

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

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GUIDE

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

By

**PRANAV B. MISTRY
M.E. CIVIL in (WRE)**

**WATER RESOURCES ENGINEERING AND MANAGEMENT INSTITUTE
FACULTY OF TECHNOLOGY AND ENGINEERING
THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA
SAMIALA - 391 410**

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Date:

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(Pranav B. Mistry)

ABSTRACT

Drought is considered as one of the most dangerous natural hazards in the today's world. 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. The drought can be classified into three categories viz. Meteorological, Hydrological and Agricultural drought. The Meteorological drought occur when actual rainfall is 25% less than the climatological mean, Hydrological drought occur when there is marked depletion of surface water causing very low stream flow and Agricultural drought occur when scarce soil moisture produces serious crop stress and affects the crop productivity.

Drought assessment is very important to manage water resources in lean period. It plays vital role in managing water demands especially in agriculture sector. In the present study North Gujarat region is chosen for study of different types of drought and its assessment using drought indices and development of drought forecasting model using soft computing techniques. The study covers five districts in North Gujarat viz., Banaskantha, Gandhinagar, Mehsana, Patan and Sabarkantha districts. Its geographical location makes it vulnerable to variations in the monsoon patterns, with rainfall being critical for agriculture in the region.

Various meteorological drought indices used to calculate number of drought years under various categories in the present study region using percent of normal (PN), percentage of departure from mean (PD), Deciles (DI), Rainfall anomaly index (RAI), standardized precipitation index (SPI), Reconnaissance drought index (RDI), China-Z index (CZI), modified china Z index (MCZI) and Z Score index. Also, precipitation concentration index and modified Fournier index is calculated for annual and seasonal basis for rainfall distribution and MFI used for identifying the years which having high and low rainfall erosivity. Aridity index viz., UNESCO Aridity index, De Martonne Aridity index, Erinc Aridity index, Thornthwaite Precipitation Effectiveness index, and Thornthwaite Moisture index are used in present study these indices helpful to determine the arid, semi-arid years. The results of all above indices was observed and analysed for assessment of droughts in North Gujarat districts using monthly rainfall, maximum temperature, minimum temperature, and potential evapotranspiration data for 1901 to 2002 years.

For Hydrological drought analysis is carried out using satellite-based remote sensing techniques to monitor hydrological droughts affected areas during 1992 to 2019 years. Different hydrological drought indices, namely Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Water Ratio Index (WRI), and Normalized difference salinity index (NDSI) used for surface water monitoring. These are most popular remote sensing indices used to assess water

bodies and changes in water content and can be valuable tools for hydrological drought assessment.

For Agricultural drought indices different Landsat data(Landsat5, 7 ETM+ and 8) during 1992 to 2019 years using Normalized difference vegetation index (NDVI), NDVI-deviation, Soil Adjusted Vegetation Index (SAVI), Vegetation Condition Index (VCI),Land surface temperature(LST), Temperature Condition Index (TCI), Vegetation Health Index (VHI) analysis over multiple years which enables the identification of changes associated with drought classification and the area affected under each category is analysed.

The trend analysis and correlation matrix analysis carried out also shows that there is highly correlation when time scale is increased and gives highly correlated between the different metrological drought indices. For prediction of drought severity class, drought forecasting model is developed using fuzzy logic approach and ANFIS approach for various combination of meteorological data for 70%-30% as training and validation period.

The 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. The study also reveals that 8%, 18% and 15% of extreme dry years, severe dry years and moderate dry years occur amongst drought years considered, which means 40% years are categorized into moderate to extreme drought years out of the total drought years using various drought indices over North Gujarat. Similarly, SPI, RDI and SPEI indices calculated for in various time scales (3, 6, 9 and 12 months) and results were analyzed. The percentage of drought years can provide valuable insights into the characteristics and trends of meteorological droughts and also rainfall variation in a North Gujarat region. The analysis of aridity index shows that 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 the region. 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. The results shows that SPI 3, SPI 6, SPI 9 and SPI 12 were well correlated with most of the other drought indices. Similarly, SPEI 3, SPEI 6, SPEI 9 and SPEI 12 showed a little less correlation with a similar time scale of other drought indices. Also, RDI 3, RDI 6, RDI 9 and RDI 12 showed a high correlation with a similar time scale of other drought indices.

The results of hydrological drought indices shows that Banaskantha district having 5.5% to 15.5%, Gandhinagar district having 1.5%-3.0%, Mehsana district having 2.5%-8.5%, Patan district having 1.5%-6.0% and Sabarkantha district having 1.2% to 4.0% water spread area in North Gujarat districts.

The average percentage of dry area in North Gujarat districts was 60.7%, 21.37%, 35.02%, 41.70% and 31.70% in Banaskantha, Gandhinagar, Mehsana, Patan, and Sabarkantha districts respectively. The results of NDVI index shows that dry area varies from 20% to 40% in North Gujarat districts. The maximum percentage variation was observed in Patan district from 30% to 42% during study period. 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. The LST analysis shows that Banaskantha and Gandhinagar district having 75% area under high temperature whereas Mehsana, Patan and Sabarkantha districts having more than 90% area. The analysis 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 1.5°C –3.5°C. A consistent increase in LST, TCI can indicate prolonged periods of above-average land surface temperatures. Observe how TCI values correspond to changes in VHI. For instance, when TCI increases and VHI decreases, it suggests that elevated temperatures are negatively affecting vegetation health.

Various Indices are used to provide quantitative assessment of the severity, location, timing and duration of drought events. The analysis of agricultural drought in North Gujarat region it is clearly evident that the severity of drought increases year wise in the same time no drought condition decreased. Also, threshold values for different indices used to determine the drought affected areas in North Gujarat. The spatio temporal maps using all above indices were developed

Amongst developed models, the best Fuzzy and ANFIS model for RDI and SPI is Model 1 and 2, wherein model 1 represents annual rainfall as input and drought severity as output. model 2 represents annual rainfall and temperature as input and drought severity as output with the RMSE ranges between 0.03 to 0.015 for training and 0.0867 to 0.15 for validation period, and co efficient of determination value for training period is 0.9999 and for validation period is 0.9946 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Drought estimation helps water resource managers to assess the severity and duration of drought conditions. This information is crucial for planning water allocations, managing reservoir levels, and implementing water conservation measures. In summary, drought estimation is a critical tool for proactive planning and management in various sectors, helping to minimize the negative impacts of water scarcity on both natural and human systems. 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.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

This chapter deals with the general introduction about drought and different definitions of drought given by various agencies. Also, the various types of drought and impact of drought on environment, followed by the objectives of the present study.

1.2 CLIMATE CHANGE AND DROUGHT

Climate change is a natural phenomenon, but the increase in greenhouse gases due to human activities, which alters the climatic system, have become triggers for more rapid changes and influencing the occurrence of extreme climatic events. Climate change contributes to increased frequency of extreme weather events, such as drought, flood, earthquake and Tsunami. The severity of the drought is likely to increase in many parts of the world. Droughts are recognized as a natural environmental catastrophe and have attracted multidisciplinary attention across all researcher fields.

Drought is not only a physical occurrence that can be defined by the weather conditions. A drought is defined as an extended period of unusually dry weather that causes water shortages and crop damage. The Intergovernmental Panel on Climate Change (IPCC) recognizes that climate change and the altered frequencies of associated extreme events such as drought and floods are expected to have negative impacts on human health.

According to IPCC's Fifth Assessment Report (AR5) based on many independent scientific analyses, new evidence, theoretical studies and computer simulations, there is greater certainty that the build-up of Greenhouse Gas in Earth's atmosphere is changing the world's climate and creating increasingly extreme and unpredictable weather. According to AR5, the computed linear trend of the globally averaged combined land and ocean surface temperature data show 0.85°C [0.65°C to 1.06°C] warming over the period 1880 to 2012, when multiple independently produced datasets exist. In the period 1901-2012, climate has shown a warming of 0.89°C [0.69°C to 1.08°C] which is mainly attributed to anthropogenic activities (IPCC 2013). Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the case of India, increasing temperature trends of the order of 0.60°C during last 112 years (IMD 2012, Rathore et al. 2013) and increase in heavy rainfall events and decrease in low and medium rainfall events (Goswami et al. 2006) have been observed.

1.3 CLASSIFICATION OF DROUGHT

The classification system for the drought of four types is based on the nature of water deficiency. Meteorological, hydrological and agricultural droughts are considered environmental droughts according to this classification and are defined as periods with insufficient precipitation, river flow or groundwater, and soil moisture, respectively. The fourth type of drought is socio-economic drought, which is associated with water resource systems failing to meet water demands. Figure 1.1 presents the classification system for drought.

Being a slow process although drought often fails to draw the attention of the world community, its impact persists even after ending of the event. A single definition of drought applicable to all spheres is difficult to formulate since concept, observational parameters and measurement procedures are different for experts of different fields. Besides, the concept of drought varies among regions of differing climates.

Conceptual Definitions of Drought

Conceptual definitions, expressed in general terms, help people understand the concept of drought. For example, drought is a protracted period of deficient precipitation resulting in extensive damage to crops, further resulting in loss of yield. Conceptual definitions may also be important in establishing drought policy.

Operational Definition of Drought

An operational definition of drought helps people to identify the beginning, end, and degree of severity of a drought. This definition is usually made by comparing the current situation to the historical average, often based on a 30-year period of record (according to World Meteorological Organization recommendations).

The following categories of drought are usually considered:

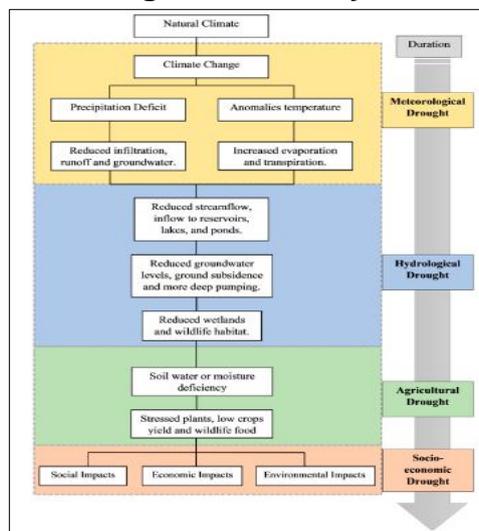


Figure 1.1: Categories of Drought and its Impact

I. Meteorological Drought

Meteorological drought is usually defined on the basis of the degree of dryness 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.

II. Hydrological Drought

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).

III. Agricultural Drought

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.

IV. Socioeconomic Drought

This occurs when physical water shortage starts to affect people, individually and collectively or, in more abstract terms, most socio-economic definitions of drought are associated with the supply and demand of an economic good.

1.4 DROUGHT SCENARIO IN INDIA

One of the worst natural calamities that affect India is the large scale incidences of droughts during the southwest monsoon season (June to September). The period between the years 1901 to 1930 was a period of frequent droughts, the frequency being once in four years. During the following 30 years, there were only two drought years, 1941 and 1951. However, the next 30 years saw 10 instances of droughts, a drought occurring once in three years on the average. The worst drought affected States are Karnataka, Tamil Nadu, Rajasthan, Gujarat, Andhra Pradesh and Maharashtra. During the seventies, about 80% of world's victims affected by drought lived in India.

An assessment of droughts in Tamil Nadu State from 1977 to 1991 reveals recurrent drinking water shortages in major parts of the state - the city of Madras in particular. The worst drought years in the past 15 years are identified as 1980, 1982, 1983, 1987 and 1989. The 1987 drought which has crippled the state's economy. The 1987 drought serves as a model chronic drought year in Tamil Nadu, and it is interesting to study its redeeming features and its management. The catchment areas did not receive any water, and there were 290 poor rainy days, 48 marginal rainy days and 27 good rainy days. The ground water level fell steeply up to 11 meters. The drought scenario of 2000 over the country is still fresh in the minds of all. More than 150

districts covering 8 States were affected by droughts. The most recent drought of 2002, ranks fifth in terms of magnitude but is unique when examined in overall terms of magnitude, spacing, Dispersion and duration. In July 2002, rainfall deficiency increased to 51%, surpassing all previous droughts. The impact of drought spread over 56% of land mass and threatened the livelihoods of 300 million people living across 18 States.

In past century, the country has experienced twenty-one large-scale droughts in the years 1891, 1896, 1899, 1905, 1911, 1915, 1918, 1920, 1941, 1951, 1965, 1966, 1972, 1974, 1979, 1982, 1986, 1987, 1988, 1999 and 2000 with greater frequencies during the periods 1891-20, 1965-90 and 1997-2000. The monsoon of 2000 was the 13th consecutive normal monsoon considering country as a whole, but on a regional basis, this was the third consecutive drought year in areas covered by the states of Rajasthan, Gujarat and Andhra Pradesh.

The drought of 1987 was one of the worst in the century. The monsoon rainfall was normal only in 14 out of 35 meteorological sub divisions in the country. The overall deficiency in rainfall was 19% as compared to 26% in 1918 and 25% in 1972 being worst years. Agricultural operations were adversely affected in 43% (58.6millionha) of cropped area in 263 districts in 15 States and 6 Union Territories. In the two worst affected states of Rajasthan and Gujarat, the rainfall was less than 50% from normal. In these states, the drought of 1987 was the third or fourth in succession resulting in distress to an unprecedented level. Gujarat is one such state where drought occurs with unfailing regularity

1.5 DROUGHT SCENARIO IN GUJARAT

Major parts of the state of Gujarat fall under arid and semi-arid climatic zone, and suffer from recurrent droughts. It has also been observed that the frequency and intensity of droughts have increased in the state over the years, resulting in serious drinking water scarcity. As per the records of the India Meteorological Department (2015), Gujarat was hit by 15 major droughts (years: 1982, 1985, 1986, 1987, 1990, 1991, 1993, 1995, 1998, 1999, 2000, 2001, 2002, 2004 and 2009) during the last three decades (1981–2010). In most of these drought years, occurrence of heat waves and high temperatures are also noticed, particularly in northern Gujarat. During this period, moderate and severe heat waves burnt the region in the years 1990, 1995, 2001, 2002, 2004 and 2010. Meteorological drought and heat waves affect water resources and water supply, damages vegetation health and reduces agricultural productivity.

The Indian sub–continent is influenced by South–West (S–W) monsoon during June–September and North–East (N–E) monsoon during October–December. Nearly 70% of the annual rainfall in India is received during the S–W monsoon. In Gujarat, rainfall is uncertain, unprecedented and unequal spatially and temporally,

and the regions of Saurashtra, Kutch and northern parts of the state face famine every third year. Since the year 1900, the state has faced scarcity of water and food almost 30 times. Substantial portions of the state are arid to semi-arid. With large parts of northern Gujarat and Saurashtra have no source of alternate irrigation, over-extraction of the limited ground water resource thus resulted in the decline of the water Table, which in turn has added stress on cultivated crops and water supplies (Gujarat State Disaster Management Plan, 2016–17).

Droughts are frequent in North Gujarat regions viz., Banaskantha, Gandhinagar, Mehsana, Patan and Sabarkantha districts due to poor and erratic rainfall distribution. The climate varies from humid in the district through sub-humid in the central part to semi-arid and arid in the northern and western parts. In 1999, Gujarat faced the worst drought of the past 100 years. Some 7,500 villages spread over 145 blocks in 15 districts were severely affected. The state has been hit by the worst drought in 100 years.

During the last three decades (1981–2010), the number of heat waves in Gujarat and some part of North Gujarat has been considerably high with moderate and severe heat waves affecting lives in the years 1990, 1995, 2001, 2002, 2004, and 2010. In major parts of Northern Gujarat, an appreciable rise in temperature coupled with deficient rainfall has been observed in the last decade (2001–2010). As a result of extreme climate, fall in groundwater table has been observed over a period of last thirty years putting immense pressure on groundwater table and demand for fresh water for drinking and household.

1.6 NEED OF THE PRESENT STUDY

North Gujarat is located in the western part of India and is largest part of Gujarat state. Its geographical location makes it vulnerable to variations in the monsoon patterns, with rainfall being critical for agriculture in the region. North Gujarat has a history of experiencing drought conditions, making it a region of interest for drought assessment. It has faced recurring droughts due to its arid and semi-arid climate, which makes it susceptible to water scarcity and agricultural challenges.

Drought can have a severe impact on various crops like cotton, groundnut, and millet, and consequently, on the livelihoods of the people in the region. The region depends heavily on irrigation for agriculture, and drought can exacerbate water scarcity issues.

Drought assessment is essential for understanding the impacts of climate change, improving water resource management, and implementing drought mitigation strategies. Agricultural drought in North Gujarat, like in other drought-prone regions, can have a significant impact on various aspects of the local economy, environment,

and society. This makes its important to study North Gujarat districts in monitoring and assessment of drought conditions.

1.7 OBJECTIVES OF THE PRESENT STUDY

1. Estimation of various meteorological drought indices over the study area i.e., north Gujarat region.
2. Estimation of drought by different climatic index over the study area.
3. Estimation of various aridity index over the study area.
4. To determine frequency of meteorological drought indices.
5. Estimation of various hydrological drought indices.
6. To determine frequency of hydrological drought indices over the study area.
7. To estimate different agricultural drought indices.
8. Computation of vegetation stress by remote sensing techniques.
9. Trend and correlation analysis of drought indices.
10. Generation of drought severity maps.
11. To construct comparisons matrix of various developed drought indices over study area.
12. To develop drought forecasting model of area considered for the study.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter covers the various research works carried out in the field of various types of drought and analysis of its different drought indices. The review of works is classified into different domains, viz. meteorological drought, hydrological drought and agricultural drought. Additionally, Literature of drought frequency analysis and trend analysis test is carried out. Also, development of drought forecasting models is also studied.

2.2 LITERATURE REVIEW ON METEOROLOGICAL DROUGHT ANALYSIS

Different drought indices like percent of normal, percentage of departure, decile, Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Standardised Precipitation evapotranspiration index (SPEI) were derived. China-Z Index (CZI) and Modified CZI (MCZI), Percentage of departure is identified based on rate deviation of yearly precipitation from the long-term yearly mean precipitation. Percent of normal is obtained by dividing the precipitation by normal precipitation for the time being considered. It interprets the deficient of rainfall from wet season to dry season and vice versa as precipitation deviation from the normal annual precipitation. Decile is calculated by interpolation technique based on ranking given to the rainfall distribution.

2.3 LITERATURE REVIEW ON HYDROLOGICAL DROUGHT ANALYSIS

Hydrological drought may be the result of long term meteorological droughts that results in the drying up of reservoirs, lakes, streams, rivers and a decline in groundwater levels. Various hydrological drought indices studied viz., NDWI, MNDWI, WRI and NDSI.

Hydrological drought analysis typically involves the assessment of water availability and the impact of drought on various water resources. The multiband rationing technique has been used to extract the water area from Landsat imageries. Surface water monitoring is a necessary component of researching ecological and hydrological processes. Three water indices, namely Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Water Ratio Index (WRI) used and these is based on the spectral index method using ArcGIS software. These are most popular remote sensing indices used to assess

water bodies and changes in water content and can be valuable tools for hydrological drought assessment.

The Normalized Difference Salinity Index (NDSI) is also calculated using Landsat data to identify areas with varying levels of salinity in water bodies. Positive NDSI values may indicate areas with higher salinity. Negative NDSI values may indicate areas with lower salinity.

2.4 LITERATURE REVIEW ON AGRICULTURAL DROUGHT ANALYSIS

Agriculture is a very crucial sector for the well existence of the socio-economic situations. Drought is a potential threat with a destructive damage to agricultural production. The necessity of a drought index specialized for agriculture led to development of various indices with explicit characteristics for Agricultural drought assessment. 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.

2.5 LITERATURE REVIEW ON TREND ANALYSIS OF DROUGHT INDICES

Parametric (distribution-dependent) or non-parametric (distribution-free) statistical tests can be used to decide whether there is a statistically significant trend. A test is said to be parametric if the change evaluated by the test can be specified in terms of one or more parameters. Linear regression is an example of a parametric test. Parametric testing procedures are widely used in classical statistics. In parametric testing, it is necessary to assume an underlying distribution for the data (often the normal distribution), and to make assumptions that data observations are independent of one another.

2.6 LITERATURE REVIEW ON DROUGHT FORECASTING METHODS

An important requirement for mitigating the impact of drought is an effective method of forecasting future drought events. Development of a new meteorological drought index based on fuzzy logic (FL) and Neuro-fuzzy models to describe and predict droughts. The developed models were compared to drought indices and correlated with multiple drought indicators. Different combinations of inputs (such as maximum temperature, mean temperature, precipitation, and potential evapotranspiration) were tested to develop the models.

CHAPTER 3

STUDY AREA AND DATA COLLECTION

3.1 GENERAL

This chapter contains the brief idea of Water Resources in Gujarat, Climate of Gujarat and overview of sub-agroclimatic zones of Gujarat. Thereafter, the description of the study area and the data required for the study are provided.

3.2 AGRICULTURE SCENARIO OF NORTH GUJARAT

North Gujarat is described as arid and semi-arid region with high temperatures. The rainy season being short (July–August), the biggest problem in both agriculture and daily life is water. The water is very precious due to scarce and bad quality of ground water. The high temperatures, sandy soils, scarce water and high wind velocity combined together make very precarious agricultural situation in the region that often leads to water stress during post–anthesis and grain development period in Kharif crops. Contrarily, high temperatures, both during seeding and maturity, are the main yield–limiting factors in Rabi crops. The summer and spring crops are feasible only where water is available.

