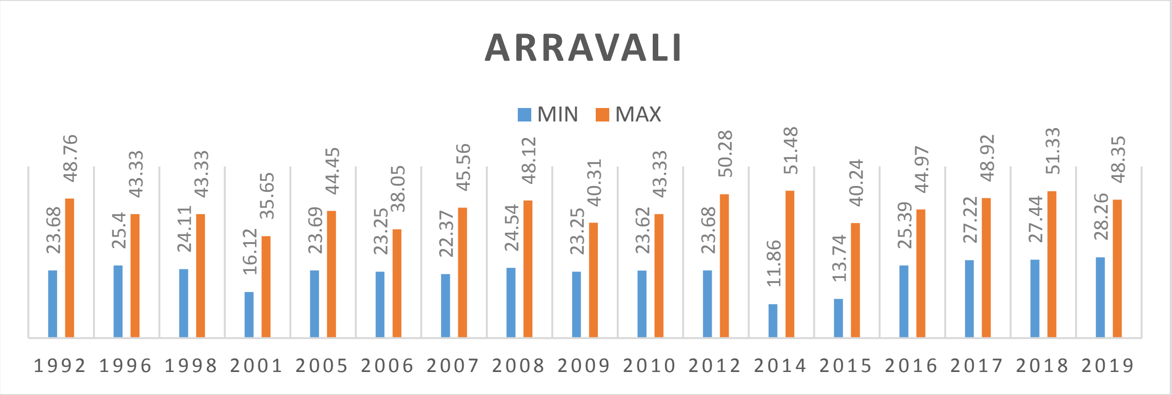
The trend analysis techniques were applied to the SPI values calculated from the 3-month to 12- month time scales. The z statistics obtained from both MK and SR tests for all districts were analysed and concluded that positive value indicates an increasing trend and negative value shoes decreasing trend. It is clearly seen from the results, for all time scales, all stations showed statistically significant downward trend. Both techniques yielded similar results for all time periods and stations. The z values for MK ranges from 1.60 to -0.94. For SPI 3 the Z statistic value is 1.61, SPI -4 the Z statistics value is 1.46, similarly for SPI-12 the value is decreasing and Z statistics value is -0.94. The same trend is observed for RDI, SPEI.

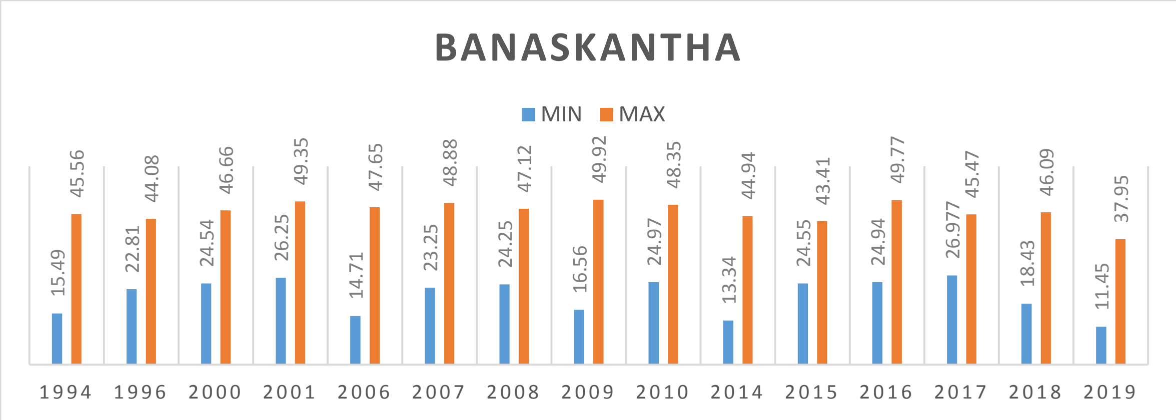
5.11 Results of Drought Severity Maps.

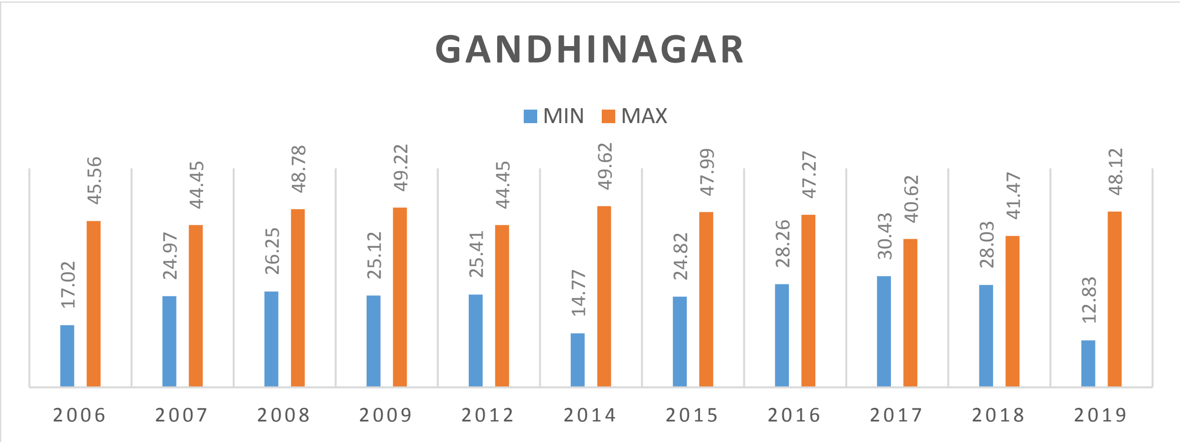
10. Generation of drought severity maps.

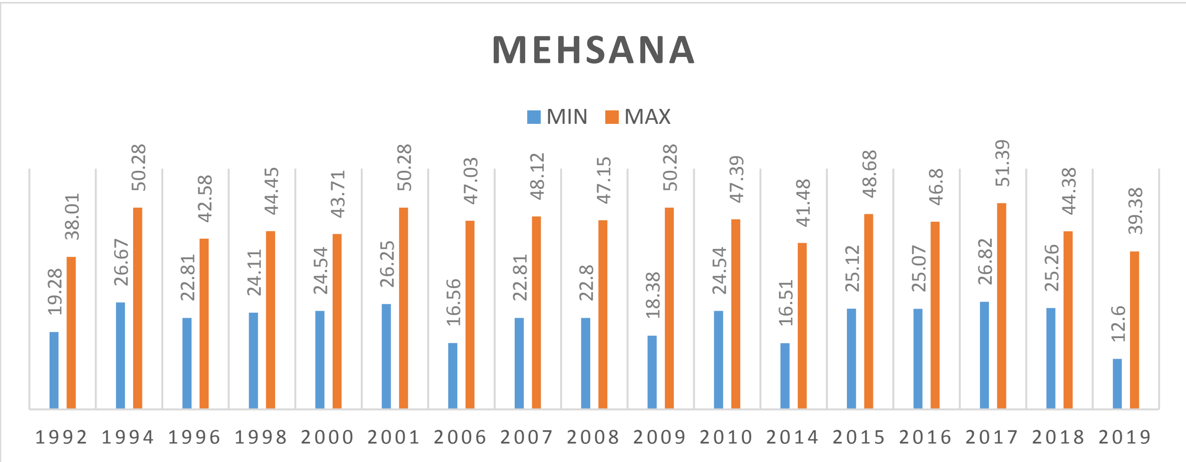
Land surface temperature acquired from satellite data represents the surface temperatures of each object within a pixel, which may be composed of several land cover types. With the help of above described equations processing of Landsat-8 thermal band 10, has been done in ArcGIS and LST maps of the study area were prepared.
LST maps were prepared from satellite data analysis represents the spatial distribution of surface temperature in the watershed. LST analysis has shown higher surface temperature in built-up and bare surfaces and low in healthy vegetated areas. The maximum LST observed in each season was 28, 40 and 380C respectively. Dry soil is usually visualized by high LST. Below table indicates that LST increased significantly from 2005 to 2010, but it decreased slightly in 2014 and 2015. Generally, dry condition has high LST and low NDVI.

