Climatological Drought Index Computation using Reconnaissance Drought Index for Sabarkantha District, Gujarat,India

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***Abstract*-— 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. Drought is one of the most common natural events that have a great negative impact on agriculture and water resources. Recently, a new index for drought assessment and monitoring is presented called Reconnaissance Drought Index (RDI). RDI is calculated based on precipitation and potential evapotranspiration. In this study, Reconnaissance Drought Index (RDI) were assessed to investigate how well these indices reflect drought conditions in Sabarkantha district. For present study rainfall and potential evapotranspiration data of 102 years (1901-2002) were used. The Results shows different drought condition for different timescales (3, 6, 9 and 12) months. The outcomes of the study shows that extreme drought occurs 7 times, severe drought occurs in 3 times and moderate drought conditions occurs in 8 times in 102 years. Also RDI 12 gives finest results as compared to other time scales and total number of drought year obtain under each time scales.**

Keywords— Drought, Meteorological drought indices, Reconnaissance drought index.

I. INTRODUCTION

Drought is considered as a major natural hazard, affecting several sectors of the economy and the environment worldwide. It affects almost all the determinants of the hydrological cycle starting from precipitation and ending with streamflow in the surface water systems or the recharge and storage in the groundwater aquifers. Therefore, the determinant to be chosen depends upon which part of the hydrological cycle we are interested to focus our analysis [2].

Droughts are the resultant of acute water scarcity due to lack of rains over extended periods of time moving various human activities and lead to problems like widespread crop failure, un-replenished ground water resources, depletion in reservoirs and shortage of drinking water. The drought prone areas in the country classified on annual rainfall departures fall either in arid, semi-arid and dry sub-humid regions where droughts occur frequently [3].

II. CHARACTERIZATION OF DROUGHT

Operational Definition

An operational definition of drought helps 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 [1]. The following categories of drought are usually considered:

a) Meteorological drought: It 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.

b)Agricultural drought: It links with 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.

c) Hydrological drought: It is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply

d) Socioeconomic drought: It 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.

In addition to type, droughts are fundamentally characterized in three dimensions: severity, duration, and spatial distribution. Additional characteristics include: frequency, magnitude (cumulated deficit), predictability, rate of onset, and timing. Unfortunately, usage of the terms severity, intensity, and magnitude is not universal, and sometimes their meanings are switched.

Duration: Depending on the region, drought's duration can vary between a week's up to a few years. Because of drought's dynamic nature, a region can experience wet and dry spells simultaneously when considering various timescales. As such, in shorter durations the region experiences dryness or wetness, while in longer-term, it experiences the opposite (NCDC 2010).

Magnitude: The accumulated deficit of water (e.g., precipitation, soil moisture, or runoff) below some threshold during a drought period.

Intensity: The ratio of drought magnitude to its duration.

Severity: Two usages are provided for drought severity: the degree of the precipitation deficit (i.e., magnitude), or the degree of impacts resultant from the deficit.

Geographic extent: The areal coverage of the drought which is variable during the event. This area can cover one or several pixels (cells), watersheds or regions.

Frequency (return period): The frequency or return period of a drought is defined as the average time between drought events that have a severity that is equal to or greater than a threshold.

III. STUDY AREA AND DATA COLLECTION

Sabarkantha is a district in Northeast of Gujarat state of India. Geographical location of the district is 23.03^o North (Latitude) and 73.39^o East (Longitude). Location map of the study area is shown in below Fig.1. Hathmati, Sabarmati, Khari, Meshwo, Vatrak, Mazum, and Harnav are the main rivers flowing through this district. Average rainfall recorded here is 500-1000 mm. The maximum temperature of the place is 40.5^o and the minimum temperature is 9.04^o.For the present study 102 years (i.e., 1901 to 2002) monthly precipitation and potential evapotranspiration data has been collected from Indian Meteorological Department (IMD), Pune.

Fig.1 Location of the Study Area

IV. METHODOLGY

Drought Identification Indices: Drought indices assimilate thousands of bits of data on rainfall, temperature, snowpack, streamflow and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, far more useful than raw data for decision making. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although, none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. Some of different meteorological drought indices were SPI, RDI, DI, EDI, SPEI, PN, PD, SPEI etc. Among these Reconnaissance Drought Index is calculated.

1. Reconnaissance drought index

A new reconnaissance drought identification and assessment index was first presented by Tsakiris, 2004 while a more comprehensive description was presented in Tsakiris et al. (2006).
The index, which is referred to as the Reconnaissance Drought Index, RDI, may be calculated by the following

equations. For illustrative purposes the yearly expressions are presented first. The first expression, the initial value (α_0), is presented in an aggregated form using a monthly time step and may be calculated for each month of the hydrological year or a complete year. The α_0 is usually calculated for the year i in an annual basis as follows**:**

$$\alpha_0^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \quad i = 1\ to\ N, and\ j = 1\ to\ 12$$

In which Pij and PETij are the precipitation and potential evapotranspiration of the month j of the year i.

A second expression, the Normalized RDI, (RDIn) is computed using the following equation for each year, in which it is evident that the parameter $\bar{\alpha}_0$ is the arithmetic mean of a_0 values calculated for the N years of data.

$$RDI_n^{(i)} = \frac{a_0^{(i)}}{\overline{a_0}} - 1$$

The third expression, the Standardized RDI (RDIst), is computed following similar procedure to the one that is used for the calculation of the SPI. The expression for the Standardized RDI is:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\widehat{a_y}}$$

In which $y^{(i)}$ is the in a_0(i), is its arithmetic mean and $\widehat{a_y}$ is its standard deviation. Below Table 1 shows RDI values range and corresponding drought classification.

Table 1 : RDI Classification

RDI Values	Drought classification
2.00 or more	Extremely wet
1.5 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0 to 0.99	Normal Conditions-wet
0 to -0.99	Normal Conditions-dry
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2 or less	Extreme drought

V. RESULTS AND ANALYSIS

The computation for RDI was carried out for drought assessment in Sabarkantha districts using Drin C Software. DrinC gives the ability to formulate a drought analysis that suits better the needs or the purpose of this study. The range for is similar to that of SPI. Its value -1 or less indicates dry condition.-1 to -1.49 moderately dry,-1.5 to -1.99 severely dry,-2 or less extremely dry. The RDI is calculated for different time scale i.e., (3, 6, 9 and 12) months. Below Fig. 2, 3, 4 and 5 shows the annual variation of RDI over the year and annual rainfall variation graph.

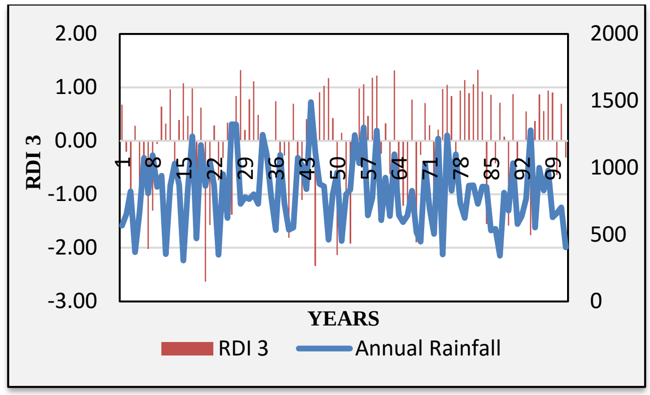

Fig. 2 Variation of RDI 3 and Annual Rainfall

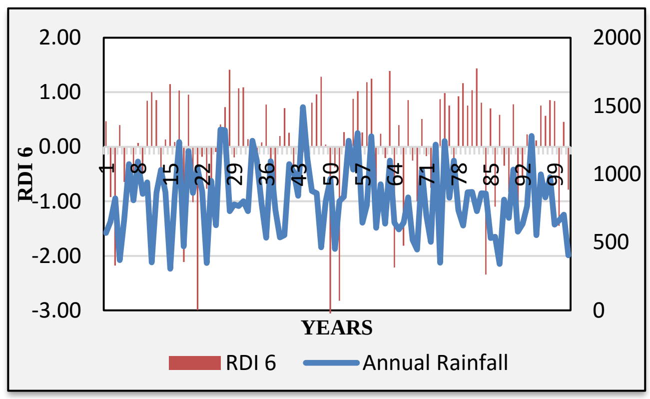

Fig. 3 Variation of RDI 6 and Annual Rainfall

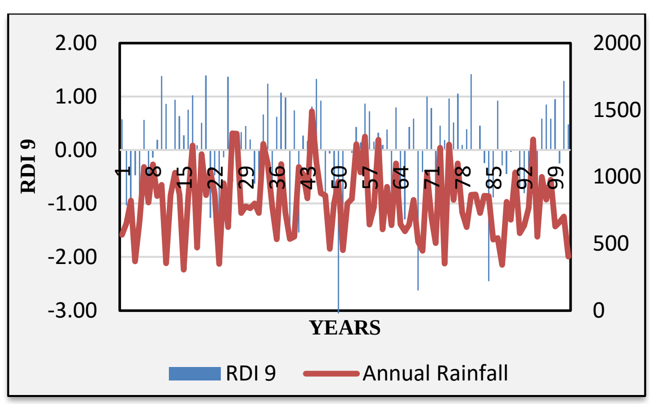

Fig. 4 Variation of RDI 9 and Annual Rainfall

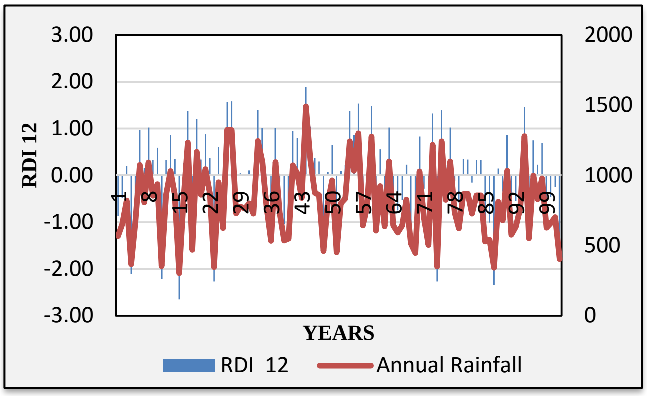

Fig. 5 Variation of RDI 12 and Annual Rainfall

From the above Figures of RDI 3, 6, 9 and 12 it is concluded that RDI 12 gives the better result among other time scale as it variation of rainfall and RDI values shows accurate relationships e.g., in the year of 1915, RDI 12 gives -2.65 values and the rainfall is 304.64 mm which falls in extreme drought condition.

Below Table 2 shows the total number of years affected by drought using RDI under different classes.

TABLE 2. TOTAL NUMBER OF YEARS AFFECTED BY DROUGHT USING RDI UNDER DIFFERENT DROUGHT CLASSES

Drought Indices	**Extreme**	**Severe**	**Moderate**	**Total**
RDI 3	4	9	9	22
RDI 6	7	1	6	14
RDI 9	3	2	12	17
RDI 12	6	3	8	17

As per RDI 3, it is observed that Extreme drought has occurred 4 times, severe drought has occurred 9 times and moderate drought has occurred 9 times in 102 years.

As per RDI 6, it is observed that Extreme drought has occurred 7 times, severe drought has occurred 1 time and moderate drought has occurred 6 times in 102 years.

As per RDI 9, it is observed that Extreme drought has occurred 3 times, severe drought has occurred 2 times and moderate drought has occurred 12 times in 102 years.

As per RDI 12, it is observed that Extreme drought has occurred 6 times in 102, severe drought has occurred 3 times in 102 years and Moderate drought has occurred 8 times in 102 years

VI. CONCLUSIONS

The drought severity of the Sabarkantha district for the year of 1901 to 2002 is assessed in this paper. The RDI method gives best result without other climatic parameters like minimum and maximum temperature, humidity and sun hours as it uses only precipitation data and Potential evapotranspiration gives accurate results. The Results derived by RDI method are similar to actual drought situation except that in extremely severe drought condition. This method is better for agricultural applications since it is simple and effective Whereas RDI values of 12 months seems more useful than the other time steps, which coincides with the drought period. Extreme drought affected years are 1904 – 1905,1911 – 1912,1915 – 1916,1923 – 1924,1974 – 1975,1987 – 1988, 1951 – 1952, 1969 – 1970, 2002 – 2003. The findings of this paper will be very handy for agriculturists and policy makers on critical issues is it affects seasonal agricultural practices such as plantation management, flood control, application of agricultural inputs (e.g. fertilizers, herbicides, etc.), water resources maintenance and management practices and so on.

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

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Abstract Drought is a natural hazard due to adverse effects in climate change in earth's environment. Drought assessment is very important to manage water resources in lean period. In the present study, drought years and degree of deficit of annual rainfall are determined by use of Standardized Precipitation Index (SPI-3 to 12 Months), and Percentage Departure from mean (PD) methods. For this study, monthly rainfall data of 102 years (1901–2002), of Banaskantha District, were used. The months of January, February, March, April, May, November, and December have been identified 68, 73, 78, 71, 68, 81, and 79 times as drought months, respectively, in the twentieth century, indicating that these months must be provided with assured Irrigation. From the annual rainfall departure analysis, the drought years have been identified and it is observed that 1901, 1904, 1911,1915,1923,1939,1969,1987, and 2002 are affected by severe drought and 1974 is affected by extreme drought condition. The study also reveals that 6, 15, and 15% of extreme dry years, severe dry years, and moderate dry years occur among drought years considered, which means 36% years are categorized into moderate to extreme drought years out of the total drought years.

Keywords Drought · Standardized precipitation index · Percentage departure from mean · Drought frequency

1 Introduction

The flood and droughts are the main two aspects of hydrological hazard. Among this drought is a potential threat with a destructive damage to agricultural as well as natural production. Drought in India occurs due to irregular monsoon rainfall in space

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and time. For the assessment of drought severity, various indices are used. Global warming will have an adverse effect on climatic conditions and water resources. So it is necessary to determine level of severity and trends to help in effective decision-making process in reducing the impact of drought. Patel et al. [4] calculated SPI for shorter and longer duration in Surat district and determined the dry and wet periods during twentieth century. Das et al. [1] showed the severity of drought in Kutch district using LANDSAT ETM+ and SPI method for drought assessment. Malakiya and Suryanarayana [2] developed SPI and RDI for assessment of the drought for Amreli district, wherein they concluded that it is better to use SPI and RDI of 12 months' index for analysis of drought for this study.

In rain-fed agriculture, rainfall has a crucial role to play for suitable crop planning. Twenty-eight years (1983–2010) daily rainfall data has been analyzed by Ray et al. [5] found various drought scenario based on weekly, monthly, seasonally and yearly at Barapani station in Ri-Bhoi district. They have also concluded that maximum drought frequency as 11 times in 28th week and as 14 times in December month. Shah et al. [6] showed in their results that SPI method showing as 50% variation of normal to wet and normal to dry conditions, respectively.

2 Study Area and Data Collection

Banaskantha is one among the 33 districts of the Gujarat state of India. The district is situated between 23°33′ and 24°45′ north latitude and 72°15' and 73°87' east longitude which shown in Fig. 1.

The annual precipitation variation between 214 and 1801 mm and annual average precipitation is 863.01 mm. For the analysis of drought monitoring, precipitation data has been collected for 102 years (i.e., 1901–2002) from Indian Meteorological Department (IMD), Pune.

3 Methodology

3.1 Standardized Precipitation Index (SPI)

The SPI method is of meteorological drought assessment and is formulated by McKee et al. in [3]. The SPI index is calculated for various shorter (3, 6, 9 months) and Longer (12, 24, 48 months). For calculation of SPI, only rainfall data is required and calculated using Drin C Software. Shahabfar and Eitzinger computed SPI with different time steps (e.g., one month, three months, and 24 months).

The Standardized Precipitation Index is calculated using the below formula and the range of different drought condition is also given in Table 1.

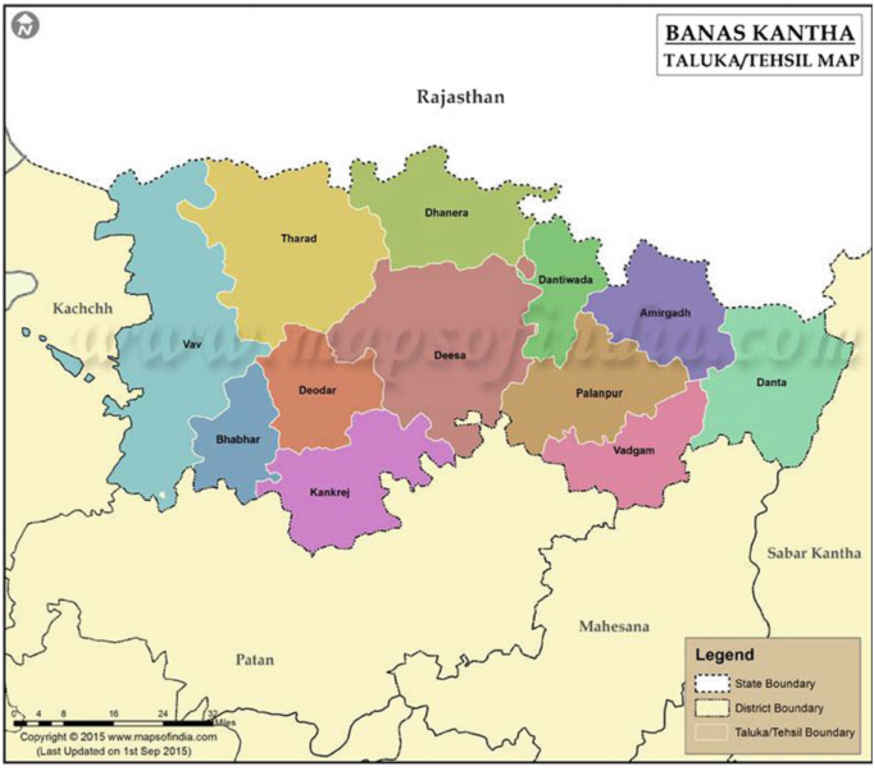

Fig. 1 Taluka map of Banaskantha

Table 1 Drought classification using SPI (McKee et al. [3])

SPI values	Drought condition
2.0 +	Extreme wet
1.5–1.99	Very wet
1.0–1.49	Moderate wet
−0.99 to +0.99	Near normal
−1.0 to −1.49	Moderate dry
−1.5 to −1.99	Severe dry
−2.0 to less	Extreme dry

$$\text{SPI} = \frac{x_i - x}{\sigma}$$

where

x the mean annual rainfall,
x_i the annual rainfall at any year and
σ the standard variation.