3.3 SUBAGROCLIMATIC ZONES OF GUJARAT

The Subagroclimatic zones of Gujarat is discussed here and Figure 3.2 shows of different subagroclimatic zones of Gujarat.

Southern Hills

This is small but largely a tribal belt covering the districts of the Dangs and Valsad. The area receives about 1793 mm of rains and the climate is semiarid, dry, sub humid, and the soil is deep black, coastal alluvium. About 43 % of the area is under forests and a similar proportion is cultivated. Irrigation is spread over about 24 % of the cultivated area.

Southern Gujarat

This subzone, covering the districts of Surat and Bharuch, has seen rapid industrial development in the recent decade or so. Over half of the land is cultivated and about a fifth of the cultivated area is irrigated. The area receives little less than 974 mm of annual rainfall.

Middle Gujarat

Although this area is well developed industrially, it is also the most agrarian in Gujarat. Nearly two-thirds of the area is under cultivation and nearly a third of this is irrigated. Rains reduce progressively as one moves into North Gujarat. In the middle

areas, which include Vadodara, Panch Mahals, and Kheda districts, the precipitation is of the order of 904 mm annually.



Figure 3.2: Sub Agroclimatic zones of Gujarat

North Gujarat

This subzone covers Banaskantha, Mehsana, Sabarkantha, Gandhinagar, and Patan districts. Land productivity is very low. Rainfall is only around 735 mm per annum. The climate is arid to semiarid and the soil is gray brown coastal alluvium. About 63 % of the area is cultivated and a little over a third of this is irrigated.

Northwest Arid

This is the vast expanse of the Kachchh district. Rainfall is only about 340 mm per annum, the climate is arid to semiarid and the soil is gray brown, deltaic alluvium. Less than 13 % of the area is cultivated. Nearly one-third of the geographical area is wastelands.

North Saurashtra

This subzone includes the districts of Amreli, Bhavnagar, Jamnagar, Rajkot, and Surendranagar. The region receives 537 mm of rainfall and the climate is dry, subhumid. The soil is medium black calcareous. About 63 % of the area is cultivated, of which 24 % is irrigated. Agricultural productivity is relatively high in Saurashtra essentially because of the cultivation of groundnut in this region.

South Saurashtra

The South Saurashtra subzone includes only the district of Junagadh at the southwestern end of the state. This area receives little better rain than the nonsouth Gujarat parts of the state. The annual precipitation is about 844 mm, the climate is dry, subhumid, and the soil is coastal alluvium, medium black. About 56 % of the region is cultivated.

From the above subagroclimatic zones North Gujarat is chosen for study. The description of study area is given below section.

3.4 DETAILS OF NORTH GUJARAT DISTRICTS

The details of North Gujarat districts is discussed below. Also, the districts of North Gujarat is shown in Figure 3.3



Districts of North Gujarat

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

Figure 3.3: Districts of North Gujarat

3.5 DATA COLLECTION AND SOURCES

The Meteorological data for North Gujarat region has been procured from India Meteorological Department (IMD), Pune. It consisted of the monthly precipitation, maximum temperature, minimum temperature, relative humidity, potential evapotranspiration are collected from 1901 to 2002, total of 102 years. These monthly climatological records have been used to identify the Meteorological drought years and rainfall deficient seasons over North Gujarat districts. Similarly for hydrological and agricultural drought analysis various band data collected from Landsat 5 images for 1992 to 2005, Landsat 7 band images for 2005 to 2012 and Landsat 8 band images for 2013 to 2019 from the satellite sources. These Landsat images data collected for months of March, April and May. The sources of satellite images data and sensor ID, Path/Row is shown in below Table 3.1.

Table 3.1: Satellite Images data with Path and Row

Satellite/Spacecraft ID	Sensor ID	Path/Row	Spatial Resolution
Landsat 5	TM	148/43, 148/44, 149/43, 149/44	30m
Landsat 7	ETM+	148/43, 148/44, 149/43, 149/44	30m
Landsat 8	OLI_TIRS	148/43, 148/44, 149/43, 149/44	30m

For the present study various data is collected from the different online sources and organizations is mention as below.

- <http://www.indiawaterportal.org/>
- <http://www.imd.gov.in/>
- www.earthexplorer.usgs.gov
- www.landviewer.org

CHAPTER 4

METHODOLOGY

4.1 GENERAL

This chapter covers the detailed outline of the procedure and methodology to calculate different meteorological drought indices, hydrological drought indices and agricultural drought indices. Also, Trend analysis test techniques for development of drought forecasting are discussed.

4.2 METEOROLOGICAL DROUGHT INDICES

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. In the current assessment study, different meteorological drought indices like percent normal (PN), Percentage of departure from mean (PD), Deciles index (DI), Standardized Precipitation Index (SPI), Reconnaissance Drought index (RDI), Standardised Potential Evapotranspiration Index (SPEI), China Z index (CZI), Modified China Index (MCZI) and the Z-Score were used for estimating drought severity. All the aforesaid indices work using precipitation, potential Evapotranspiration and temperature data.

Percent of Normal computed by dividing the actual precipitation by the "normal" precipitation (typically considered to be a 30-year mean) and multiplying by 100 is typically expressed in percentages given by (Willeke et al. 1994) for drought assessment.

Percentage of Departure from Mean (Annual) indicates the departure of any precipitation events from its mean. 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.

Standardized Precipitation Index (SPI) was developed by McKee et al (1993). The SPI is based only on precipitation. SPI can be computed at different time scales and hence can quantify water deficit so different duration. SPI was designed to demonstrate that it is possible to simultaneously go through wet conditions on one or more time scales and dry conditions at another time scale. The calculation of the index needs only precipitation record. It is calculated by considering the precipitation anomaly with regard to the average value for a given time scale, separated by its standard deviation.

Reconnaissance drought index identification and assessment index was first presented by Tsakiris (2004) while a more comprehensive description was presented in Tsakiris et al. (2005). For short reference periods (e.g. monthly or 3-months) which may include zero values for the cumulative precipitation of the period, the RD_{1st} can be calculated based on a composite cumulative distribution function including the probability of zero precipitation and the gamma cumulative probability. Positive values of RD_{1st} indicate wet periods, while negative values indicate dry periods compared with the normal conditions of the area.

Standardized precipitation evapotranspiration index (SPEI) index was developed by Vicente-Serrano et al. (2010). It is calculated in the same way as that of SPI, but instead of using the time series of precipitation, it uses the monthly difference between precipitation and potential evapotranspiration (PET). The SPEI is another meteorological drought index that considers the variability of both precipitation and temperature to predict drought conditions in a region.

4.3 CLIMATIC DROUGHT INDEXES

The characterization of the drought periods by climatic indexes has been using De Martonne Aridity Index (IdM); Seleaninov Hydrothermic Index (his); and Donciu Climate Index (IcD). The correlation established between the assured rainfall (A %) for years and climatic indexes provide the polynomial expression, statistically very significant.

Also, **Precipitation concentration index** was calculated on a seasonal scale for winter (December-January-February), spring (March-April-May), summer (June-July-August), autumn (September-October-November), and on supra-seasonal scales for wet (October to March) and dry (April to September) seasons. Oliver (1980) suggested that PCI values of less than 10 represent a uniform precipitation distribution (i.e., low precipitation concentration); PCI values from 11 to 15 denote a moderate precipitation concentration; values from 16 to 20 denote irregular distribution and values above 20 represent a strong irregularity (i.e., high precipitation concentration) of precipitation distribution.

4.4 ARIDITY INDEXES

Increased aridity due to climate change is a growing environmental problem of the agricultural land. 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 using different well known aridity models viz., UNESCO Aridity index, Erinc Aridity index, Thornthwaite Precipitation Effectiveness index, Thornthwaite Moisture index and De Martonne Aridity index are used.

UNESCO (1979) proposed a method for aridity mapping from the ratio of precipitation (P) to potential evapotranspiration (ET_o).

Erinc (1996) calculated aridity index by taking the ratio of total annual rainfall (P) to the annual mean maximum temperature (Tmax) as shown;

Thornthwaite's Moisture index is defined using the mean annual rainfall and mean annual potential evapotranspiration. Reddy & Reddy (1973) defined the moisture limits for broad climatic zones into eight groups namely, Hyper arid, arid, dry semi-arid, wet semi-arid, dry sub-humid, wet sub-humid, humid and very humid.

DROUGHT FREQUENCY

Drought frequency was also calculated to assess relative vulnerability of regions to various intensity of drought using the formula

$$\text{Drought Proneness} = \frac{\text{Number of droughts under each category}}{\text{Total number of droughts}} \times 100$$

4.5 HYDROLOGICAL DROUGHT INDICES

Hydrological drought may be the result of long term meteorological droughts that results in the drying up of reservoirs, lakes, streams, rivers and a decline in groundwater levels.

Hydrological drought refers to deficiencies in surface and subsurface water supplies. It is measured as stream flow, and as lake, reservoir and groundwater levels. There is usually a delay between the lack of rain and less measurable water in streams, lakes and reservoirs. When rainfall decreases or rainfall deficit takes place over an extended time period, the shortage will be reflected by the reduced surface water and reduced groundwater.

Based on the fact that water has strongest absorption while vegetation has strongest reflectivity at near infra-red, McFeeters S.K. (1996) proposed the method of **NDWI** to highlight water body.

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 Infrared (Band 5). The value of the WRI for water bodies is greater than 1.

4.6 AGRICULTURAL DROUGHT INDICES

Agriculture is a very crucial sector for the well existence of the socio-economic situations. Drought is a potential threat with a destructive damage to agricultural

production. The necessity of a drought index specialized for agriculture led to development of various indices with explicit characteristics for Agricultural drought assessment. The various remotely sensed data serves as input for the various methods, which are used for the identification, monitoring and assessment of the drought. It is facilitated by several satellite based indices like (NDVI, SAVI, VCI, LST, TCI, VHI,) in Visible, Near Infrared and Thermal Infrared and Microwave regions, to target and analyze the concerned areas.

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.

Soil Adjusted Vegetation Index (SAVI) was developed as a modification of the NDVI. The SAVI is used to correct the influence of soil brightness. For Classification the range for highly vegetation is >0.60 , moderate vegetation ranges from 0.30 to 0.60, slight dense 0.00 to 0.30 and no vegetation < 0.00 .

Vegetation Condition Index (VCI) was developed by Kogan (1995) to discriminate overall differences in ecosystem productivity, by separating short-term weather component from long-term ecological component. VCI was developed as a normalisation of NDVI, by scaling NDVI values from 0 – 1 using their relative minimum and maximum values for that composite period and location. VCI values range from 0 – 1, with low values representing stressed vegetation conditions, middle values representing fair vegetation conditions and high values representing optimal vegetation conditions. VCI value is being measured in percentage ranging from 1 to 100.

Temperature Condition Index (TCI) is an LST derived algorithm developed by Kogan (1995) to determine temperature related vegetation stress and excessive wetness related stress. This algorithm is similar to VCI, it is a normalisation of LST, scaled from 0 – 1 with conditions estimated relative to their minimum and maximum temperature values for that time period. It is significant to note that this index was developed as an inverse ratio to VCI. Therefore, TCI values ranging from 0 – 1 indicate changes from unfavourable conditions (high temperature) to most optimal conditions closer to one (low temperatures).

Vegetation Health Index (VHI) from the joint information of VCI and TCI. The TCI teams up along with VCI to forms VHI as a substitute index characterizing vegetation health. The value for VHI less than 40 represents presence of vegetation stress and greater than 60 favors good condition for vegetation.

4.7 TREND ANALYSIS TEST

Generally parametric (distribution-dependent) or non-parametric (distribution-free) statistical tests can be used to decide whether there is a statistically significant trend. A test is said to be parametric if the change evaluated by the test can be specified in terms of one or more parameters. Linear regression is an example of a parametric test. Parametric testing procedures are widely used in classical statistics. In parametric testing, it is necessary to assume an underlying distribution for the data (often the normal distribution), and to make assumptions that data observations are independent of one another.

4.8 DROUGHT FORECASTING MODELS

Soft computing techniques, including FL and ANFIS models, were used in the present study to assess and monitor drought. The most important step in developing a satisfactory estimation model is the selection of proper input variables, since these variables determine the model structure and affect the accuracy of the model. Selection of proper input variables is done using the correlation coefficient between the variables.

Different components of the FL controller structure, including the inputs, fuzzifier units, databases, rule bases, fuzzy inference engines, defuzzifier units, and outputs. The algorithm first defines the linguistic variables and terms. For instance, if the variable to be measured is temperature, it is necessary to set a range of degrees to translate the measurement in fuzzy terms [0, 1]. Membership functions must be constructed as they are essential in the fuzzification and defuzzification processes.

4.8.1 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive Neuro Fuzzy Inference system (ANFIS) is the famous hybrid approach for modeling the complex non-linear systems, which combines the features of both fuzzy and neural network. The ANFIS having a learning algorithm which composed of least square and back propagation method called hybrid learning algorithm.

4.8.2 Evaluation of the Performance of the Models

The performances of the developed models were compared using statistical evaluation performance indices, namely the coefficient of correlation (r), coefficient of determination (R^2), Root Mean-squared error (RMSE) and Maximum Absolute Error (MAE) is the most commonly used measure of success of numeric estimation. The values of these performance indices were computed from the observed and predicted values of the dependent variable. They were calculated for both the training and validation data sets.

CHAPTER 5 RESULTS AND ANALYSIS

5.1 ESTIMATION OF VARIOUS METEOROLOGICAL DROUGHT INDICES OVER THE STUDY AREA

In the current assessment study, different meteorological drought indices i.e., percent normal (PN), Percentage of departure from mean (PD), deciles index (DI), Standardized Precipitation Index (SPI), Reconnaissance Drought index (RDI), Standardised Potential Evapotranspiration Index (SPEI), China Z Index(CZI), Modified China Z Index (MCZI) and the Z-Score were used for estimating drought severity and drought years in North Gujarat districts. All the aforesaid indices calculated using precipitation data, temperature data and potential evapotranspiration data.

Percent of Normal Index it was observed that extreme drought condition occurs in the year 1901, 1904, 1911, 1915, 1923, 1974, 1987, severe drought condition occurred during 1936, 1939, 1948, 1951, 1960, 1968, 1969, 2002, moderate drought condition occurred during 1902, 1905, 1918, 1920, 1925, 1930, 1932, 1935, 1940, 1949, 1957, 1962, 1972, 1985, 1986, 1991, 1995, 1999.

During the period of (1901-1930) there were total nine (11 nos) drought events, for (1930-1960) there were five (10 drought events) and (1960-1990) total 12 drought events were observed. It was observed that every 3 to 4 years drought condition was occurred in Banaskantha district. Below Figure 5.1 shows percentage of normal index plot for Banaskantha District.

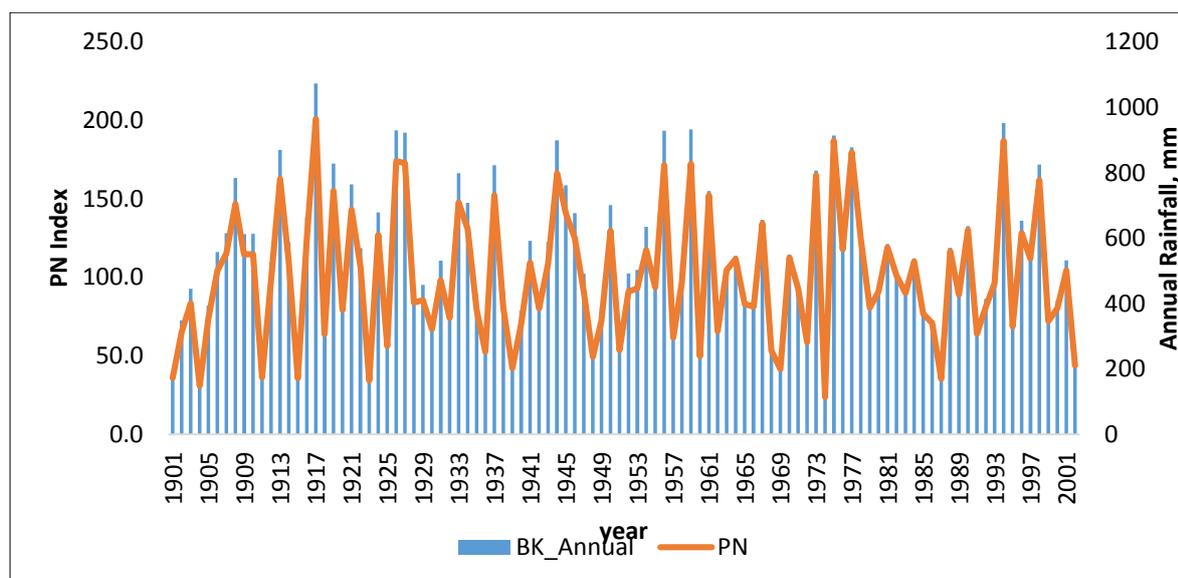


Figure 5.1: Percentage of Normal Plot for Banaskantha District

1.1.2 Percentage of Departure from Mean for Annual Rainfall

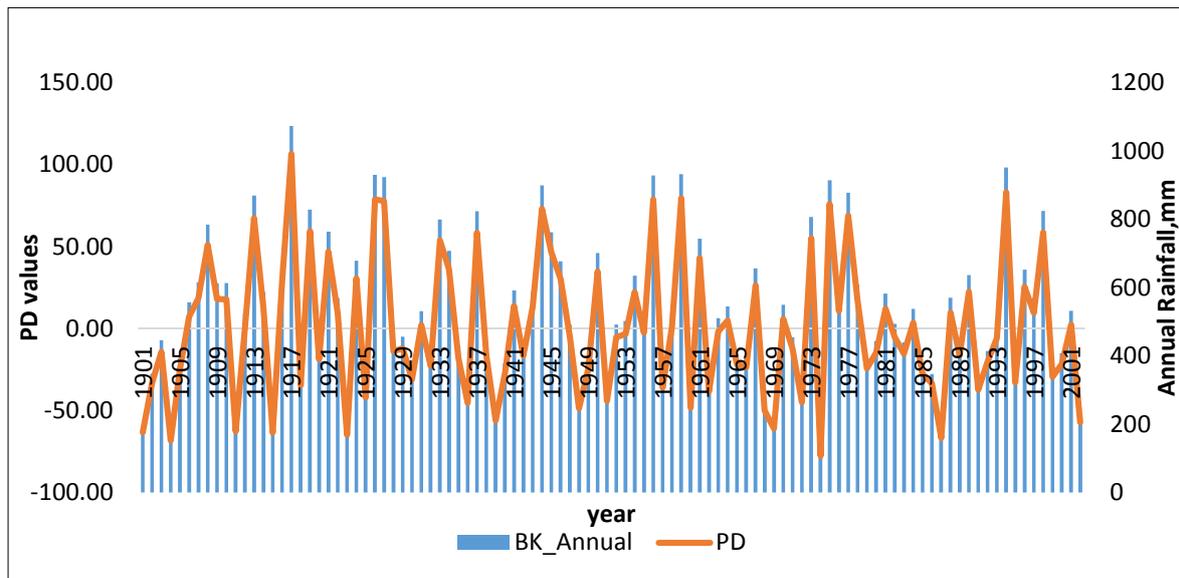


Figure 5.2: Percentage of Departure from Mean and Annual Rainfall for Banaskantha district

1.1.3 Rainfall Anomaly Index

From the results it is observed that extreme dry condition occurs in the year of 1901, 1904, 1911, 1915, 1923, 1939, 1969, 1974, 1987, and 2002 during this year the average rainfall is about 186.40 mm. Also, very dry condition occurred during 1903, 1905, 1920, 1928, 1932, 1935, 1938, 1942, 1949, 1965, 1966, 1979, 1980, 1983, 1989, 1992 and 2000 years and during very dry years the average rainfall is around 419.64 mm during study period.

1.1.4 Deciles

The deciles were estimated for the study area having 102 years (i.e., 1901 to 2002) of monthly rainfall data. The class of deciles 1-2 (20% lower), which is considered much below the normal and are drought affected years. From the analysis, the much below normal DI is concerned with value of 10 percent in 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1951, 1957, 1960, 1962, 1968, 1969, 1972, 1974, 1987, 1991, and 2002 years respectively which is 21 number of years.

1.1.5 Standardized Precipitation Index

The results of SPI were estimated for the study area with 102 years (i.e., 1901 to 2002) of rainfall data. Below Table 5.8 shows the classification of drought years obtain using SPI 12 time steps for Banaskantha district.

Table 5.8: Drought years obtained using SPI 12 month time steps

Classification	Range	Year
Extremely Dry	-2 to less	1904 – 1905, 1974 – 1975, 1987 – 1988
Severe Dry	-1.5 to -1.99	1901 – 1902, 1911 – 1912, 1915 – 1916, 1923 – 1924, 1939 – 1940, 1969 – 1970, 2002 – 2003
Moderate Dry	-1.0 to -1.49	1925 – 1926, 1936 – 1937, 1948 – 1949, 1951 – 1952, 1960 – 1961, 1968 – 1969, 1972 – 1973

1.1.6 Reconnaissance Drought Index

The results of RDI were estimated for the study area with 102 years (i.e., 1901 to 2002) of rainfall and PET data. Below Table 5.9 shows the classification of drought years obtain using RDI 12 time steps for Banaskantha district.