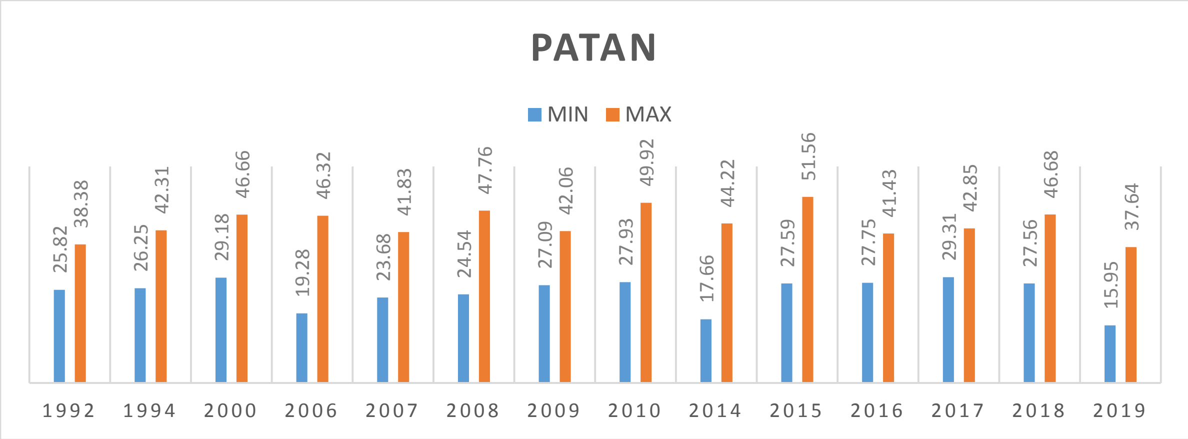
The results indicated that VHI decreased more than 50 percent, from 30.86 in 2000 to 14.66 in 2015.This figure implied that drought extent in research area has been significant throughout, from mild drought to severe drought. The LST when correlated with the vegetation index it can be used to detect the agricultural drought of a region, as demonstrated in this work.
This study attempts to identify the spatio-temporal extent of agricultural drought over Subang and Karawang using satellite-borne remote sensing data based on Vegetation Health Index (VHI).




BANASKANTHA
MIN
MAX
15.49
45.56
22.81
44.08
24.54
46.66
26.25
49.35
14.71
47.65
23.25
48.88
24.25
47.12
16.56
49.92
24.97
48.35
13.34
44.94
24.55
43.41
24.94
49.77
26.977
45.47
18.43
46.09
11.45
37.95
1994
1996
2000
2001
2006
2007
2008
2009
2010
2014
2015
2016
2017
2018
2019


GANDHINAGAR
MIN
MAX
17.02
45.56
24.97
44.45
26.25
48.78
25.12
49.22
25.41
44.45
14.77
49.62
24.82
47.99
28.26
47.27
30.43
40.62
28.03
41.47
12.83
48.12
2006
2007
2008
2009
2012
2014
2015
2016
2017
2018
2019


MEHSANA
MIN
MAX
19.28
38.01
26.67
50.28
22.81
42.58
24.11
44.45
24.54
43.71
26.25
50.28
16.56
47.03
22.81
48.12
22.8
47.15
18.38
50.28
24.54
47.39
16.51
41.48
25.12
48.68
25.07
46.8
26.82
51.39
25.26
44.38
12.6
39.38
1992
1994
1996
1998
2000
2001
2006
2007
2008
2009
2010
2014
2015
2016
2017
2018
2019



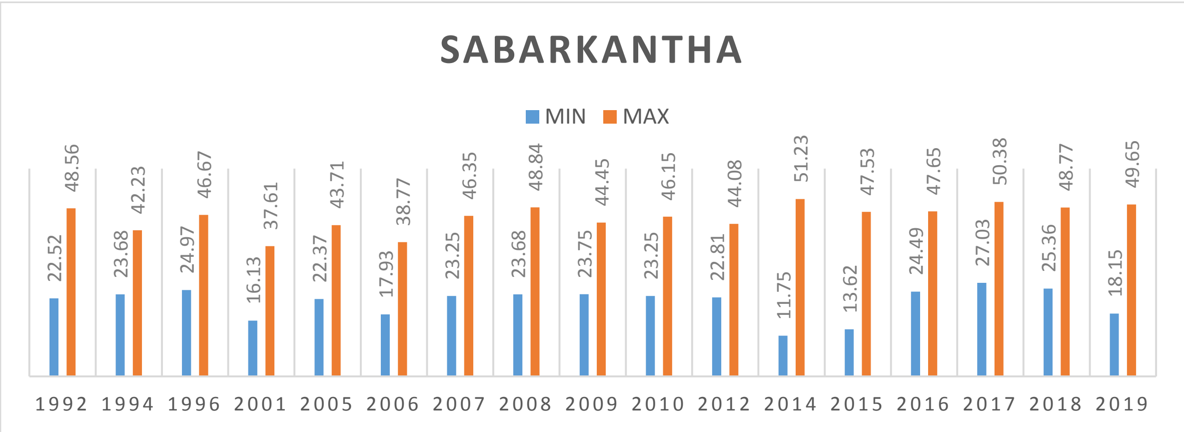
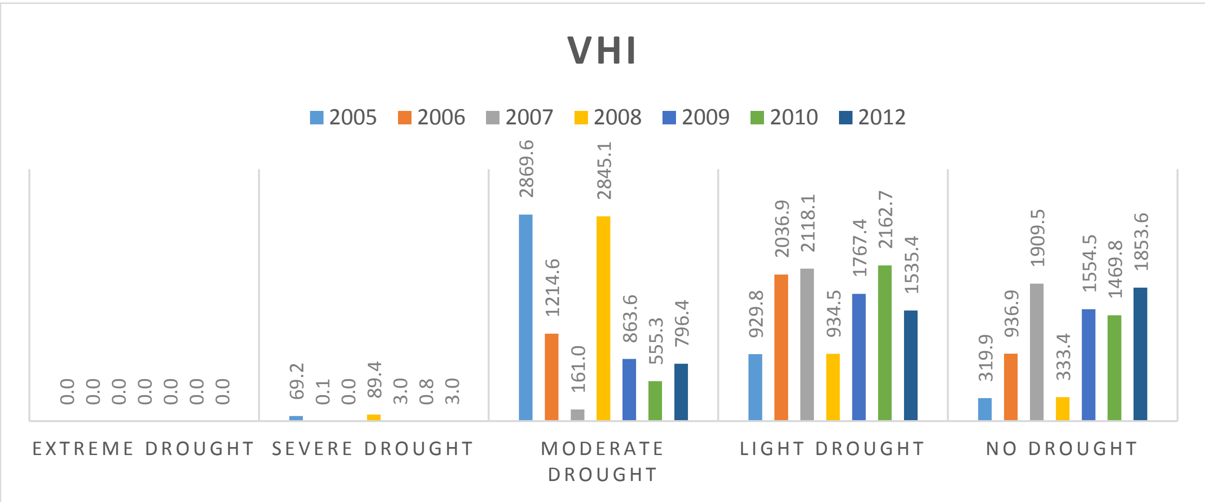