Table 2 Drought classification on percentage departure from normal (IMD 1971)

Percentage departure from normal	Intensity of drought	Code
>0.0	No drought	M0
0 to −25	Mild drought	M1
−25 to −50	Moderate drought	M2
−50 to −75	Severe drought	M3
−75 or less	Extreme drought	M4

Table 3 Seasonal rainfall in mm for Banaskantha district

Rainfall parameters	June	July	August	Sept	Winter (Jan–Feb)	Pre-monsoon (March–May)	SW monsoon (June–Sept)
Mean rainfall	60.70	196.75	152.91	82.61	1.51	2.90	123.24
Standard deviation	55.73	124.49	109.35	94.00	3.23	6.89	95.89

3.2 Percentage Departure from Mean

This index is calculated using the below equation:

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

where P_d is the percentage of departure from mean; P_i is monthly rainfall at any time, and P is the mean rainfall. Also, various codes assigned to each drought condition based on its value are given in Table 2.

4 Results and Discussion

The statistical parameters for the rainfall data for Banaskantha for 102 years were determined and are given in Table 3, which indicates that there are high fluctuations in occurrence of rain ranging from maximum rainfall 1072.68 mm in the year of 1917 and minimum rainfall 115.74 mm in the year of 1974 in the study area.

The monthly analysis of rainfall for Banaskantha district is given in Table 4. The same is based on assumption that a month is with drought when the rainfall for the month is less than half of the average rainfall for this month. The percentage of drought in a month was calculated as (number of drought months for a particular month/total number of drought months) multiplied by 100, for example, for January, the percentage of drought month is equal to 9.379%. Also, the highest average rainfall

Table 4 Drought analysis based on monthly rainfall for Banaskantha

Year	Average rainfall	Half of average rainfall	No. of drought months	Percentage of drought months
Jan	1.554	0.777	68	9.379
Feb	1.473	0.737	73	10.069
Mar	2.528	1.264	78	10.759
Apr	0.641	0.321	71	9.793
May	5.532	2.766	68	9.379
Jun	60.703	30.351	43	5.931
Jul	196.74	98.373	23	3.172
Aug	152.90	76.455	25	3.448
Sep	82.608	41.304	51	7.034
Oct	8.800	4.400	65	8.966
Nov	5.088	2.544	81	11.172
Dec	1.113	0.556	79	10.897

was observed as 196.75 mm in the month of July and lowest average rainfall was observed in the month of April as 0.641 mm in the span of 102 years. The months of February, March, April, November, and December have 73, 78, 71, 81, and 79 times drought months, respectively, indicating that these months must be provided with assured irrigation. The months of July and August had minimum number of drought months, i.e., 23 and 25, respectively.

4.1 Results of PD

The percentage of annual rainfall departures in Banaskantha district is computed. Also, from the annual rainfall departure analysis, the drought years have been identified and it is observed that 1901, 1904, 1911,1915,1923,1939,1969,1987, and 2002 years are affected by severe drought and 1974 year affected by extreme drought condition. The precipitation data of Banaskantha which is collected from IMD, Pune shows maximum Precipitation as 1073 mm in 1917 year and minimum precipitation as 116 mm in 1974 year. The percentage departure from normal is given in depicted in Fig. 2.

4.2 Results of SPI

The study of Standardized Precipitation Index produced the drought severity at 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 months' time steps, in the Banaskantha district of North

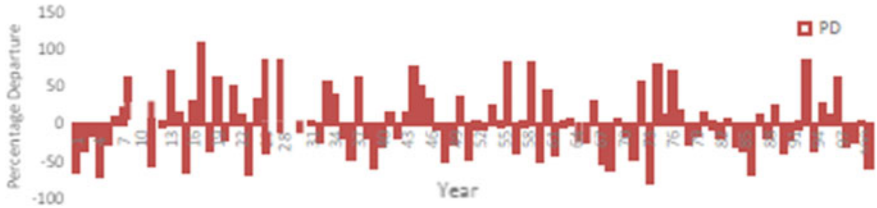

Fig. 2 Percentage of departure from mean in Banaskantha in twentieth century

Table 5 Total number of years affected by drought in diverse conditions for altered SPI time scale

SPI time scale/conditions	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
Extreme dry	0	0	2	3	4	3	2	4	2	3
Severe dry	9	8	4	4	3	4	7	4	10	7
Moderate dry	12	12	16	11	10	8	5	8	5	7
Near normal	63	62	60	63	65	69	67	69	74	66
Moderate wet	10	11	11	12	11	13	15	11	3	11
Very wet	8	7	6	9	9	4	6	4	6	7
Extreme wet	0	2	3	0	0	1	0	2	2	1
Total years	102	102	102	102	102	102	102	102	102	102

Gujarat, India. The total number of years affected by drought in different conditions for various altered SPI timescales are given in Table 5 and also shown in Fig. 3.

From Fig. 4, it is shown that only 1% year is obtained as the extreme wet conditions in the last 102 years because the average annual rainfall of Banaskantha is only 520 mm. Also from Fig. 5, it reveals that out of the drought years, 36% years are categorized into moderate to extreme drought years, which includes 6% extreme dry, 15% severe dry, and 15% moderate dry years.

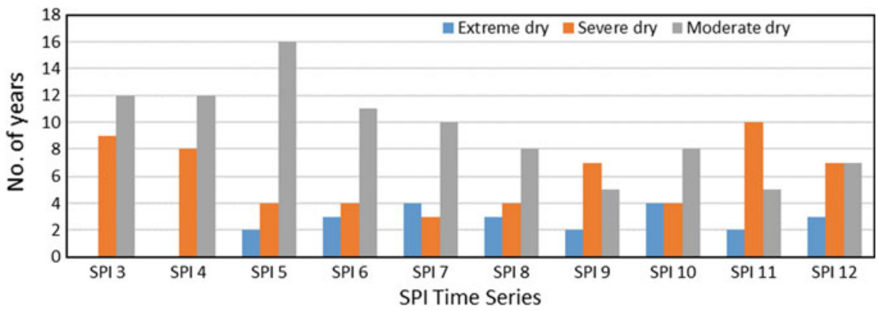

Fig. 3 Drought conditions in various SPI timescales

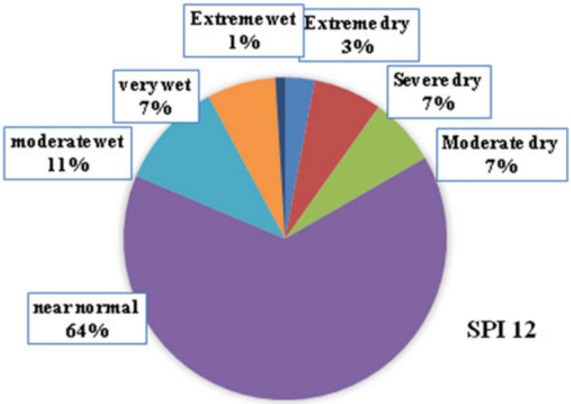

Fig. 4 Distribution of wet and dry periods (SPI 12 months)

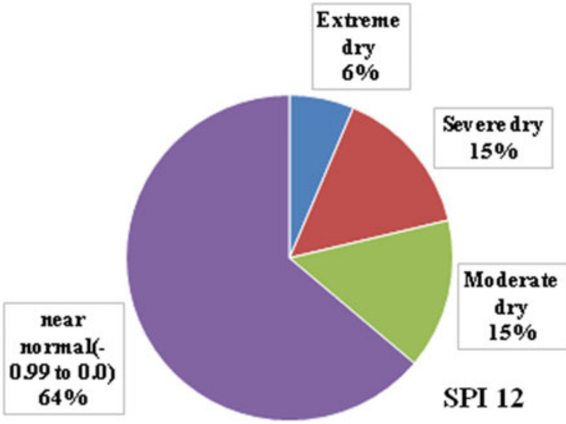

Fig. 5 Frequency of drought condition

5 Conclusions

The highest annual average rainfall was observed in Banaskantha as 196.75 mm in July and lowest in the month of April as 0.641 mm in the span of 102 years. In the present study, drought months are February, March, April, November, and December with total number of drought months with 73, 78, 71, 81, and 79, respectively, which indicatesthat these months must be provided with assured Irrigation. Similarly, months of July and August had minimum number of drought months, i.e., 23 and 25, respectively.

From the results, it is concluded that 1901, 1904, 1911, 1915, 1923, 1939, 1969, 1987, and 2002 are affected by severe drought and 1974 is affected by extreme drought condition. The results of SPI 12 show it is shown that only 1% year considered as extreme wet conditions and 6, 15 and 15% of extreme dry years, severe dry years, and moderate dry years for 102 years which means 36% years are categorized into moderate to extreme drought years out of the total drought years.

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Analysis of Drought Periods for Mehsana during 20th Century

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ABSTRACT

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, for identification of drought years Monthly Rainfall Analysis, Percent Normal Index (PNI) and Percentage Departure from Mean (PD) for the years (1901-2002) for Mehsana district, Gujarat. For this study rainfall data is analyzed to find out monthly, seasonal and yearly drought periods. From the results and analysis of Monthly Rainfall, it is concluded that the months of February, March, November and December have been identified 75, 85, 78 and 81 times as drought months respectively indicating that these months must be provided with assured irrigation. It is found that as per PNI no drought years are observed as 36 years whereas in PD the same has been observed as 48 years. It is also observed that from Percent of Normal Index and Percentage Departure from Mean, the severe drought years were 1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987 and 2002.The study also reveals that according to PNI, 17% years, 3% years and 9% years are observed as Moderate drought, Extreme drought and severe drought years respectively. Wherein PD, 29% years, 15% years and 10% years are observed as Mild Drought, Moderate drought and Severe drought conditions respectively.

Keywords: *Monthly Rainfall Analysis, Percent of Normal Index, Percentage Departure from Mean, Drought Severity.*

INTRODUCTION

Drought is a complex phenomenon, and is caused by below average precipitation. It also effects on the masses in a developing country like India and all over the world. Rainfall by the south-west monsoon is notorious for its vagaries. When the principal monsoons starts from southwest side and northeast side when it fail or are deficient or scanty drought will start to occur (Gupta et al. (2011)). Monsoon disaster will cause reduction in crop yield, drying up ecosystems and scarcity of water results to the rural and urban communities.

Das et al. (2016) in their study addressed water deficiency and drought occurrence over Kutch district, Gujarat. Earth observation data and Standardized Precipitation Index were used to analyze drought severity, wherein daily rainfall data over the study area were obtained from

Indian Meteorological Department for the period of study (1990-2014) and geo-referenced for further analyses. Dry areas in India include about 94 Mha & also about 300 million human live in these areas; more than 50 percent of the region is affected by lack of drought once every four years. Ray et al. (2012) proposed in rain-fed agriculture, rainfall has a crucial role to play for suitable crop planning for analysis of weekly, monthly, seasonal and yearly meteorological drought occurrence in Ri-Bhoi district.

STUDY AREA AND DATA COLLECTION

Mehsana district is located between 23^{o}58' latitude and 72^o 36' longitude and elevation is 83 meters height that is equal to 272 feet which is shown in below Figure 1. Mehsana is about 75 km from Ahmedabad. The major crops of Mehsana are Potato, Cotton, Tobacco, Oilseeds, Castor Seeds, Cumin, Psyllium and Anise. The average rainfall in Mehsana district is 697 mm. The maximum temperature of the place is 43^o and the minimum temperature is 12^o. The River flowing through Mehsana district is rupen (156 km) and Sabarmati (371 km). For assessment of drought monthly rainfall (1901-2002) are collected from State water data center, Gandhinagar.

Figure 1: District Map of Mehsana

METHODOLOGY

For computation and identification of drought spells various meteorological drought indices were used. Also, monthly rainfall analysis is also carried out for the percentage of drought months.

Percent of Normal Index

Percent of Normal index is calculated by dividing the actual rainfall by the "Normal" rainfall (considered to be a 30-year mean) and multiplying by 100. Equation (1) is used for calculation of this index.

$$\mathbf{I = \frac{P}{P_{30}} * 100} \qquad \textbf{(1)}$$

The characterization of drought condition using PNI is shown in below **Table 1**.

Table 1: Drought classes based on PNI

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

Percentage Departure from Mean

The yearly amount of drought was also determined using the values suggested by Indian Meteorological Department (1971). The percentage departure from mean of rainfall is assessed using the following equation (2).

$$\mathbf{P_d = \left[\frac{P_i - \bar{P}}{\bar{P}}\right] * 100} \qquad \textbf{(2)}$$

Here, Pd is the percentage departure; Pi is the rainfall at any time and $\bar{p}$ is the mean rainfall. . The classification of this method is shown below in Table 2.

Table 2: Percentage Departure from Normal (IMD Classification)

Percentage Departure From Normal	**Intensity of Drought**
> 0.0	No Drought
0 to -25	Mild Drought
-25 to -50	Moderate Drought
> -50	Severe Drought

RESULTS AND ANALYSIS

The Monthly rainfall of Mehsana shows that maximum part, of annual rainfall comes from monsoon season which is from June to September. The various statistical parameters like (annual mean rainfall, standard deviation) of the rainfall data for Mehsana for 102 years were determine and given in Table 3. Which indicates that there are high fluctuations in occurrence of rain ranging from maximum rainfall 1195.33 mm in the year of 1959 and minimum rainfall

214.017 mm in the year of 1987 in the study area. It was observed that Post monsoon season is suffered by drought and lake of humidity.

Table 3: Seasonal Rainfall in mm for Mehsana district

Rainfall Parameters	June	July	August	Sept	Winter (Jan-Feb)	Pre-monsoon (March to May)	SW monsoon (June to Sept)
Mean Rainfall	75.61	241.94	172.9	105.91	1.24	3.85	149.09
Standard Deviation	57.85	126.12	108.53	109.62	2.48	7.53	100.53

The monthly analysis of rainfall for Mehsana district is given in Table 4. The same is based on assumption that a month is with drought when the rainfall for the month is less than half of the Average rainfall for this month. The percentage of drought in a month was calculated as (number of drought months for a particular month/ total number of drought months) multiplied by 100, for example, January, the percentage of drought month is equal to 10.34%. Also, the highest average rainfall was observed as 241.94 mm in the month of July and lowest average rainfall was observed in the month of April as 0.641 mm in the span of 102 years. The months of February, March, April, November and December have 75, 85, 70, 78 and 81 times drought months respectively, indicating that these months must be provided with assured Irrigation. The moths of July and August had minimum number of drought months i.e., 17 and 20 respectively.

Table 4: Drought Analysis based on Monthly Rainfall for Mehsana district

Month	Average Rainfall	Half of Average Rainfall	No. of Drought Months	Percentage of Drought Months
Jan	1.78	0.89	72.00	10.34
Feb	0.69	0.35	75.00	10.78
Mar	2.39	1.19	85.00	12.21
Apr	0.52	0.26	70.00	10.06
May	8.64	4.32	64.00	9.20
Jun	75.61	37.80	29.00	4.17
Jul	241.94	120.97	17.00	2.44
Aug	172.90	86.45	20.00	2.87
Sep	105.91	52.96	42.00	6.03
Oct	14.39	7.19	63.00	9.05
Nov	6.75	3.38	78.00	11.21
Dec	1.11	0.56	81.00	11.64
Total			**696.00**	**100.00**

Based on the methodology of the IMD drought assessment method and Percent of Normal Index, the drought severity estimates were arrived and discussed below in Table 5 and 6.

Table 5: Results of Percent of Normal Index

Classification	Years	No
Moderate Drought	1901,1925,1929,1935,1936,1938,1939,1940,1949,1957, 1960,1965,1969,1985,1986,1991,1995	**17**
Extreme Drought	1904,1911,1987	**03**
Severe Drought	1915,1918,1923,1948, 1951, 1968, 1972, 1974, 2002	**09**

Table 6: Results of Percentage of Departure from Mean

Classification	Years	No
Mild Drought	1902,1903,1905,1916,1920,1929,1930,1932,1935,1938, 1947,1949,1952,1962,1964,1966,1971,1978,1979,1980, 1982,1984,1988,1989,1992,1993,1999,2000,2001	**29**
Moderate Drought	1901,1925,1936,1939,1940,1951,1957,1960,1965,1968, 1969,1985,1986,1991,1995	**15**
Severe Drought	1904,1911,1915,1918,1923,1948,1972,1974,1987,2002	**10**

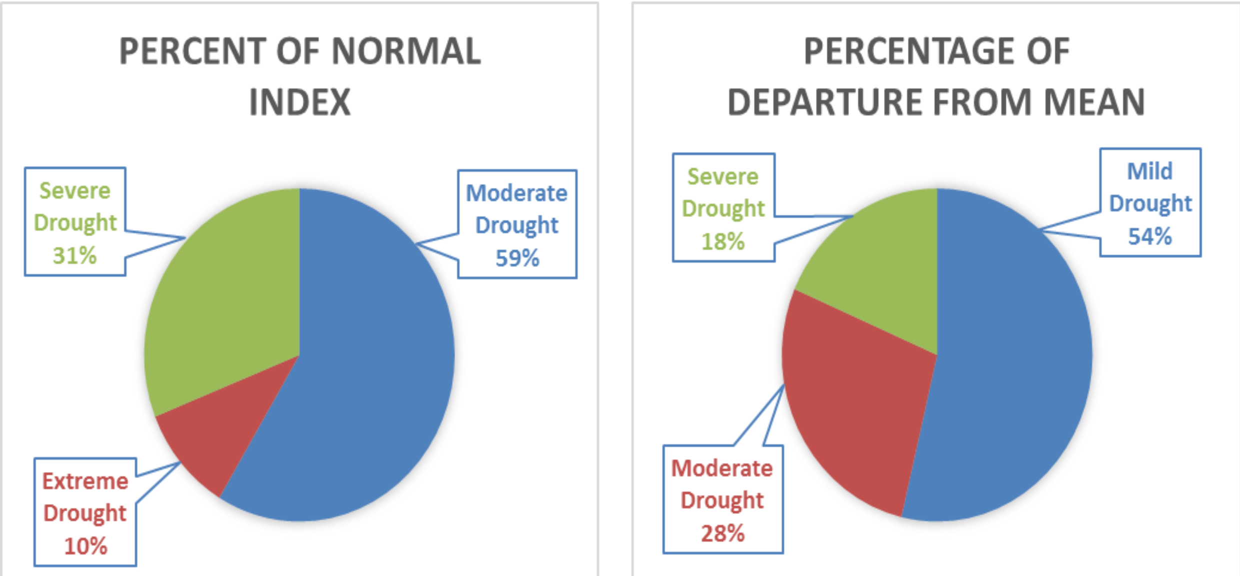

Figure 2: Percentage of Drought Conditions using PNI and PD

From the analysis, it is shown that only 1% year is obtained as the extreme wet conditions in the last 102 years, because the average annual rainfall of Mehsana is only 632.62 mm.Also from the Figure 2, it reveals that out of the drought years, The study also reveals that according to PNI, 17% years, 3% years and 9% years are observed as Moderate drought, Extreme drought and severe drought years respectively. Wherein PD, 29% years, 15% years and 10% years are observed as Mild Drought, Moderate drought and severe drought conditions respectively.