- As per RDI 3, it is observed that extreme drought has occurred 0 times, severe drought has occurred 14 times and moderate drought has occurred 06 times in 102 years.
- As per RDI 6, it is observed that extreme drought has occurred 5 times, severe drought has occurred 3 time and moderate drought has occurred 7 times in 102 years.
- As per RDI 9, it is observed that extreme drought has occurred 5 times, severe drought has occurred 4 times and moderate drought has occurred 4 times in 102 years.
- As per RDI 12, it is observed that extreme drought has occurred 4 times in 102, severe drought has occurred 6 times in 102 years and moderate drought has occurred 6 times in 102 years.

1.1.7 Standardised Precipitation Evapotranspiration Index

The classification of drought years obtain using SPEI 12 time steps under different class for Banaskantha district SPEI Index it was observed that extreme drought condition occurred in 1973 year, severe drought condition occurred during 1901, 1904, 1911, 1915, 1923, 1968, 1986 moderate drought condition occurred during 1925, 1936, 1939, 1948, 1951, 1960, 1967, 1971, 2002. Also, from above Table it was observed total 17 years as drought years that every 3 to 4 years drought condition was occurred in Banaskantha district.

1.1.8 China Z Index & Modified China Z Index

The (1901-2002) viz., 102 historical years assessed using China Z index and Modified China Z index from the analysis, Dry years are observed as total 24 number of years. The extreme dry years as 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002.

Also, moderate drought years as 1905, 1930, 1957, and 1962 in Banaskantha district.

1.1.9 Z- Score Index

From this method, Out of the 102 study period dry years are observed in 17 years. The results shows that severe drought conditions occurred during 1901, 1904, 1911, 1915, 1923, 1974, 1987 and moderate dry years as 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 2002 in Banaskantha district.

Both Z-Score and SPI can be used in drought analysis, the Z-Score is a general statistical measure that can be applied to various data types, whereas SPI is specifically designed for characterizing drought conditions based on precipitation data. SPI is widely used in meteorology and hydrology for drought monitoring and early warning systems.

5.1.6 Comparative Analysis of Meteorological drought indices over the study area

The monthly rainfall data for 102 years (i.e. 1901 to 2002) shows that the maximum rainfall is 1072.68 mm in 1917 and minimum rainfall is 115.23 mm in 1974 in Banaskantha district. Also, the maximum rainfall is 1261.90 mm in 1959 and minimum rainfall is 237.90 mm in 1911 in Gandhinagar district. Similarly there are high fluctuations of rainfall ranging from maximum rainfall is 1195.33 mm in 1959 and minimum rainfall is 214.01 mm in 1987 for the Mehsana district. Rainfall data of Patan district shows that maximum rainfall is 1085.20 mm in 1956 and minimum rainfall is 144.60 mm in 1974 was observed. For Sabarkantha district rainfall data shows that the highest average rainfall was observed as 320.35 mm in the month of July and lowest average rainfall was observed in the month of March as 1.1261 mm in the span of 102 years in Sabarkantha district.

The comparative study of monthly rainfall analysis for drought the result shows that for the months of March, November and December have 81, 81, 79 times respectively, indicating that these months must be provided with assured Irrigation. Similarly, the months of July and August had minimum number of drought months i.e., 17, 20 times respectively. Also, the percentage of drought in the month of October to march is 9% to 12% for all districts.

- The results of meteorological drought indices for **Banaskantha** district shows that extreme drought condition occurred during 1901, 1904, 1911, 1915, 1923, 1974, 1987, severe drought condition occurred during 1936, 1939, 1948, 1951, 1960, 1968, 1969, 2002, moderate drought condition occurred during 1902, 1905, 1918, 1920, 1925, 1930, 1932, 1935, 1940, 1949, 1957, 1962, 1972, 1985, 1986, 1991, 1995, 1999 years.

- **Gandhinagar** district shows that extreme drought condition occurs in the year 1911, 1918, 1987 severe drought condition occurred during 1904, 1915, 1923, 1948, 1951, 1968, 1972 moderate drought condition occurred during 1901, 1925, 1936, 1939, 1940, 1947, 1957, 1960, 1965, 1969, 1971, 1974, 1985, 1986, 1991, 1995, 2002 years
- **Mehsana** district shows that extreme drought condition occurs in the year 1911, 1918, 1987 severe drought condition occurred during 1904, 1915, 1923, 1948, 1951, 1968, 1972 moderate drought condition occurred during 1901, 1925, 1936, 1939, 1940, 1947, 1957, 1960, 1965, 1969, 1971, 1974, 1985, 1986, 1991, 1995, 2002 years
- **Patan** district rainfall data analysed and it was observed that extreme drought condition occurs in the year 1904, 1911, 1923, 1968, 1974, 1987 severe drought condition occurred during 1901, 1915, 1925, 1936, 1939, 1957, 1960, 1969, 1972, 2002 moderate drought condition occurred during 1902, 1918, 1929, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1962, 1966, 1986, 1991, 1995, 1999. From this results it is observed that extreme dry condition the average rainfall is about 222.58 mm. Also, during moderate dry years the average rainfall is around 307.94 mm during study period.
- **Sabarkantha** district results shows that severe drought condition occurred during 1904, 1911, 1915, 1923, 1948, 1974, 1987 and moderate drought condition occurred during 1901, 1918, 1936, 1939, 1940, 1951, 1965, 1968, 1969, 1972, 1979, 1985, 1986, 1991, 1995, 1999, 2002. It was also observed that there were 24 number of year's identified as dry years during 102 years.

A disadvantage of using the percent of normal index is that the mean, or average precipitation is often not the same as the median precipitation. Therefore SPI, RDI and SPEI indices should be used for drought monitoring. Dividing the total no of years into 3 periods i.e., (1901-1930) as period 1, (1931-1960) as period 2, (1961-2002) as period 3, it can be noted that the frequency of drought during (1901-1930) there were around 8-10 drought years, during (1930-1960) total 6-9 drought years, during the period of (1960-1990) total 8-12 drought events.

5.2 ESTIMATION OF DROUGHT BY DIFFERENT CLIMATIC INDEX OVER THE STUDY AREA

Drought year has been analyzed by three different climatic indexes viz., Mortone aridity index, Seleaninoy hydrothermic index and Donciu climatic index for the period of 1901 to 2002 in North Gujarat districts. The analysis was performed in yearly basis of rainfall data. Though the study gives an identification about the drought

condition of the study area to face the drought adaptability and remedial measure for the alleviation of the drought for the reason concerned.

- Mortone Aridity Index shows excessive droughty conditions for 2 times, very droughty for 8 times and droughty for 7 times, medium dry conditions for 37 times and excessive rainy years for 9 times in Banaskantha district.
- Seleaninov Hydrotheremic Index shows very droughty conditions for 3 times, droughty conditions for 14 times, medium dry conditions for 19 times and excessive rainy years for 11 times in Banaskantha district.
- Donciu Climate Index shows droughty conditions for 13 times, medium dry conditions for 40 times and excessive rainy years for 23 times in Banaskantha district.

The comparative analysis shows that droughty condition occurred 7 times viz., 1925, 1936, 1948, 1951, 1960, 1968, and 1972. Very droughty condition occurred 8 times viz., 1901, 1911, 1915, 1923, 1939, 1969, 1987, and 2002. Also, excessive droughty occurred 2 times viz., 1904, 1974. The results also shows that 15.3% years falls under dry category and medium dry condition shows 31.3% years and excessive rainy condition shows 14.3% in Banaskantha district.

Results of Precipitation Concentration Index for Banaskantha district

it was observed that summer season PCI index shows 23.5% uniform, 56.9% moderate uniform, 17.6% as irregular precipitation and 2% as strong irregular precipitation distribution over 1901 to 2002. Also, during April to September months there is 47.1% irregular precipitation trend was observed.

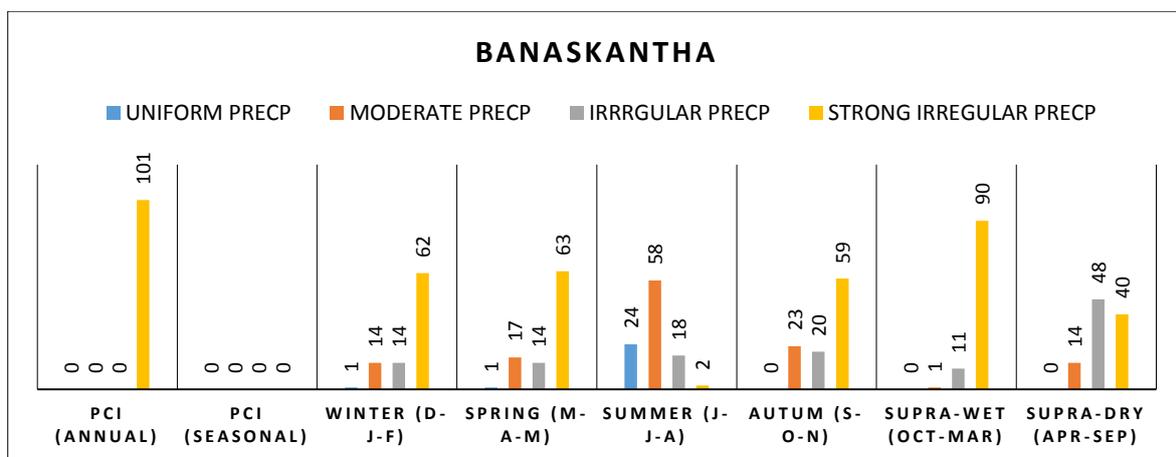


Figure 5.12: Precipitation Concentration Index for various seasons for Banaskantha district

Results of Modified Fournier Index for Banaskantha district

The results shows that total 03 years having very low and 08 years having low rainfall erosivity and 13 years as moderate rainfall erosivity during (1901 to 2002).The corresponding years for low erosivity as 1901, 1904, 1911, 1915,1923, 1939, 1962, 1969, 1974, 1987 and 2002. The average rainfall during these years as 207.01 mm whereas annual average rainfall for entire set of data considered the district is around 520.10 mm.

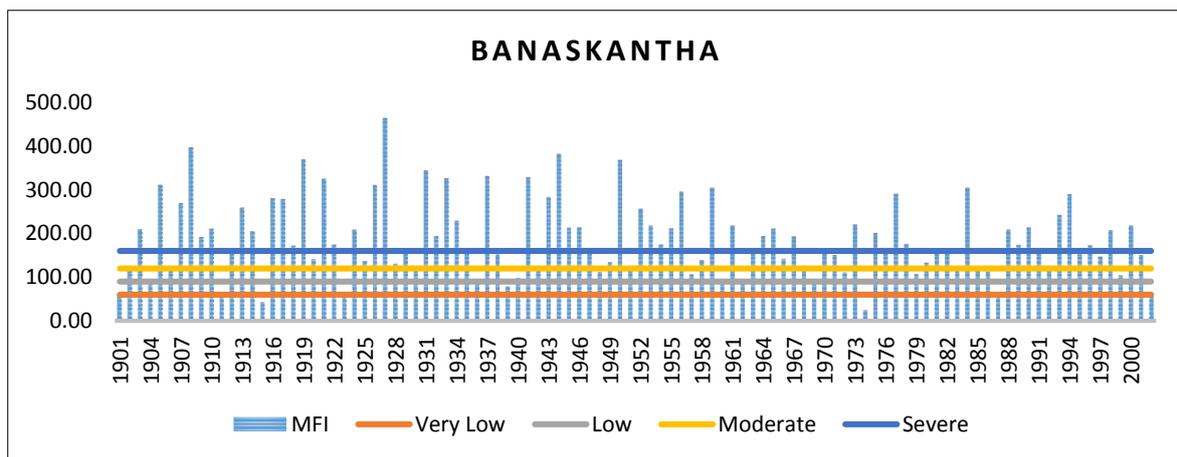


Figure 5.13: Modified Fournier Index for Banaskantha district

Comparative analysis of Climatic indices over North Gujarat region

- The results of **Banaskantha** district shows that 1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 1974, 1987 and 2002 years were severely affected by drought. Also, 1902, 1903, 1905, 1917, 1918, 1920, 1928, 1929, 1930, 1932, 1935, 1938, 1940, 1942, 1947, 1949, 1952, 1953, 1955, 1957, 1962, 1965, 1966, 1971, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 23.5% uniform, 56.9% moderate uniform, 17.6% as irregular precipitation and 2% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 47.1% irregular precipitation trend was observed.
- The results of **Gandhinagar** district shows that 1904, 1911, 1915, 1918, 1923, 1948 1951, 1960, 1965, 1968, 1972, 1974, 1987, 1995, 2002 years were severely affected by drought. Also, 1901, 1902, 1903, 1905, 1916, 1920, 1924, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1947, 1949, 1952, 1957, 1964, 1966, 1969, 1971, 1978, 1979, 1980, 1982, 1984, 1985, 1986, 1989, 1991, 1992, 1993, 1997, 1999, 2000, 2001 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 20.59% uniform, 70.59% moderate uniform, 6.86% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period.

Also, during April to September months there is 54.90% irregular precipitation trend was observed.

- The results of **Mehsana** district shows that 1901, 1904, 1911, 1915, 1918, 1923, 1936, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1991, 1995, 2002 years were severely affected by drought. Also, 1902, 1903, 1905, 1910, 1916, 1920, 1925, 1929, 1930, 1932, 1935, 1938, 1947, 1949, 1952, 1962, 1964, 1966, 1971, 1978, 1979, 1980, 1982, 1984, 1988, 1989, 1992, 1993, 1997, 1999, 2000, 2001 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 27.45% uniform, 64.71% moderate uniform, 5.88% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 57.84% irregular precipitation trend was observed.
- The results of **Patan** district shows that 1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002 years were severely affected by drought. Also, 1902, 1903, 1905, 1918, 1920, 1929, 1930, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1952, 1953, 1956, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1992, 1993, 1999, 2000 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 20.60% uniform, 62.70% moderate uniform, 13.70% as irregular precipitation and 2.90% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 55.90% irregular precipitation trend was observed.
- The results of **Sabarkantha** district shows that 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1969, 1974, 1987, 2002 years were severely affected by drought. Also, 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 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 26.50% uniform, 66.70% moderate uniform, 5.90% as irregular precipitation and 1.0% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 53.90% irregular precipitation trend was observed.

From the above all results it was concluded that Patan district had more dry year with highest frequency about 18.9% of extreme and 30.39% of medium dry events whereas Sabarkantha and Gandhinagar district had least percentage of dry years which is about 9.47%, 11.43% of extreme dry and 26.78%, 29.40% medium dry

events during study period. Also, Patan district had minimum excessive rainy years which is about 12.03% compared to other districts.

5.3 ESTIMATION OF VARIOUS ARIDITY INDEX OVER THE STUDY AREA

The Comparative analysis of different aridity indices used in North Gujarat region is shown below.

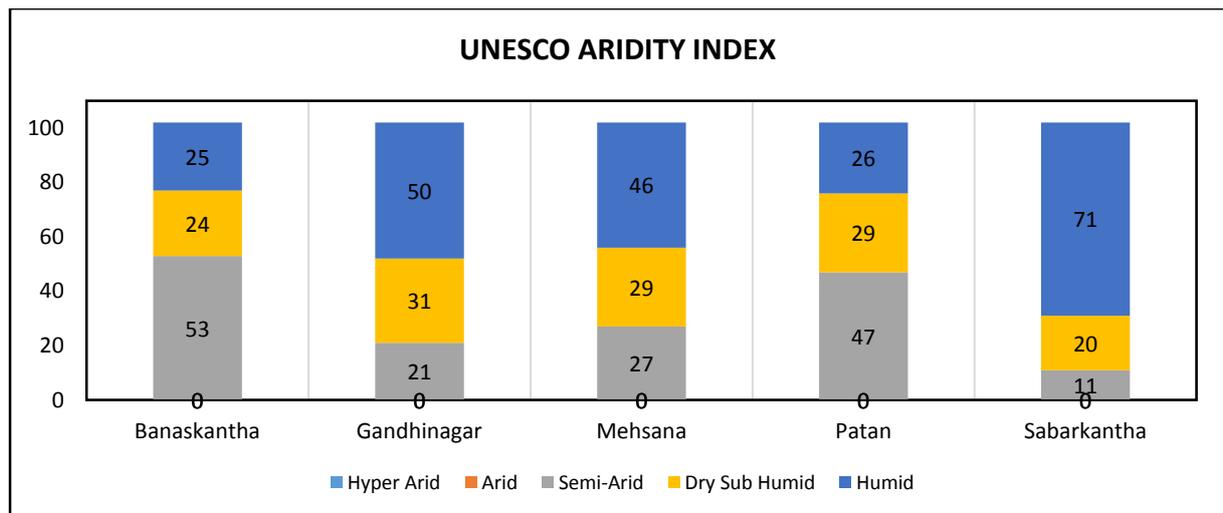


Figure 5.51: Graphical representation of UNESCO Aridity Index over North Gujarat region

From the above Figure 5.51 it was observed that Sabarkantha district is more humid compared to other North Gujarat district. The district having 71 years humid, 20 years as dry sub humid and 11 years as semi-arid. Whereas Banaskantha district having highest number of semi-arid year with 53 years and Gandhinagar having least number of semi-arid years as 21.

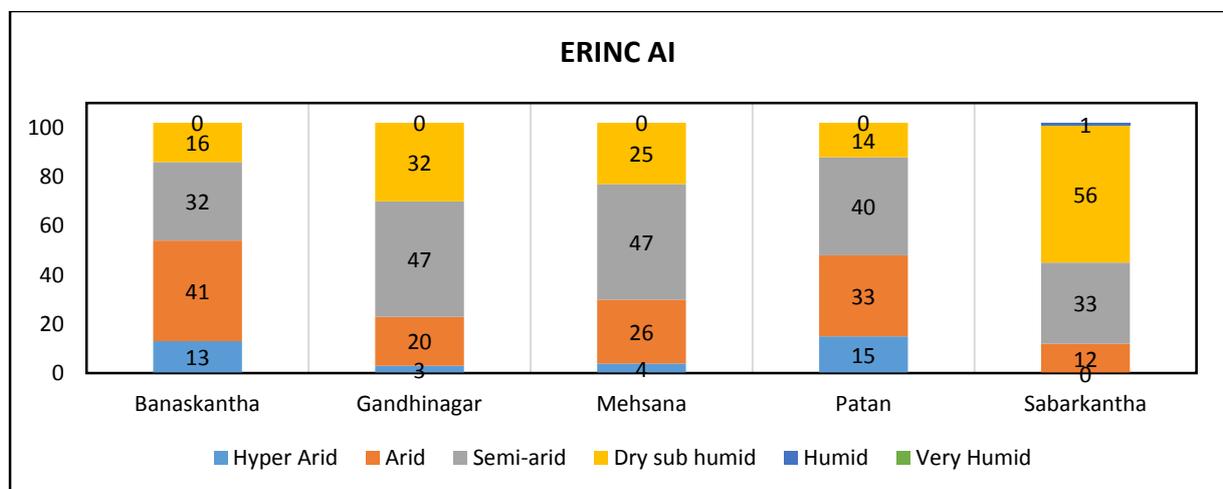


Figure 5.52: Graphical representation of Erinc Aridity Index over North Gujarat region

The comparative results of **Erinc aridity index** is shown in above Figure 5.52 from this it was concluded that Banaskantha district is very humid whereas Gandhinagar is less humid number of years. Also, Sabarkantha district having highest number of years 56 with dry sub humid category and Patan district having 14 number of years.

The Comparative analysis of **Thornthwaite’s precipitation effectiveness index** over North Gujarat districts is shown in above Figure 5.53. From this it is concluded that Banaskantha district is more humid whereas Gandhinagar district is less humid with 17 years and 4 years respectively over 1901 to 2002 study period. Also, Sabarkantha district having highest number of years with dry sub humid (64 years).

The comparative results of **Thornthwaite Moisture Index**, it was concluded that Banaskantha, Patan and Sabarkantha district having 18% years as dry semi-arid. Also, 20 to 25% years as humid in North Gujarat district.

The results of **De Martonne's AI Index** over North Gujarat region, the results shows that Sabarkantha district has 8 to 10% of the district is arid while 15% area is semi-arid. Also, Gandhinagar district is less semi-arid with 19% of the total study area.

5.4 FREQUENCY ANALYSIS OF METEOROLOGICAL DROUGHT INDICES OVER THE STUDY AREA

Drought frequency was calculated for the different drought classes for various drought indices. Frequency of meteorological drought indices shows that the occurrence duration and percentage of drought events over a given time period.