Figure 5.15: Land Surface Temperature of North Gujarat Districts



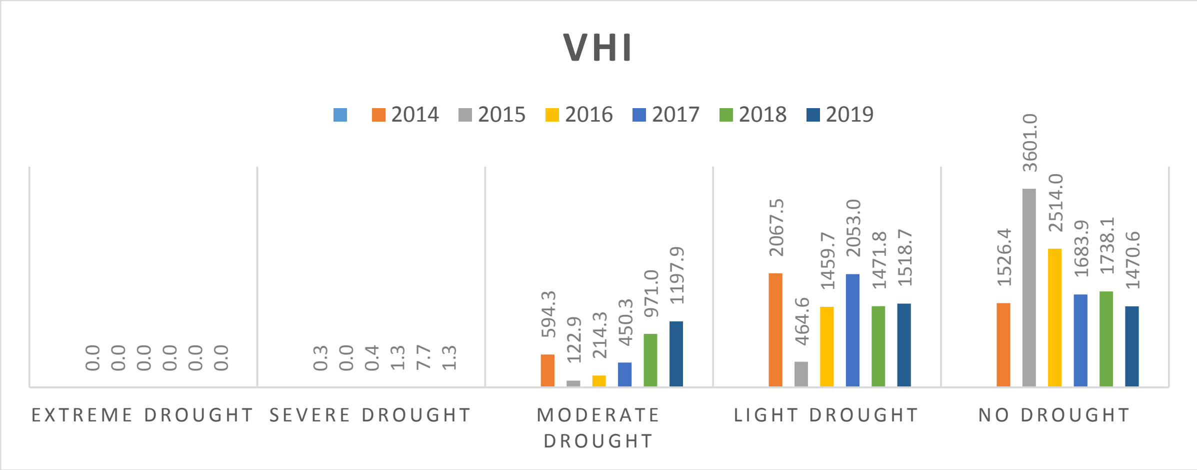


Figure 5.16: Classification Drought using VHI

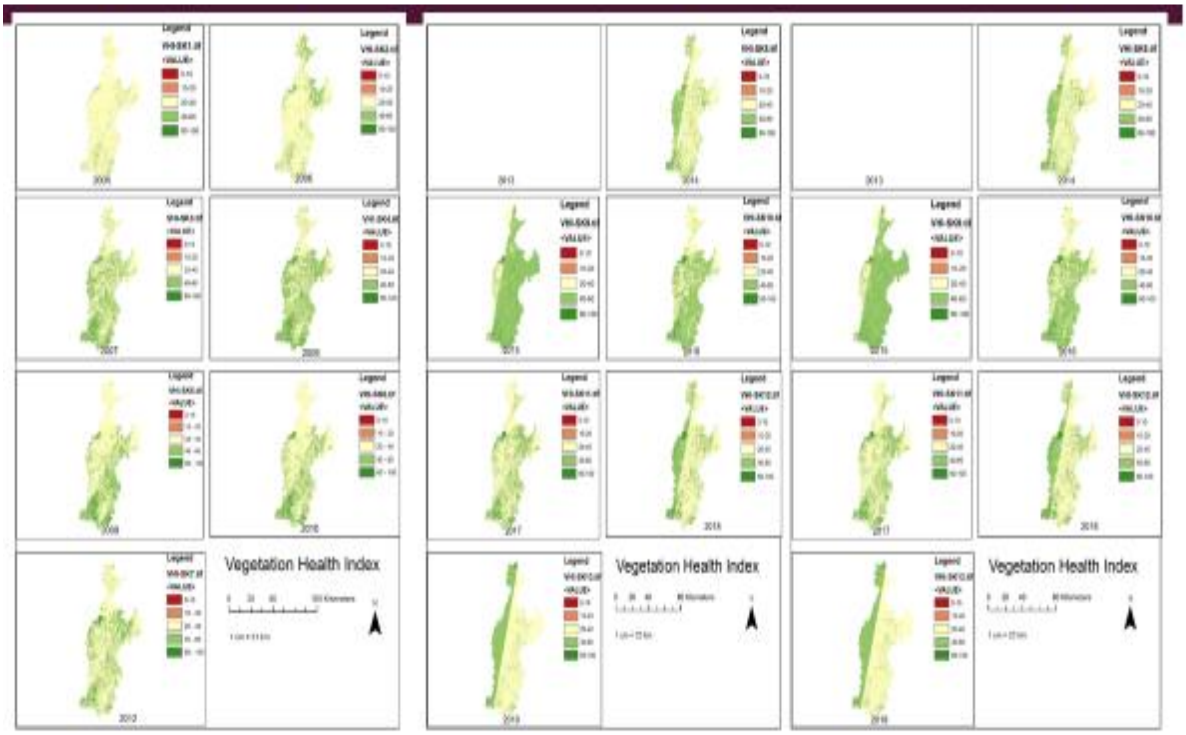
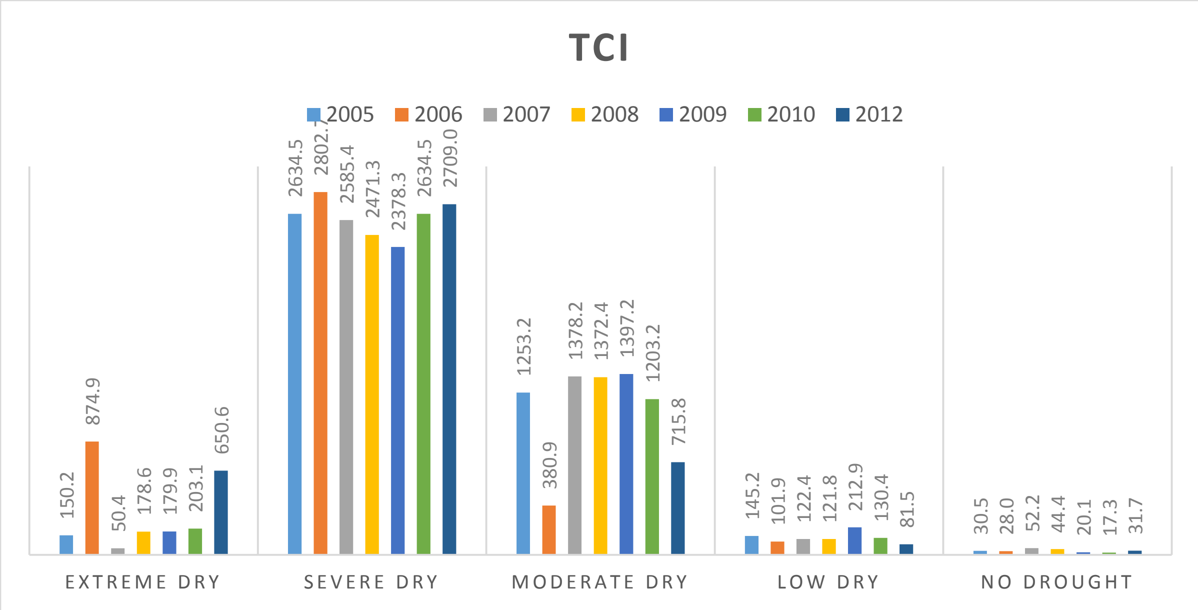