CONCLUSIONS

In the present study of Mehsana district drought analysis carried out for 102 years and it shows that more than 25% years of arid measures for the 20th Century. From the monthly rainfall analysis, it may be concluded that the months of February, March, November and December have been identified 75, 85, 78 and 81 times as drought months respectively showing that these months must be provided with secure irrigation. Drought analysis based on 102 years of monthly rainfall record showed that there was a severe drought in 1915,1918,1923,1948,1951,1968,1972,1974,and 2002 using PNI and PD method Similarly in Extreme drought in 1904,1911 and 1987. Mild drought conditions though occurred in majority of the years which is about 29 years.

It is also concluded that as per PNI, 17% years, 3% years and 9% years are observed as Moderate drought, Extreme drought and severe drought years respectively. Wherein as per PD, 29% years, 15% years and 10% years are observed as Mild Drought, Moderate drought and severe drought conditions respectively. No scanty drought year was experienced in the study area during the period of analysis. The information on this paper will as be very handy for agriculturists and policy makers on critical issues is it affects seasonal agricultural practices such as plantation management, flood control, application of agricultural inputs water resources maintenance and management practices and so on.

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Meteorological Drought Assessment in Banaskantha, Gujarat

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Abstract

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, monthly rainfall and potential evapotranspiration data for 102 years (i.e., 1901 to 2002) were collected and analysed for drought assessment. The dry periods were calculated using meteorological drought indices i.e. Reconnaissance Drought Index for various time scales of RDI-3, RDI-6, RDI-9 and RDI-12. The outcomes of the study shows that RDI-12 gives finest results as compared to other time scales because it considers all 12-month of hydrologic year for calculation. Amongst the period considered, the normal dry, moderate drought, severe drought and extreme drought conditions occurred for 29%, 6%, 6% and 4% respectively. Considering only the drought years i.e. (46 Years) normal dry, moderate drought, severe drought and extreme drought conditions exists for 65%, 13%, 13% and 9% respectively. It is recommended that more accurate predictions are achieved using longer duration of RDI-12 index in drought monitoring systems for water resources planning and water management in the present study.Based on the findings of this research, it is recommended that the RDI index should be used as the proper drought index in drought monitoring systems for water resources planning and management in Banaskantha.

Keyword- Drought Assessment, Reconnaissance Drought Index

I. INTRODUCTION

Drought is a complex and least understood phenomenon which generally occurs due to the below normal availability of water for a considerable period which can extend to regions, countries or continents. Even though drought is a recurring phenomenon and affects all geographical areas, but its impacts are more severe in arid and semi-arid regions where there already exists high natural variability in the rainfall pattern. The main characteristics include severity, intensity, areal extent, progression and withdrawal of droughts. Drought severity, duration and its spatial extent are some of the important characteristics (Thomas et al. 2015).

Drought indices are important elements of drought monitoring and assessment since they simplify complex interrelationships between many climate and climate-related parameters. Indices make it easier to communicate information about climate anomalies to diverse user audiences and allow scientists to assess quantitatively climate anomalies in terms of their intensity, duration, frequency and spatial extent (Wilhite et al. 1985).

II. LITERATURE REVIEW

Tigkas et al. (2013) studied the Reconnaissance Drought Index (RDI) (initial or normalized expressions) as a single climatic index for the detection of possible climatic changes. Using data for various reference periods (12, 6, 3 months).Similarly, Thomas et al. (2015) considered RDI by considering Penman-Monteith method used to estimate PET to analyse the climate change impacts on the drought scenario in Bundelkhand region. Also, spatio-temporal variation of drought has been investigated and it was found that every drought events has its own characteristics in terms of its areal extent, its progression, withdrawal and severity. Tigkas et al. (2015) presented a summary of the RDI theory with some practical applications and RDI can be calculated for any time step, and effectively related with agricultural drought and directly linked to the climate conditions of the area. Mistry and Suryanarayana (2018) studied SPI in Banaskantha and shown that 6%, 15% and 15% of Extreme dry years, severe dry years and Moderate dry years occur amongst drought years considered, which means 36% years are categorized into moderate to extreme drought years out of the total drought years.

Lunagaria and Suryanarayana (2015) estimated dry periods using analysis of RDI-3, RDI-6, RDI-9 and RDI 12.and concluded that it was better to use RDI of 12 months' index for analysis of drought for Sabarkantha district. Patel et al. (2017) had calculated SPI for 4, 6, 12, 24 and 48 months' time scales in Surat District. The area experienced more than 20% years of dry and wet events for the 20th Century. It is observed that the years 1942, 1945 and 1959 are identified as severe wet events for the time scale considered. Malakiya and Suryanarayana (2016) developed SPI and RDI for assessment of the drought for Amreli district, wherein they concluded that it is better to use SPI and RDI of 12 months' index for analysis of drought for this study.

Numerous drought indices with various intricacy have been utilised in several climatic regions. Presently, the Reconnaissance Drought Index (RDI), which is considered as a powerful index of meteorological drought, is acquisitioning approval primarily in semi-arid and arid climatologic areas. Because RDI is based on precipitation (P) and potential evapotranspiration (PET), it assesses the PET estimation effects on the characterisation of drought severity computed by RDI.

III. STUDY AREA AND DATA COLLECTION

Banaskantha is one among the thirty three districts of the Gujarat state of India. The administrative headquarters of the district is Palanpur. The main rivers in the district are Banas, Saraswati River and Sipu. Banaskantha District includes the area around the Bank of Banas River.

The District is situated between 23º33' to 24º45' North Latitude and 72º15' to 73º87' East Longitude. The climate of this district is characterized by a hot summer and dryness in the non-rainy seasons. The cold season starts from December to February is followed by the hot season from March to May. The south-west monsoon season is from June to September and post monsoon season from October and November. The annual rainfall varies between 214 mm to 1,801 mm. The annual average rainfall of Banaskantha district is 863.01 mm and average temperature of is 26.97º C. For the present analysis of drought calculation 102 years (i.e., 1901 to 2002) precipitation and potential evapotranspiration data has been collected from website of Indian Water Portal.

Fig. 1: Taluka Map of Banaskantha

IV. METHODOLOGY

A. Reconnaissance Drought Index

A new reconnaissance drought identification and assessment index was first presented by (Tsakiris, 2004) while a more comprehensive description was presented in (Tsakiris et al. 2006). The index, which is referred to as the Reconnaissance Drought Index, RDI, may be calculated by the following equations. For illustrative purposes the yearly expressions are presented first. The first expression, the initial value (α0), is presented in an aggregated form using a monthly time step and may be calculated for each month of the hydrological year or a complete year. The α0 is usually calculated for the year i in an annual basis as follows:

$$\alpha_0^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \quad i = 1 \text{ to } N, \text{and } j = 1 \text{ to } 12 \tag{1}$$

In which P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the month j of the year i. A second expression, the Normalized RDI, (RDIn) is computed using the following equation for each year, in which it is evident that the parameter $\bar{a}_0$ is the arithmetic mean of $a_0$values calculated for the N years of data.

$$RDI_n^{(i)} = \frac{a_0^{(i)}}{\bar{a}_0} - 1 \tag{2}$$

The third expression, the Standardized RDI (RDIst), is computed following similar procedure to the one that is used for the calculation of the SPI. The expression for the Standardized RDI is:

$$\mathrm{RDI}_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\widehat{a_y}} \qquad (3)$$

In which y $^{(i)}$ is the in $a_0{}^{(i)}$, is its arithmetic mean and $\widehat{a_y}$ is its standard deviation. Below Table 1 shows RDI values range and corresponding drought classification.

RDI Values	*Drought classification*
2.00 or more	*Extremely wet*
1.5 to 1.99	*Severely wet*
1.00 to 1.49	*Moderately wet*
0 to 0.99	*Normal Conditions-wet*
0 to -0.99	*Normal Conditions-dry*
-1 to -1.49	*Moderate drought*
-1.5 to -1.99	*Severe drought*
-2 or less	*Extreme drought*

Table 1: Classification of RDI

V. RESULTS AND ANALYSIS

The rainfall of Banaskantha is shown in below figure 1 which shows between rainfall and time. The coefficient of determination (r^2) shows that 0.28% variation in rainfall is explained by time. The total rainfall received in a given period at a location is highly variable from one year to another year. The variability depends on the type of climate and length of the considered period. In general it can be stated that the drier the climate, the higher the variability of rainfall in time. The same hold for the length the period: the shorter the period the higher the annual variability of rainfall in that period.

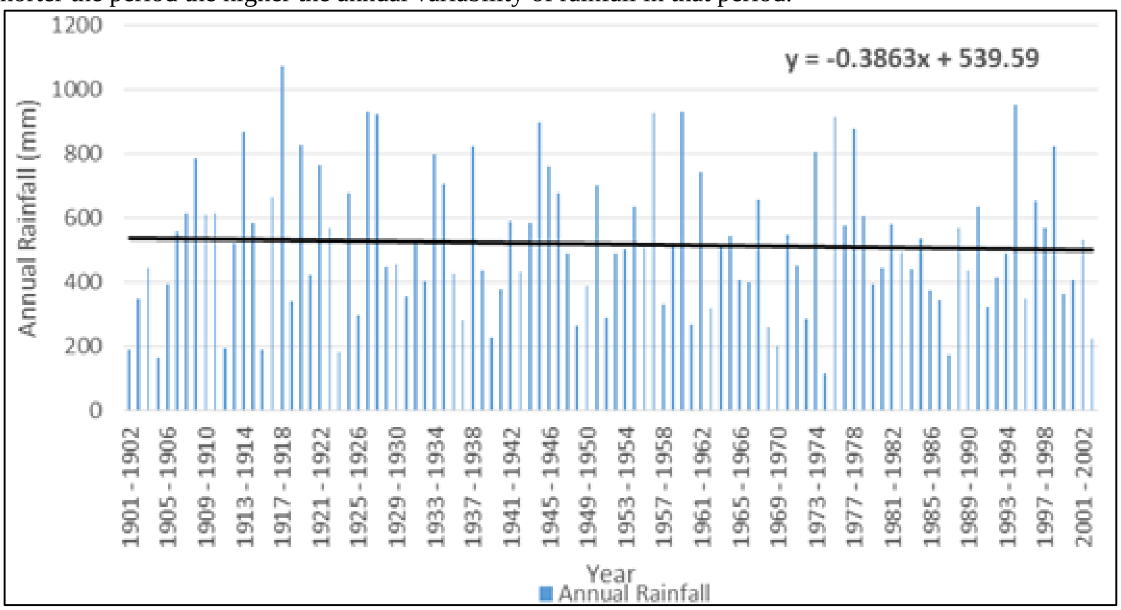

Fig. 2: Annual Rainfall over Banaskantha district

A. Analysis of Reconnaissance Drought Index

The computation for RDI was carried out for drought assessment using DrinC tool. DrinC gives the ability to formulate a drought analysis that suits better the needs or the purpose of this study.

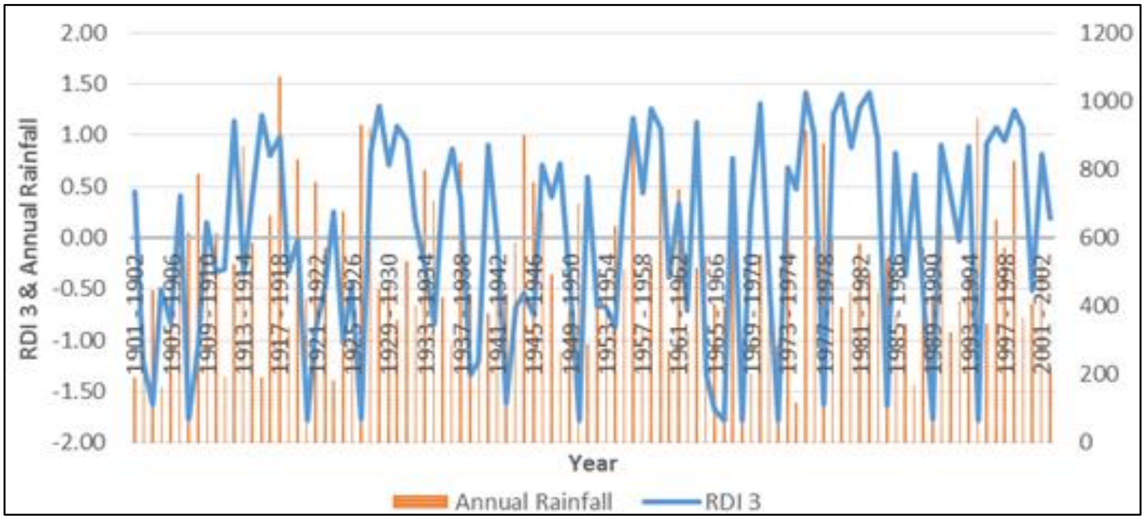

Fig. 3: Variation of Annual Rainfall and RDI 3

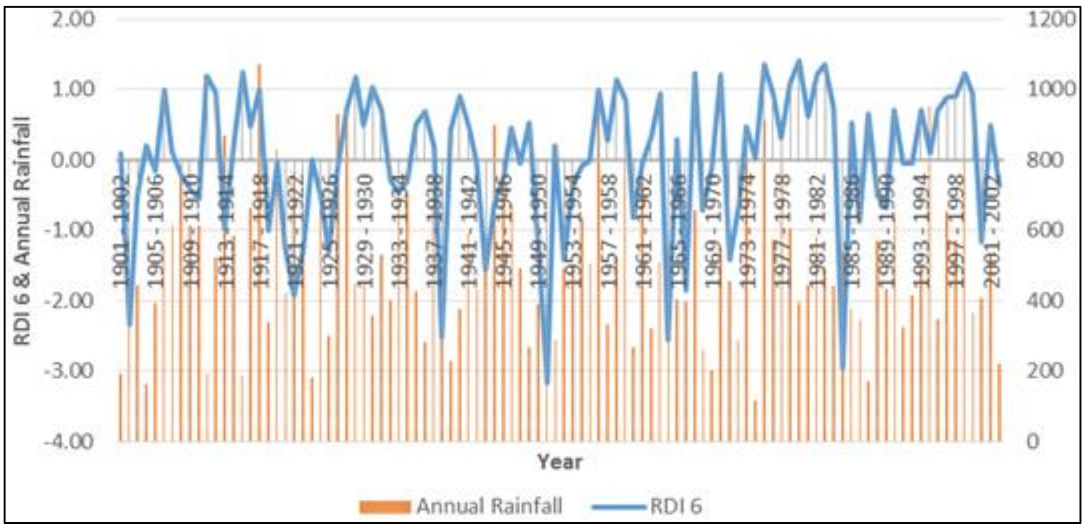

Fig. 4: Variation of Annual Rainfall and RDI 6

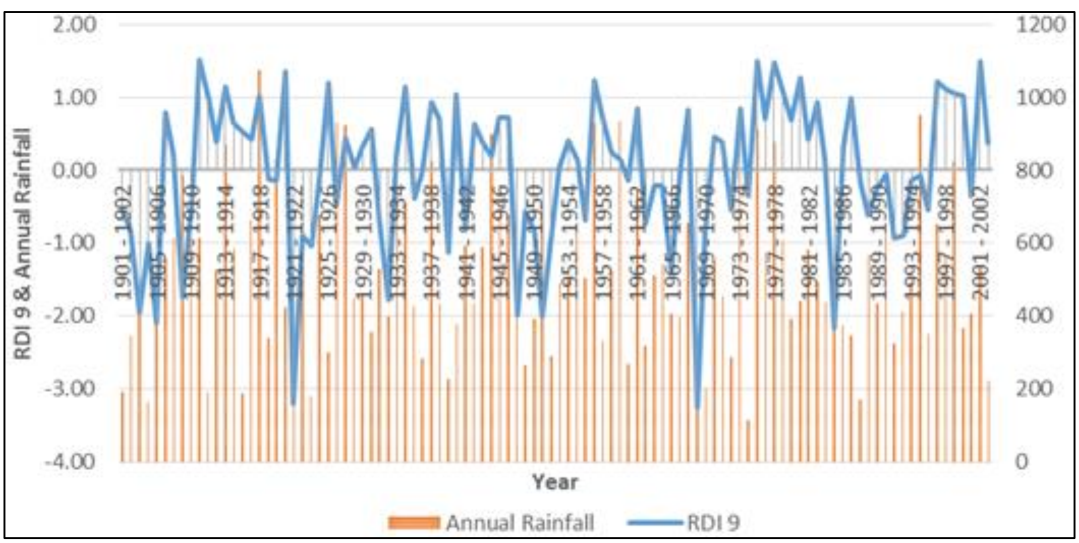

Fig. 5: Variation of Annual Rainfall and RDI 9

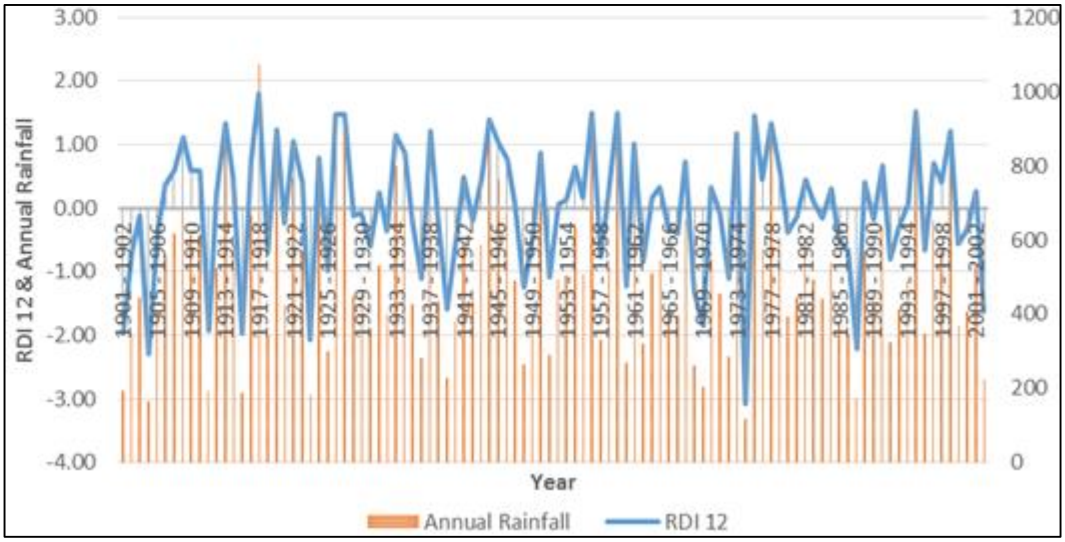

Fig. 6: Variation of Annual Rainfall and RDI 12

The Figures 3, 4, 5 and 6 shows annual rainfall and deviation of computed RDI values for different time scales RDI 3, RDI 6, RDI 9 and RDI 12 respectively. When the period of analysis is short, the variation between positive and negative values are seen more frequently and when the period of analysis increases, it is observed that the variation between positive and negative values are fewer. Below figure 7 shows the classification and number of year during various condition of RDI.