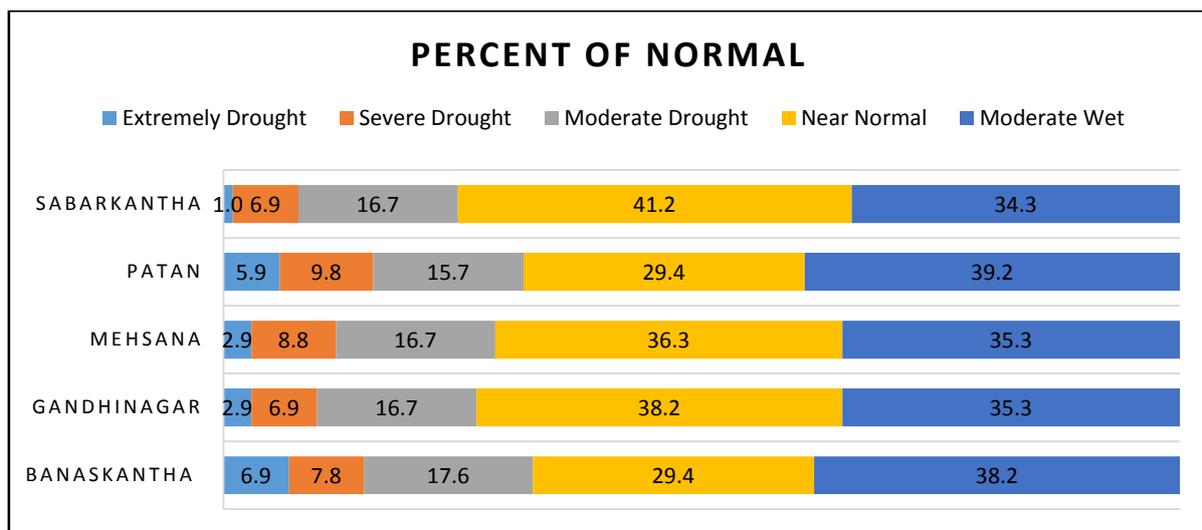


Figure 5.56: Frequency Analysis of PN

The results shows that Banaskantha district having 32% of drought events where Gandhinagar districts having 27% years as drought years. Also, from the analysis it

was observed that Banaskantha and Patan had extreme droughts (7 and 6 events, respectively), while Gandhinagar and Mehsana had 3 events during 102 years. Similarly, for severe drought events Banaskantha, Mehsana and Patan (8, 9 and 10 events respectively). From the analysis it is observed that Sabarkantha and Gandhinagar have less percentage of drought frequency which about 8% and 10% while Banaskantha and Patan have more drought events.

Percentage of Departure from Mean Index

The results shows that Banaskantha and Patan had more droughts events (28 and 30 events, respectively), while Gandhinagar and Mehsana had 23 and 25 events during 102 years. While Sabarkantha had 23 events of drought (7 and 16 years). Sabarkantha district has highest amount of rainfall during study period of 102 years. From the graph it is observed that Sabarkantha and Gandhinagar have less percentage of drought frequency which about 22% and 21% while Banaskantha and Patan have 27% and 29% more drought events.

Rainfall Anomaly Index

The Sabarkantha district results shows that very dry years as 10 years (9.8%), Moderate dry years as 21 years (20.59%), Slight dry year as 8 years (7.8%), Extreme wet years as 4 years (3.9%), Very wet years as 8 number of years (7.84%). Similar for other class and districts the results as shows in above Table 4.3 and Figure 4.3. From the above index it was observed that Banaskantha district had less number of very dry and extreme wet as 3.92% and 9.80% respectively. Also, Sabarkantha district had highest percentage of moderate drought as 20.59%.

Standardised Precipitation Index

The standardized precipitation index (SPI) is used for drought estimation, which serves as an ideal tool for drought monitoring and analysis. The SPI has been computed for four time scales, viz., 3- (3m-SPI), 6- (6m-SPI), 9- (9m-SPI) and 12-month time scale (12m-SPI).

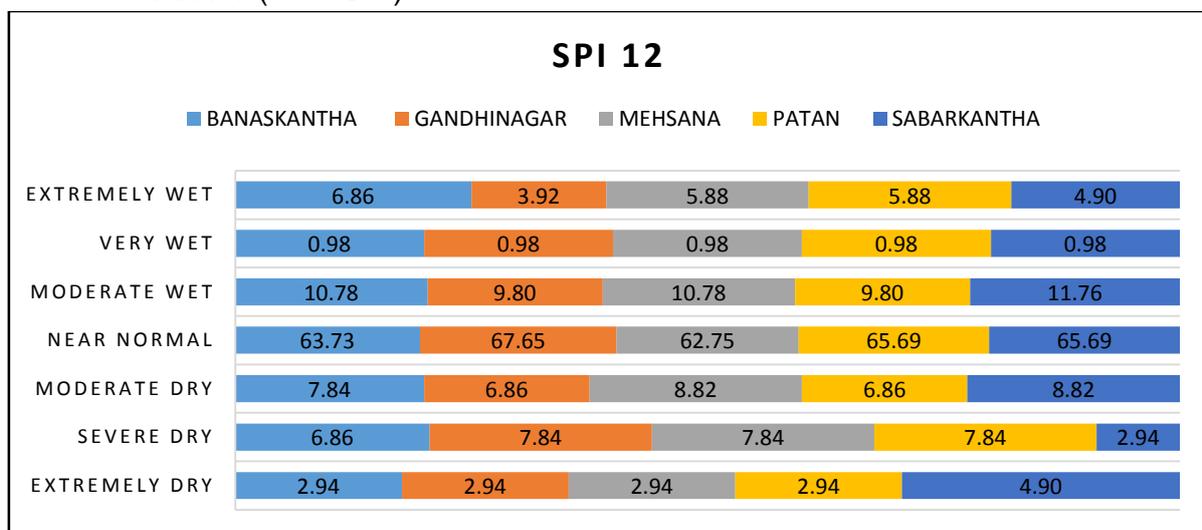


Figure 5.59: Frequency Analysis of SPI 3, 6, 9, 12

It was observed that in Sabarkantha district is less affected by severe drought condition as only 3% whereas other districts having 8% years. For 12 month SPI it was observed that 60% to 67% of the years were classified as near normal condition. While the percentages ranged from 6% to 9% for moderately drought and for severely drought conditions as 2% to 8% in particular north Gujarat region. It is observed 65% years in North Gujarat district having near normal condition, 18% years as drought affected and 16% as wet condition during study period viz. 1901 to 2002.

Reconnaissance Drought Index

It was observed that in Sabarkantha district is less affected by severe drought condition as only 3% whereas other districts having 5 to 8% years. For 12 month RDI it was observed that 25% to 30% of the years were classified as near normal- dry condition. While the percentages ranged from 5% to 8% for moderately drought and for severely drought conditions as 3% to 7% in particular North Gujarat region. It is observed 35 to 40% years in North Gujarat district having near normal-wet condition, 18% years as drought affected and 16% as wet condition during study period.

Standardised Precipitation Evapotranspiration Index

The results of Banaskantha district shows that extreme wet (8 years), Moderate wet (9 years) whereas extreme dry and severe dry as 1 years and 8 years respectively. Where, Patan district shows severe dry and moderate dry as 9 years, moderate wet and extreme wet years as 9 years. For 12 month SPEI it was observed that 60% to 65% of the years were classified as near normal. While the percentages ranged from 5% to 8% for moderately drought and for severely drought conditions as 3% to 7% in particular north Gujarat region. It is observed 35 to 40% years in north Gujarat district having near normal-wet condition, 18% years as drought affected and 16% as wet condition during study period.

China Z Index & Modified China Z Index

It is also observed that Banaskantha district having 19.6% years as extreme dry years and having 8.8% years as very wet conditions. The results also shows that Gandhinagar district having less dry conditions. The results of Modified China Z index shows that Banaskantha district having more dry years compared to other districts with 18 years. From the above Table 5.119 and Figure 5.63 it was observed that in Sabarkantha and Gandhinagar district is less affected by drought condition and having less near normal conditions with 52 years. It is also observed that Banaskantha district having 19.6% years as extreme dry years and having 8.8% years as very wet conditions. The results also shows that Gandhinagar district having less dry conditions.

The **comparative results of meteorological drought indices** shows that Banaskantha and Patan had more droughts events (28 and 30 events, respectively), while Gandhinagar and Mehsana had 23 and 25 events during 102 years. While Sabarkantha had 23 events of drought (7 and 16 years). The Sabarkantha district results shows that very dry years as 10 years (9.8%), Moderate dry years as 21 years (20.59%), Slight dry year as 8 years (7.8%), Extreme wet years as 4 years (3.9%), Very wet years as 8 number of years (7.84%). Also, Sabarkantha and Gandhinagar districts have less percentage of drought frequency which about 22% and 21% while Banaskantha and Patan have 27% and 29% more drought events. The percentage of drought years can provide valuable insights into the characteristics and trends of meteorological droughts and also rainfall variation in a North Gujarat region.

For 12 month SPI, RDI and SPEI it was observed that 18% to 20% years were classified as drought years. It is also observed that 50% to 60% years in north Gujarat district having near normal condition dry conditions, and 16% as wet condition during study period. By analyzing the frequency distribution of drought indices, one can estimate the probability of experiencing drought events of different magnitudes.

5.5 ESTIMATION OF VARIOUS HYDROLOGICAL DROUGHT INDICES OVER STUDY AREA

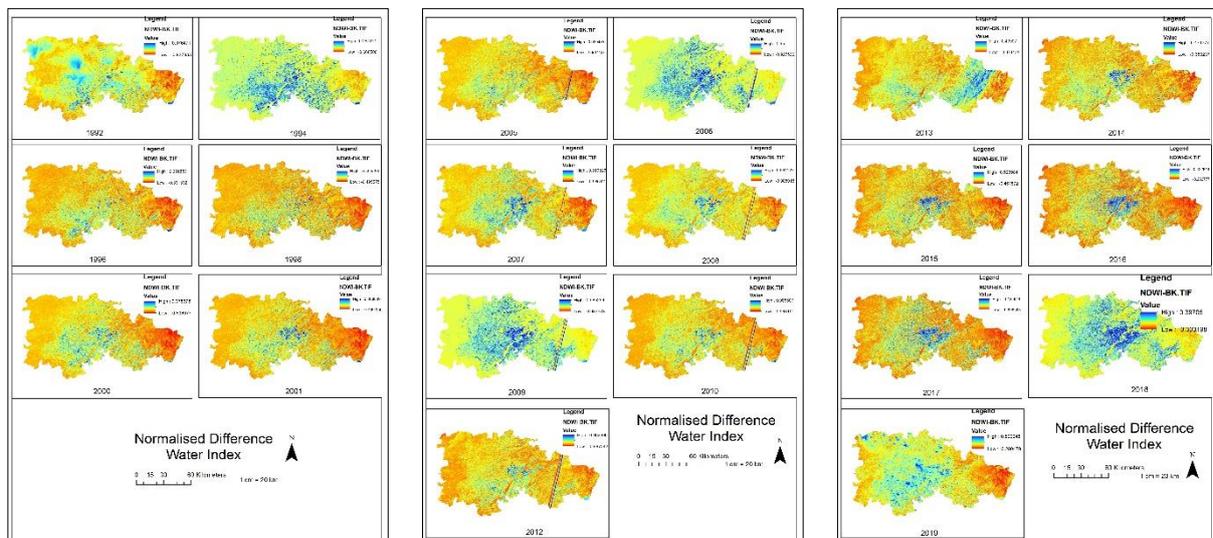
Hydrological drought analysis typically involves the assessment of water availability and the impact of drought on various water resources. The multiband rationing technique has been used to extract the water area from Landsat imageries. Surface water monitoring is a necessary component of researching ecological and hydrological processes. Three water indices, namely Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Water Ratio Index (WRI) used and these is based on the spectral index method using ArcGIS software.

5.5.1 Estimation of Hydrological drought indices over Banaskantha district

It was observed that the minimum area and maximum water spread area obtained by NDWI index was 67.40 Sq.km area in 2001 year and 1842.8 Sq.km area in 2018 year. The average water spread area for the studied period was 754.40 Sq.km with a standard deviation (SD) of 524.20 sq. km area. The percentage of water spread area in the district is varies from 5.5% to 15.5% in Banaskantha district during the period of study.

Similarly, the results of MNDWI index shows that minimum water spread area in 2001 year with 7.77 sq.km area and maximum water spread area 84.97 sq.km area in 2012, 91.59 sq.km area in 2019 observed. Also, the average water spread area in the district is 287.93 sq.km area in Banaskantha district during the period of study.

Below Map 5.1 shows the spatio-temporal changes of NDWI index over Banaskantha district. Very low values of NDWI (negative values) were recorded near river basin area. The threshold value between -0.98 and +0.98 has been observed during 2005 to 2012. Threshold value between -0.22 and +0.50 has been observed during 2013 to 2019 which is used to estimate the water spread mapping.



Map 5.1: Normalized Difference Water Index Map of Banaskantha district

The results of WRI shows that in 1998 year least water spread area which is 1672.90 Sq.km area (15.70%). The average water spread area in Banaskantha district is 6122.0 Sq.km which is 57.60% with standard deviation of 2803.71 Sq.km having 26.37% variation in water bodies during study period.

The results of NDSI index shows that minimum 768.30 Sq.km area having very low saline characteristics which covers an area 7.2% of the district. The moderate saline area in the district was 5795.70 Sq.km area (54.22%) which is maximum in 2006 year and for minimum moderate area observed in 1998 which covers 484.30 Sq.km area which is 4.6% of the district. From the analysis it was observed that average 3027.60 sqkm area which is around 28.5% area of Banaskantha districts having moderate saline characteristics during the study period.

Comparative analysis of Hydrological drought indices over North Gujarat district

NDWI is more sensitive to changes in the water content and turbidity, making it effective for detecting open water bodies. MNDWI, on the other hand, is designed to

be sensitive to the presence of both water and built-up areas. It tends to highlight urban features in addition to water bodies.

The average water spread area for the studied period was 754.40 sq.km and percentage water spread area in the district varies from 5.5% to 15.5% in Banaskantha district. From the analysis of NDSI it was observed that average 3027.60 sq.km area which is around 28.5% area of **Banaskantha** districts having moderate saline characteristics.

The average water spread area for the studied period was 92.70 sq.km with a standard deviation (SD) of 42.8 sq. km area and the percentage water spread area in the district varies from 1.5 % to 9.8% of the Gandhinagar district area. From the analysis of NDSI it was observed that average 321.97 sq.km area which is around 11.80% area of **Gandhinagar** districts having moderate saline characteristics.

The average water spread area for the studied period was 203.40 sq.km with a standard deviation (SD) of 67.10 sq. km area and the percentage water spread area in the district varies from 2.5% to 8.2% of the Mehsana district area. From the analysis of NDSI it was observed that average 973.50 Sq.km area which is around 23.80% area of **Mehsana** districts having moderate saline characteristics.

The average water spread area for the studied period was 99.9 Sq.km with a standard deviation (SD) of 85.90 sq. km area and the percentage water spread area in the district varies from 1.5 % to 6.2% of the Patan district area. From the analysis of NDSI it was observed that average 2860.0 Sq.km area which is around 46.20% area of **Patan** districts having moderate saline characteristics.

The average water spread area for the studied period was 73.5 sq.km with a standard deviation (SD) of 81.40 sq. km area and the percentage water spread area in the district varies from 2.5 % to 5.5% of the Sabarkantha district area. From the analysis of NDSI it was observed that average 2785.20 Sq.km area which is around 24.99% area of **Sabarkantha** districts having moderate saline characteristics.

5.6 FREQUENCY ANALYSIS OF HYDROLOGICAL DROUGHT INDICES OVER NORTH GUJARAT REGION

NDWI is primarily focused on detecting the presence of water, so an increase in values of NDWI generally correlates with an increase in water area. The results of NDWI of Banaskantha district shows that minimum water spread as 67.40 sq.km while maximum water spread area as 1842.80 sq.km which is maximum amongst North Gujarat districts. The minimum water spread area in Gandhinagar district of North Gujarat having 165.30 sq.km.

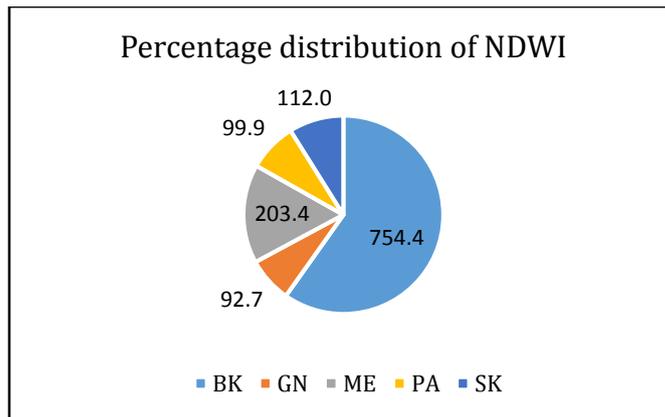


Figure 5.70: NDWI distribution for North Gujarat districts

Figure 5.70 shows the results of percentage of water spread in North Gujarat districts. From the analysis it can be concluded that Banaskantha districts having maximum water spread area which is 754.40 sq.km area while Gandhinagar district having very less water spread area. The Banas River is significant river in North Gujarat. It flows through the districts of Banaskantha and Sabarkantha which reflects in above results that Banaskantha district having 754.40 Sq.km area and 112.0 sq.km in Sabarkantha.

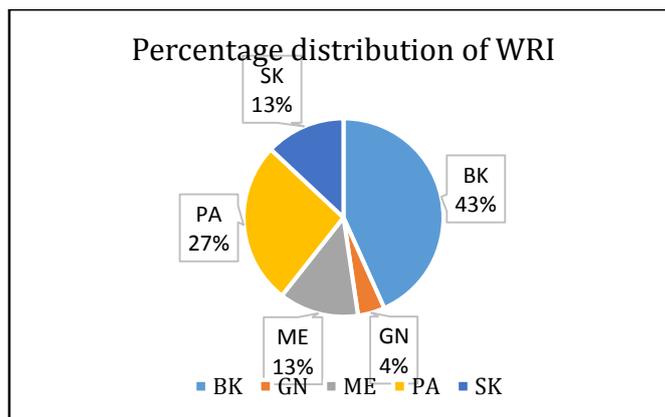


Figure 5.71: WRI distribution for North Gujarat region

The results of NDWI index and WRI index yields near about same results as NDWI is a remote sensing index that uses the reflectance values of the near-infrared (NIR) and shortwave infrared (SWIR) bands. Where WRI index calculated using $(GREEN+RED) / (NIR+MIR)$ bands. The value of the WRI for water bodies is greater than 1.

Figure 5.71 shows the results of percentage of water spread in North Gujarat districts. From the analysis it can be concluded that Banaskantha districts having maximum water spread area which is 43% while Gandhinagar district having least water spread area as only about 4%. Mehsana districts having 13% water spread area and Patan district having again high water percentage area as 27%. The main

reason behind these variation is due to the passing of river and having water holding structures in the districts.

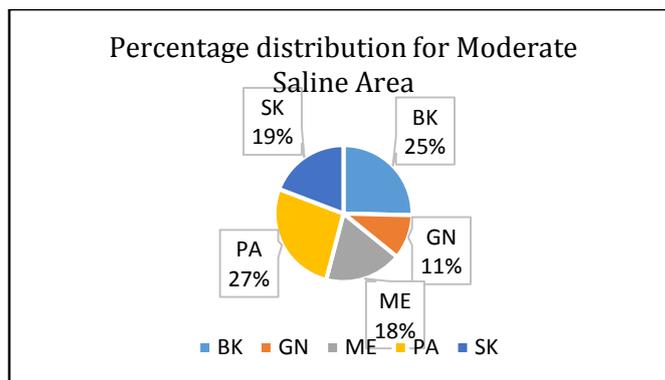


Figure 5.72: NDSI distribution for North Gujarat region

Figure 5.72 shows percentage distribution of moderate saline area in North Gujarat region. The result shows that as NDWI value increases, NDSI value decreases. Gandhinagar district having very less salinity problem compared other North Gujarat districts.

5.7 ESTIMATION OF AGRICULTURAL DROUGHT INDICES OVER THE STUDY AREA

Long term sequence of Landsat data were used in the present study to monitor the amount of drought area in North Gujarat districts. Landsat images of different years 1992 to 2019 at different intervals were studied and analyzed. NDVI images have been generated using the red and near infrared bands of Landsat sensors, and the minimum, maximum and mean values of NDVI for different years have been calculated separately.

NDVI analysis for Banaskantha district

Table 5.121: Classification of NDVI for Banaskantha district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme dry	< 0	16.52	15.61	18.53	38.78	24.14	39.33	19.37
Severe dry	0.0 to 0.2	8280.0	6140.4	5554.1	5440.4	5489.7	4952.7	8264.3
Moderate dry	0.2 to 0.4	2316.7	4234.7	4331.7	4167.1	3999.6	4505.6	2293.2
Moderate wet	0.4 to 0.6	17.58	240.00	726.21	983.77	1117.3	1132.9	53.89
Extreme wet	> 0.6	0.00	0.00	0.33	0.63	0.01	0.00	0.00

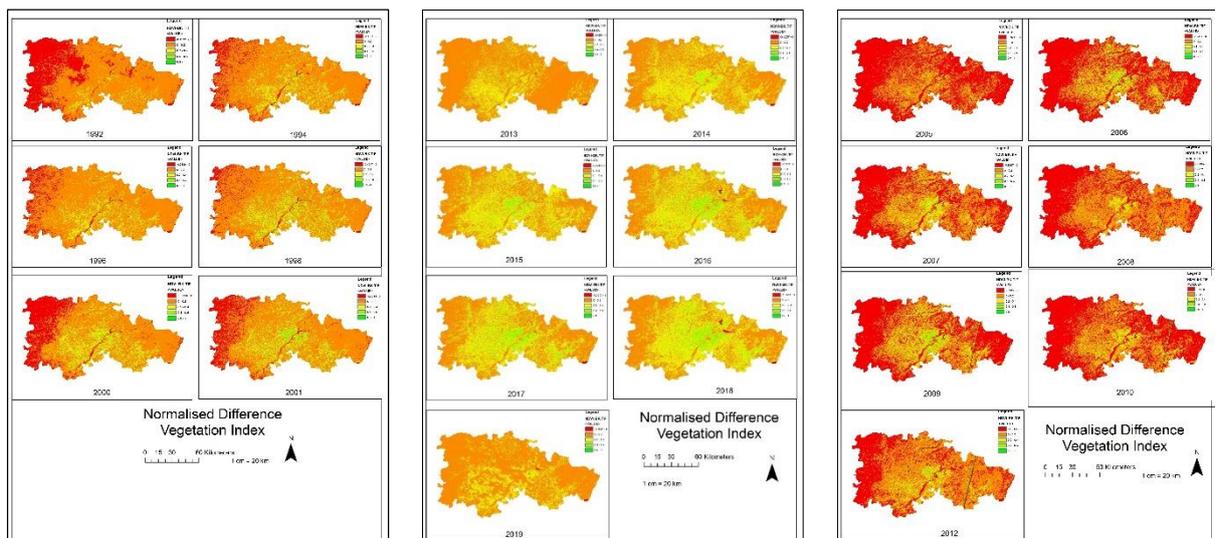
(Area in square kilometres)

The results of the NDVI index shows that the maximum percentage of extreme dry area in the year 2018 with 38.39 Sq.km, which is 0.40% maximum percentage of severe dry areas in the year 1996 with 8307.70 sq. km, which is 78.10%, and during that year the rainfall was 384.96 mm in the study region. Also, moderate dry areas as 1321.40 Sq.km, which is 12.40% of the study area. Similarly, the minimum percentage of dry areas in the year 2006 with 3059.90 sq. km which is 28.80% of the area, and during that year the rainfall was 827.93 mm in the study region.