Figure 5.17: Vegetation Health Index Map of Sabarkantha District



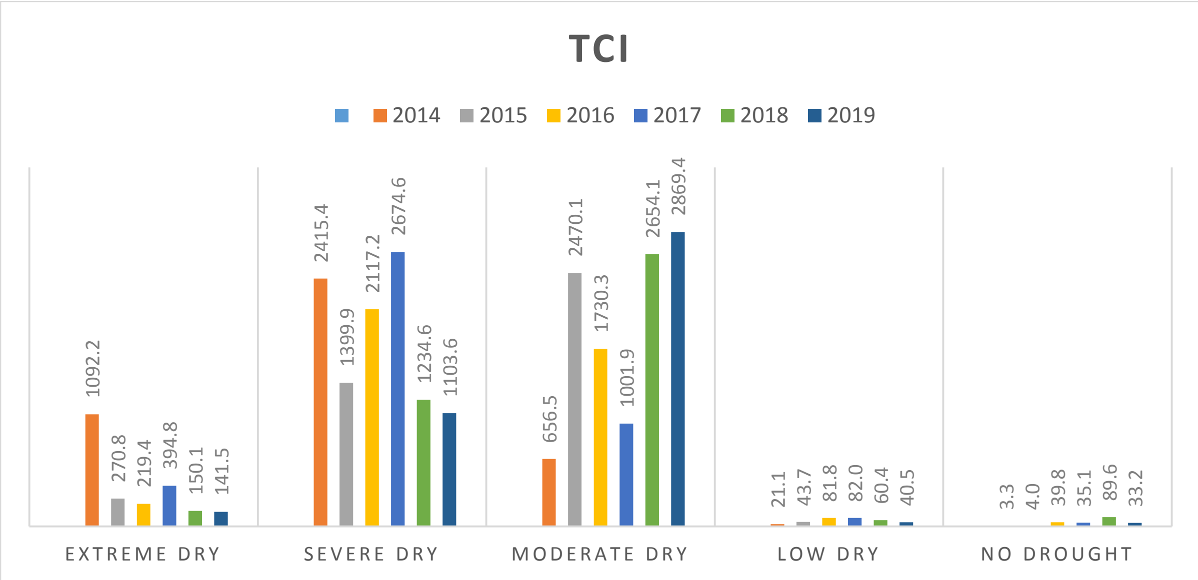


Figure 5.18: Classification Drought using TCI

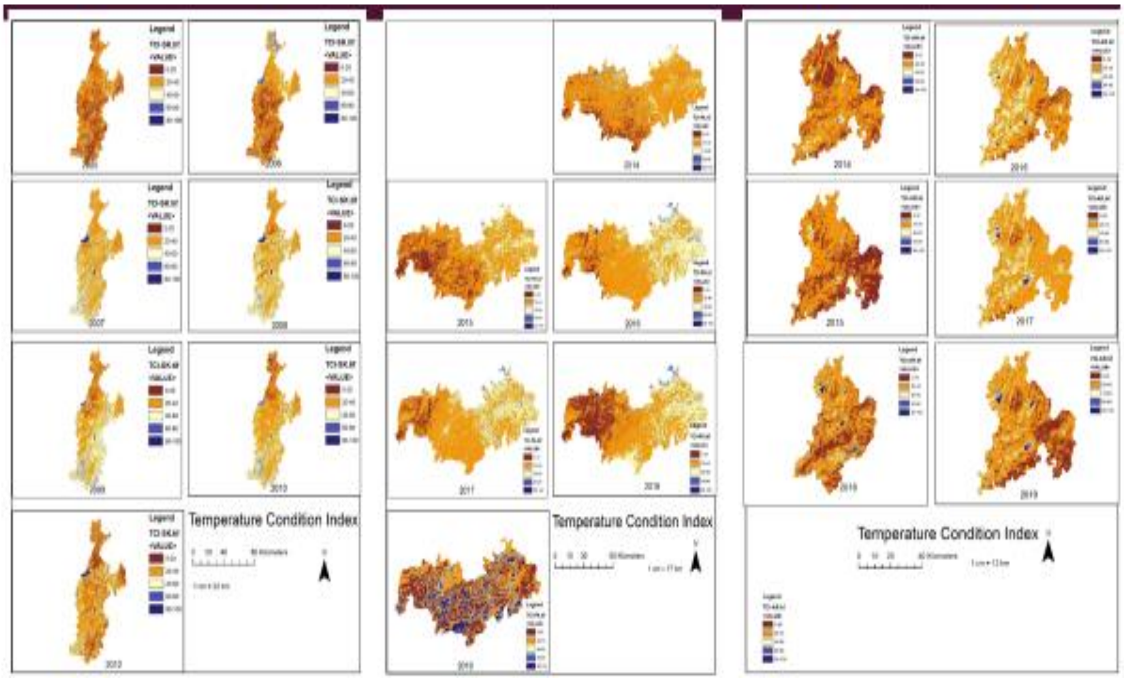


Figure 5.19: Temperature Condition Index Map of North Gujarat District

In addition, it can also be employed to explain drought severity classes in the research areas through composite analysis of both vegetation health by vegetation condition and temperature condition of vegetation. The results of VHI estimates can contribute to monitoring onset of agricultural drought as early warning system.

The high value of TCI index indicates that the healthy condition of the crop. The TCI value of the year 2007, 2008, 2009 and 2010 are below the normal range. Since the rainfall was less than normal, temperature remains high, as a result low TCI values were observed.