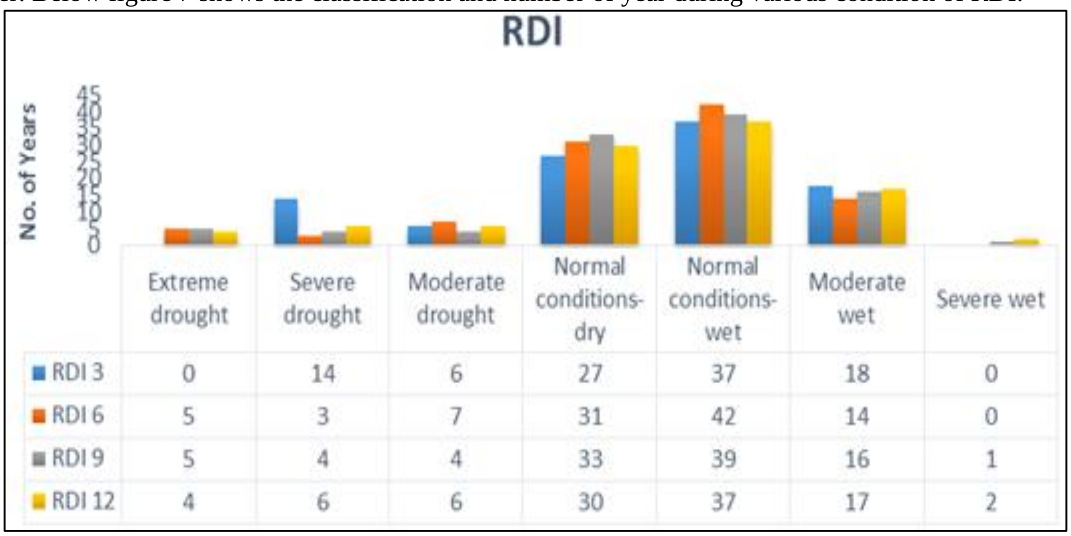

Fig. 7: Number of Years under various conditions during 20th Century

RDI	*Extreme Drought*	*Severe Drought*	*Moderate Drought*
RDI 3	*No events*	*1903, 1907, 1920, 1926, 1942, 1950, 1965, 1966, 1968, 1972, 1977, 1984, 1989, 1994*	*1902, 1908, 1924, 1938, 1939, 1964,*
RDI 6	*1902, 1938, 1950, 1964, 1984,*	*1921, 1943, 1966*	*1920, 1922, 1925, 1949, 1952, 1971, 2000*
RDI 9	*1905, 1921, 1950, 1968, 1984*	*1903, 1908, 1932, 1947*	*1904, 1923, 1939, 1965*
RDI 12	*1904, 1923, 1974, 1987*	*1901, 1911, 1915, 1939, 1969, 2002*	*1936, 1948, 1951, 1960, 1968, 1972*

Table 2: Number of Drought Affected Year for various time scales

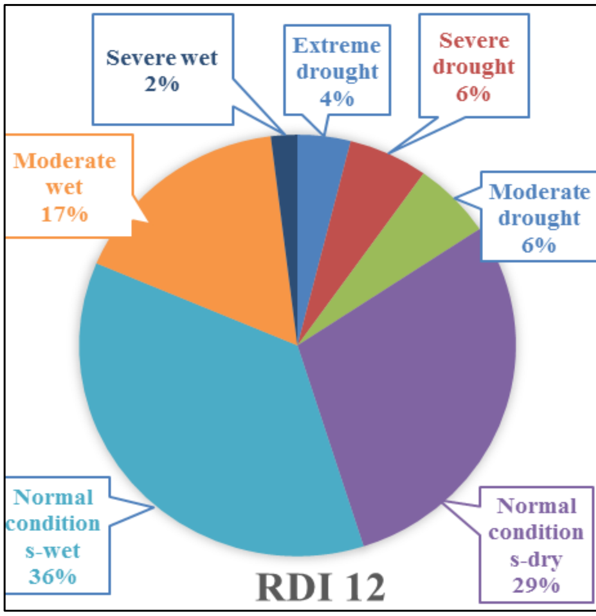

Fig. 8: Distributions of Wet and Dry period (RDI 12)

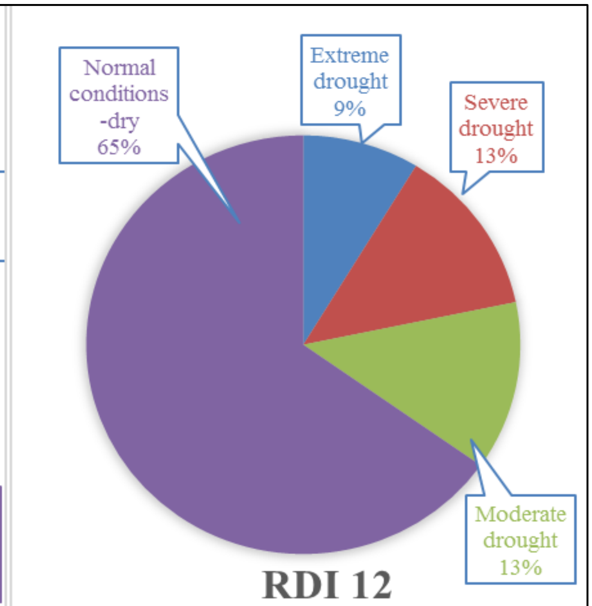

Fig. 9: Frequency of Drought Condition

Figure 8 shows frequency RDI 12 indicator, where figure 9 shows only frequency of drought years it is shown that extreme wet conditions is never occurred in the last 102 years. Only severe conditions occurred only 2% amongst 102 years so it is indicating that Banaskantha Taluka falls under scarcity rainfall for the period of time in the last 102 years, because the average annual rainfall of Banaskantha is only 520 mm which is very low. Also, from the above figure it shows that amongst the period considered, the normal dry, moderate drought, severe drought and extreme drought conditions occurred for 29%, 6%, 6% and 4% respectively. Considering only the drought years i.e. (46 Years) normal dry, moderate drought, severe drought and extreme drought conditions exists for 65%, 13%, 13% and 9% respectively.

VI. Conclusions

The RDI method gives best results without other climatic parameters like minimum and maximum temperature, humidity and sun hours as it uses only Precipitation data and Potential evapotranspiration gives accurate results. From the results and analysis it is concluded that extreme drought condition occurred in 1904, 1923, 1974 and 1987 years. Severe drought condition occurred in 1901, 1911, 1915, 1939, 1969 and 2002 years and Moderate drought conditions occurred in the year 1936, 1948, 1951, 1960, 1968, and 1972. The outcomes of the study shows that RDI-12 gives finest results as compared to other time scales because it considers all 12-month of hydrologic year for calculation. Amongst the period considered, the normal dry, moderate drought, severe drought and extreme drought conditions occurred for 29%, 6%, 6% and 4% respectively. Considering only the drought years i.e. (46 Years) normal dry, moderate drought, severe drought and extreme drought conditions exists for 65%, 13%, 13% and 9% respectively.

In general, the present results have shown that the most part of Banaskantha has been affected by drought. So, there is a need to undergo future researches on these region so as to improve the water resource management and development programs and to resolve the socio-economic and agricultural problems faced by the people in these parts of the country.

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SOUVENIR & ABSTRACTS VOLUME

Andhra University,
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14:00 – 15:30 hrs **Technical Session-2**
Extreme events - Forecast and mitigation

Chairperson: Prof. D.T. Shete **Co- Chairperson: Prof. Anuja Tigga**

Time-hrs	**Title**	Authors
14:00-14:30	***Invited talk:*** **Challenges in Hydrological Modeling for Flood Forecasting in a Data Scarce Basin: A case Study of Chennai River Basin**	Balaji Narasimhan IIT-Madras
14:30-14:36	Extreme hydrological events in January 2022: A case study over Telangana and Andhra Pradesh states	Sunanda M and Harsha Soni
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14:42-14:48	Stream flow in the Rushikulya river basin, Odisha-Trends, extremes and climate linkages	D. Panda, Rashmi Rani Anand and M. Devi
14:48-14:54	Flow modelling of Chennai's Adyar sub-basin to predict and manage the extreme weather events using MIKE SHE	M. Rinisha Kartheeshwari and L. Elango
14:54-15:00	Review on climate change effect on Tsunami wave height and infrastructure	Seeram Madhuri and Pramod Kumar
15:00-15:06	Drought assessment and monitoring using different indices in Panchmahal District, Gujart, India	Pranav B Mistry and T.M.V. Suryanarayana
15:06-15:12	Understanding the impact of soil moisture variability on temperature extremes over the Indian region	Naresh Ganeshi, Milind Mujumdar, Yuhei Takaya, Bhupendra Singh, Mangesh Goswami, R. Krishnan and Toru Terao
15:12-15:18	A correlation study between the relative humidity and air temperature at Kalingpatnam coastal site, Andhra Pradesh - A case study	Y.R. Bhagat and S.P. Hedaoo
15:18-15:30	Discussions	
15:30-15:45	Break	

weathers like flash floods, highest & coldest temperature and sequential events like volcanic eruption, earthquake and tsunami are affecting majorly the infrastructure. Amid all this, the responsibility of the civil engineers is increased to design innovative infrastructures that can be serviceable even in the changing climate. Designing the near-shore structures considering the climate change is a tough challenge especially to encounter the tsunami loads. These forces are difficult to predict as various factors such as inundation depth, wave velocity, wave height, run-up and debris are to be assumed accurately. A brief literature review has been presented to expose the contribution of climate change on the tsunami wave height and coastal infrastructure.

* * *

DROUGHT ASSESSMENT & MONITORING USING DIFFERENT INDICES IN PANCHMAHAL DISTRICT, GUJARAT, INDIA

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ABSTRACT

Present study aims to compare meteorological drought indices viz., Percent of Normal, Percentage departure from mean, Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Effective Drought Index (EDI) and Standardized Precipitation Evapotranspiration Index (SPEI) for their suitability in Panchmahal district during 1973-2002 with 875 annual average rainfall. Hence, the performance evaluation of different drought indices is necessary for identifying a suitable drought index. Also, Trend analysis is conducted for various time series using nonparametric trend tests (Mann-Kendall and Sen's slope) for different drought indices. From the results of meteorological indices the extreme drought occurs in 1974 with 434.19 mm, severe drought in 1987 with 489.50mm and 2002 with 546.93mm and moderate drought in 1985 with 620.84 mm. The most severe and extreme affected drought years were 1974, 1985, 1987 and 2002. Also, Near Normal dry conditions observed in the years 1979 ,1982, 1986, 1989, 1995, 1991, 1992, 1999, 2000, 2001 amongst 30 years. Also, Pearson's correlation coefficient matrix is developed for different indices and timescales and SPI-12 gives better correlation with RDI-12 (H" 0.997). The results of this study can aid policymakers in the development of drought mitigation strategies in the future. The obtained results may provide some scientific support for fighting against droughts.

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Mapping of agricultural drought using Remote Sensing and GIS in Sabarkantha district, North Gujarat, India

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Abstract

Drought is a climatic anomaly, characterized by deficient supply of moisture, resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of the entire factors. Satellite-based remote sensing techniques have been widely used to monitor droughts affected areas. Agriculture drought is mainly dependent on low rainfall which results in agricultural production. In recent years, Remote Sensing (RS) and Geographic Information System (GIS) have played a remarkable role in assessment of various types of hazards either natural or man-made. This paper emphasize upon the use of RS & GIS in the field of drought risk evaluation. The district is located between 23.8477° N and 72.9933° E longitudes. The study was conducted with satellite images of Landsat 8 data from 2013 to 2019 year. Various agricultural drought indices have been used to assess the intensity of agricultural drought and to detect drought affected areas using Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Vegetation Condition Index (VCI), Normalized Difference Builtup Index (NDBI), and Land Surface Temperature (LST). The results shows that NDVI decreased by 4% to 6% and NDWI decreased by 1% to 2% in the study area, while LST shows a significant increase by 0.35°C–2.5°C. This relationship revealed that when rainfall increases, NDVI, VCI also tends to decrease. Also there is increase in NDBI As a result, the occurrence of agricultural drought increased. From the VCI analysis as extreme, high and moderate drought areas respectively in the study area. This study suggests that the effect of drought could be reduced through involving the smallholder farmers in a wide range of on and off-farm practices. This study may help to improve the existing agricultural drought monitoring systems carried out in North Gujarat in general and Sabarkantha in particular.

Keywords: *Agricultural drought, remote sensing and GIS, Rainfall, NDVI, NDWI, NDBI, LST, VCI.*

1. Introduction

Drought is a natural event that occurs frequently or intermittently in almost any type of climate. It is generally the result of a natural decrease in precipitation over a period of time (Badaq Jamali et al. 2005). The drought phenomenon is recurrent in the study area that becomes the most vulnerable drought prone area of Bangladesh. Unfortunately, drought condition has received less attention and has less scientific research work compare to other calamities like flood or cyclone. The impact of drought can be much higher and can occur greater loss than flood, cyclone and storm surge (Alam et al., 2012).

Drought can be monitored effectively over large areas using remote sensing technology. Satellite-borne remote sensing data provides a synoptic view of Earth surface, and therefore can be used to evaluate drought occurrence spatially. Several remotely-sensed drought indices have been developed and applied, which include duration, intensity, severity, and spatial extent. Among those indices, the Normalized Difference Vegetation Index (NDVI) as a probe for vegetation health has been one of most commonly used approaches to drought events monitoring(Gu et al., 2007). To improve the approach, it has been advisable to combine vegetation index and temperature. A combined NDVI and land surface temperature (LST) provides strong correlation and gives useful information to identification of agricultural drought as an early warning system (Mishra et al, 2015).

Remote multispectral and hyperspectral measurements have been an imperative source of data for drought and vegetation dynamics assessment. Several multispectral vegetation indices (VIs) have been employed to appraise growing vegetation attributes in recent decades (Adam et al., 2010; Yang et al., 2012). RS and GIS are features of earth observation science and have contributed an advanced system for arranging, analyzing, manipulating and storing the information about the spatial components including drought and vegetation health. Hence, remotely sensed data and GIS techniques have been utilized in recent decade to monitor urban features as well as the environmental changes (Adefisan et al., 2015)

The impacts of drought have been assessed through the estimation of green vegetation in drought-affected areas either as long or short-term dryness using vegetation indices such as Normalized Difference Water Index (NDWI), Soil Adjusted Total Vegetation Index (SATVI), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST) and Normalized Drought Dryness Index (NDDI) in the prior research, particularly in an arid or semi-arid and mild Mediterranean ecosystem where vegetation is sporadic (Gu et al., 2007).

Land Surface Temperature (LST) is defined as the temperature at interface between the Earth’s surface and its atmosphere1. It is an important parameter in all physical processes of surface energy and water balance at local and global scales. LST is playing a key role in land surface processes, not only, because of having climatic importance, but also due to its control of the sensible and latent heat flux exchange (Niclòs et al. 2009, Brunsell et al, 2003).

Traditionally, Drought monitoring has been based on data gathered from local weather stations, which lack the spatial coverage needed for real time monitoring and classification of drought pattern (Ying et al., 2007). The rainfall along with temperature is used to determine the soil moisture condition, it is a key component for growth of the plant. Hence, Vegetation growth pattern change due to changes in rainfall and temperature. High temperature and low soil moisture increase water stress level, which is the primary reason of crop failure. Satellite based drought indicators are useful for identification of drought zone and its severity. The NDVI is a popular index used in worldwide for predication of drought (Keshri et al., 2009).

Several studies have developed drought indices and examined their capabilities in monitoring and characterizing agricultural drought, where rainfall was solely used as an early indicator McKee et al., 1993) while NDVI and LST were used to represent soil moisture stress. Agriculture sector is most affected by the onset of drought as it is highly reliable on the weather, climate, soil moisture etc. Agricultural drought is nothing but the decline in the productivity of crops due to irregularities in rainfall, increase in the temperature rate etc., which causes a decrease in the soil moisture. The role of remote sensing and GIS in agricultural drought detection, assessment and management is becoming crucial these days as they provide up to date information in different range of spatial and temporal scales which is hectic and time consuming when done by traditional methods such as Field Survey, and sampling questionnaires. (Arshad et al (2008), Hasan and Saiful, (2011))

2. Study area and data collection

The Sabarkantha district is the part of North Gujarat and lies between 23º 03' to 24º 30' N and 72º 43' to 73º 39' E and, covering an area of 7,259.60 km^2 which is shown in below figure 1. It is surrounded by Banaskantha and Mehsana districts in the west; Ahmedabad, Gandhinagar, Kheda and Panchmahals districts in the south and Sirohi, Udaipur and Dungarpur districts (Rajasthan) in the north and east. The climate of this district is characterized by a hot summer and dryness in the non-rainy seasons. The cold season from December to February is followed by the hot season from March to May. The south-west monsoon season is from June to September, the post monsoon season is from October and November. The annual rainfall varies between 214 mm to 1,625 mm. The annual average rainfall is 863.01 mm and average temperature is 26.97º C. The major river flowing through study area is River Ravi, which originates from the Himalayan region.