NDVI-Deviation analysis for Banaskantha district

NDVI deviation for the year 1994 shows that 2879.40 Sq.km as dry area and 708.70 Sq.km as normal dry. The maximum dry area was observed in 2019 year as 4921.30 Sq.km and normal dry area as 141.40Sq.km. Similarly, the minimum dry area was observed in 2006 year as 2269.80 Sq.km and normal dry area as 1012.40 Sq.km. The average deviation in dry area as 464.28 Sq.km and 208.66 Sq.km in normal dry area in Banaskantha district. The percentage of dry area varies from 21.35% to 46.30% and percentage of Normal dry area varies from 1.5% to 10.87% respectively during study period. Also, in decrease in the percentage of normal areas could signify prolonged stress on vegetation. It is observed that from 2013 to 2019 the dry percentage area has increased whereas in 2009 year the percentage of dry area in minimum.

Map Generation: An effort has been made to develop the spatial distribution of different drought severity classes. Below Maps 5.16 and 5.17 shows developed Maps using NDVI index and NDVI deviation for Banaskantha district.



Map 5.2: Normalized Difference Vegetation Index Map of Banaskantha District

Comparative analysis of agricultural drought Indices over North Gujarat region

- The results of **Banaskantha** district for NDVI index shows that the maximum percentage of severe dry areas in the year 1996 with 8307.70 sq. km, which is 78.10%, and during that year the rainfall was 384.96 mm in the study region. Also, moderate dry areas as 1321.40 Sq.km which is 12.40% of the study area. The minimum percentage of dry areas in the year 2006 with 3059.90 sq. km which is 28.80% of the area, and during that year the rainfall was 827.93 mm in the study region. The percentage of dry area varies from 21.35% to 46.30% and percentage of Normal dry area varies from 1.5% to 10.87% respectively during study period.
- The results of **Gandhinagar** district for the NDVI index shows that the maximum percentage of severe dry areas in the year 1994 with 1276.30 sq. km, which is 74.0%, and during that year the rainfall was 474.61 mm in the study region. Moderate dry areas as 382.60 sq.km which is 22.20% of the study area. The minimum percentage of dry areas in the year 2006 with 699.50 sq. km which is 40.06% of the area, and during that year the rainfall was 627.54 mm in the study region. Also, the minimum moderate dry percentage in 2006 year with 5.60% area with 96.50 sq.km during this year the annual rainfall is 954.49mm. The percentage of dry area varies from 27.04% to 48.58% and percentage of Normal dry area varies from 0.94 % to 10.27 % respectively during study period.
- The results of **Mehsana** district for the NDVI index shows that the maximum percentage of severe dry areas in the year 1992 with 3531.60 sq. km, which is 80.40%, and during that year the rainfall was 485.16 mm in the study region. Moderate dry areas as 788.30 sq.km, which is 17.90% of the study area. The minimum percentage of dry areas in the year 2005 with 1655.60 sq. km which is 37.70% of the area, and during that year the rainfall was 827.90 mm in the study region. Also, the minimum moderate dry percentage in 2006 year with 5.20% area with 228.90 sq.km during this year the annual rainfall is 827.93 mm. The percentage of dry area varies from 25.48 % to 42.47 % and percentage of Normal dry area varies from 2.28 % to 10.69 % respectively during study period.
- The results of **Patan** district for the NDVI index shows that the maximum percentage of severe dry areas in the year 2018 with 5784.90 sq. km, which is 96.0%, and during that year the rainfall was 284.77 mm in the study region. Also, moderate dry areas as 1075.0 sq.km, which is 17.8% of the study area. Similarly, the minimum percentage of dry areas in the year 2008 with 15.0 sq. km which is 0.20% of the area, and during that year the rainfall was 421.8 mm in the study region. The percentage of dry area varies from 30.41 % to 42.58 % and percentage of Normal dry area varies from 1.09 % to 4.38 % respectively during study period.

- The results of **Sabarkantha** district the NDVI index shows that the maximum percentage of severe dry areas in the year 1992 with 3660.10 sq. km, which is 87.40%, and during that year the rainfall was 585.35 mm in the study region. Also, moderate dry areas as 403.7 Sq.km, which is 9.6% of the study area. Similarly, the minimum percentage of dry areas in the year 2005 with 1186.60 sq.km which is 28.30% of the area, and during that year the rainfall was 775.20 mm in the study region. Also, the minimum moderate dry percentage in 2005 year with 2.70% area with 114.30 Sq.km during this year the annual rainfall is 775.20 mm. The percentage of dry area varies from 23.27 % to 38.14 % and percentage of Normal dry area varies from 1.94 % to 6.21 % respectively during study period.

5.8 COMPUTATION OF VEGETATION STRESS USING VARIOUS INDICES OVER STUDY REGION

Results of VCI for Banaskantha district

The Vegetation Condition Index (VCI) is a valuable tool for assessing and interpreting changes over time period. The VCI values over 2013 to 2019 years using Landsat data for Banaskantha district is analyzed and results shown in below Table 5.136.

Table 5.136: Classification of VCI for Banaskantha district

Classification	Range	2013	2014	2015	2016	2017	2018
Extreme Drought	< 10	6.3	0.9	0.0	0.0	0.0	0.0
Severe Drought	10 to 20	170.3	19.9	0.1	1.5	0.0	25.7
Moderate Drought	20 to 30	1610.1	220.2	15.4	36.3	9.8	30.2
Light Drought	30 to 40	4251.3	2141.9	72.4	80.8	18.8	930.8
No Drought	> 40	4592.9	8247.9	10543	10512	10602	9644

(Area in Sq.km)

From the above Table 5.136 it was observed that in the year 2018 the severe drought covers an area of 25.7 sq.km which is 0.24% the total district. Moderate drought conditions, and Light drought conditions covers area of 30.2 sq.km and 930.80 sq.km respectively. The average drought percentage 9 % in the Banaskantha district. The results of VCI index shows that moderate drought having 20.8 percent and light drought having 55.10 percent during study period of 1992 to 2019 in the district.

Results of NDVI and SAVI for Banaskantha district

SAVI results of 2019 year shows that the non-vegetation class falls in the range of less than 0.00 which covers 19.4 sq. km area of the district which is 0.18% of the total area of the district. The Slightly dense vegetation threshold value ranges from 0.00 to 0.30, it covers 77.74% of the total district area which comprises 8264.80 sq.km. Also, Moderate dense vegetation in the districts covers 21.56% of the total area which is 2292.80 sq. km of the district. The highly dense area in the district is 53.9 sq.km. The annual average rainfall was 690.82 mm during this year. The drought conditions can stress vegetation, so monitoring rainfall and precipitation patterns is crucial in assessing vegetation stress. The study also observed a change in vegetation from 46.59% to 78.48% during study period of 1992 to 2019.

NDVI results of 2019 year shows that the non-vegetation threshold value less than 0.00 which covers 19.40 sq. km area of the district which is 0.18% of the total area of the district. The Slightly dense vegetation class, which falls in the range of 0.00 to 0.30, it covers 92% of the total area which covers 10201 sq. km of the district. Also, Moderate dense vegetation in the districts comprise 3.85 % of the total vegetation area which is 410.5 sq. km of the district. The study also observed a change in vegetation from 70.02 % to 95.12 % during study period of 1992 to 2019.

This graphical representation for the study period for year 1992 to 2019 is shown in below Figure 5.88, which shows that comparisons of dense percentage area between SAVI index and NDVI index for Banaskantha district.

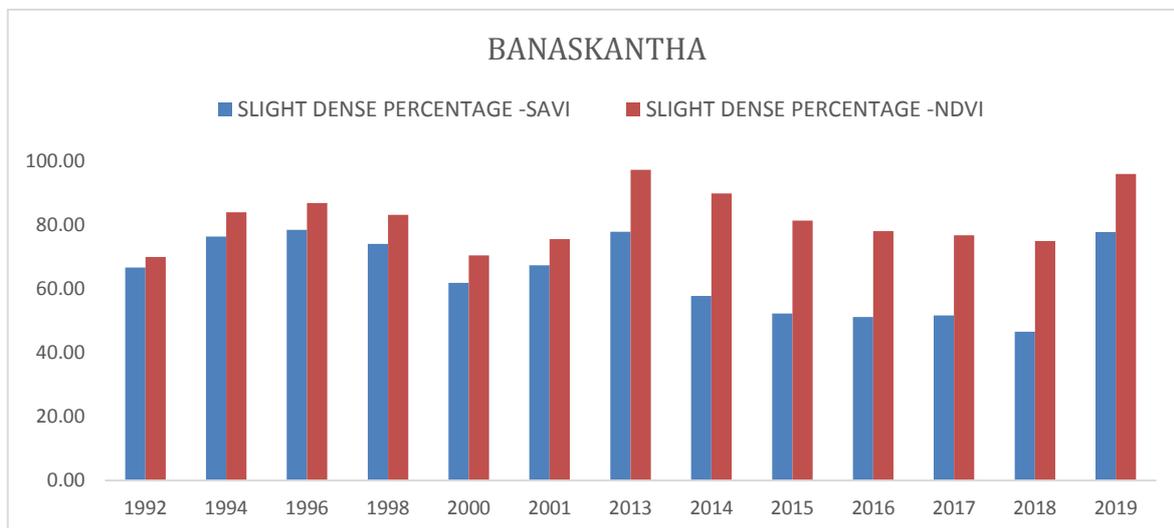


Figure 5.88: Dense percentage area between SAVI and NDVI for Banaskantha district

From the above Figure 5.88 it the result of SAVI shows that minimum vegetation was observed in 2018 year as 46.59% and maximum vegetation was observed in 1996 year as 78.48%. Similarly, NDVI shows that minimum vegetation was observed in

2000 year as 70.47% and maximum vegetation was observed in 2013 year as 97.24%. The average vegetation in Banaskantha district was 64.61% during study period.

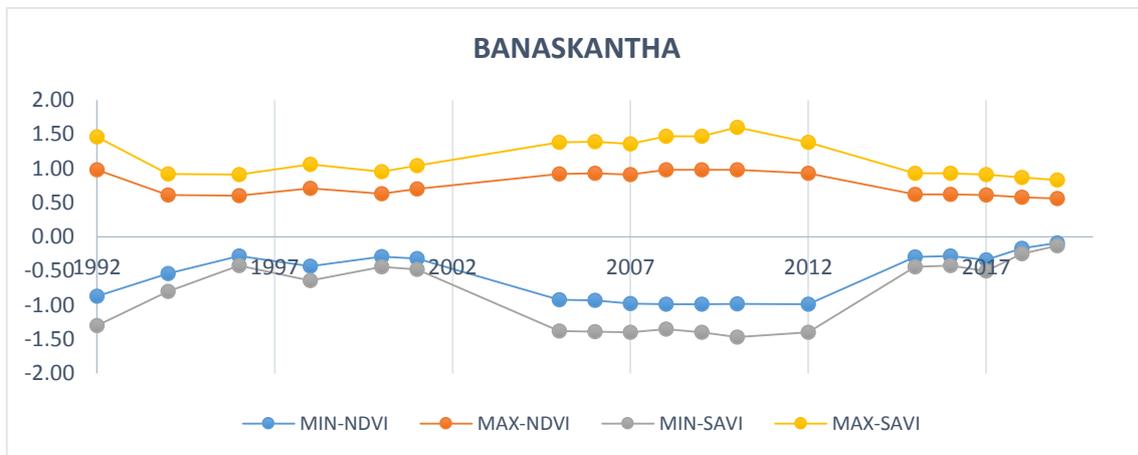


Figure 5.89: Max and Min values of NDVI and SAVI over Banaskantha district

The threshold values of maximum, minimum NDVI with the maximum, minimum SAVI to determine which index was shown in above Figure 5.89. The minimum NDVI value is -0.99 and maximum NDVI value is 0.98 and the minimum SAVI value is -1.47 and maximum SAVI value is 1.60. From the analysis it was observed that NDVI tends to be more sensitive to changes in vegetation density and less affected by soil brightness variations. Therefore, it often provides higher values when vegetation is at its peak.

This decline in vegetation is a matter of significant ecological importance and warrants careful consideration and proactive measures.

5.8.6 Comparative analysis of vegetation stress analysis over North Gujarat region

The results of VCI index shows that moderate drought having 20.8 percent and light drought having 55.10 percent during study period in the **Banaskantha** district. The results of SAVI shows that minimum vegetation was observed in 2018 year as 46.59% and maximum vegetation was observed in 1996 year as 78.48%. Similarly, NDVI shows that minimum vegetation was observed in 2000 year as 70.47% and maximum vegetation was observed in 2013 year as 97.24%. The average vegetation in district was 64.61% during study period.

The results of VCI index shows that Moderate drought conditions, and Light drought conditions covers area of 29.4 Sq.km and 186.7 Sq.km respectively. The average drought percentage 12.15 % in the **Gandhinagar** district. The results of SAVI shows that minimum vegetation was observed in 2015 year as 40.58% and maximum vegetation was observed in 1994 year as 74.55%. Similarly, NDVI shows that

minimum vegetation was observed in 2006 year as 63.71% and maximum vegetation was observed in 1992 year as 89.45%. The average vegetation in district was 59.12% during study period.

The results of VCI index shows that moderate drought having 23.6 percent and light drought having 53.25 percent during study period in **Mehsana** district. The results SAVI shows that minimum vegetation was observed in 2014 year as 46.15% and maximum vegetation was observed in 1992 year as 80.86%. Similarly, NDVI shows that minimum vegetation was observed in 2010 year as 55.99% and maximum vegetation was observed in 1992 year as 93.55%. The average vegetation in Mehsana district was 59.83% during study period.

The results of VCI index shows that 10.5 Sq.km area under extreme dry conditions 46.6 sqkm area as severe dry and 4439.70 Sq.km area as moderate dry conditions in **Patan** district. The average drought percentage 34 % in the district. The results SAVI shows that minimum vegetation was observed in 2010 year as 16.35% and maximum vegetation was observed in 2019 year as 89.19%. Similarly, NDVI shows that minimum vegetation was observed in 2005 year as 15.75% and maximum vegetation was observed in 2019 year as 98.55%. The average vegetation in district was 57.80% during study period.

The results of VCI index shows that maximum extreme dry area was 24.5 Sq.km severe dry area as 24.00 Sq.km and moderate dry area as 779.0 Sq.km during the study period. The average drought percentage 28 % in the **Sabarkantha** district. The results SAVI shows that minimum vegetation was observed in 2009 year as 37.41% and maximum vegetation was observed in 1992 year as 87.60%. Similarly, NDVI shows that minimum vegetation was observed in 2010 year as 40.90% and maximum vegetation was observed in 2019 year as 93.40%. The average vegetation in district was 63.47% during study period.

5.9 TREND ANALYSIS OF METEOROLOGICAL DROUGHT INDICES OVER THE STUDY AREA

Linear regression analysis is a parametric test and one of the most commonly used methods to detect a trend in a data series. The relationship between two variables (dependent and independent) by fitting a linear equation to the observed data this can be done by using the scatter plot. Linear regression is extensively used to determine long-term trends in various meteorological parameters and various drought indices. A positive slope value indicates an increasing trend, and a negative value indicates a decreasing trend. A numerical measure of this association between the variables is the correlation coefficient, which range between -1 to +1.

Mann-Kendall Test and Sen's Slope Estimation these two non-parametric test is used to detect the presence of a significant trend (upward or downward) in a time series dataset for summer, winter, monsoon and annual rainfall data series. Also, for temperature data. The results of Trend analysis of drought indices such as SPI (Standardized Precipitation Index), RDI (Reconnaissance Drought Index), and SPEI (Standardized Precipitation Evapotranspiration Index) for different time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 were analyzed.

The Comparative analysis of MK test and Sen's slope estimator shows that there is maximum negative trend was observed in Sabarkantha district compared to other districts for rainfall data. The annual rainfall recorded at Sabarkantha shows a significant negative trend with Z value of -0.944 and its corresponding Sen's slope value is -0.724. For summer season rainfall shows a significant negative trend with Z value of -1.340 and its corresponding Sen's slope value is -0.038. Similar, for winter season rainfall shows a significant positive trend with Z value of 1.456 and its corresponding Sen's slope value is 0.058.

The comparative analysis of trend analysis of temperature (1901-2002) shows a significant falling trend for July month with average Z value of -1.167 and its corresponding Sen's slope value is -0.003. However, increasing trend for December month with Z value of 4.51 and its corresponding Sen's slope value is 0.018 during 1901 to 2002. During (Dec, Jan and Feb) the Z statistics values as 4.077 and Sen's slope value as 0.010 during study period, which shows that annual temperature is increasing over the decades.

The results of the Mann-Kendall and Sen's Slope estimator tests for different drought indices with various time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 for SPI, RDI, SPEI over the North Gujarat districts shows similar results that in Sabarkantha district having maximum Z value for above said indices. From the above results it was observed that SPI and RDI shows similar results for different time scales while SPEI behave in some different trend for time scale.

The results of for SPI index shows that value of Z is -0.94 with Sen's slope value as 0.23. For RDI index value of Z is -0.96 with Sen's slope value as 0.26 and for SPEI index value of Z is -0.94 with Sen's slope value as 0.17. For 12 month time scale all three indices gave nearly same results. By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. It was also observed that Sen's slope value for RDI is showing higher value than SPI and SPEI. Also, maximum trend value of Z statistics for RDI indices is obtained. The falling trend indicates the increasing severity of meteorological drought in the region.

By analyzing rainfall, temperature trends, it's possible to identify prolonged periods of above average values, which can contribute to the development of drought conditions. Analyzing long-term rainfall and temperature trends is crucial for

assessing the impact of climate change on drought patterns. Rising global temperatures, driven by human activities, can alter the frequency and intensity of drought events.

5.10 DEVELOPMENT OF DROUGHT SEVERITY MAPS USING VARIOUS INDICES OVER THE STUDY AREA

The spatial distribution of surface temperature using LST is shown in below Table 5.156 for Banaskantha district. However, the same for the years 1994 to 2019 are showing in below Figure 5.103.

Table 5.156: Classification of LST for Banaskantha district

Classification	Range	2006	2007	2008	2009	2010
Low Temperature	00 to 15	0.0	0.0	0.0	0.0	0.0
Medium Temperature	15 to 25	38.5	42.2	11.4	9.5	0.0
Average Temperature	25 to 35	2178.4	5542.5	1061.8	1402.8	640.4
High Temperature	35 to 45	8368.1	5045.1	9551.0	8220.2	9516.0

The results of 2006 shows that 8368.10 sq.km area of the district was under high temperature (35 to 45°C) which 78.27 % of the district. Also, 2178.40 sq.km area of the district having average temperature (25 to 35°C) which is 20.48% of the total area of the district. The dry soil area is usually visualized by high LST. Also, LST analysis has shown higher surface temperature in built-up and bare surfaces and low in healthy vegetated areas.

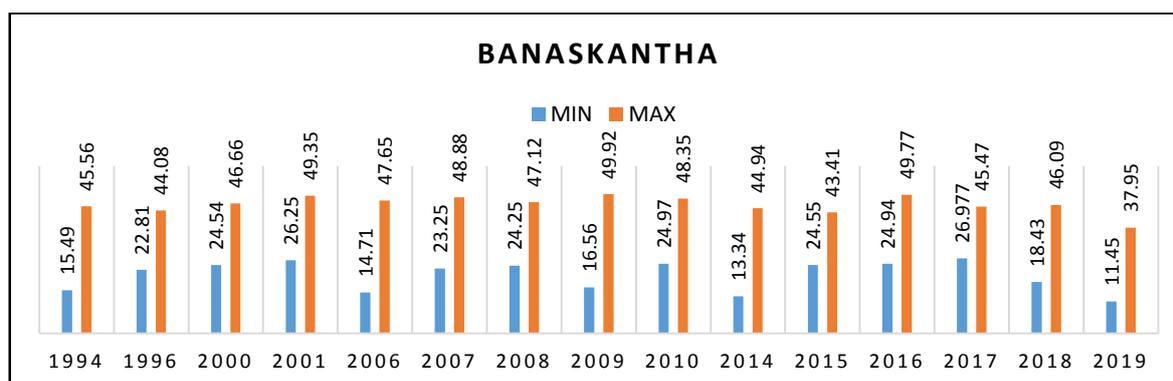


Figure 5.103: Maximum and Minimum LST for Banaskantha district

From the above Figure 5.103 shows the time series plot of maximum and minimum temperature obtain using LST methodology for Banaskantha district. The maximum area under 25 to 35 degree temperature was observed in 2007 year which is 5542.50 Sq.km area and minimum area was observed in 2015 year which 236.30 Sq.km. Similarly for the maximum area under 35 to 45 degree temperature was observed in 2008 year with 9551.0 Sq.km area and minimum area was observed in 2007 year with 5045.10 Sq.km.