5.12 Results of comparisons matrix of various developed drought indices over study area.

11. To construct comparisons matrix of various developed drought indices over study area.

Table 5.33: Correlation Matrix of Meteorological Drought Indices

	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
SPI 3	1									
SPI 4	0.90277	1								
SPI 5	0.8722	0.95846	1							
SPI 6	0.8488	0.92763	0.96739	1						
SPI 7	0.82961	0.91793	0.96012	0.98859	1					
SPI 8	0.66813	0.74712	0.7862	0.77797	0.78123	1				
SPI 9	0.3618	0.41567	0.39792	0.33699	0.33405	0.46449	1			
SPI 10	-0.0352	0.0291	0.00482	-0.0281	-0.0322	0.01272	0.42595	1		
SPI 11	0.0004	0.0964	0.0971	0.05791	0.05672	0.0606	0.34628	0.76891	1	
SPI 12	0.01252	0.10718	0.09919	0.06314	0.05711	0.03012	0.26952	0.68657	0.90088	1

	RDI 3	RDI 4	RDI 5	RDI 6	RDI 7	RDI 8	RDI 9	RDI 10	RDI 11	RDI 12
RDI 3	1									
RDI 4	0.8498	1								
RDI 5	0.78016	0.92059	1							
RDI 6	0.74381	0.86459	0.93458	1						
RDI 7	0.72824	0.85494	0.92966	0.98993	1					
RDI 8	0.58161	0.70563	0.77473	0.78146	0.7842	1				
RDI 9	0.4233	0.52268	0.50942	0.41725	0.4113	0.52776	1			
RDI 10	-0.0157	0.07967	0.03243	-0.0071	-0.0145	-0.0034	0.37216	1		
RDI 11	-0.0175	0.10882	0.10007	0.06221	0.05545	0.0331	0.30444	0.76132	1	
RDI 12	-0.0121	0.11282	0.09219	0.05403	0.04254	-0.0008	0.23287	0.68408	0.90777	1

	SPEI 3	SPEI 4	SPEI 5	SPEI 6	SPEI 7	SPEI 8	SPEI 9	SPEI 10	SPEI 11	SPEI 12
SPEI 3	1									
SPEI 4	0.918042	1								
SPEI 5	0.460433	0.479612	1							
SPEI 6	0.116329	0.100282	0.29447	1						
SPEI 7	0.062285	0.043733	0.084286	0.494457	1					
SPEI 8	0.098769	0.092627	0.062117	0.401563	0.777118	1				
SPEI 9	0.06116	0.056118	-0.02825	0.309056	0.680985	0.891945	1			
SPEI 10	0.047632	0.047903	-0.03936	0.299364	0.666912	0.882208	0.997985	1		
SPEI 11	0.051006	0.050828	-0.03857	0.295515	0.662408	0.881314	0.995892	0.998271	1	
SPEI 12	0.051333	0.050394	-0.03938	0.298377	0.662034	0.88292	0.995864	0.998091	0.999756	1

	CZI 3	CZI 6	CZI 9	CZI 12
CZI 3	1			
CZI 6	0.158215	1		
CZI 9	-0.04533	0.19045	1	
CZI 12	-0.01649	0.196268	0.951246	1

	MCZI 3	MCZI 6	MCZI 9	MCZI 12
MCZI 3	1			
MCZI 6	0.202573	1		
MCZI 9	-0.08046	0.199261	1	
MCZI 12	-0.04116	0.196442	0.951318	1

Selection of time step in identification of onset of any long term drought is very important. The results is given above Table 5.33

Drought indices compared at 3-month time step may lead to erroneous assessment of drought characteristics because sometimes a short term excess may terminate the long term drought and divide a prevailing drought event in to two short events and this may not be appropriate.

Therefore, while comparing drought indices, the drought severity should be computed using higher time step of the drought index. The time step should be chosen in such a way, so that at least one significant rainfall month is included in the time step.

A correlation matrix of comparison of SPI, RDI and SPEI values for the Sabarkantha district was carried out at 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 months was carried out. Results showed significant correlations and non-significant correlations.

Comparison of SPI, RDI, SPEI, CZI, and MCZI indicated that all these indices are highly correlated for same timesteps and the correlation increases at higher time step with higher correlations at 9 and 12-month timesteps. The classification of Meteorological drought indices is given below Table 5.34

Table 5.34: Drought Years obtain using various Meteorological Drought Indices

PN		
Classification	**Range**	**Year**
Severe Drought	-50 to -75	1904,1911,1915,1923,1974,1987,2002
Moderate Drought	-25 to -50	1901,1918,1936,1939,1940,1948,1951,1960,1965, 1968,1969,1972,1985,1986,1991,1995
Mild Drought	0.0 to -25	1902,1903,1905,1907,1925,1928,1929,1930,1931, 1932,1935,1938,1949,1952,1957,1958,1962,1964, 1966,1971,1978,1979,1982,1988,1989,1992,1993, 1999,2000,2001

PD		
Classification	**Range**	**Year**
Severe Drought	-50 to -75	1904,1911,1915,1923,1948,1974,1987
Moderate Drought	-25 to -50	1901,1918,1936,1939,1940,1951,1965,1968,1969,1972, 1979,1985,1986,1991,1995,1999,2002
Mild Drought	0.0 to -25	1902,1903,1905,1920,1925,1928,1929,1930,1931,1932, 1935,1938,1957,1958,1960,1962,1964,1966,1971,1978, 1982,1989,1992,1993,1997,2000,2001

RAINFALL ANAMOLY INDEX		
Classification	**Range**	**Year**
Extremely dry	≤ -3.0	1904,1911,1915,1923,1974,1987
Very dry	-2.0 to -2.99	1918,1948,1951,1968,1969,1972,2002
Moderate dry	-1.0 to -1.99	1901,1902,1905,1925,1936,1939,1940,1957,1960, 1962,1964,1965,1966,1979,1985,1986,1991,1992, 1995,1999,2000

DECILES		
Classification	**Range**	**Year**
Much Below Normal	01-02	1901 – 1902,1904 – 1905,1911 – 1912,1915 – 1916, 1918 – 1919,1923 – 1924,1936 – 1937,1939 – 1940, 1940 – 1941,1948 – 1949,1951 – 1952,1968 – 1969, 1969 – 1970,1972 – 1973,1974 – 1975,1985 – 1986, 1986 – 1987,1987 – 1988,1991 – 1992,1995 – 1996, 2002 – 2003
Below Normal	03-04	1902 – 1903,1905 – 1906,1925 – 1926,1928 – 1929, 1932 – 1933,1957 – 1958,1960 – 1961,1962 – 1963, 1964 – 1965,1965 – 1966,1966 – 1967,1971 – 1972, 1978 – 1979,1979 – 1980,1982 – 1983,1989 – 1990, 1992 – 1993,1999 – 2000,2000 – 2001,2001 – 2002

SPI 12		
Classification	**Range**	**Year**
Extremely Dry	-2 to less	1911 – 1912,1915 – 1916,1923 – 1924, 1974 – 1975,1987 – 1988
Severe Dry	-1.5 to -1.99	1904 – 1905,1969 – 1970,2002 – 2003
Moderate Dry	-1.0 to -1.49	1918 – 1919,1936 – 1937,1939 – 1940, 1948 – 1949,1951 – 1952,1968 – 1969, 1972 – 1973,1985 – 1986, 1986 – 1987