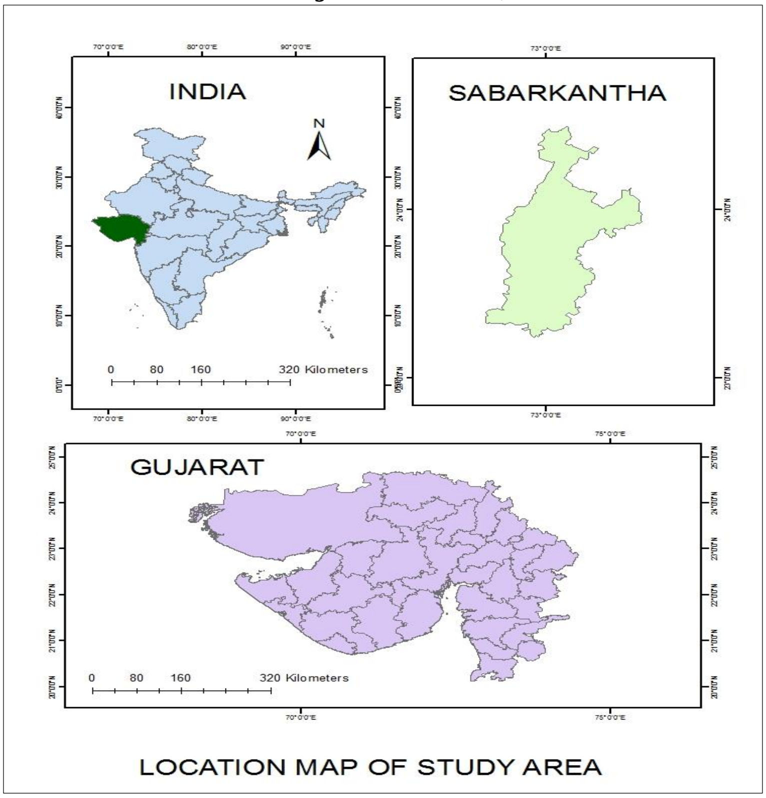


Figure 1: Location Map of Study Area

2.1 Methodology

For the current study, methodology representing the steps and flow of work is explained in the section below. Below Table 1 shows Landsat 8 band characteristics. Landsat 8 measures different ranges of frequencies along the electromagnetic spectrum – colour, although not necessarily a colour visible to the human eye. Each range is called a band, and Landsat 8 has 11 bands. Landsat numbers its red, green, and blue sensors as 4, 3, and 2. Landsat 8 view of the Los Angeles area, May 13th, 2013. The image is rotated so north is up. All image data courtesy of the U.S. Geological Survey.

Table 1: Landsat 8 Band Characteristics

Band No.	Description	Wavelength (mm)	Band No.	Description	Wavelength (mm)
1	Coastal Aerosol	0.430 - 0.450	6	SWIR 1	1.570 – 1.650
2	Blue	0.450 - 0.510	7	SWIR 2	2.110 – 2.290
3	Green	0.530 - 0.590	8	Panchromatic	0.500 – 0.680
4	Red	0.640 - 0.670	9	Cirrus	1.360 – 1.380
5	Near Infrared	0.850 - 0.880	10	TIRS 1	10.60 – 11.19
			11	TIRS 2	11.50 – 12.51

Normalised Difference Vegetation Index (NDVI)

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

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

Normalised Difference Water Index (NDWI)

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

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

Normalized Difference Built-up Index (NDBI)

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

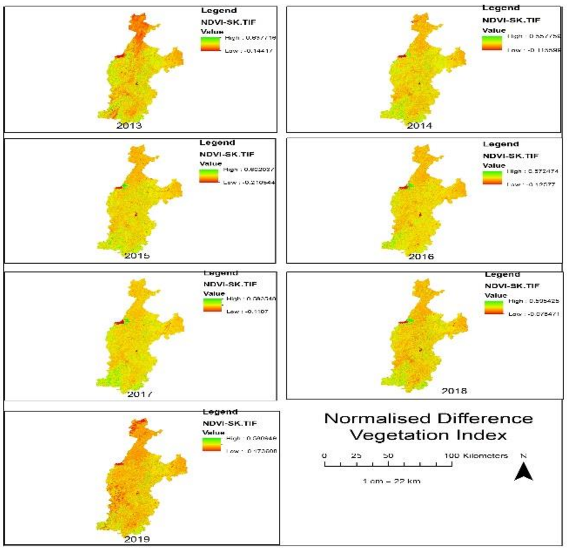
$$\mathrm{NDBI} = \frac{(\mathrm{SWIR} - \mathrm{NIR})}{(\mathrm{SWIR} + \mathrm{NIR})}$$

Vegetation Condition Index (VCI)

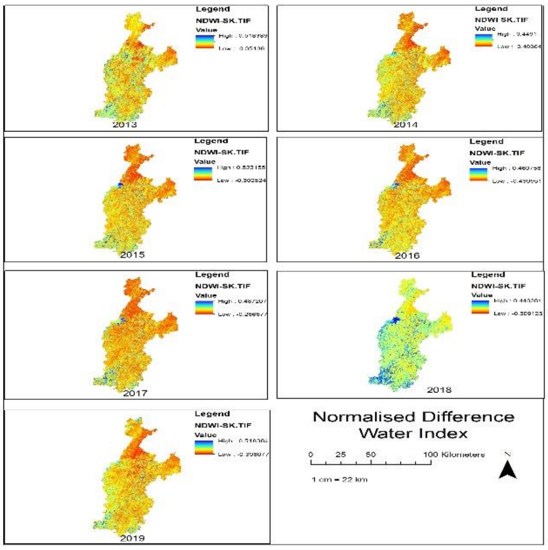
VCI is a widely used algorithm for estimating vegetation condition based on NDVI min and max value. The VCI is expressed in percentage (%) and gives an idea where the observed value is situated between the extreme values (minimum and maximum) in the previous years. The below equation was used to calculate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

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

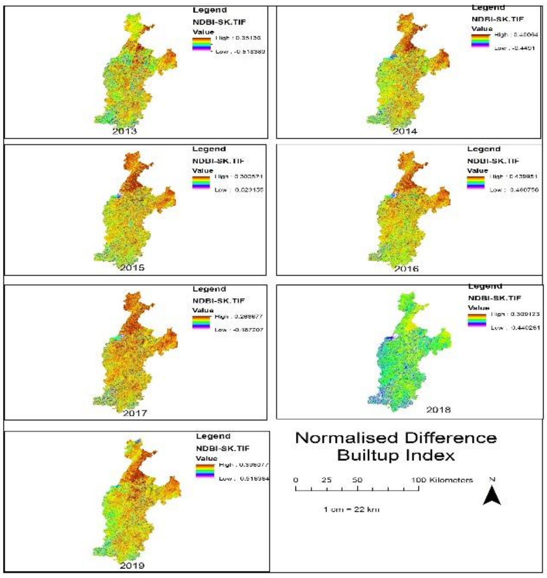
3. Results and Analysis



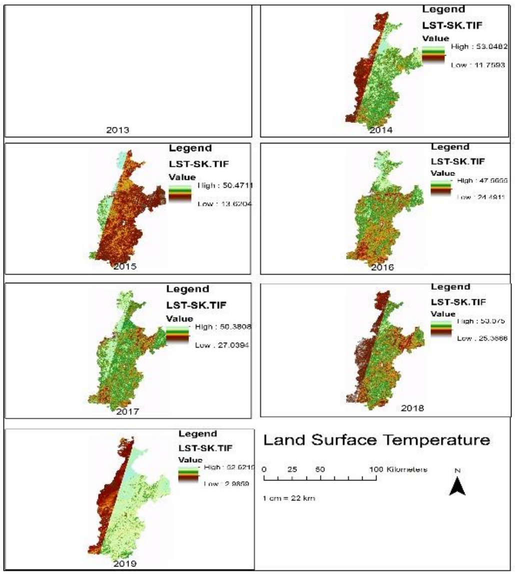
(a) Normalised Difference Vegetation Index



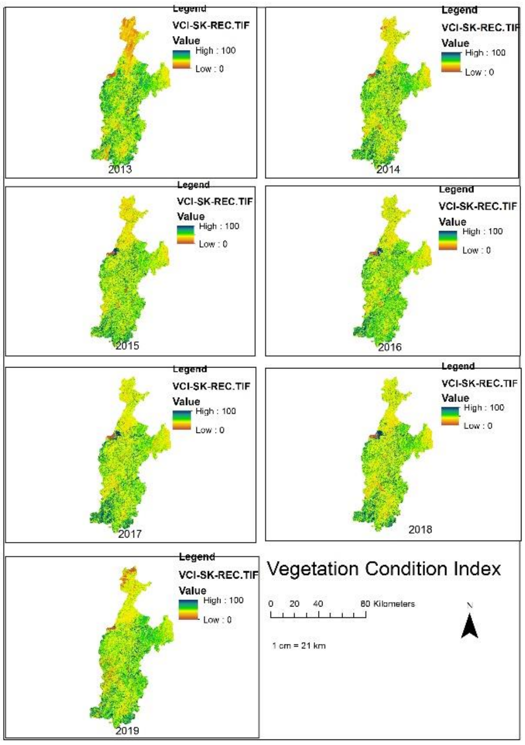
(b) Normalised Difference Water Index



(c) Normalised Difference Builtup Index



(d) Land Surface Temperature



(e)Vegetation Condition Index

Figure 2: Maps of Agriculture Drought Indices

Long term sequence of Landsat data were used in the present study to monitor drought extent in Sabarkantha district from 2013 to 2019. NDVI has become the main tool to describe vegetation phenology, which high NDVI values show healthy and dense vegetation. The values of NDVI were difficult to obtain because of fluctuations of vegetation responses each month. Generally, high values of NDVI were recorded in wet seasons, while lowest values were in dry seasons. The diversity in NDVI indicates spatial variation in vegetation health within the study areas are presented in Fig. 2(a). The NDWI results reveal that the areas with low NDWI values are susceptible to drought severity while the areas with high NDWI means little or no drought occurrence as asserted by previous investigations which is presented in Fig. 2(b). Similarly, Builtup index is also evaluated using Band (5 and 6) which is shown in Fig. 2(c).

According to the image statistics, Maximum NDVI value was decreased from year 2013 to 2019 while minimum NDVI value was increased slightly. However the mean NDVI value was decreased from 2013 to 2019.Therefore it express the greenness of the vegetation was decreased during study period.

In year 2018, average rainfall in Sabarkantha district is only 427.15 mm due to which vegetation in the study area decreased drastically compare with the previous years. Also, the Land Surface Temperature in 2018 year lowest compare to other years which is shown in below Table 2. Similarly, in the year 2017, average rainfall in district is 912.30 mm where vegetation area is increases and LST is showing same trend as LST and NVI is highly correlated with each other and with rainfall.

Land features characteristics for 2018 revealed changes in land use dynamics with the percentage of the area covered for each feature for the year. There exists increased in builtup area which is around 4% in last seven years (from 85% to 89%).

Table 2: Obtain Values for LST and NDVI

	2013	2014	2015	2016	2017	2018	2019
LST min	22.81	11.75	13.62	24.59	27.03	25.36	13.78
LST max	44.08	43.04	47.50	47.56	48.05	43.07	42.62
NDVI min	-0.1447	-0.1155	-0.2105	-0.1257	-0.1107	-0.0784	-0.1736
NDVI max	0.6337	0.5577	0.6020	0.5724	0.5925	0.5954	0.5809
NDVI Avg	0.1965	0.2070	0.2093	0.1962	0.2010	0.2061	0.1869

The summary of the characteristics from the seven years of drought assessments is presented in this study. The Computed value of LST max & LST min as presented in Table 2 to assess the drought occurrence in the study area between the years 2013 and 2019. Monthly records during dry season in 2016 and 2017 showed the highest temperatures, which were over 47°C, while the lowest temperatures were recorded in 2018.

Values of VCI range from 0 to 100, revealing the stress of reduced water availability, and temperature increases upon vegetation during dry season (the smaller the values are, the greater the stress upon vegetation health is). The VCI maps were categorized simply into seven levels of drought severity, from no drought to extreme (green to red, respectively) which is shown in below Table 3 and 4. Also, same shown in above fig. 2(e). The rate of increasing the area of moderately and highly stressed are very high.

Table 3: Classification of Vegetation Condition Index

	Vegetation Condition Index						
Classification	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
1 ED	21.09	24.80	23.32	23.34	27.82	28.80	16.86
2 SD	341.19	51.62	29.79	19.99	35.57	112.29	151.51
3 MD	2269.07	1998.75	1443.87	1145.29	1989.08	2397.88	1965.74
4 NN	1106.36	1446.96	1959.50	2281.74	1467.29	1022.97	1607.37
5 MW	343.94	422.22	474.89	495.73	371.69	349.77	295.90
6 SW	98.16	181.73	189.89	155.35	194.03	189.28	110.89
7 EW	8.69	62.44	67.25	67.09	103.03	87.53	40.25
Total Km^2 Area	**4188.48**	**4188.48**	**4188.48**	**4188.48**	**4188.48**	**4188.48**	**4188.48**

Table 4: Percentage Area of Vegetation Condition Index

	Percentage Area of Vegetation Condition Index						
Classification	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
1 ED	0.504	0.592	0.557	0.557	0.664	0.687	0.402
2 SD	8.147	1.233	0.711	0.477	0.849	2.681	3.618

3 MD	54.18	47.72	34.47	27.34	47.49	57.25	46.93
4 NN	26.41	34.55	46.78	54.48	35.03	24.42	38.38
5 MW	8.21	10.08	11.33	11.83	8.87	8.35	7.06
6 SW	2.34	4.33	4.53	3.70	4.63	4.52	2.64
7 EW	0.206	1.483	1.599	1.599	2.455	2.083	0.955
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

4. Conclusions

The data analysed here result is focused on April-May month because southwest monsoon mainly starts from July to September is the main time period for agriculture and at the end of season if the area is suffering from drought it means the entire area will be affected by dry condition. It is also found that in the year 2013 and 2018 more than 60% of area is under dry condition. The results shows that NDVI decreased by 4% to 6% and NDWI decreased by 1% to 2% in the study area, while LST shows a significant increase by 0.35°C–2.5°C. Similarly, built up area is increased by 4% during study period. The maximum LST observed in each season was 28, 40 and 38° C respectively. Land features characteristics for 2018 revealed changes in land use dynamics with the percentage of the area covered for each feature for the year. There exists increased in builtup area which is around 4% in last seven years (from 85% to 89%). The strong positive correlation found between LST and NDBI means more be the built-up area high is the surface temperature. This study suggests that the effect of drought could be reduced through involving the smallholder farmers in a wide range of on and off-farm practices. This study may help to improve the existing agricultural drought monitoring systems carried out in North Gujarat in general and Sabarkantha in particular.

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Dry and Wet Period Analysis using Meteorological Drought Indices in Sabarkantha district Gujarat, India

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Abstract

Drought assessment is very important to manage water resources in lean period. In the present study, identification of drought years and extent of deficit of annual rainfall is accomplished by use of three meteorological based drought indices like the Standardized Precipitation Evapotranspiration index (SPEI), China-Z index (CZI) and Modified China-Z index (MCZI) on 1, 3, 6, 9 and 12 month (short term and long term) timescales using monthly precipitation and temperature data from 1901 to 2002 at Sabarkantha to specify the drought conditions in present study area. The analysis of multiple time steps in drought indices make it harder to decide the best time step to show the drought conditions. The months of January, March, November and December have been identified 76, 79, 77 and 80 times as drought months respectively in the 20^{th} century, indicating that these months must be provided with assured Irrigation. It is observed that 1904, 1911, 1915, 1923, 1974, 1987 and 2002 affected by severe drought condition in SPEI-12. The China Z Index and Modified China Z index shows that's 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995 and 2002 affected by extreme drought. The study also reveals that only 1% year obtain as extreme wet conditions. From result it shows that 23% years are categorised into moderate to extreme drought years, which includes 15% Moderate dry, 8% severe dry years.

Keywords: ***Drought analysis, Drought months, Standardized precipitation evapotranspiration Index, China Z- index, Modified China Z-index, Dry and Wet Percentage.***

1. INTRODUCTION

Floods and droughts are the two important aspects of hydrological hazard. Floods usually result either from heavy precipitation (rain or snow) or from rapid snowmelt or glacier discharge. Droughts are caused by dry weather conditions in which evaporation exceeds the available surface water. They are frequently characterized by water shortages. Understanding the causes and forecasting of heavy or scant precipitation and high evaporative demand (and hence of floods and droughts) form an important objective of any climate research scenario. These two types of extreme hydrological events are important to understand the climate.

Mistry and Suryanarayana (2019) studied drought scenario using precipitation indices in Banaskantha district. Patel et al. (2017) calculated SPI for 4, 6, 12, 24 and 48 months' time scales in Surat District. The area experienced more than 20% years of dry and wet events for the 20th Century. It is observed that the years 1942, 1945 and 1959 are identified as severe wet events for the time scale considered. McKee et al. (1993) developed the Standardized Precipitation Index (SPI) to monitor the status of drought in Colorado. Ju et al. (1997) introduced China-Z Index (CZI) drought index to the National Meteorological Centre of China (NMCC) in the early 1990s. Wu et al. (2001) evaluated the SPI, CZI and ZSI on 1-, 3-, 6-, 9- and 12-month time scales using monthly precipitation totals for four locations in China and concluded that SPI, CZI, and ZSI were all useful for defining, detecting, and monitoring droughts.

Vicente-Serrano et al. (2012) compared SPEI, PDSI and SPI at the global scale for the 1901-2009 period and reported that the SPEI had better capability in identifying drought conditions and suggested its use if the drought variables for drought assessment are not a prior known. Morid et al. (2006) compared seven indices, viz., EDI, SPI, PDN, DI, Z-index, China- Z index (CZI) and modified CZI (MCZI) for six stations representing different climates in Teheran province, Iran. Redmond (2002), Smakhtin and Hughes (2007) examines a drought index suitable for one region may not be applied specifically for other regions due to the inherent complexity of drought phenomena, difference in hydro-climatic conditions and watershed characteristics). Therefore, several researchers across the globe have compared different drought indices with an aim of finding suitable drought index for a particular region or basin.