The results also shows that average 7877.60 Sq.km area of the district under high temperature during the study period 1994 to 2019 years. The average minimum temperature was 22.80°C and average maximum temperature was 45.09°C during study period. The Increasing LST values over time can indicate a warming trend and potentially more frequent drought conditions. The rising temperatures can lead to more frequent and severe drought events, impacting water resources and ecosystems. It was also observed that the annual average mean LST value has been increased 3.25°C during study period.

Results of Temperature Condition Index and Vegetation Health Index for Banaskantha district

The results of the **TCI indices** for the 2018 year shows that 4566.50 sq. km. area and 5667.30 Sq.km area fall under extreme dry and severe dry conditions, which are 42.95 % and 53.31%, of the total area of the Banaskantha district respectively. The study also, observed that moderately dry area is 394.40 Sq.km area which is 3.70% of the study area. The average drought area in Banaskantha district is 3206.50 sq.km or 30.15% of the district during study period. The average dry conditions varies from 17.5% to 44.20%.

The results of the **VHI indices** for the 2018 year shows that 2458.30 sq. km. area and 4238.40 Sq.km area fall under moderate drought and light drought conditions, which are 23.12 % and 39.86 %, of the total area of the Banaskantha district respectively. The study also, observed that the area is 3932.80 Sq.km area which is 36.99 % of the study area having no drought conditions.

Similar for remaining year the results were analyzed for maximum and minimum drought percentage area estimations and the years experiencing maximum amount of drought areas. Also, from the results it was observed that average 3 to 5% of area having severe drought conditions, 12 to 20% area having moderate drought conditions and 20 to 50% area having light drought conditions and 20 to 30% percentage area having no drought conditions during study period.

Graphical Representation of TCI and VHI for Banaskantha district

The inverse relationship between TCI and VHI is particularly relevant in the context of drought monitoring. Analysts and researchers use these indices to assess the impact of drought on vegetation. A decrease in VHI, coupled with an increase in TCI, can signal the presence of drought conditions and stress on plant health.

Below Figure 5.104 and 5.105 shows drought severity classification for Temperature condition index and Vegetation health index respectively.

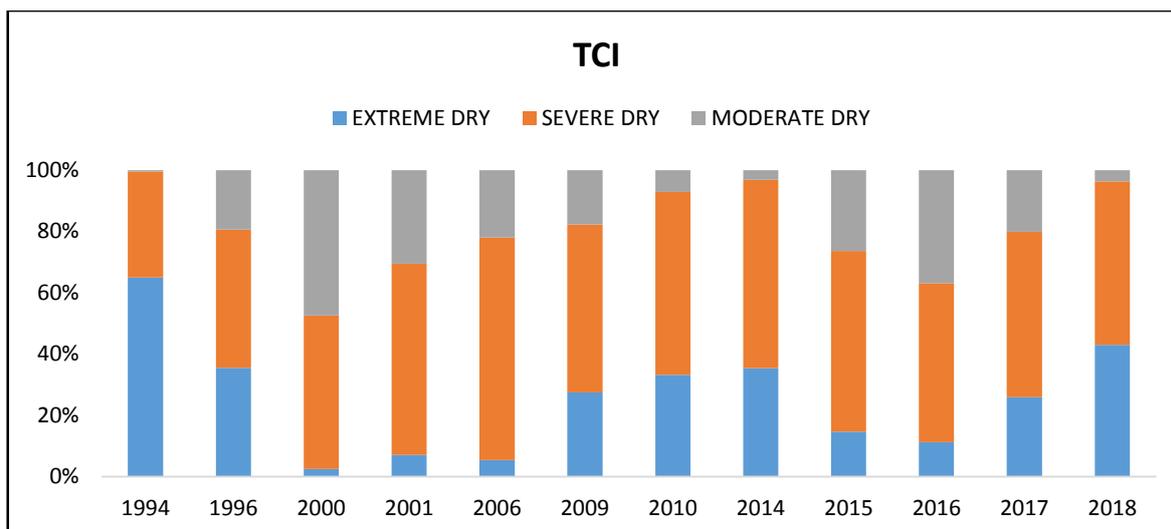


Figure 5.104: Drought severity distribution using TCI over Banaskantha district

From the above Figure 5.104 shows that the maximum extreme dry area was observed in 1994 which is 64.9% (6903.0 Sq.km area). Also, maximum severe dry area was observed in 2006 which is 71.9% (7639.8 Sq.km area). The Moderate dry was observed in 2008 year which is 60.5% (6429.6 Sq.km area). It was also observed that average extreme dry area was around 18%, severe dry area as 45% and moderate dry area was 30% during the study period.

The results of VHI indices for the year 1996 to 2018 is also analysed for different years interval which is shown in below Figure 5.105. The graph shows comparisons of the amount of dry area, percentage of dry area with corresponding annual rainfall for the year. The analysis showed that as the rainfall in the area increases, the dryness decreases.

5.10.6 Comparative Analysis of different Indices over North Gujarat district

Results obtained for Banaskantha district

The results of **Banaskantha** district shows that maximum area for 25 to 35 degree temperature was observed in 2007 year which is 5542.50 Sq.km area and minimum area was observed in 2015 year which 236.30 Sq.km. Similarly, for the maximum area under 35 to 45 degree temperature was observed in 2008 year with 9551.0 Sq.km area and minimum area was observed in 2007 year with 5045.10 Sq.km. The results also shows that average 7877.60 Sq.km area of the district under high temperature during the study period 1994 to 2019 years. The average minimum temperature was 22.80°C and average maximum temperature was 45.09°C during study period.

From the analysis of TCI it was observed that the maximum extreme dry area was observed in 1994 which is 64.9 % (6903.0 Sq.km area). Also, maximum severe dry area was observed in 2006 which is 71.9% (7639.8 Sq.km area). The Moderate dry was observed in 2008 year which is 60.5% (6429.6 Sq.km area). The average extreme dry area was around 18%, severe dry area as 45% and moderate dry area was 30% during the study period.

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2000 with 9513.8 sq. km, which is 89.5%, and during that year the rainfall was 258.40 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 3558.10 sq. km which is 33.5% of the area, and during that year the rainfall was 696.09 mm in the study region. The average percentage of dry area was 60.7% in **Banaskantha** district with annual average rainfall 445.20 mm during study period.

Results obtained for Gandhinagar district

The results of **Gandhinagar** district shows that maximum area under 25 to 35 degree temperature was observed in 2006 year which is 1118.3 Sq.km area and minimum area was observed in 2015 year which 410.10 Sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 1296.80 Sq.km area and minimum area 587.60 Sq.km. The results also shows that average 835.20 Sq.km area or 48.43% of the district under high temperature during the study period.

From the analysis of TCI it was observed that the maximum extreme dry area was observed in 2014 which is 23.10% (397.40 Sq.km area). Also, maximum severe dry area was observed in 2014 which is 68.10% (1173.80 Sq.km area). The Moderate dry was observed in 2016 year which is 61.1% (1053.6 Sq.km area). The average extreme dry area was around 5%, severe dry area as 30% and moderate dry area was 30% during the study period.

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2014 with 819 sq. km, which is 47.48%, and during that year the rainfall was 738.28 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 126.80 sq. km which is 7.35% of the area, and during that year the rainfall was 543.16 mm in the study region. The average percentage of dry area was 21.37% in **Gandhinagar** district with annual average rainfall 710.59 mm during study period.

Results obtained for Mehsana district

The results of **Mehsana** district shows maximum area under 25 to 35 degree temperature was observed in 2001 year which is 3425.70 Sq.km area and minimum area was observed in 2010 year which 147.10 Sq.km. Similarly for the maximum

area under 35 to 45 degree temperature was 4236.70 Sq.km area and minimum area 942.60 Sq.km. The results also shows that average 3088.10 Sq.km area or 70.23% of the district under high temperature during the study period. The average minimum temperature was 22.36°C and average maximum temperature was 45.96°C during study period.

The results of TCI shows that maximum extreme dry area was observed in 2006 which is 33.70% (1481.10 Sq.km area).Also, maximum severe dry area was observed in 2014 which is 68.20% (2993.70 Sq.km area). The Moderate dry was observed in 2007 year which is 72.50% (3181.40 Sq.km area). The average extreme dry area was around 12%, severe dry area as 48.90% and moderate dry area was 28.0% during the study period.

The results of the VHI index shows that the maximum percentage of dry areas in the year 2014 with 2232.40 sq. km, which is 50.8%, and during that year the rainfall was 733.0 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2006 with 399.50 sq. km which is 9% of the area, and during that year the rainfall was 922.90 mm in the study region. The average percentage of dry area was 35.02% in **Mehsana** district with annual average rainfall 672.70 mm during study period.

Results obtained for Patan district

The results of **Patan** districts shows that maximum area under 25 to 35 degree temperature was observed in 2007 year which is 1583.10 Sq.km area and minimum area was observed in 2006 year which 86.60 sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 5937.0 sq.km area and minimum area 4129.50 Sq.km. The results also shows that average 4489.70 sq.km area or 74.54% of the district under high temperature during the study period. The average minimum temperature was 24.97°C and average maximum temperature was 44.26°C during study period.

The results of TCI index shows that the maximum extreme dry area was observed in 2006 which is 47.10% (2839.20 sq.km area). Also, maximum severe dry area was observed in 2008 which is 84.80% (5108.40 sq.km area). The Moderate dry was observed in 2000 year which is 28.0% (1688.50 sq.km area).

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2008 with 3875.6 sq. km, which is 64.30%, and during that year the rainfall was 421.9 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2006 with 1263.80 sq. km which is 21.0% of the area, and during that year the rainfall was 859.60 mm in the study region. The average percentage of dry area was 41.70% in **Patan** district with annual average rainfall 574.0 mm during study period.

Results obtained for Sabarkantha district

The results obtain for **Sabarkantha** district maximum area under 25 to 35 degree temperature was observed in 2006 year which is 3543.90 sq.km area and minimum area was observed in 2005 year which 280.70 sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 3905.70 Sq.km area and minimum area 535.90 Sq.km. The results also shows that average 3955.10 sq.km area or 94.43% of the district under high temperature during the study period. The average minimum temperature was 21.46°C and average maximum temperature was 46.04°C during study period.

The results of TCI shows that maximum extreme dry area was observed in 2014 which is 26.10% (1092.20 sq.km area).Also, maximum severe dry area was observed in 1994 which is 73.60% (3081.10 sq.km area). The Moderate dry was observed in 2019 year which is 68.50% (2869.40 sq.km area).

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2007 with 2279.10 sq. km, which is 54.40%, and during that year the rainfall was 580.08 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 555.30 sq. km which is 13.30% of the area, and during that year the rainfall was 1033.59 mm in the study region. The average percentage of dry area was 31.70% in district with annual average rainfall 734.50 mm during study period.

5.11 CONSTRUCTION OF COMPARSIONS MATRIX OF VARIOUS DROUGHT INDICES OVER THE STUDY AREA

A correlation matrix is a statistical method which shows that how strong and in what direction variables (viz, SPI, RDI, SPEI, CZI, and MCZI) are correlated. The correlation coefficient measures the extent to which two pairs of variables are related which two pairs amongst. (SPI3, SPI4, SPI5, SPI6, SPI7, SPI8, SPI9, SPI10, SPI11 and SPI 12).The procedure is carried out for RDI3, RDI 4, RDI 5, RDI 6, RDI 7, RDI 8, RDI 9, RDI 10, RDI 11 and RDI 12. Similarly, for SPEI, CZI and MCZI indices. These coefficients typically range from -1 to 1, where -1 indicates a perfect negative correlation, 1 indicates a perfect positive correlation, and 0 indicates no correlation.

5.11.1 Correlation matrix of meteorological drought indices for Banaskantha district

The selection of time step in identification of onset of any long-term drought is very important. Different Drought indices compared at 1-month to 12-month time steps. Here 1-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 so this may not be useful to estimation or prediction. A correlation matrix is developed for SPI, RDI, SPEI, CZI and MCZI indices at various time scales as described and are given in Table 5.171 for Banaskantha district. The results can help to understand how different drought indices time scales relate to each other.

Table 5.171: Correlation matrix of drought indices for Banaskantha district

(A) Standardized Precipitation Index

	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
SPI 3	1.000									
SPI 4	0.924	1.000								
SPI 5	0.896	0.962	1.000							
SPI 6	0.833	0.902	0.942	1.000						
SPI 7	0.828	0.898	0.939	0.995	1.000					
SPI 8	0.732	0.805	0.850	0.889	0.891	1.000				
SPI 9	0.388	0.404	0.412	0.401	0.398	0.517	1.000			
SPI 10	0.043	0.121	0.110	0.066	0.062	0.068	0.408	1.000		
SPI 11	0.030	0.107	0.101	0.036	0.039	0.058	0.363	0.780	1.000	
SPI 12	0.046	0.125	0.114	0.054	0.054	0.062	0.295	0.693	0.918	1.000

(B) Reconnaissance Drought Index

	RDI 3	RDI 4	RDI 5	RDI 6	RDI 7	RDI 8	RDI 9	RDI 10	RDI 11	RDI 12
RDI 3	1.000									
RDI 4	0.857	1.000								
RDI 5	0.802	0.935	1.000							
RDI 6	0.738	0.878	0.944	1.000						
RDI 7	0.734	0.874	0.941	0.996	1.000					
RDI 8	0.632	0.764	0.834	0.870	0.870	1.000				
RDI 9	0.390	0.400	0.418	0.390	0.389	0.532	1.000			
RDI 10	0.015	0.119	0.086	0.048	0.048	0.034	0.351	1.000		
RDI 11	-0.005	0.095	0.068	0.014	0.019	0.009	0.313	0.767	1.000	
RDI 12	0.002	0.102	0.069	0.019	0.021	0.007	0.260	0.675	0.923	1.000

High positive correlations can be shown in green colour, while high negative correlations can be shown in red colour. Whereas yellow colour shows average correlation. Some observation from Table 5.171 shows that SPI 4 is not very well correlated with SPI 10, SPI 11, and SPI 12. Also, SPI 7 is not correlated with SPI 10, SPI 11. The statistically significant correlation is moderate upto 8 month scale and gives higher significance at higher scales of 9 to 12 month. Also, SPI 10 is very well correlated with SPI 11, SPI 11 with SPI 12 so as long time scale considered the results will improved.

The results of SPI indices for different time scale ranging from 0.03 to 1.0. Similarly, for results of RDI indices for different time scale ranging from 0.02 to 1.0. Also, results of SPEI indices for different time scale ranging from 0.017 to 1.0. The CZI and SPEI indices had the lowest correlation than SPI.

Based on this above comparative analysis it is concluded that SPI and RDI indices with 12 months' time scale gives best results ($=0.99$) for modelling and management of drought in North Gujarat district. While SPEI and CZI, MCZI index gives some less correlation between them.

Overall for North Gujarat districts meteorological drought indices (SPI and RDI) with higher time steps is found to be good choice for assessment of drought characteristics and monitoring of drought condition, because of its capability of timely detection of drought onset and realistic quantification of severity of drought events in study area.

5.12 DEVELOPMENT OF DROUGHT FORECASTING MODELS USING SOFT COMPUTING TECHNIQUES OVER STUDY AREA

Development of drought forecasting models and early warning of the drought phenomena is increasingly being applied in present study. In present study Fuzzy logic approach and ANFIS approach used for development of drought forecasting models.

Fuzzy Logic (FL) model operates on an if-then "principle, where the if "is a vector of fuzzy premises and the then "is a vector of fuzzy consequences, to apply this principles efficiently, a Fuzzy Inference System (FIS) is a control system built using fuzzy set theory based on combining the fuzzy sets from each rule through aggregation operator to get a fuzzy set result, then defuzzify the fuzzy set for each output variable. A fuzzy set is totally characterized by a membership function (MF).

ANFIS (Adaptive Neuro-Fuzzy Inference System) is a hybrid computational model that combines the adaptability of neural networks with the interpretability of fuzzy logic. ANFIS employs a specific structure and learning algorithm to create a system capable of handling complex and uncertain relationships. ANFIS combines the principles of fuzzy logic and neural networks, using a hybrid learning algorithm to adapt to data and optimize its parameters.

5.12.1 Fuzzy Logic approach for RDI and SPI

This study aims to develop a new meteorological drought index based on fuzzy logic (FL) approach to predict droughts condition in North Gujarat districts. Below Table 5.176 shows various combination of input data which was compared with two drought indices (viz., SPI and RDI) for each districts.

Table 5.176: Input/output data for various model developed

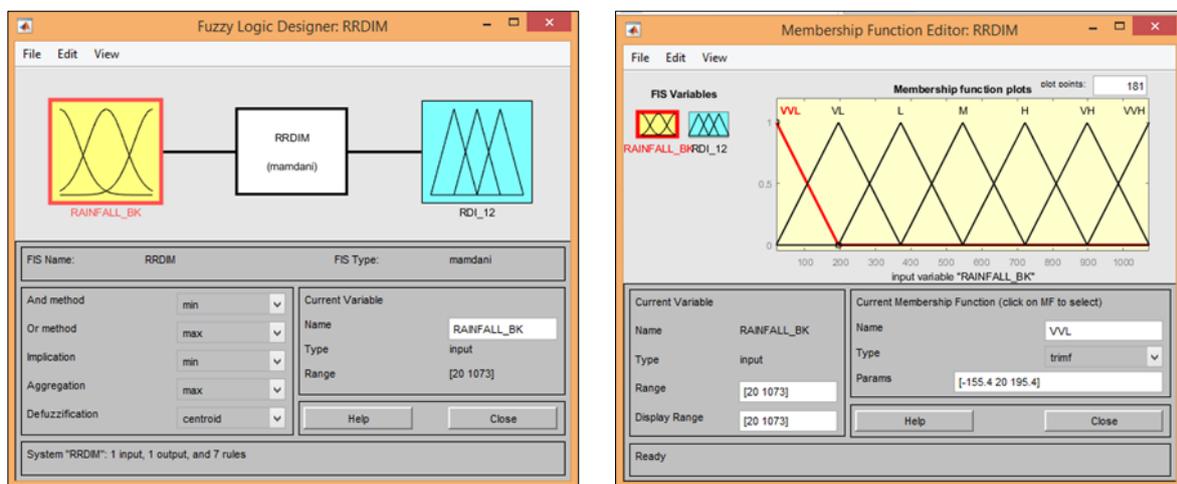
Model No.	Input Data	Output Data
1	Annual Rainfall	SPI 12, RDI 12
2	Annual Rainfall, Maximum Temperature, Minimum Temperature	SPI 12, RDI 12
3	Annual Rainfall, Average Temperature	SPI 12, RDI 12
4	Annual Rainfall, Average Temperature, Potential Evapotranspiration	SPI 12, RDI 12
5	SPI 9, SPI 10, SPI 11 RDI 9, RDI 10, RDI 11	SPI 12 RDI 12

Five Fuzzy Logic Models i.e., FL Model 1, FL Model 2, FL Model 3, FL Model 4 and FL Model 5 have been developed considering data set of 70%-30% for training and validation respectively. The performance evaluation of the Fuzzy Logic models was done by calculating Coefficient of Correlation (r), Coefficient of determination (R^2), Root Mean Squared Error (RMSE); Mean Absolute Error (MAE),. As the RMSE, MAE values on data were comparatively less, the prediction model is reliable and efficient and can be used for drought prediction. Below Table shows different combinations of model for drought forecasting model.

Fuzzy Logic Model 1 for Banaskantha district

Annual Rainfall –RDI 12, Annual Rainfall –SPI12

Below Figure 5.118 shows the steps implicated in a fuzzy based system. The system functional components can be classified into two function. First, the fuzzy rule base to describe the membership functions of the fuzzy sets to be used in the fuzzy rules. Second, the decision-making section that Rule editor perform the inference procedures on the rules.