RDI 12		
Classification	**Range**	**Year**
Extreme Drought	-2 or less	1904 – 1905,1911 – 1912,1915 – 1916,1923 – 1924, 1974 – 1975,1987 – 1988
Severe Drought	-1.5 to -1.99	1951 – 1952,1969 – 1970,2002 – 2003
Moderate Drought	-1 to -1.49	1918 – 1919,1936 – 1937,1939 – 1940,1948 – 1949, 1968 – 1969,1972 – 1973,1985 – 1986,1986 – 1987

By computation of PNI index and analysis the highest PNI value was found in 1915 year with 37.15 value. Also extreme drought condition occurs only 1 time i.e., 1915 year. Severe drought conditions were found in 1904,1911,1918,1923,1974,1987,2002 years and moderate drought conditions 17 times. From the annual rainfall departure analysis, the drought years have been identified and it's observed that 1904,1911,1915,1923,1974,1987,2002 years are affected by severe drought condition. Results shows that maximum SPI values -2.41 is for 12 month timescale in the year 1915 which is Extreme dry condition. Extreme dry condition of drought were observed in 1911-1912,1915-1916,1923-1924,1974-1975 and 1987-1988.

5.13 Results of drought forecasting model of area consider for the study.

12. To develop drought forecasting model of area consider for the study.

Model Preparations: Different models were prepared for the prediction of Drought for North Gujarat districts. Models were prepared using different forecasting methods viz., (1) MLR (2) NFTOOL (3) ANN (4) ANFIS (5) FUZZY

In this study, rainfall, maximum temperature, minimum temperature, potential evapotranspiration, SPI-3, SPI-6, SPI-9, RDI-3, RDI-6 and RDI-9 data are used to develop SPI-12 and RDI-12 for drought forecasting. The data are divided into sets of 70-30 % ratio. For example 70 % data for training period and 30 % data for validation period to develop model for above said methods. The performance evaluation of different model was done by calculating Root Mean Square Error (RMSE); Mean Absolute Error (MAE), Coefficient of Correlation(r) and Coefficient of determination (R2) for prediction accuracy.

ANFIS

ANFIS is the fuzzy-logic based paradigm that grasps the learning abilities of ANN to enhance the intelligent system's performance using knowledge gained after learning. Using a given input-output data set, ANFIS constructs a fuzzy inference system whose membership function parameters are tuned or adjusted using hybrid type of neural algorithms.

FUZZY

Fuzzy rules take the form IF (condition) THEN (action), where conditions and actions are linguistic labels applied to input and output variables, for example " if (rainfall is very-very low then extreme drought) and (very low then severe drought) and (moderate rainfall then normal condition)". So in present study, SPI 12 and RDI 12 may be described with linguistic variable such as 'very-very low', 'very low', 'medium', and 'high', 'very high', very-very-high'. While the drought is characterized into categories: 'no Drought', 'Moderate', 'severe', and 'extreme'. Sixty four fuzzy based rules of the same structure and logic above-mentioned were prepared to characterize the stochastic behaviour of drought. Fuzzy logic toolbox, designed to work in MATLAB environment which provides a graphical user interface (GUI) for building models, is used in this study to design the Fuzzy Logic methodology.

Table 5.35: Developed Fuzzy Logic Model

SABARKANTHA - SPI - FUZZY			
		70	30
SK - R - SPI	R	0.9795	0.9755
	R^2	0.9594	0.9516
	RMSE	0.2762	0.2819
	MAE	0.2219	0.2197
SK - R -T -T - SPI	R	0.9730	0.9726
	R^2	0.9467	0.9460
	RMSE	0.2864	0.2899
	MAE	0.2319	0.2219
SK - R - T - SPI	R	0.9684	0.9738
	R^2	0.9378	0.9483
	RMSE	0.3144	0.2904
	MAE	0.2720	0.2248
SK - R-T-P - SPI	R	0.9736	0.9730
	R^2	0.9480	0.9467
	RMSE	0.2822	0.2825
	MAE	0.2274	0.2192

SABARKANTHA - RDI - FUZZY			
		70	30
SK - R - RDI	R	0.9768	0.9748
	R^2	0.9540	0.9503
	RMSE	0.3637	0.3505
	MAE	0.2938	0.2796
SK - R-T-T - RDI	R	0.9683	0.9723
	R^2	0.9376	0.9453
	RMSE	0.0000	0.3265
	MAE	0.2781	0.2659
SK - R-T - RDI	R	0.9634	0.9737
	R^2	0.9282	0.9481
	RMSE	0.3586	0.3160
	MAE	0.2863	0.2582
SK - R-T-P - RDI	R	0.9705	0.9729
	R^2	0.9418	0.9465
	RMSE	0.3353	0.3113
	MAE	0.2546	0.2501

BANASKANTHA - RDI - FUZZY			
		70	30
BK-R-RDI	R	0.9677	0.9362
	R^2	0.9364	0.8765
	RMSE	0.2659	0.3667
	MAE	0.2043	0.2438
BK-R-T-T-RDI	R	0.9677	0.9722
	R^2	0.9364	0.9452
	RMSE	0.0000	0.2548
	MAE	0.2043	0.1973
BK-R-T-RDI	R	0.9589	0.9390
	R^2	0.9194	0.8816
	RMSE	0.3018	0.3565
	MAE	0.2288	0.2288
BK-R-T-P-RDI	R	0.9635	0.9412
	R^2	0.9284	0.8859
	RMSE	0.2896	0.3523
	MAE	0.2272	0.2337

BANASKANTHA - SPI - FUZZY			
		70	30
BK-R-SPI	R	0.9803	0.9690
	R^2	0.9610	0.9389
	RMSE	0.2241	0.2664
	MAE	0.1805	0.1981
BK - R-T-T - SPI	R	0.9680	0.9697
	R^2	0.9370	0.9403
	RMSE	0.2882	0.2605
	MAE	0.2327	0.1923
BK - R - T - SPI	R	0.9667	0.9663
	R^2	0.9345	0.9337
	RMSE	0.2928	0.2836
	MAE	0.2266	0.2133
BK - R-T-P - SPI	R	0.9754	0.9709
	R^2	0.9515	0.9426
	RMSE	0.2514	0.2612
	MAE	0.2046	0.2031