2. STUDY AREA AND DATA COLLECTION

The Sabarkantha district is the part of North Gujarat and lies between 23º 03' to 24º 30' N and 72º 43' to 73º 39' E and, covering an area of 7,259.60 km^2 which is shown below in figure 1. It is surrounded by Banaskantha and Mehsana districts in the west; Ahmedabad, Gandhinagar, Kheda and Panchmahals districts in the south and Sirohi, Udaipur and Dungarpur districts (Rajasthan) in the north and east. The climate of this district is characterized by a hot summer and dryness in the non-rainy seasons. The cold season from December to February is followed by the hot season from March to May. The south-west monsoon season is from June to

September, the post monsoon season is from October and November. The annual rainfall varies between 214 mm to 1,801 mm. The annual average rainfall is 863.01 mm and average temperature is 26.97° C. For the analysis of drought monitoring, precipitation, maximum temperature, minimum temperature data has been collected for 102 years (i.e., 1901 to 2002) from Indian Meteorological Department (IMD), Pune.

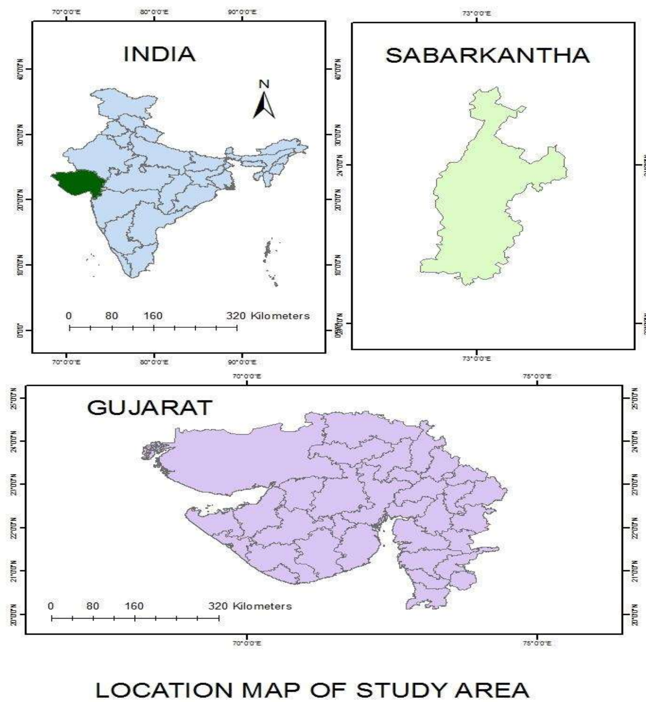

Figure 1: Location Map of Study Area

3. METHODOLOGY

Standardised Precipitation Evapotranspiration Index

The standardised 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 (Vicente-Serrano et al. 2010) is another meteorological drought index that considers the variability of both precipitation and temperature to predict drought conditions in a region. The index has been used in the variety of drought analyzing studios recently (Jiang et al. 2015; Jin et al. 2019; Wang et al. 2019). The first step to calculate the SPEI is the estimation of monthly potential evapotranspiration (PET). Then, the water balance equation is used to calculate the monthly deficit (Di).

$$D_i = P_i - PET_i$$

Where Pi is the total precipitation value at the month i. Finally, the evolved deficit values are standardized and fitted to a log-logistic distribution function. The SPEI value at the month i is the standardized values of the exceeding probability (p) of a given Di and is calculated by Eq.

$$\mathrm{SPEI_i} = \mathrm{W_i} - \frac{2.515517 + 0.802853\mathrm{W_i} + 0.010328\mathrm{W_i^2}}{1 + 1.432788\mathrm{W_i} + 0.189269\mathrm{W_i^2} + 0.001308\mathrm{W_i^3}}$$

While for P≤0.5, $W_i = \sqrt{-2lnp}$ while, if P>0.5, $W_i = \sqrt{-2\ln(1-p)}$, and the sign of the resultant SPEI is reversed for P > 0.5

In this study, SPEI package developed by Beguería and Vicente-Serrano (2013) available in R (R Development Core Team 2011) is used and fitted the data to the log-logistic distribution. It is worthy to mention that the log-logistic model was suggested by Vicente-Serrano et al. (2010) in the original SPEI methodology.

CZI (China-Z Index) and MCZI (Modified CZI)

The National Climate Center of China developed the CZI in 1995 as an alternative to the SPI (Ju et al., 1997). The CZI is calculated as:

$$\mathrm{CZI_{ij}} = \frac{6}{\mathrm{C_{si}}}\left(\frac{\mathrm{C_{si}}}{2} * \varphi_{ij} + 1\right)^{\left(\frac{1}{3}\right)} - \frac{6}{\mathrm{C_{si}}} + \frac{\mathrm{C_{si}}}{6}$$

Where, i is the time scale of interest and j is the current month; CZI_{ij} means the CZI's amount of the current month (j) for period i; C_{si} is the coefficient of skewness; and φ_{ij} is the standardized variation. Furthermore, the MCZI can also be calculated using the formula above but substituting the median precipitation for mean precipitation. The classification of dryness and wetness is shown in below Table 1.

Table 1. Classes of dryness/wetness grade according to SPEI, CZI and MCZI values.

Class	**Range**
Extreme dry	≤ -2.0
Severe dry	-1.5 to -1.99
Moderate dry	-1.0 to -1.49
Near normal	0.99 to -0.99
Moderate wet	1.0 to 1.49
Very wet	1.5 to 1.99
Extreme wet	≥ 2.0

4. Results and Analysis

The statistical parameters of the rainfall data for Sabarkantha for 102 years were analysed and are given in Table 2, which indicates that there are high fluctuations in occurrence of rain ranging from maximum rainfall 1490.45mm in1944 and minimum rainfall 304.63 mm in 1915 in the study area.

Table 2: Seasonal Rainfall in mm for Sabarkantha district

Rainfall parameters	June	July	August	Sept	Winter (Jan-Feb)	Pre-monsoon (March to May)	SW monsoon (June to Sept)
Mean Rainfall	98.61	320.35	231.97	124.55	1.97	4.60	193.87
Standard Deviation	76.71	147.76	137.55	123.53	1.11	5.59	102.19

The monthly analysis of rainfall for Sabarkantha district is given in Table 3. The same is based on assumption that a month is with drought when the rainfall for the month is less than half of the average rainfall for this month. The percentage of drought in a month was calculated as (number of drought months for a particular month/ total number of drought months) multiplied by 100 viz for January, the percentage of drought month is equal to 11.18 %. Also, 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. The months of March, November and December have 79, 77 and 80 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 09 and 13 respectively.

Table 3: Drought Analysis based on Monthly Rainfall for Sabarkantha district

Year	Average Rainfall, mm	Half of Average Rainfall	No. of Drought Months	Percentage of Drought Months
Jan	2.76	1.38	76	11.18
Feb	1.18	0.59	72	10.59
Mar	1.13	0.56	79	11.62
Apr	1.62	0.81	70	10.29
May	11.06	5.53	64	9.41
Jun	98.61	49.31	34	5.00
Jul	320.35	160.18	13	1.91
Aug	231.98	115.99	9	1.32
Sep	124.56	62.28	43	6.32
Oct	11.74	5.87	63	9.26
Nov	5.96	2.98	77	11.32
Dec	1.89	0.94	80	11.76
Total number of Drought Months			680	100%

Also, SPEI time series calculations are developed using SPEI Package (Beguería and Vicente-Serrano 2017) in R environment. The monthly PET is estimated using Thornthwaite method. Below Figure 2,3,4 and 5 shows the SPEI, CZI and MCZI drought indices for various time series at 3-, 6-, 9- and 12-month timescales which is calculated using rainfall and temperature measurements in the period 1901–2002 in Sabarkantha district. Figure 6 shows that the frequency of different drought events is not identical always. For an example, while the SPEI-3 pattern shows not a single year falls under extreme drought similar results identified for CZI-3 and MCZI-3 during the study period.

The CZI and MCZI uses solely precipitation whereas the SPEI is based on both precipitation and temperature. Hence, it must be considered before making any decision. Considering the location of stations, it is obvious that the North Gujarat of India is more vulnerable to the long-term droughts. Since the degree of significance of SPEI-12 patterns and their acceleration rates are smaller than the CZI and MCZI, it is concluded that the temperature, slowly but surely, affects the drought patterns in the region. This can be an early warning for future droughts as the temperature rises or precipitation occurs less frequently. Through comparing MCZI and CZI indices, we found that MCZI represented the range of wet years better than CZI, while CZI represented the dry years better than MCZI.

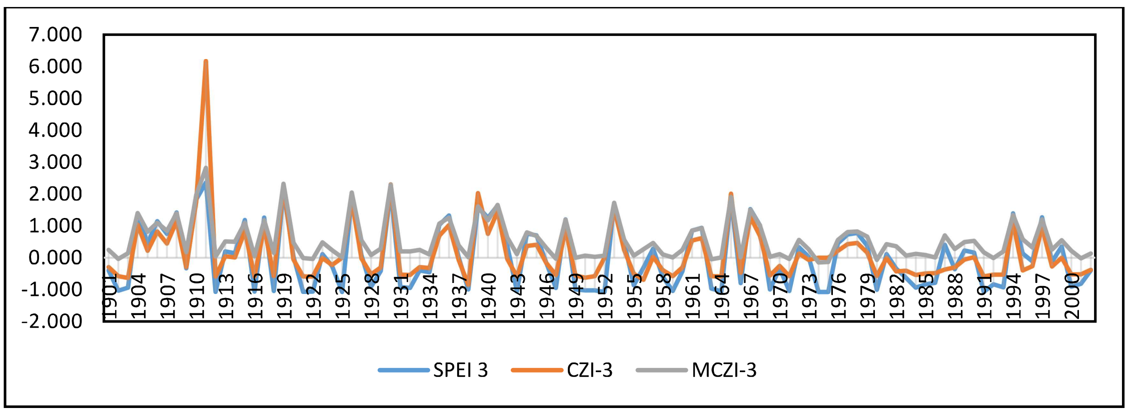

Figure 2: Comparisons of SPEI, CZI and MCZI for 3 Month Time Scale

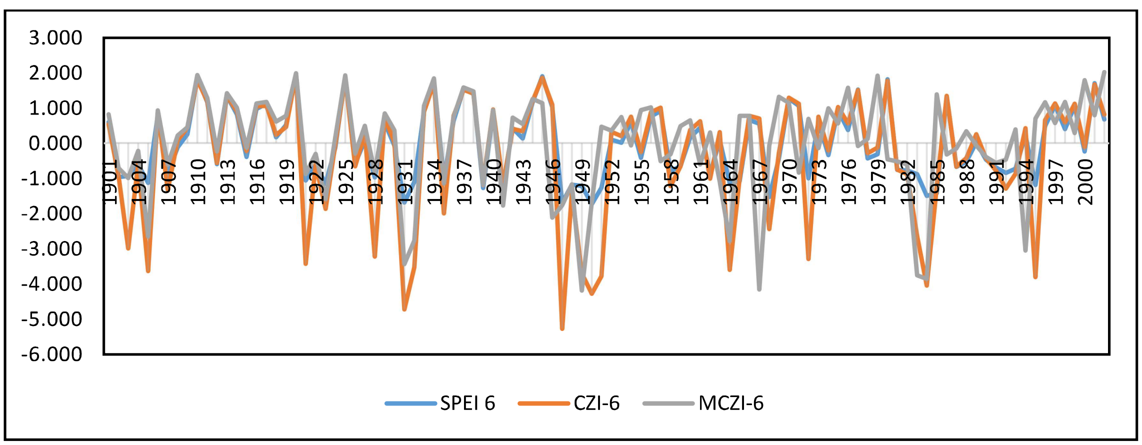

Figure 3: Comparisons of SPEI, CZI and MCZI for 6 Month Time Scale

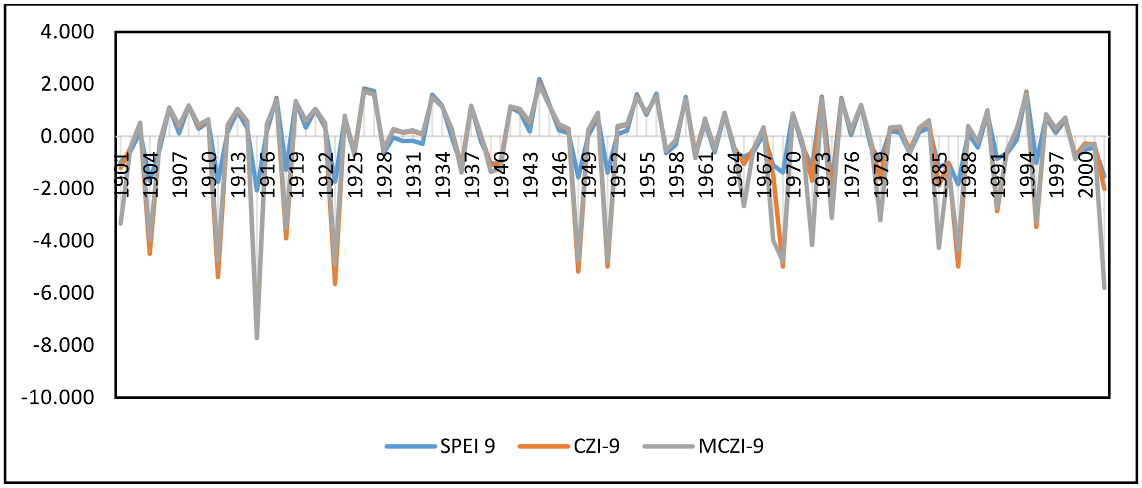

Figure 4: Comparisons of SPEI, CZI and MCZI for 9 Month Time Scale

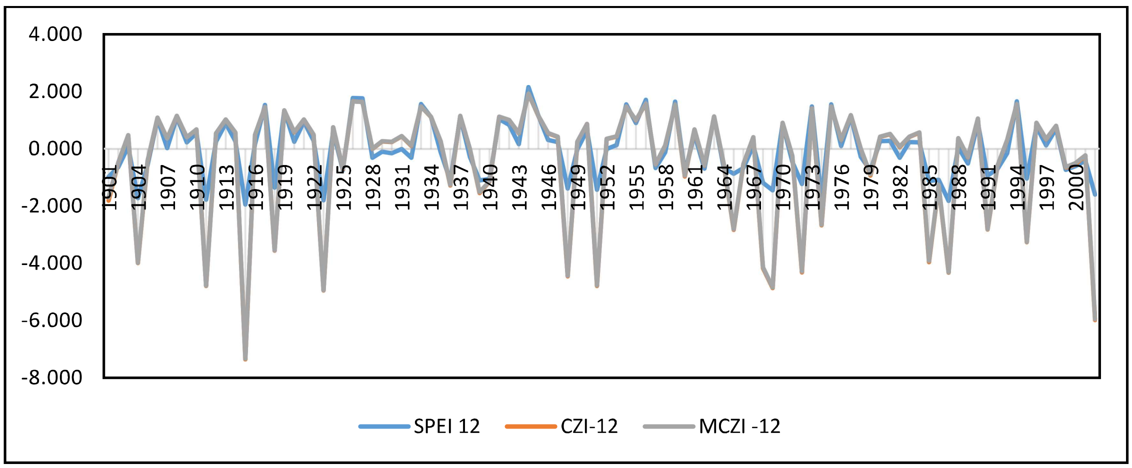

Figure 5: Comparisons of SPEI, CZI and MCZI for 12 Month Time Scale

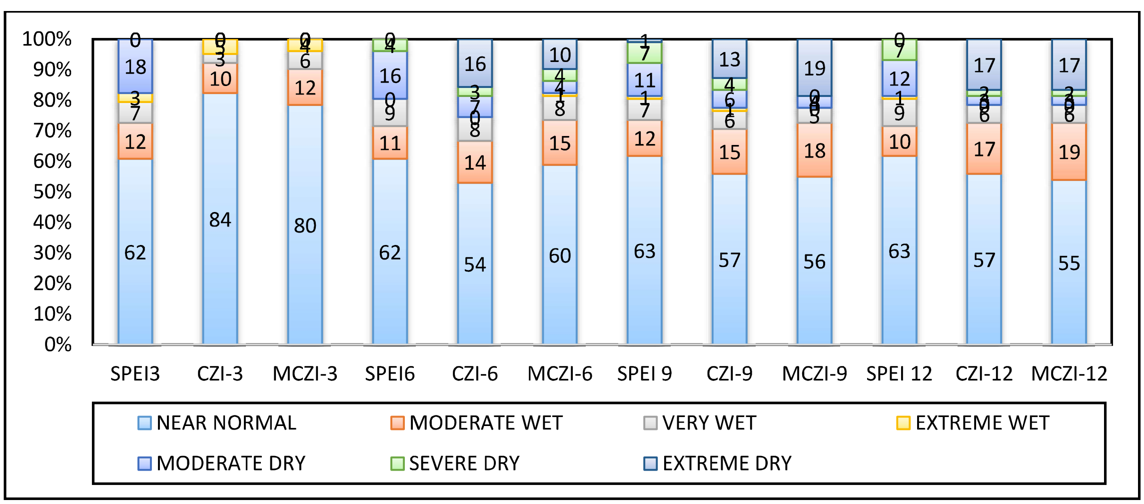

Figure 6: Drought Frequency as per Various Indices for Different Time Scales

The annual average rainfall of Sabarkantha district is 812.83mm for 102 years.SPEI 12 index shows severe dry years as 1904, 1911, 1915, 1923, 1974, 1987, 2002 with annual rainfall 352.89 mm. while moderate dry years as 1918, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1985, 1986, 1995 with annual rainfall 507.89 mm. Similarly, CZI 12 and MCZI 12 index extreme dry years as 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995, 2002 with average rainfall 445.31 mm and severe dry year as 1901, 1939 with average annual rainfall 551.11 mm.