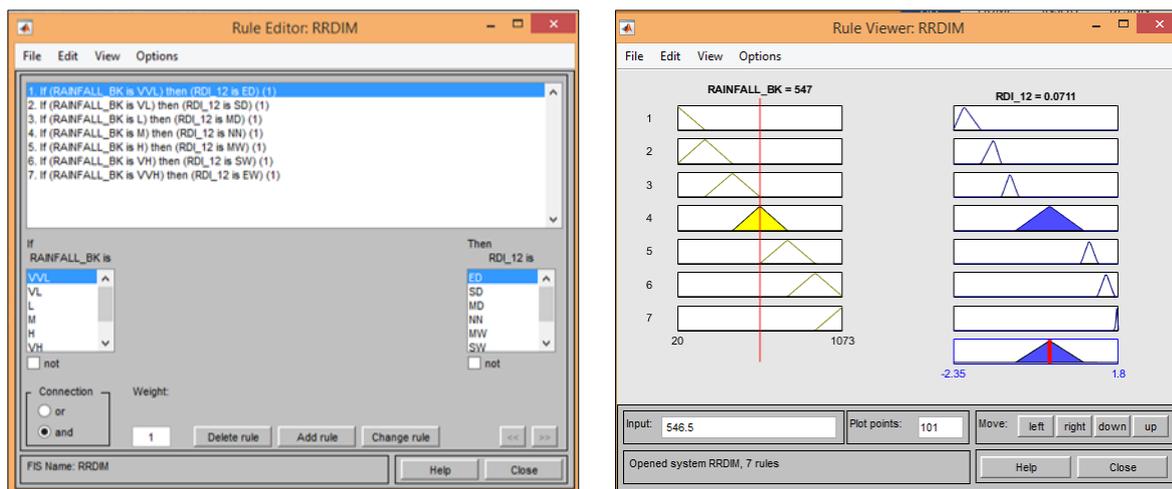


Figure 5.118: Fuzzy Logic structure of Model 1 for Banaskantha district

For development of annual rainfall and RDI 12 model, annual rainfall and SPI 12 model, the triangular membership function is most suitable for input and output parameters since computational is most straightforward in manner, which is represented. The triangular membership function is the simplest membership function, formed by using straight lines and named “Trim”. It’s nothing more than a collection of three points forming a triangle. In rule-based fuzzy systems, the relationships between variables are represented by means of fuzzy if-then rules.

The annual rainfall range is divided into seven fuzzy levels as Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH). Also, the ranges of rainfall and output variables is also shown in below Table 12.2. The linguistic expressions for various fuzzy levels are as follows Table 5.177 (a), 5.177(b):

Table 5.177: Linguistic variable for different parameters for Model 1

Parameters	Linguistic variable
Rainfall	Very-very low, Very low, Low, Medium, High, Very high, Very-very high
Maximum Temperature	Low temperature, Medium temperature, High temperature
Minimum Temperature	Low temperature, Medium temperature, High temperature
Potential evapotranspiration	Low PET, Medium PET, High PET
SPI 12 / RDI 12	Extreme dry, Severe dry, Moderate dry, Near Normal, Moderate wet, Severe wet, Extreme wet

The performance of developed model for Banaskantha rainfall and RDI 12 (BK-R-RDI), rainfall and SPI 12 (BK-R-SPI) is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.178.

Table 5.178: Performance Indices of FL Model 1 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-RDI		BK-R-SPI	
	70%	30%	70%	30%
R	0.9677	0.9362	0.9803	0.9690
R ²	0.9364	0.8765	0.9610	0.9389
RMSE	0.2659	0.3667	0.2241	0.2664
MAE	0.2043	0.2438	0.1805	0.1981

It is observed from Table 5.178 that root mean squared error (RMSE) values vary from 0.20 to 0.27 and 0.25 to 0.37 during training and testing respectively. During training and testing, values of correlation coefficient (r) vary from 0.95 to 0.98 and 0.93 to 0.96 respectively. Also, mean absolute error (MAE) values vary from 0.18 to 0.20 and 0.19 to 0.25 during training and testing respectively.

Below Figures 5.123, 5.124 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Banaskantha district.

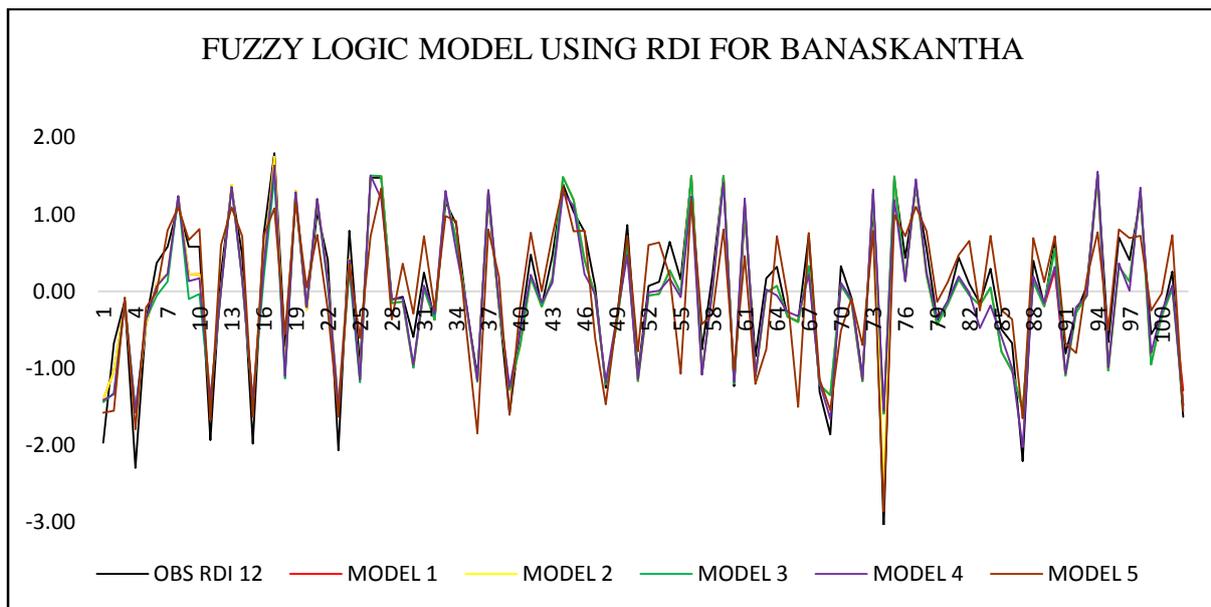


Figure 5.123: Graphical representation of Fuzzy Logic Models using RDI for Banaskantha

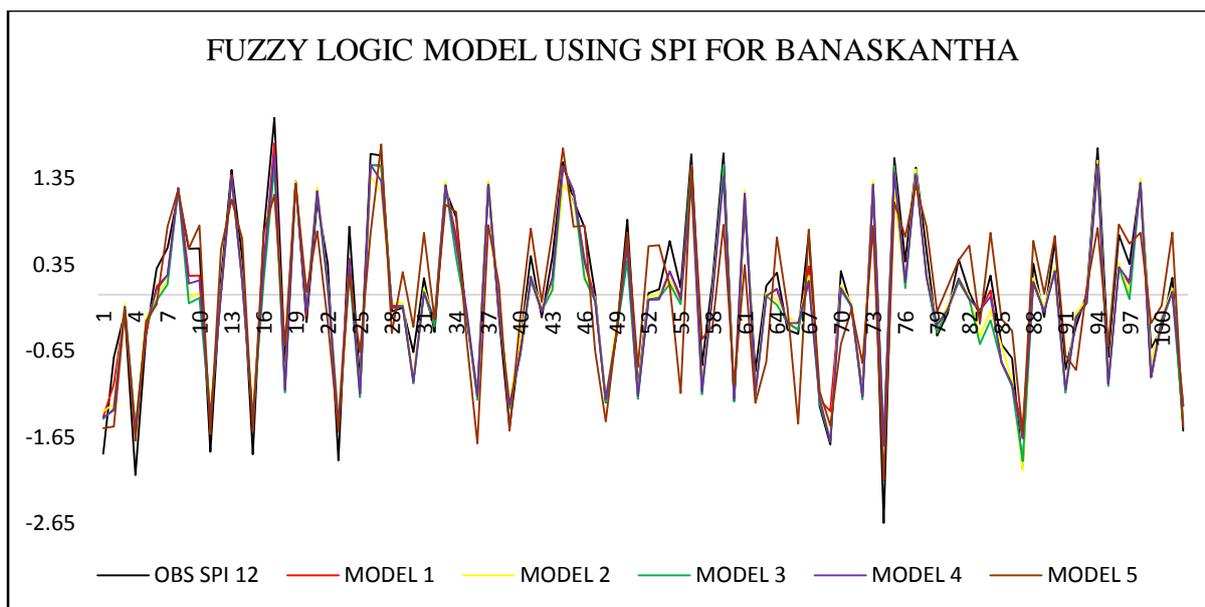


Figure 5.124: Graphical representation of Fuzzy Logic Models using SPI for Banaskantha

The above different models was developed with combinations of different meteorological variables (Rainfall, Max. temperature, Min. temperature, Avg. temperature, Potential evapotranspiration), SPI 9, SPI 10, SPI 11 and RDI 9, RDI 10, RDI 11 were used as input data for estimating the drought severity estimation. The results of the predictability of fuzzy logic models are compared with those of derived values of SPI and RDI which are obtain from DrinC tool.

Amongst all five models, the best Fuzzy Logic model for RDI is Fuzzy Logic (FL) Model 2 with the RMSE of 0.0002 by training and 0.2548 by validation of the model, and co efficient of determenation by training of the model is 0.9364 and by validation of the model is 0.9452 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall and temperature given. For estimation of RDI both rainfall and PET needed so here Model 2 is developed using combination of both rainfall and temperature data which gives accurate results.

Amongst all five models, the best Fuzzy Logic model for SPI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2241 by training and 0.2664 by validation of the model, and co-efficient of determenation by training of the model is 0.9610 and by validation of the model is 0.9389 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given. For estimation of SPI only rainfall is required and developed model is also giving same results.

Finally, the developed models were found to be suitable to make effective extreme point predictions.

ANFIS approach for RDI and SPI

There are no fixed rules for developing an ANFIS, even though a general framework can be followed based on previous successful applications in engineering. The selection of proper input and output data possess the prime importance and needs to be selected carefully. Here the development of drought forecasting model was done using rainfall and other data as input and drought indices data as output.

ANFIS Architecture Mamdani (1974) documented that the fuzzy inference system (FIS) consists of four major components. This study aimed to establish a new soft computing model for drought monitoring and assessment. ANFIS has been effectively utilized for modelling and predicting complex hydrologic systems and processes. This model combines the learning skills of ANNs and the inference system of FL models.

ANFIS Model 1 for Banaskantha district

The Model 1 is combination of annual rainfall as input data and output as RDI 12 and SPI 12 separately. Below Figure 5.133 shows a simplified adaptive neuro-fuzzy inference system for Model 1. The developed architecture includes one input membership functions, one output membership functions, and 7 fuzzy rules.

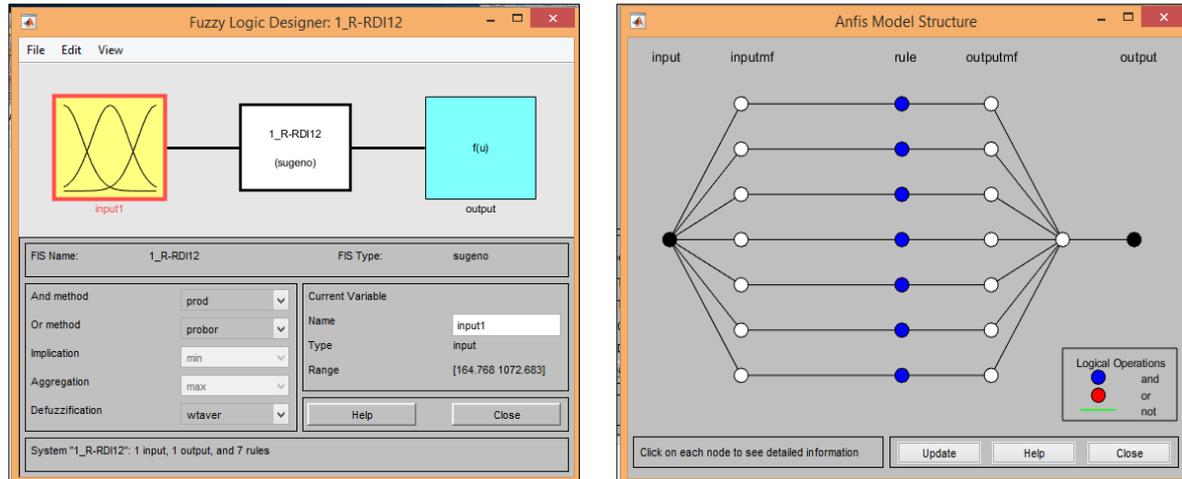


Figure 5.133: ANFIS structure of Model 1 for Banaskantha district

The performance of developed model for rainfall and RDI 12, rainfall and SPI 12 is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.206.

Table 5.206: Performance Indices of ANFIS Model 1 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-RDI		BK-R-SPI	
	70%	30%	70%	30%

R	0.9730	0.9905	1.0000	0.9952
R ²	0.9467	0.9810	0.9999	0.9904
RMSE	0.2336	0.1534	0.0096	0.1061
MAE	0.0398	0.0392	0.0058	0.0240

It is observed from Table 5.206 that root mean squared error (RMSE) values vary from 0.23 to 0.0096 and 0.1534 to 0.1061 during training and testing respectively. During training and testing, values of correlation coefficient (r) vary from 0.9730 to 1.00 and 0.9905 to 1.00 respectively. Also, mean absolute error (MAE) values vary from 0.0398 to 0.006 and 0.035 to 0.024 during training and testing respectively.

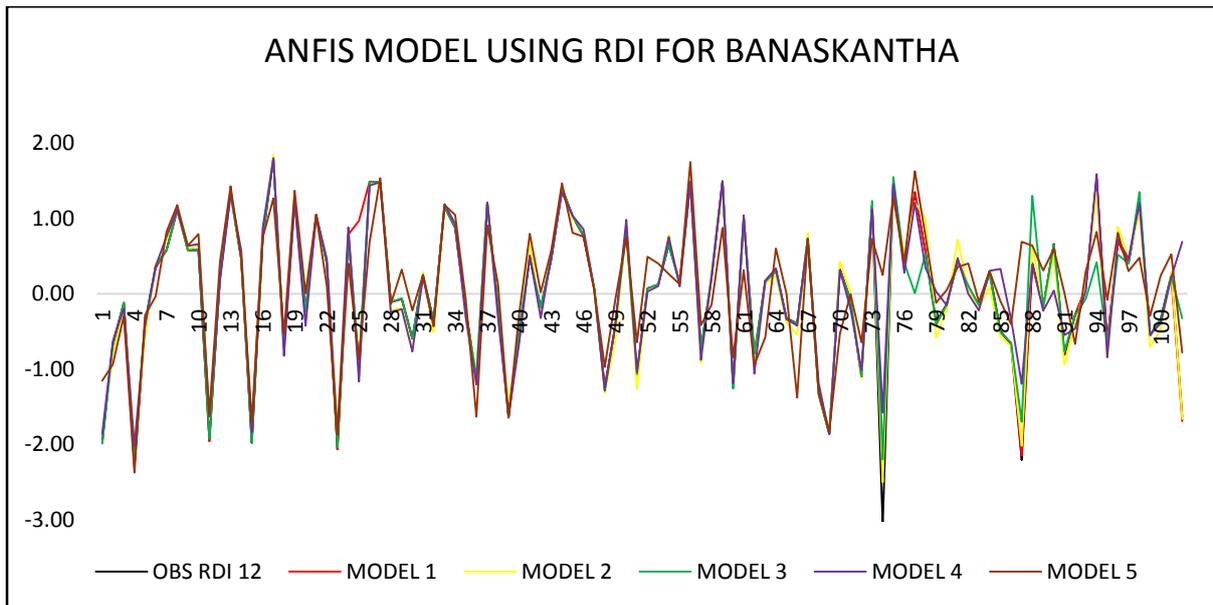


Figure 5.138: Graphical representation of ANFIS Models using RDI for Banaskantha

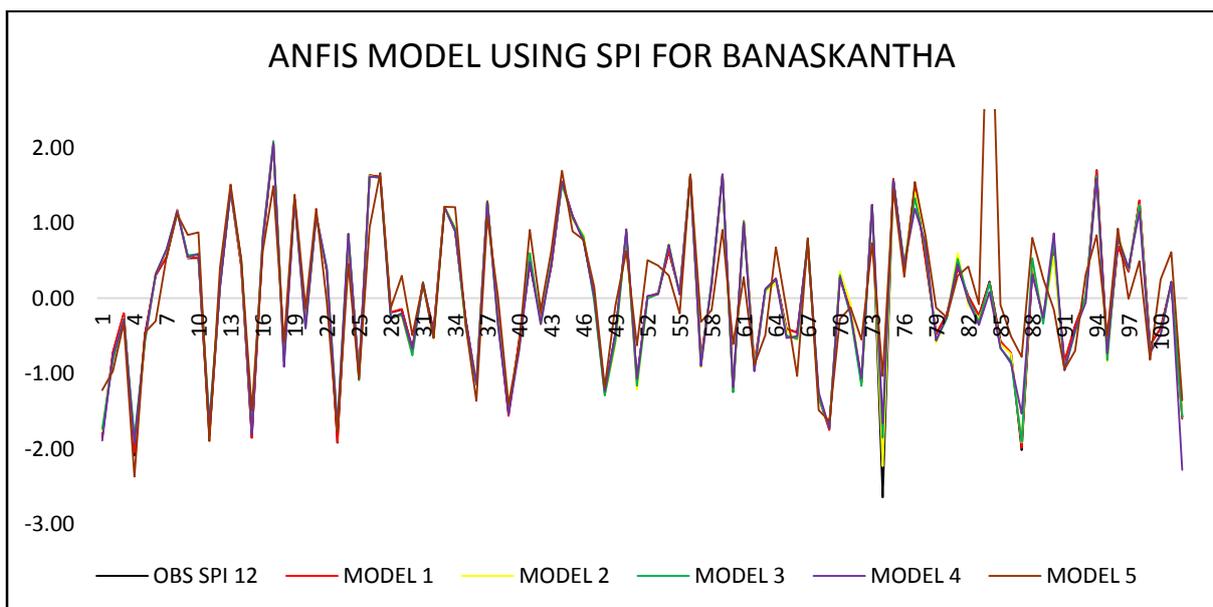


Figure 5.139: Graphical representation of ANFIS Models using SPI for Banaskantha

Amongst all five models, the best ANFIS model for RDI is Model 1 with the RMSE of 0.2336 by training and 0.1534 by validation of the model, and co efficient of determination by training of the model is 0.9467 and by validation of the model is 0.9810 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models, the best ANFIS model for SPI is Model 1 with the RMSE of 0.0096 by training and 0.1061 by validation of the model, and co efficient of determination by training of the model is 0.9999 and by validation of the model is 0.9904 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

5.12.3 Comparative analysis of drought forecasting models in North Gujarat region

Drought prediction is a real problem for local administrations and water resources planners. So in the present study different models were developed using different combinations of input data. Almost all the models were found to be suitable to make effective extreme point predictions. Continuous monitoring and validation of the model against real-world data are essential to improve its accuracy and reliability in drought forecasting. Amongst all developed five models, the best Fuzzy and ANFIS model for RDI and SPI is Model 1 and 2 with the RMSE ranges between 0.03 to 0.015 for training and 0.0867 to 0.15 for validation period, and co efficient of determination value for training period is 0.9999 and for validation period is 0.9946 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL

The conclusions derived from the overall results of North Gujarat districts using Meteorological drought indices, Hydrological drought indices and Agricultural drought indices are discussed. Also, the trend analysis of drought indices (SPI, RDI, and SPEI) and the conclusions from developed drought forecasting models are discussed. The derived conclusions for various districts, considering the above said drought indices are discussed hereafter.

6.2 BANASKANTHA DISTRICT

The 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 67, 73, 81, 55, 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 and different meteorological drought indices it is observed that extreme drought 1901, 1904, 1911, 1915, 1923, 1939, 1969, 1974, 1987, and 2002. The severe drought condition occurred during 1903, 1905, 1920, 1928, 1932, 1935, 1938, 1942, 1949, 1965, 1966, 1979, 1980, 1983, 1989, 1992, and 2000. Also, Moderate drought condition occurred during 1902, 1918, 1925, 1930, 1936, 1940, 1948, 1951, 1957, 1960, 1962, 1968, 1972, 1985, 1986, 1991, 1995, and 1999. The results of PN, PD, RAI, SPI 12, RDI12 and SPEI 12 shows that Banaskantha district having 32% of drought condition during study period. The annual rainfall shows a significant negative trend with Z value as -0.307 and its corresponding Sen's slope value is -0.245. For summer season rainfall shows a significant negative trend with Z value as -0.661 and its corresponding Sen's slope value is -0.011. Similar, for winter season rainfall shows a significant positive trend with Z value of 2.651 and its corresponding Sen's slope value is 0.094. By comparing results of SPI, RDI and SPEI indices for MK test and Sen's slope estimator shows that there is an increasing trend as time scales is increased.

The results of PCI shows that summer season having 23.5% uniform precipitation, 56.9% moderate uniform, 17.6% as irregular precipitation and 2% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 47.1% irregular precipitation trend was observed. The comparative study of different aridity index shows that 5 to 18% of the year is arid while 35% area is humid. This data analysis and results will be a good predictor for agricultural scientist, agronomist and hydrologist to plan according the climate of the region.

The results obtain using Hydrological drought indices shows that average water spread area using NDWI index for the studied period was 754.40 Sq.km and percentage water spread area in the district varies from 5.5% to 15.5% in and NDSI index shows that average 3027.60 sqkm area which is around 28.5% districts having moderate saline characteristics during 1992 to 2019 years. Similarly, the results of MNDWI index shows that minimum water spread area in 2001 year with 7.77 Sq.km area and maximum water spread area 84.97 sqkm area in 2012, 91.59 Sq.km area in 2019 observed. Also, the average water spread area in the district is 287.93 sqkm area in Banaskantha district during the period of study.