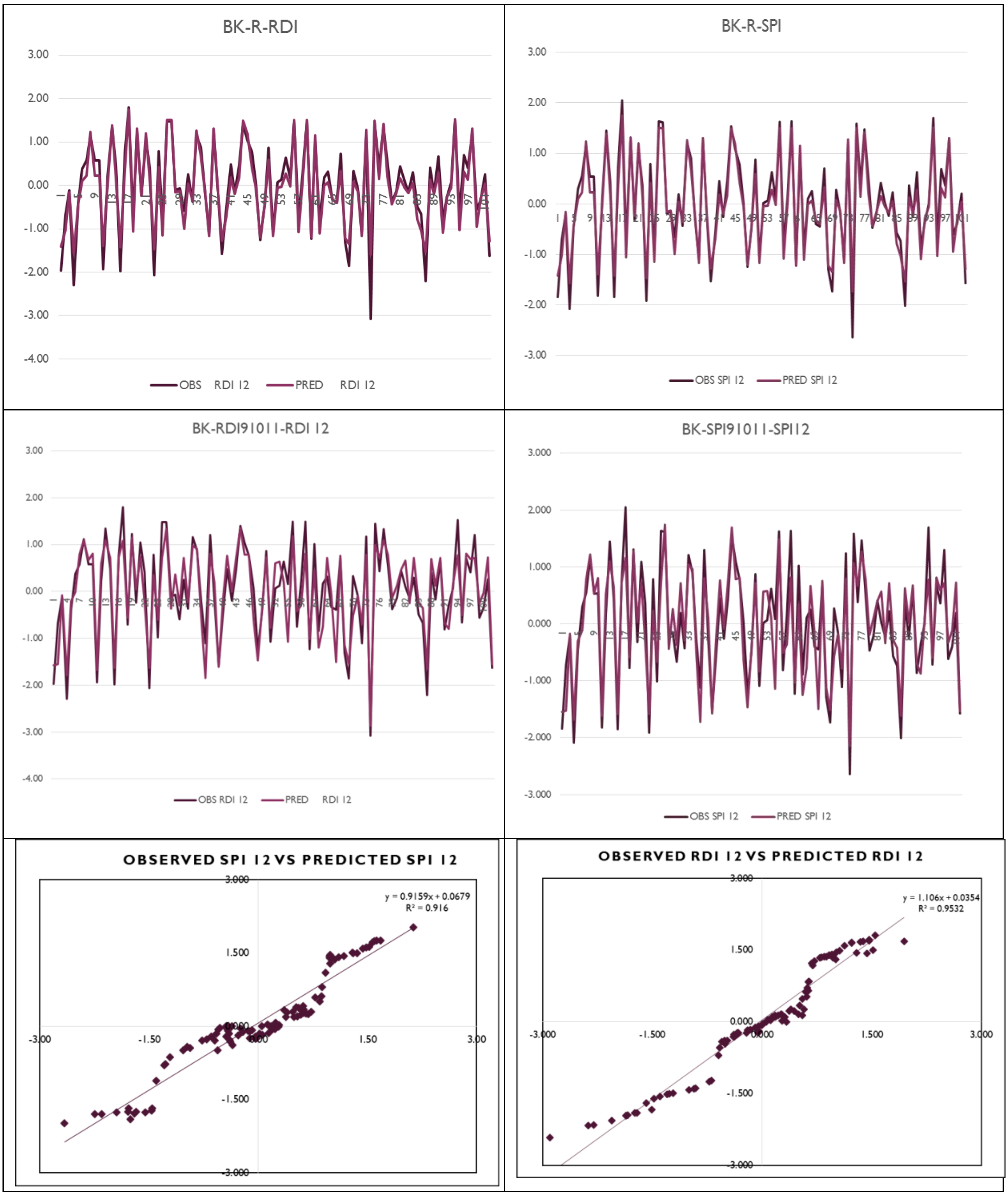


Figure 5.20 Observed vs Predicted SPI 12 and RDI 12 Model

The results of forecasting models and observed values are compared and performances of models were evaluated.

CHAPTER 6
CONCLUSIONS

Drought is one of the most common natural events that have a great negative impact on agriculture and water resources. Drought is one of the natural disasters that in comparison with the other disasters are of tremendous importance due to intensity, duration, areal extent, economic damages and long term effects. In the present study, drought years and degree of deficit of annual rainfall are determined in North Gujarat district by use of different meteorological drought indices viz., Percent of Normal Index, Percentage departure from mean (PD), Standardized Precipitation Index (SPI- 3 to 12 Months), Reconnaissance Drought Index (RDI- 3 to 12 Months), Rainfall Anomaly, Standardized precipitation evapotranspiration index (SPEI – 3 to 12 Months), China Z index and Modified China Z index using monthly rainfall, maximum temperature , minimum temperature, potential evapotranspiration data. For this study, monthly rainfall data of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 68, 73, 78, 71, 68, 81, 79 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation. From the annual rainfall departure analysis, the drought years have been identified and it is observed that 1901, 1904, 1911,1915,1923,1939,1969,1987,2002 are affected by severe drought and 1974 is affected by extreme drought condition. The study also reveals that 6%, 15% and 15% of Extreme dry years, severe dry years and Moderate dry years occur amongst drought years considered, which means 36% years are categorized into moderate to extreme drought years out of the total drought years. Wet and dry periods were compared using trend analysis of SPI-3, SPI-6, SPI-9 & SPI-12 values PN and PD values. This study provides a preliminarily idea about the climate of North Gujarat districts is mostly arid in nature. It is revealed that almost 37% of the area possess semi-arid to 18% as arid zone and 48% as dry sub humid in Sabarkantha district.

Various agricultural drought indices have been developed to assess the intensity of agricultural drought and to detect drought affected areas using Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Vegetation Condition Index (VCI), Normalized Difference Built-up Index (NDBI), and land surface temperature (LST). The results shows that NDVI decreased by 4% to 6% and NDWI decreased by 1 to 2% in the study area, while LST shows a significant increase by *1.5ºC –3*.5°C. This relationship revealed that when rainfall increases, NDVI, VCI also tends to decrease. Also there is increase in NDVI As a result, the event of agricultural drought increased. From the VCI analysis as extreme, high and moderate drought areas respectively in the study area. This study suggests that the effect of drought could be reduced through involving the smallholder farmers in a wide range of on and off-farm practices. This study may help to improve the existing agricultural drought monitoring systems carried out in different parts of Gujarat. The results will be useful in future for planning, designing and operating irrigation system and crop planning too.

REFERENCES

Abdullah H M., (2014), “Standardized precipitation evapotranspiration index (SPEI) based drought assessment in Bangladesh”, Proceedings of 5th International Conference on Environmental Aspects of Bangladesh [ICEAB 2014], PP 40-42.

Achugbu and Anugwo, (2016), “Drought Trend Analysis in Kano Using Standardized Precipitation Index”, FUOYE Journal of Engineering and Technology, Volume 1, Issue 1, September 2016 ISSN: 2579-0625 (Online), PP 2579-0617.

ALAM M., and SARKER T., (2014), “Precipitation Distribution and Erosivity in Bangladesh: 1981-2010”, EUROPEAN ACADEMIC research vol.I, Issue 12, PP 5167-5177.

Babu C. M., Hemalatha T and Naik B R., (2016), “Comparison of remote sensing based indices for Drought monitoring in Anantapur”, International Journal of Applied Research 2016; 2(1): PP 449-456

Belayneh A., and Adamowski J. (2013). “Drought forecasting using new machine learning methods”. Journal of Water and Land Development. No. 18 PP 3–12.