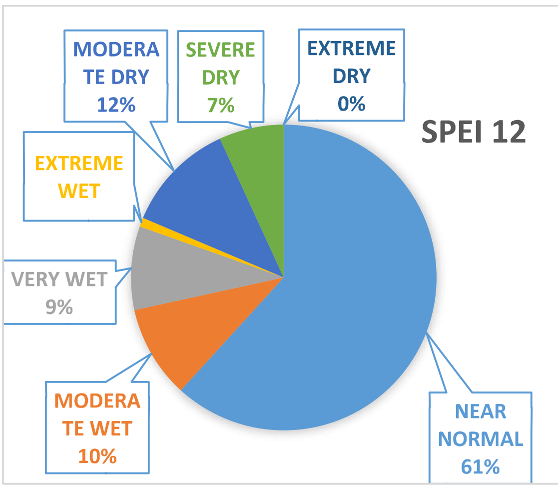

Figure 7: Distribution of Wet and Dry Periods as per SPEI 12

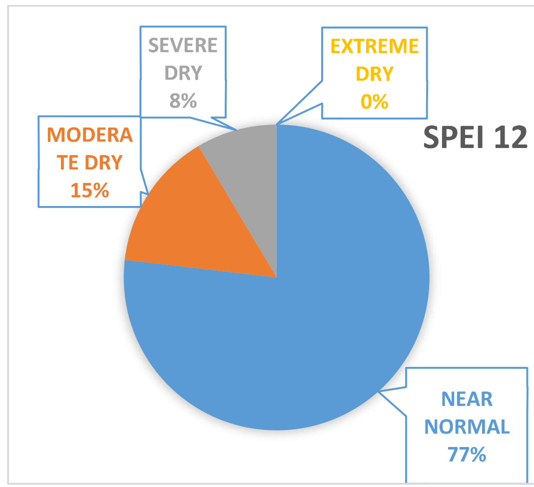

Figure 8: Frequency of Drought conditions as per SPEI 12

Figure 7 shows distribution of wet and dry periods of SPEI 12 indicator, whereas Figure 8 shows only frequency of drought years. From the Figure 7, it is shown that only 1% year is obtained as the extreme wet conditions in the last 102 years, because the average annual rainfall of Sabarkantha is only 790 mm. From the Figure 8, it reveals that out of the drought years, 23% years are categorised into moderate to extreme drought years, which includes 15% Moderate dry, 8% severe dry years.

5. CONCLUSIONS

The highest average rainfall in Sabarkantha 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 time period of 102 years. The months of March, November and December have 79, 77 and 80 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 09 and 13 respectively. From the results and analysis of SPEI, CZI and MCZI it was concluded that Severe dry years as 1904, 1911, 1915, 1923, 1974, 1987, 2002 and Moderate dry years as 1918, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1985, 1986, 1995. It is shown that only 1% year is obtained as the extreme wet conditions in the last 102 years, because the average annual rainfall of Sabarkantha is only 790 mm. It also reveals that out of the drought years, 23% years are categorised into moderate to extreme drought years, which includes 15% Moderate dry, 8% severe dry years. Overall, the SPEI is more suitable than the CZI and MCZI for applications examining characteristics of climate change and drought variation in present area because it considers both precipitation and evapotranspiration data. This study was limited to historical meteorological drought indices. The findings would be more beneficial if hydrologic, agricultural, and socioeconomic droughts are considered in future studies.

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ASSESSMENT & MONITORING OF AGRICULTURAL DROUGHT INDICES USING REMOTE SENSING TECHNIQUES AND THEIR INTER-COMPARISON

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ABSTRACT

Agricultural drought is nothing but the decline in the productivity of crops due to irregularities in the rainfall as well as decrease in the soil moisture, which in turn affects the economy of the nation. As the Indian agriculture is largely dependent on the Monsoon, a slight change in it affects the production as well as the crop yield drastically. The agricultural drought monitoring, assessment as well as management can be done more accurately with the help of geospatial techniques like Remote Sensing. In present study agriculture drought is estimated in vadodara district. The purpose of the study is to analyze the vegetation stress in the Vadodara district with the calculation of NDVI, NDWI, MNDWI, WRI, NDBI and NDSI indices values. The results of NDVI values shows agricultural fields more susceptible to drought. Similarly, decreasing trend was observed in NDWI index which is 22.12% to 19.3% from 2013 to 2018.The builtup index (NDBI) is increasing by 1.85% in last 5 years. The Water ratio index is also showing decreasing trend in study area by 22.35% to 14.29%. The intercomparisions of NDVI and all other indices with rainfall data provides very useful information for agricultural drought monitoring and early warning system for the farmers. The findings of this research will be of interest to local agriculture authorities, like plantation and meteorology departments to understand drier areas in the state to evaluate water deficits severity and cloud seeding points during drought.

Key words: Agricultural drought Indices, NDVI, NDWI, MNDWI, WRI and NDBI.

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1. INTRODUCTION

Drought is a natural event that occurs frequently or intermittently in almost any type of climate. It is generally the result of a natural decrease in precipitation over a period of time (Badaq Jamali et al. 2005). The drought phenomenon is recurrent in the study area that becomes the most vulnerable drought prone area of Bangladesh. Unfortunately, drought condition has received less attention and has less scientific research work compare to other calamities like flood or cyclone. The impact of drought can be much higher and can occur greater loss than flood, cyclone and storm surge (Alam et al., 2012).

Drought can be monitored effectively over large areas using remote sensing technology. Satellite-borne remote sensing data provides a synoptic view of Earth surface, and therefore can be used to evaluate drought occurrence spatially. Several remotely-sensed drought indices have been developed and applied, which include duration, intensity, severity, and spatial extent. Among those indices, the Normalized Difference Vegetation Index (NDVI) as a probe for vegetation health has been one of most commonly used approaches to drought events monitoring (Gu et al., 2007).

Remote multispectral and hyperspectral measurements have been an imperative source of data for drought and vegetation dynamics assessment. Several multispectral vegetation indices (VIs) have been employed to appraise growing vegetation attributes in recent decades (Adam et al., 2010; Yang et al., 2012). RS and GIS are features of earth observation science and have contributed an advanced system for arranging, analyzing, manipulating and storing the information about the spatial components including drought and vegetation health. Hence, remotely sensed data and GIS techniques have been utilized in recent decade to monitor urban features as well as the environmental changes (Adefisan et al., 2015)

The impacts of drought have been assessed through the estimation of green vegetation in drought-affected areas either as long or short-term dryness using vegetation indices such as Normalized Difference Water Index (NDWI), Soil Adjusted Total Vegetation Index (SATVI), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST) and Normalized Drought Dryness Index (NDDI) in the prior research, particularly in an arid or semi-arid and mild Mediterranean ecosystem where vegetation is sporadic (Gu et al., 2007).

There are many other remote-sensing-based drought indices which used for drought assessment, e.g. NDWI (Normalised Difference Water Index), VCI (Vegetation Condition Index), and VHI (Vegetation Condition Index). This research aims to compare these indices to understand the differentiation between each index, and its application for monitoring drought in vadodara district.

1.1 Objectives of the Present Study

The specific objectives of this study are to: Calculating and mapping of Normalize Difference Vegetation Index, Normalised Difference Water Index, Water Ratio Index, Normalised Difference Builtup Index, Normalised Difference Salinity Index and Soil Adjusted vegetation Index using Landsat 8 satellite image; and analyze the changes between these indices for the year of 2013 to 2018 in Vadodara district.

2. STUDY AREA AND DATA COLLECTION

The present study area is the Vadodara District in the Gujarat State of India. Total geographical Area of the district is 420 Sq. Kms. The Vadodara lies between 22°30’North, 73°19’East.The study Area is located 39 m above the Mean sea level. The important soil types encountered in the area

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can be broadly categorized into Loamy and clay soil. Climate condition is summer period of March, April, May, May and June reaching a maximum temperature of up to 46°C. The temperatures drop in December and the low temperatures continue up to February, touching a minimum of 13°C in January. Vadodara has an average annual rainfall of 750 to about 900 mm. This study focus on the agricultural drought assessment in Vadodara district using Landsat 8 data. Through the analysis different agricultural indices vegetation stress, percentage of water and percentage of builtup index is calculated.

3. METHODOLOGY

For the current study, methodology representing the steps and flow of work is explained in the section below. Below Table 1 shows Landsat 8 band characteristics. Landsat 8 measures different ranges of frequencies along the electromagnetic spectrum – colour, although not necessarily a colour visible to the human eye. Each range is called a band, and Landsat 8 has 11 bands. Landsat numbers its red, green, and blue sensors as 4, 3, and 2. Landsat 8 view of the Los Angeles area, May 13th, 2013. The image is rotated so north is up. All image data courtesy of the U.S. Geological Survey.

Table 1: Landsat 8 Band Characteristics

Band No.	**Description**	**Wavelength (mm)**	**Band No.**	**Description**	**Wavelength (mm)**
1	Coastal Aerosol	0.430 - 0.450	6	SWIR 1	1.570 – 1.650
2	Blue	0.450 - 0.510	7	SWIR 2	2.110 – 2.290
3	Green	0.530 - 0.590	8	Panchromatic	0.500 – 0.680
4	Red	0.640 - 0.670	9	Cirrus	1.360 – 1.380
5	Near Infrared	0.850 - 0.880	10	TIRS 1	10.60 – 11.19
			11	TIRS 2	11.50 – 12.51

In the present scenario, various bands were used for drought assessment and for each method offers its advantages and disadvantages. Following are some of the proposed methods to extract water bodies and estimation of vegetation stress and changes in builtup area which are considered in this study. For the current study, methodology representing the steps and flow of work is explained in the section below.

NDVI

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

NDWI

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

NDWI proved to work well in separating water body and vegetation but has limitations when it comes to soil and built up area.

MNDWI

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

NDBI

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

4. RESULT AND ANALYSIS

Multi-temporal and multi-resolution remote sensing images can provide basic data for analyzing urban spatial information and thermal environment effectively. The present study analyses the potential of LANDSAT-8 in mapping different agricultural drought indices and interprets their relationship with NDVI, NDWI, MNDWI and NDBI using ArcGIS software.

The Normalized Difference Vegetation Index (NDVI) is a Landsat derived vegetation indicator obtained from the red band and near-infrared (NIR) band ratio of vegetation reflectance in the electromagnetic radiation. Theoretically, NDVI threshold value ranges between -1 to +1. When the temperature is greater, the NDVI value is lesser which points out the decrease in the vegetation density. The decrease in soil moisture due to lack or untimely onset of rainfall along with the increased temperature causes the agricultural drought to be severe.

In the present study area, NDVI value ranges from between -0.14 to 0.58, average NDVI value is 0.23. Contrary to this, in the Normalized Difference Salinity Index (NDSI), the sand particles have higher reflectance in red band and lesser in near infrared band, so the NDSI value ranges between -0.58 to 0.15 which is also shown in below Table 2. Owing to higher NDSI value, of the area, scanty or low vegetation cover is observed. Hence, a low NDVI has been observed.

Similarly, NDWI was used in this analysis to assess the reflection of water content in the soil and on plant surfaces. The NDWI unit has no dimensions and ranges between -1 and +1 depending on the amount of surface water present. A higher NDWI value indicates a high-water content in the plant. Low NDWI values indicate low vegetation water content and thus the NDWI rate decreases during periods of water stress. As precipitation increases, the NDWI value increases. The average NDWI value representing the water content of vegetation decreases numerically, 0.41, 0.39, 0.43, 0.42 and 0.41 for the given area from 2013 to 2018.

The results of NDBI have shown the maximum surface temperature in Built-Up areas. Therefore, it have been predicted that built-up areas or urbanization is a inducing much surface temperature variations. The average value of NDBI is 0.53, 0.58, and 0.60 which is increasing year to years so builtup area of present study region is also increasing by 1% to 1.85% during study period.

According to obtained NDVI value for the year, (Fig. 3) a total of 262.29 km^2 area had NIL vegetation, whereas scanty and low vegetation was found in 1296 km^2 and 1375 km^2 of area respectively. Generally, a declining trend was observed during 2013 to 2014 and then the trend was increasing in the area. By computing the values of NDVI and other indices of each month for the years 2013 to 2018 in a line graph, The Figures represents the line graph obtained for average rainfall and average value of all vegetation indices over study period.

Table 2: Comparisons of Average Values Drought Indices

			2013	**2014**	**2016**	**2017**	**2018**
1	NDVI	Minimum	-0.1448	-0.2079	-0.1513	-0.1685	-0.1716
		Maximum	05833	0.5413	0.5562	0.5749	0.5842
2	NDWI	Minimum	-0.5316	-0.5881	-0.6085	-0.5174	-0.5765
		Maximum	0.4160	0.3997	0.4306	0.4288	0.4134
3	MNDWI	Minimum	-0.6868	-0.7113	-0.7448	-0.6400	-0.7232
		Maximum	0.2543	0.2802	0.2503	0.2942	0.2404
4	NDBI	Minimum	-0.4160	-03990	-0.4306	-0.4288	-0.4103
		Maximum	0.5316	0.5881	0.6085	0.5174	0.5234
5	NDSI	Minimum	-0.5833	-0.5413	-0.5562	-0.5749	-0.5842
		Maximum	0.1448	0.2079	0.1513	0.1685	0.1716

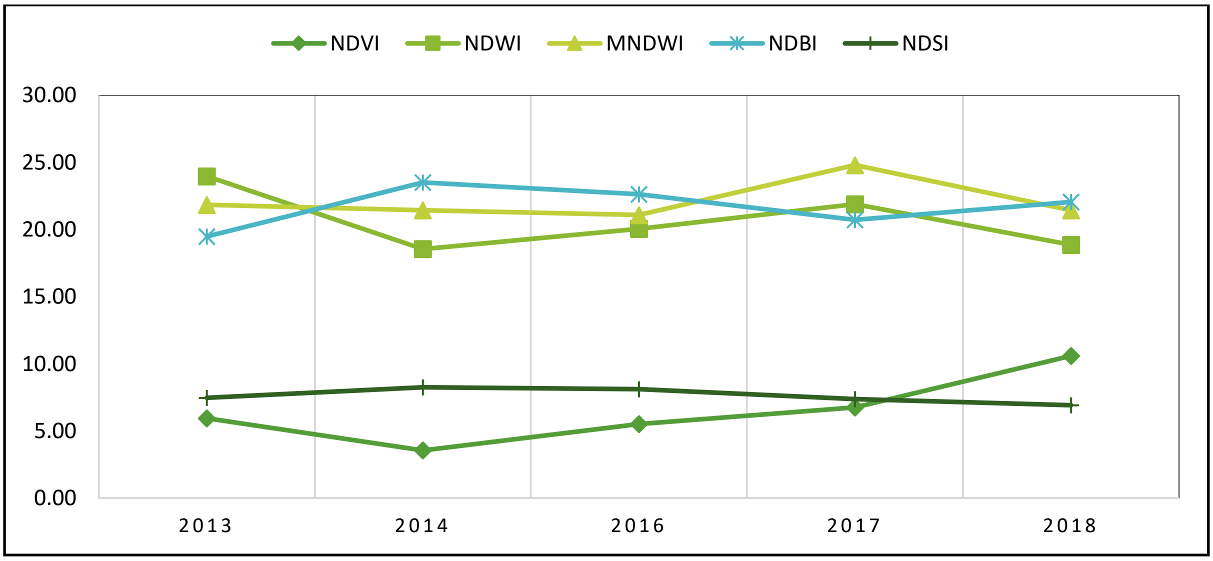

Figure 1: Comparisons of Vegetation Indices

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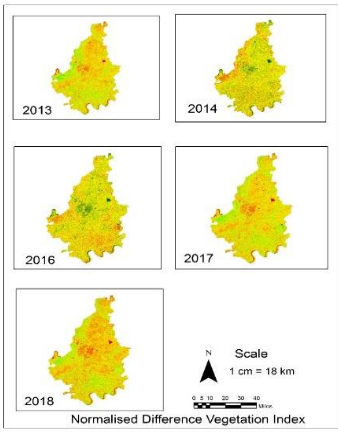
<td>
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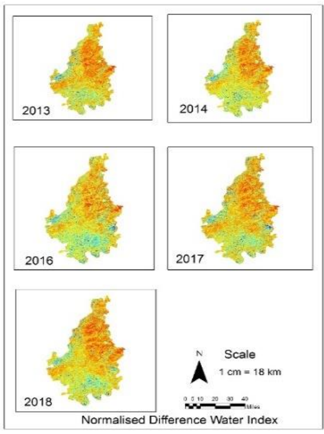
<td>
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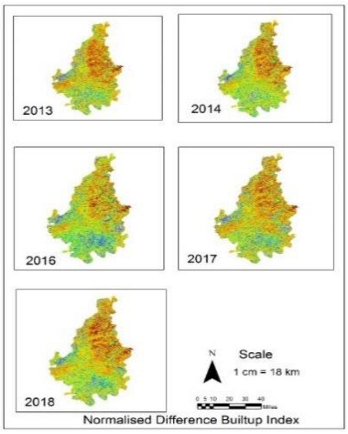
<td>
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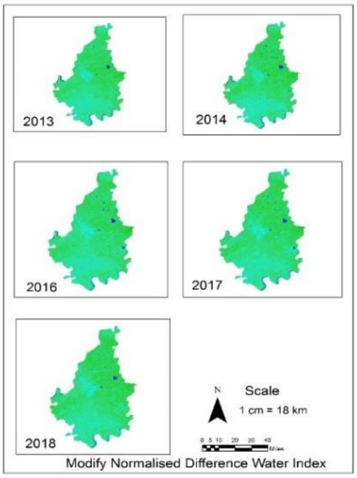
<td>
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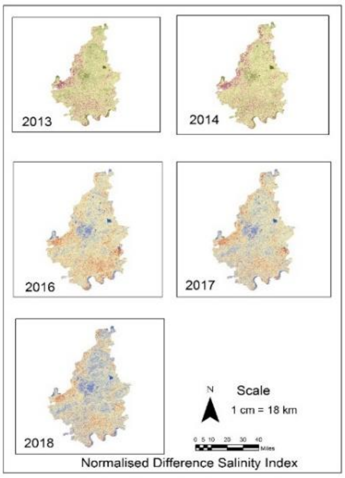
<td>
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<td>a) Normalised Difference Vegetation Index

b) Normalised Difference Water Index

c) Normalised Difference Builtup Index

d) Modified Normalised Difference Water Index

e) Normalised Difference Salinity Index</td>
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5. CONCLUSİONS

Agricultural drought is one of the most frequent natural disasters in India's southern part. Remote sensing-based drought indices give advantages in terms of continuous monitoring of land surface. This study aims to compare different agriculture drought indices in vadodara district using Landsat 8 data for 2013 to 2018 years and to monitor the agricultural drought. Increasing temperature and altered precipitation patterns, leads to the extreme weather events like Drought which drastically affects the agricultural production. The average NDWI value representing the water content of vegetation decreases numerically, 0.41, 0.39, 0.43, 0.42 and 0.41 for the given area from 2013 to 2018. Similarly, decreasing trend was observed in NDWI index which is 22.12% to 19.3% from 2013 to 2018.The builtup index (NDBI) is increasing by 1.85% in last 5 years. The Water ratio index is also showing decreasing trend in study area by 22.35% to 14.29%. NDVI value shows a total of 262.29 km^2 area had NIL vegetation, whereas scanty and low vegetation was found in 1296 km2 and 1375 km^2 of area respectively. Similarly, NDSI and WRI with NDWI shows trend with increasing. The negative and positive correlation were observed between NDVI, and precipitation for different seasons due to the higher uncertainty of precipitation.