Agricultural drought assessment is carried out using various RS and GIS approaches the results of NDVI shows that the maximum percentage of severe dry areas in the year 1996 with 8307.70 sq. km, which is 78.10%, and during that year the rainfall was 384.96 mm in the study region. Also, moderate dry areas as 1321.40 Sq.km, which is 12.40% of the study area. The minimum percentage of dry areas in the year 2006 with 3059.90 sq. km which is 28.80% of the area, and during that year the rainfall was 827.93 mm in the study region. The percentage of dry area varies from 21.35% to 46.30% and percentage of Normal dry area varies from 1.5% to 10.87% respectively using NDVI deviation. Similarly, the results of VCI index shows that moderate drought having 20.8 percent and light drought having 55.10 percent during study period of 1992 to 2019. The results of LST shows that 7877.60 Sq.km area of the district under high temperature. The minimum temperature was 22.80°C and maximum temperature was 45.09°C during study period. The average percentage of dry area was 60.7% in Banaskantha district using TCI, VHI indices.

The best Fuzzy Logic model for SPI and RDI using Fuzzy Logic (FL) Model 1 with the RMSE of 0.2241 by training and 0.2664 by validation of the model, and co-efficient of determination by training of the model is 0.9610 and by validation of the model is 0.9389 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

6.3 GANDHINAGAR DISTRICT

The 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 72, 76, 82, 70, 63, 80, 81 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation.

From the annual rainfall data and various meteorological drought indices the years 1911, 1918, 1987 as extreme dry. Severe dry years as 1904, 1915, 1923, 1948, 1951, 1960, 1965, 1968, 1972, 1974, 1995, 2002. The moderate dry year as 1901, 1925, 1929, 1936, 1939, 1940, 1947, 1957, 1966, 1969, 1971, 1985, 1986, 1991,

1992, 1999 Similar results were obtained using climatic drought index 1904, 1911, 1918, 1923, 1968, 1972 and 1987 years as very extreme drought and 1915, 1948, 1951, 1960, 1965, 1974, and 2002 as drought years. The study of aridity indices shows that 18 years identified as arid years and 34 years as semi-arid years out of 102 years in Gandhinagar district. The frequency analysis reveals that 7%, 15% and 16% of extreme dry years, severe dry years and moderate dry years occur amongst drought years considered, which means 38% years are categorized into moderate to extreme drought years out of the total drought years. The PCI index shows that for summer season is 20.59% uniform, 70.59% moderate uniform, 6.86% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 54.90% irregular precipitation trend was observed. The annual rainfall of Gandhinagar shows a significant negative trend with Z value of -0.057 and its corresponding Sen's slope value is -0.032. For summer season rainfall shows a significant negative trend with Z value of -1.646 and its corresponding Sen's slope value is -0.038. Similar, for winter season rainfall shows a significant positive trend with Z value of 1.913 and its corresponding Sen's slope value is 0.076. Similar trend analysis of SPI 12 as Z is -0.06 with Sen's slope value as 0.03. For RDI the value of Z is -0.07 with Sen's slope value as 0.09 and for SPEI the value of Z is -0.06 with Sen's slope value as -0.060. By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. From the results it was observed that Sen's slope value for RDI is showing higher value than SPI and SPI. Also, maximum trend value of Z statistics for RDI indices is obtained.

The average water spread using NDWI index for the studied period was 92.70 Sq.km with a standard deviation (SD) of 42.8 sq. km area and the percentage water spread area in the district varies from 1.5% to 9.8%. From the analysis of NDSI it was observed that average 321.97 Sq.km area which is around 11.80% having moderate saline characteristics. Similarly, the results of MNDWI index shows that minimum water spread area in 2007 year as 5.92 Sq.km area and maximum water spread area as 15.22 Sq.km area in 2005, 14.37 Sq.km area in 2006 observed. Also, the average water spread area in the district is 64.27 Sq.km area during study period of 1992 to 2019. The results of hydrological drought indices shows that the water ratio index in Gandhinagar district the medium dry condition and medium water condition varies from 27% to 33% and 65% to 72% respectively.

The results of NDVI index shows that the maximum percentage of severe dry areas in the year 1994 with 1276.30 sq. km, which is 74.0%, and during that year the rainfall was 474.61 mm in the study region. Moderate dry areas as 382.60 Sq.km, which is 22.20% of the study area. The minimum percentage of dry areas in the year 2006 with 699.50 sq. km which is 40.06% of the area, and during that year the rainfall was 627.54 mm in the study region. The percentage of dry area varies from 27.04% to 48.58% and percentage of Normal dry area varies from 0.94 % to 10.27 % respectively during study period of 1992 to 2019. Similarly, VCI index shows that

Moderate drought conditions, and Light drought conditions covers area of 29.4 Sq.km and 186.7 Sq.km respectively. The results of LST shows that average 835.20 Sq.km area or 48.43% of the district under high temperature during the study period. The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2014 with 819 sq. km, which is 47.48%, and during that year the rainfall was 738.28 mm in the study region.

The results of best Fuzzy Logic model for RDI 12 and SPI 12 is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2434 by training and 0.2379 by validation of the model, and co efficient of determination by training of the model is 0.9546 and by validation of the model is 0.9616 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

6.4 MEHSANA DISTRICT

The monthly rainfall of Mehsana district of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 72, 75, 85, 70, 64, 78, 81 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation.

From this results of meteorological drought indices extreme dry condition occurs in the year of 1904, 1987 during this year the average rainfall is about 248.49 mm. Also, very dry condition occurred during 1901, 1911, 1915, 1918, 1923, 1948, 1951, 1968, 1972, 1974, 1995, 2002 years and during moderate dry years 1925, 1929, 1936, 1939, 1940, 1957, 1960, 1965, 1966, 1969, 1985, 1986, 1991, 1999 the average rainfall is around 342.08 mm during study period. The results of Mehsana district for climatic index show that 1901, 1904, 1911, 1915, 1918, 1923, 1936, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1991, 1995, 2002 years were severely affected by drought. Also, 1902, 1903, 1905, 1910, 1916, 1920, 1925, 1929, 1930, 1932, 1935, 1938, 1947, 1949, 1952, 1962, 1964, 1966, 1971, 1978, 1979, 1980, 1982, 1984, 1988, 1989, 1992, 1993, 1997, 1999, 2000, 2001 years were medium dry condition during the study period. The PCI index shows that for summer season is 27.45% uniform, 64.71% moderate uniform, 5.88% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 57.84% irregular precipitation trend was observed. The frequency analysis reveals that 8%, 14% and 16% of extreme dry years, severe dry years and Moderate dry years occur amongst drought years considered, which means 38% years are categorized into moderate to extreme drought years out of the total drought years using SPI12, RDI 12, and SPEI 12.

The annual rainfall recorded at Mehsana shows a significant negative trend with Z value of -0.211 and its corresponding Sen's slope value is -0.171. For summer season rainfall shows a significant negative trend with Z value of -1.650 and its corresponding Sen's slope value is -0.044. Similar, for winter season rainfall shows a significant positive trend with Z value of 2.046 and its corresponding Sen's slope value is 0.109. The results of meteorological drought indices trend analysis shows that the SPI 12 the value of Z is -0.21 with Sen's slope value as 0.14. For RDI 12 value of Z is -0.22 with Sen's slope value as 0.189 and for SPEI value of Z is -0.21 with Sen's slope value as -0.040. By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased.

The results of NDWI index shows that average water spread area was 203.40 Sq.km with a standard deviation (SD) of 67.10 sq. km area and the percentage water spread area in the district varies from 2.5 % to 8.2% of the Mehsana district area. From the analysis of NDSI it was observed that average 973.50 Sq.km area which is around 23.80% area of Mehsana districts having moderate saline characteristics. Similarly, the results of MNDWI index shows that minimum water spread area in 1996 year with 3.87 Sq.km area and maximum water spread area 82.27 sqkm area in 2012, 61.14 Sq.km area in 2010 observed. Also, the average water spread area in the district is 74.80 Sq.km area (1.75%) in Mehsana district. The results of hydrological drought indices shows that the water ratio index in Mehsana district the medium dry condition and medium water condition varies from 21% to 30% and 65% to 78% respectively.

The results Agricultural drought indices for the NDVI index shows that the maximum percentage of severe dry areas in the year 1992 with 3531.60 sq. km, which is 80.40%, and during that year the rainfall was 485.16 mm in the study region. Moderate dry areas as 788.30 Sq.km, which is 17.90% of the study area. The minimum percentage of dry areas in the year 2005 with 1655.60 sq. km which is 37.70% of the area, and during that year the rainfall was 827.90 mm in the study region. Also, the minimum moderate dry percentage in 2006 year with 5.20% area with 228.90 Sq.km during this year the annual rainfall is 827.93 mm. The percentage of dry area varies from 25.48 % to 42.47 % and percentage of Normal dry area varies from 2.28 % to 10.69 % respectively during study period of data set. The results of VCI index shows that moderate drought having 23.6 percent and light drought having 53.25 percent during study period in the district.

LST results shows that maximum area under 35 to 45 degree temperature was 4236.70 Sq.km area and minimum area 942.60 Sq.km. The results also shows that average 3088.10 Sq.km area or 70.23% of the district under high temperature during the study period. The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2014 with 2232.40 sq. km, which is 50.8%, and during that year the rainfall was 733.0 mm in the study region. The average

percentage of dry using TCI area was 35.02% in Mehsana district with annual average rainfall 672.70 mm during study period.

The best Fuzzy Logic model for RDI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2698 by training and 0.2658 by validation of the model, and coefficient of determination by training of the model is 0.9567 and by validation of the model is 0.9574 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

6.5 PATAN DISTRICT

The 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 72, 75, 82, 80, 70, 77, 79 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation.

From the meteorological drought indices the result shows that extreme dry condition occurs in the year of 1901, 1904, 1911, 1915, 1923, 1925, 1939, 1960, 1968, 1969, 1972, 1974, 1987, and 2002 during this year the average rainfall is about 222.58 mm. Also, severe dry condition occurred during 1902, 1918, 1929, 1935, 1936, 1940, 1947, 1948, 1949, 1951, 1957, 1962, 1966, 1986, 1991, 1995 years and during moderate dry years 1902, 1918, 1929, 1935, 1936, 1940, 1947, 1948, 1949, 1951, 1957, 1962, 1966, 1986, 1991, 1995 the average rainfall is around 307.94 mm during study period.

The results of climatic index shows that 1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002 years were severely affected by drought. Also, 1902, 1903, 1905, 1918, 1920, 1929, 1930, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1952, 1953, 1956, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1992, 1993, 1999, 2000 years were medium dry condition during the study period. The PCI shows that for summer season is 20.60% uniform, 62.70% moderate uniform, 13.70% as irregular precipitation and 2.90% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 55.90% irregular precipitation trend was observed. The study of aridity indices shows that 18 years identified as arid years and 34 years as semi-arid years out of 102 years in Patan district.

The frequency analysis reveals that 7%, 16% and 15% of extreme dry years, severe dry years and moderate dry years occur amongst drought years considered, which means 38% years are categorized into moderate to extreme drought years out of the total drought years.

The results of NDWI index for Hydrological drought analysis shows that average water spread area for the studied period was 99.9 sq.km with a standard deviation (SD) of 85.90 sq. km area and the percentage water spread area in the district varies from 1.5 % to 6.2% of the Patan district area. Similarly, the results of MNDWI index shows that minimum water spread area in 2009 year with 10.64 Sq.km area and maximum water spread area 47.23 sq.km area in 2014, 44.81 Sq.km area in 2012 observed. Also, the average water spread area in the district is 33.70 sqkm area during study period. From the analysis of NDSI it was observed that average 2860.0 sq.km area which is around 46.20% area of Patan districts having moderate saline characteristics. The results of hydrological drought indices shows that the water ratio index in district the medium dry condition and medium water condition varies from 22% to 30% and 67% to 90% respectively.

The results of Agricultural drought indices using NDVI index shows that the maximum percentage of severe dry areas in the year 2018 with 5784.90 sq. km, which is 96.0%, and during that year the rainfall was 284.77 mm in the study region. Also, moderate dry areas as 1075.0 Sq.km, which is 17.8% of the study area. Similarly, the minimum percentage of dry areas in the year 2008 with 15.0 sq. km which is 0.20% of the area, and during that year the rainfall was 421.8 mm in the study region. The results of NDVI-deviation shows that percentage of dry area varies from 30.41 % to 42.58 % and percentage of Normal dry area varies from 1.09 % to 4.38 % respectively during study period.

The results of VCI index shows that 10.5 sq.km area under extreme dry conditions 46.6 sqkm area as severe dry and 4439.70 sq.km area as moderate dry conditions in Patan district. The results of LST shows that maximum area under 35 to 45 degree temperature was 5937.0 sq.km area which is 98%. The results also shows that average 4489.70 sq.km area or 74.54% of the district under high temperature during the study period. The average minimum temperature was 24.97°C and average maximum temperature was 44.26°C during study period. The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2008 with 3875.6 sq. km, which is 64.30%, and during that year the rainfall was 421.9 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2006 with 1263.80 sq. km which is 21.0% of the area, and during that year the rainfall was 859.60 mm in the study region. The average percentage of dry area was 41.70% in Patan district with annual average rainfall 574.0 mm during study period.

The best Fuzzy Logic model for RDI and SPI is Fuzzy Logic (FL) Model 4 with the RMSE of 0.2749 by training and 0.2647 by validation of the model, and co efficient of determination by training of the model is 0.9491 and by validation of the model is 0.9361 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall, average temp and PET data given.

6.6 SABARKANTHA DISTRICT

The 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 various meteorological drought indices it is observed that extreme dry condition occurs in the year of 1904, 1911, 1915, 1923, 1974, and 1987 during this year the average rainfall is about 310 mm. Also, very dry condition occurred during 1918, 1948, 1951, 1968, 1969, 1972, 2002 years and during very dry years the average rainfall is around 390 mm during study period.

The results of Sabarkantha district for various climatic indices shows that 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1969, 1974, 1987, 2002 years were severely affected by drought. Also, 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 years were medium dry condition during the study period. The result of PCI shows that for summer season is 26.50% uniform, 66.70% moderate uniform, 5.90% as irregular precipitation and 1.0% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 53.90% irregular precipitation trend was observed. The study of aridity indices shows that 18 years identified as arid years and 34 years as semi-arid years out of 102 years in Sabarkantha district. The frequency analysis reveals that 6%, 15% and 13% of extreme dry years, severe dry years and Moderate dry years occur amongst drought years considered, which means 34% years are categorized into moderate to extreme drought years out of the total drought years.

The annual rainfall recorded at Sabarkantha shows a significant negative trend with Z value of -0.944 and its corresponding Sen's slope value is -0.724. For summer season rainfall shows a significant negative trend with Z value of -1.340 and its corresponding Sen's slope value is -0.038. Similar, for winter season rainfall shows a significant positive trend with Z value of 1.456 and its corresponding Sen's slope value is 0.058.

For 12 month time scale all three indices gave nearly same results. For SPI value of Z is -0.94 with Sen's slope value as 0.23. For RDI value of Z is -0.96 with Sen's slope value as 0.26 and for SPEI value of Z is -0.94 with Sen's slope value as 0.17. By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. From the results it was observed that Sen's slope value for RDI is showing higher value than SPI and SPEI. Also, maximum trend value of Z statistics for RDI indices is obtained.

The results of hydrological drought indices using NDWI shows that average water spread area for the studied period was 99.9 sq.km with a standard deviation (SD) of 85.90 sq. km area and the percentage water spread area in the district varies from 2.5 % to 5.5% of the Sabarkantha district area. Similarly, the results of MNDWI index shows that minimum water spread area in 2009 year with 13.01 Sq.km area and maximum water spread area 40.51 sq.km area in 2006, 54.14 sq.km area in 2007 observed. Also, the average water spread area in the district is 26.12 Sq.km area. From the analysis of NDSI it was observed that average 2785.20 Sq.km area which is around 24.99% area of Sabarkantha districts having moderate saline characteristics. The results of hydrological drought indices shows that the water ratio index in Sabarkantha district the medium dry condition and medium water condition varies from 22% to 30% and 54% to 70% respectively.

The results of Agricultural drought indices using NDVI index shows that the maximum percentage of severe dry areas in the year 1992 with 3660.10 sq. km, which is 87.40%, and during that year the rainfall was 585.35 mm in the study region. Also, moderate dry areas as 403.7 Sq.km, which is 9.6% of the study area. Similarly, the minimum percentage of dry areas in the year 2005 with 1186.60 sq. km which is 28.30% of the area, and during that year the rainfall was 775.20 mm in the study region. Also, the minimum moderate dry percentage in 2005 year with 2.70% area with 114.30 Sq.km during this year the annual rainfall is 775.20 mm. The results of NDVI deviation shows that percentage of dry area varies from 23.27 % to 38.14 % and percentage of Normal dry area varies from 1.94 % to 6.21 % respectively during study period 1992 to 2019 years.

The results of VCI index shows that maximum extreme dry area was 24.5 sq.km severe dry area as 24.00 sq.km and moderate dry area as 779.0 sq.km during the study period. The results also shows that average 3955.10 sq.km area or 94.43% of the district under high temperature during the study period. The average minimum temperature was 21.46°C and average maximum temperature was 46.04°C during study period. The average percentage of dry area using VCI and TCI was 31.70% in Sabarkantha district with annual average rainfall 734.50 mm during study period.

The best Fuzzy Logic and ANFIS models for RDI and SPI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2762 by training and 0.2819 by validation of the model, and coefficient of determination by training of the model is 0.9594 and by validation of the model is 0.9516 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

6.7 RECOMMENDATIONS

It has been found from the conclusions that by analysing the meteorological drought indices the considered districts of North Gujarat under the study area drought has been occurred almost nearing to 50% of the years considered therefor it is strictly recommended that the proper planning of water conservation structures and at the same time management of available water resources should be well planned.

Looking at the analysis of Hydrological drought indices, the water spread in the study area is comparatively minimum in almost all the districts the efforts are to be made towards increasing water bodies and if possible, towards river water management.

By analysing at the Agricultural drought indices the percentage of dry areas is quite high as per some of the indices considered, it is recommended to have better watershed management practices, proper selection of crops/ improvement in agricultural practices by better cropping pattern and by planning drought resistant variety of crops in drought affected areas. Even the techniques of lined ponds or farm ponds plays an important role and may act as potential game changers.

Looking at the all the three types of drought, amongst the five districts the measures are to be taken in Banaskantha and Patan at the first place followed by Gandhinagar, Mehsana and Sabarkantha.

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List of Research Papers Published from the present study

Sr No	Publication/Publishers	Title of Paper	ISSN/ISBN, Date
1	22 nd International Conference on Hydraulics, Water Resources and Coastal Engineering (HYDRO 2017)	Meteorological Drought Analysis Using SPI, PNI & PD in Sabarkantha District, Gujarat	21 st to 23 rd December 2017 Vol 3, PP 2025-2033
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	16 th -18 th February 2018
3	23 rd International Conference On Hydraulics, Water Resources And Coastal Engineering (HYDRO 2018)	Analysis of Drought Periods for Mehsana During 20 th Century	19 th to 21 st December 2018
4	1 st National Conference On "Emerging Research And Innovations In Civil Engineering" (ERIC 2019)	Meteorological Drought Assessment In Banaskantha, Gujarat	15 th & 16 th February , 2019 ISBN: 978-93-53463-53-3 PP 22
5	24 th International Conference (Hydraulics, Water Resources, Coastal Engineering) (HYDRO 2019)	Assessments of Meteorological Drought Indices Using SPI and RDI in Mehsana Region, Gujarat, India	18 th -20 th December, 2019 BS Publications ISBN:978-93-8935-484-3 PP 1874-1880 (Volume II)
6	38 th & 39 th 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	25 th – 26 th Feb, 2022
7	Ecological Perspective (ECOPERS) : An International Academic Journal	Dry and Wet Period Analysis using Meteorological Drought Indices in Sabarkantha district Gujarat, India	E ISSN: 2792-0062 Vol. 3 No. 1 (2023): July – 2023
8	Ecological Perspective (ECOPERS) : An International Academic Journal	Assessment & Monitoring of Agricultural Drought Indices Using Remote Sensing Techniques and their Inter-Comparison	E ISSN: 2792-0062 Vol. 3 No. 1 (2023): July - 2023

9	GAU Research Journal, Gujarat Agricultural Universities Research Journal UGC CARE Listed Journal	Spatial Monitoring of Agricultural Drought Using Multiple Drought Indices Using GIS Approach in Sabarkantha district of North Gujarat Region	will be published in issue 48 (2). ISSN 0250-5193
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Book Chapter Publication

1. Book Chapter published in Water Science and Technology Library, Hydrological Modeling: Hydraulics, Water Resources and Coastal Engineering, Volume 109, PP 21-29

Assessments of Meteorological Drought Indices Using SPI and RDI in Mehsana Region, Gujarat, India

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ISBN 978-3-030-81357-4, ISBN 978-3-030-81358-1 (eBook),
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2. Book chapter published in Innovations in Infrastructure, Advances in Intelligent Systems and Computing, Springer, Singapore, Volume 757, PP 267-274.

Categorization of Drought during Twentieth Century Using Precipitation in Banaskantha District, Gujarat, India

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