Boudad B., Sahbi H.,and Manssouri I.(2017), “Analysis of meteorological and hydrological drought based in SPI and SDI index In the Inaouen Basin (Northern Morocco)”, Journal of Materials and Environmental Sciences ISSN : 2028-2508, Volume 9, Issue 1, PP 219-227.

Byun H.R., and Kim D .W. (2010) “Comparing the Effective Drought Index and the Standardized Precipitation Index”. In: López-Fran cos A. (comp.), López-Fran cos A. (collab.). Economics of drought and drought Preparedness in a climate change context. Zaragoza : CIHEAM / FAO / ICARD A / GD AR / CEIGRAM / MARM, 2 01 0. PP 85-89.

Choudhary S, Garg P.K. and Ghosh S.K., (2013), “Drought Analysis Using Digital Image Processing & Meteorological Data”, International Journal of Advanced Remote Sensing and GIS 2013, Volume 2, Issue 1, PP 280-302.

Das S, Choudhury M R, Gandhi S., and Joshi V., (2016) “Application of Earth Observation Data and Standardized Precipitation Index Based Approach for Meteorological Drought Monitoring, Assessment and Prediction Over Kutch, Gujarat, India.” International Journal of Environment and Geoinformatics 3 (2), PP 24-37.

Gaikwad S. V., and Kale K.V. (2015), “Agricultural Drought Assessment of Post Monsoon Season of Vaijapur Taluka Using Landsat8”, IJRET: International Journal of Research in Engineering and Technology eissn: 2319-1163 | pissn: 2321-7308 PP 405-412.

Iskander, S.M., Rajib, M.A. and Rahman, M.M. (2014) “Trending Regional Precipitation Distribution and Intensity: Use of Climatic Indices”. Atmospheric and Climate Sciences, 4, PP 385-393.

Keka Israt A., Matin I., Rahman M. and Banu D.A., (2012), “Analysis of Drought In Eastern Part of Bangladesh”, Daffodil International University Journal Of Science And Technology, Volume 7, Issue 1, January 2012 PP 20-27.

Kwak J., Yeon So, Kim, Jong So, Lee, and Hung So, Kim. (2012), “Drought Severity-Duration-Frequency Analysis of Hydrological Drought Based on Copula Theory”, Hydrology Days 2012.

Mahajan D. R, Dodamani B.M., (2015), “Trend Analysis of Drought Events Over Upper Krishna Basin in Maharashtra”, International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015), Aquatic Procedia 4 (2015) PP 1250 – 1257.

Nithya D., and Suja Rose,(2014), “ Assessing Agricultural Vulnerability Using Geomatic Technology: A Case Study Of Srivilliputhur Taluk Of Virudhunagar District, Tamil Nadu”, International Journal of Advancement in Remote Sensing, GIS and Geography, ISSN 2321–835, IJARSGG (2014) Vol.2, No.2, PP 11-17

Pathak A., Channaveerappa, and Dodamani B.M., (2016), “Comparison of two hydrological drought indices, Perspectives in Science, www.elsevier.com/pisc (2016) 8, PP 626—628.

Patel N. R., Suryanarayana T.M.V. and Shete D.T. (2017): “Analyzing Extreme Events Using Standardized Precipitation Index during the 20th Century for Surat District, India”. (Springer Nature Singapore Pte Ltd. 2018 M. Majumder (ed.), Application of Geographical Information Systems and Soft Computation).PP 41-50.

Pius B., and Marszelewski W., (2014), “An Attempt To Assess The Influence Of Dry And Wet Periods Upon River Runoff. An Example of the Drwęca River (POLAND)”, 2nd International Conference - Water resources and wetlands. 11-13 September, 2014 Tulcea (Romania); Available online at http://www.limnology.ro/water2014/proceedings.html, ISSN: 2285-7923; PP 285-292.

Ray Lala I.P., Bora1 P.K., Ram1 V., Singh1 A.K., Singh2 R. And Feroze2 S.M., (2012), “Meteorological Drought Assessment in Barapani, Meghalaya”, Journal of Indian Water Resources Society, Vol 32, No. 1-2, PP 56-61.

Shamsnia S., (2014), “Comparison of Reconnaissance Drought Index (RDI) And Standardized Precipitation Index (SPI) For Drought Monitoring In Arid And Semiarid Regions”, Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231-6345 (Online) An Open Access, Vol. 4 (3) July-September, PP 39-44.

Tigkas D, Vangelis H., and Tsakiris G., (2015), “The RDI as a composite climatic index “, European Water 41: PP 17-22

Zarch M., Malekinezhad H.,Mohammad H., Mohammad T.,and Mohammad R., (2011), “Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran”, Water Resour Manage (2011) 25:3485–3504.

Publications

Sr. No.	Conference Title	Paper Title

1.	22nd International Conference On Hydraulics, Water Resources And Coastal Engineering (HYDRO 2017)	Meteorological Drought Analysis Using SPI, PNI & PD in Sabarkantha District, Gujarat
2.	Parul University International Conference On Engineering & Technology (Picet-2018): Smart Construction	Climatological Drought Index Computation Using Reconnaissance Drought Index For Sabarkantha District, Gujarat, India
3.	International Conference On Hydraulics, Water Resources And Coastal Engineering (HYDRO 2018)	Analysis of Drought Periods For Mehsana During 20th Century
4.	1st National Conference On “Emerging Research And Innovations In Civil Engineering” (ERIC 2019)	Meteorological Drought Assessment In Banaskantha, Gujarat
5.	24th XXIV HYDRO 2019 International Conference (Hydraulics, Water Resources, Coastal Engineering)	Assessments of Meteorological Drought Indices Using SPI and RDI in Mehsana Region, Gujarat, India
6.	38th & 39th AHI Annual Convention and National Seminar on “Hydrology” Focal theme on ‘Changing Climate and Extreme Hydrological Events’	Drought Assessment & Monitoring Using Different Indices In Panchmahal District, Gujarat, India

Paper Title	**Scopus Publications**
Categorization of Drought during Twentieth Century Using Precipitation in Banaskantha District, Gujarat, India.	Innovations in Infrastructure. Advances in Intelligent Systems and Computing, vol. 757. pp 267-274 Springer, Singapore, https://doi.org/10.1007/978-981-13-1966-2_23, Print ISBN 978-981-13-1965-5, Online ISBN 978-981-13-1966-2
Assessments of Meteorological Drought Indices Using SPI and RDI in Mehsana Region, Gujarat, India	Book Chapter published in Water Science and Technology Library, Hydrological Modelling : Hydraulics, Water Resources and Coastal Engineering, Volume 109, PP 21-29 ISSN 0921-092X ISSN 1872-4663 (electronic) Water Science and Technology Library ISBN 978-3-030-81357-4 ISBN 978-3-030-81358-1 (eBook) R. Jha et al. (eds.), Hydrological Modelling, Water Science and Technology Library 109, https://doi.org/10.1007/978-3-030-81358-1_3