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DRY AND WET PERIOD ANALYSIS USING METEOROLOGICAL DROUGHT INDICES IN SABARKANTHA DISTRICT GUJARAT, INDIA

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ABSTRACT

Drought assessment is very important to manage water resources in lean period. In the present study, identification of drought years and extent of deficit of annual rainfall is accomplished by use of three meteorological based drought indices like the Standardized Precipitation Evapotranspiration index (SPEI), China-Z index (CZI) and Modified China-Z index (MCZI) on 1, 3, 6, 9 and 12 month (short term and long term) timescales using monthly precipitation and temperature data from 1901 to 2002 at Sabarkantha to specify the drought conditions in present study area. The analysis of multiple time steps in drought indices make it harder to decide the best time step to show the drought conditions. The months of January, March, November and December have been identified 76, 79, 77 and 80 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation. It is observed that 1904, 1911, 1915, 1923, 1974, 1987 and 2002 affected by severe drought condition in SPEI-12. The China Z Index and Modified China Z index shows that's 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995 and 2002 affected by extreme drought. The study also reveals that only 1% year obtain as extreme wet conditions. From result it shows that 23% years are categorised into moderate to extreme drought years, which includes 15% Moderate dry, 8% severe dry years.

Key words: Drought analysis, Drought months, Standardized precipitation evapotranspiration Index, China Z- index, Modified China Z-index, Dry and Wet Percentage.

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1. INTRODUCTION

Floods and droughts are the two important aspects of hydrological hazard. Floods usually result either from heavy precipitation (rain or snow) or from rapid snowmelt or glacier discharge. Droughts are caused by dry weather conditions in which evaporation exceeds the available surface water. They are frequently characterized by water shortages. Understanding the causes and forecasting of heavy or scant precipitation and high evaporative demand (and hence of floods and droughts) form an important objective of any climate research scenario. These two types of extreme hydrological events are important to understand the climate.

Mistry and Suryanarayana (2019) studied drought scenario using precipitation indices in Banaskantha district. Patel et al. (2017) calculated SPI for 4, 6, 12, 24 and 48 months' time scales in Surat District. The area experienced more than 20% years of dry and wet events for the 20th Century. It is observed that the years 1942, 1945 and 1959 are identified as severe wet events for the time scale considered. McKee et al. (1993) developed the Standardized Precipitation Index (SPI) to monitor the status of drought in Colorado. Ju et al. (1997) introduced China-Z Index (CZI) drought index to the National Meteorological Centre of China (NMCC) in the early 1990s. Wu et al. (2001) evaluated the SPI, CZI and ZSI on 1-, 3-, 6-, 9- and 12-month time scales using monthly precipitation totals for four locations in China and concluded that SPI, CZI, and ZSI were all useful for defining, detecting, and monitoring droughts.

Vicente-Serrano et al. (2012) compared SPEI, PDSI and SPI at the global scale for the 1901-2009 period and reported that the SPEI had better capability in identifying drought conditions and suggested its use if the drought variables for drought assessment are not a prior known. Morid et al. (2006) compared seven indices, viz., EDI, SPI, PDN, DI, Z-index, China- Z index (CZI) and modified CZI (MCZI) for six stations representing different climates in Teheran province, Iran. Redmond (2002), Smakhtin and Hughes (2007) examines a drought index suitable for one region may not be applied specifically for other regions due to the inherent complexity of drought phenomena, difference in hydro-climatic conditions and watershed characteristics). Therefore, several researchers across the globe have compared different drought indices with an aim of finding suitable drought index for a particular region or basin.

2. STUDY AREA AND DATA COLLECTION

The Sabarkantha district is the part of North Gujarat and lies between 23º 03' to 24º 30' N and 72º 43' to 73º 39' E and, covering an area of 7,259.60 km^2 which is shown in below figure 1. It is surrounded by Banaskantha and Mehsana districts in the west; Ahmedabad, Gandhinagar, Kheda and Panchmahals districts in the south and Sirohi, Udaipur and Dungarpur districts (Rajasthan) in the north and east. The climate of this district is characterized by a hot summer and dryness in the non-rainy seasons. The cold season from December to February is followed by the hot season from March to May. The south-west monsoon season is from June to September, the post monsoon season is from October and November. The annual rainfall varies between 214 mm to 1,801 mm. The annual average rainfall is 863.01 mm and average temperature is 26.97° C. For the analysis of drought monitoring, precipitation, maximum temperature, minimum temperature data has been collected for 102 years (i.e., 1901 to 2002) from Indian Meteorological Department (IMD), Pune.

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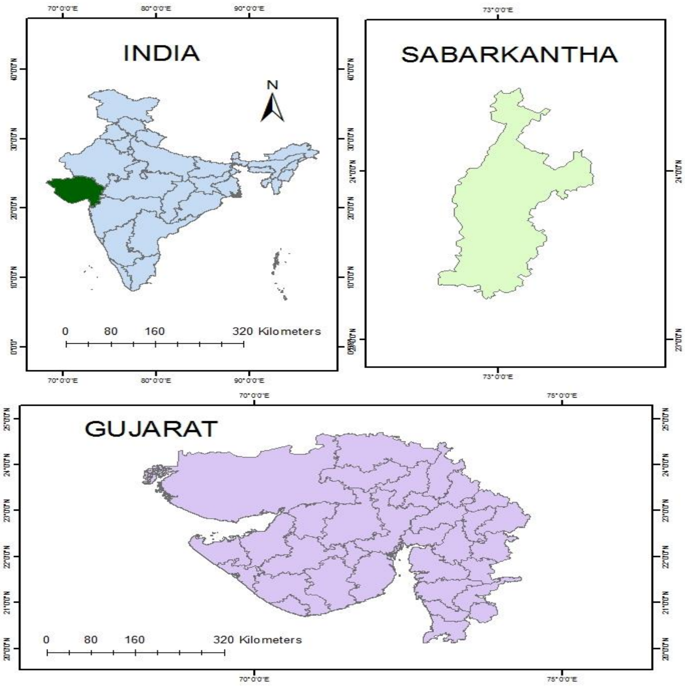

Figure 1. Location Map of Study Area

3. METHODOLOGY

3.1. Standardised Precipitation Evapotranspiration Index

The standardised 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 (Vicente-Serrano et al. 2010) is another meteorological drought index that considers the variability of both precipitation and temperature to predict drought conditions in a region. The index has been used in the variety of drought analyzing studios recently (Jiang et al. 2015; Jin et al. 2019; Wang et al. 2019). The first step to calculate the SPEI is the estimation of monthly potential evapotranspiration (PET). Then, the water balance equation is used to calculate the monthly deficit (Di).

$$D_i = P_i - PET_i$$

Where Pi is the total precipitation value at the month i. Finally, the evolved deficit values are standardized and fitted to a log-logistic distribution function. The SPEI value at the month i is the standardized values of the exceeding probability (p) of a given Di and is calculated by Eq.

$$SPEI_i = W_i - \frac{2.515517 + 0.802853W_i + 0.010328W_i^2}{1 + 1.432788W_i + 0.189269W_i^2 + 0.001308W_i^3}$$

While for P≤0.5, $W_i = \sqrt{-2lnp}$ while, if P>0.5, $W_i = \sqrt{-2\ln(1-p)}$, and the sign of the resultant SPEI is reversed for P > 0.5

In this study, SPEI package developed by Beguería and Vicente-Serrano (2013) available in R (R Development Core Team 2011) is used and fitted the data to the log-logistic distribution. It is worthy to mention that the log-logistic model was suggested by Vicente-Serrano et al. (2010) in the original SPEI methodology.

CZI (China-Z Index) and MCZI (Modified CZI)

The National Climate Center of China developed the CZI in 1995 as an alternative to the SPI (Ju et al., 1997). The CZI is calculated as:

$$\mathrm{CZI_{ij}} = \frac{6}{\mathrm{C_{si}}}\left(\frac{\mathrm{C_{si}}}{2} * \varphi_{\mathrm{ij}} + 1\right)^{\left(\frac{1}{3}\right)} - \frac{6}{\mathrm{C_{si}}} + \frac{\mathrm{C_{si}}}{6}$$

Where, i is the time scale of interest and j is the current month; CZI_{ij} means the CZI's amount of the current month (j) for period i; C_{si} is the coefficient of skewness; and φ_{ij} is the standardized variation. Furthermore, the MCZI can also be calculated using the formula above but substituting the median precipitation for mean precipitation. The classification of dryness and wetness is shown in below Table 1.

Table 1. Classes of dryness/wetness grade according to SPEI, CZI and MCZI values.

Class	Range
Extreme dry	≤ -2.0
Severe dry	-1.5 to -1.99
Moderate dry	-1.0 to -1.49
Near normal	0.99 to -0.99
Moderate wet	1.0 to 1.49
Very wet	1.5 to 1.99
Extreme wet	≥ 2.0

4. RESULT AND ANALYSIS

The statistical parameters of the rainfall data for Sabarkantha for 102 years were analysed and are given in Table 2, which indicates that there are high fluctuations in occurrence of rain ranging from maximum rainfall 1490.45mm in1944 and minimum rainfall 304.63 mm in 1915 in the study area.

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Table 2: Seasonal Rainfall in mm for Sabarkantha district

Rainfall parameters	June	July	August	Sept	Winter (Jan-Feb)	Pre-monsoon (March to May)	SW monsoon (June to Sept)
Mean Rainfall	98.61	320.35	231.97	124.55	1.97	4.60	193.87
Standard Deviation	76.71	147.76	137.55	123.53	1.11	5.59	102.19

The monthly analysis of rainfall for Sabarkantha district is given in Table 3. The same is based on assumption that a month is with drought when the rainfall for the month is less than half of the average rainfall for this month. The percentage of drought in a month was calculated as (number of drought months for a particular month/ total number of drought months) multiplied by 100 viz for January, the percentage of drought month is equal to 11.18 %. Also, 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. The months of March, November and December have 79, 77 and 80 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 09 and 13 respectively.

Table 3: Drought Analysis based on Monthly Rainfall for Sabarkantha district

Year	Average Rainfall	Half of Average Rainfall	No. of Drought Months	Percentage of Drought Months
Jan	2.76	1.38	76	11.18
Feb	1.18	0.59	72	10.59
Mar	1.13	0.56	79	11.62
Apr	1.62	0.81	70	10.29
May	11.06	5.53	64	9.41
Jun	98.61	49.31	34	5.00
Jul	320.35	160.18	13	1.91
Aug	231.98	115.99	9	1.32
Sep	124.56	62.28	43	6.32
Oct	11.74	5.87	63	9.26
Nov	5.96	2.98	77	11.32
Dec	1.89	0.94	80	11.76
Total number of Drought Months			680	100%

Also, SPEI time series calculations are developed using SPEI Package (Beguería and Vicente-Serrano 2017) in R environment. The monthly PET is estimated using Thornthwaite method. Below Figure 2,3,4 and 5 shows the SPEI, CZI and MCZI drought indices for various time series at 3-, 6-, 9- and 12-month timescales which is calculated using rainfall and temperature

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measurements in the period 1901–2002 in Sabarkantha district. From the Figure 6 shows that the frequency of different drought events is not identical always. For an example, while the SPEI-3 pattern shows not a single year falls under extreme drought similar results identified for CZI-3 and MCZI-3 during the study period.

The CZI and MCZI uses solely precipitation whereas the SPEI is based on both precipitation and temperature. Hence, it must be considered before making any decision. Considering the location of stations, it is obvious that the North Gujarat of India is more vulnerable to the long-term droughts. Since the degree of significance of SPEI-12 patterns and their acceleration rates are smaller than the CZI and MCZI, it is concluded that the temperature, slowly but surely, affects the drought patterns in the region. This can be an early warning for future droughts as the temperature rises or precipitation occurs less frequently. Through comparing MCZI and CZI indices, we found that MCZI represented the range of wet years better than CZI, while CZI represented the dry years better than MCZI.

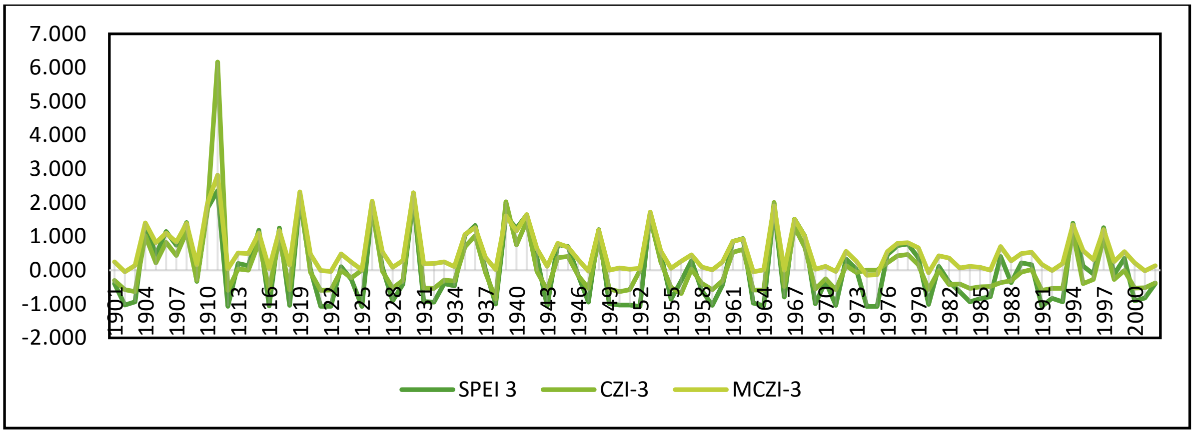

Figure 2: Comparisons of SPEI, CZI and MCZI for 3 Month Time Scale

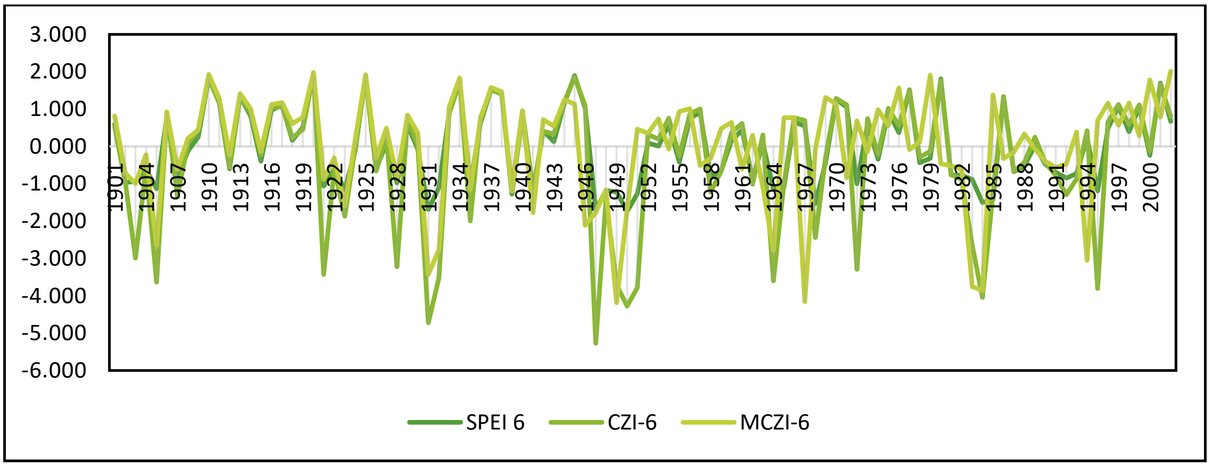

Figure 3: Comparisons of SPEI, CZI and MCZI for 6 Month Time Scale

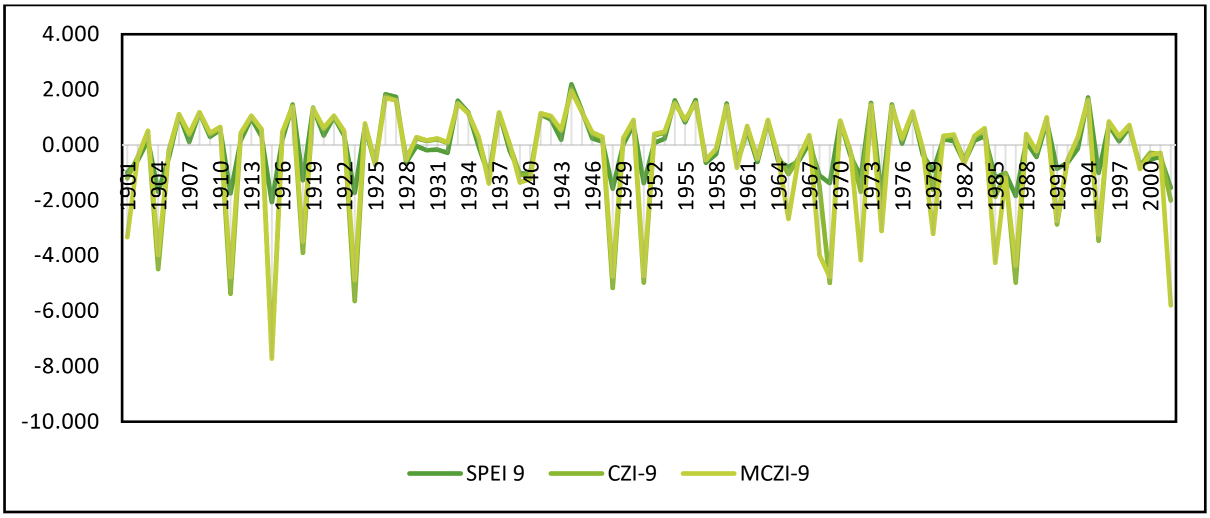

Figure 4: Comparisons of SPEI, CZI and MCZI for 9 Month Time Scale

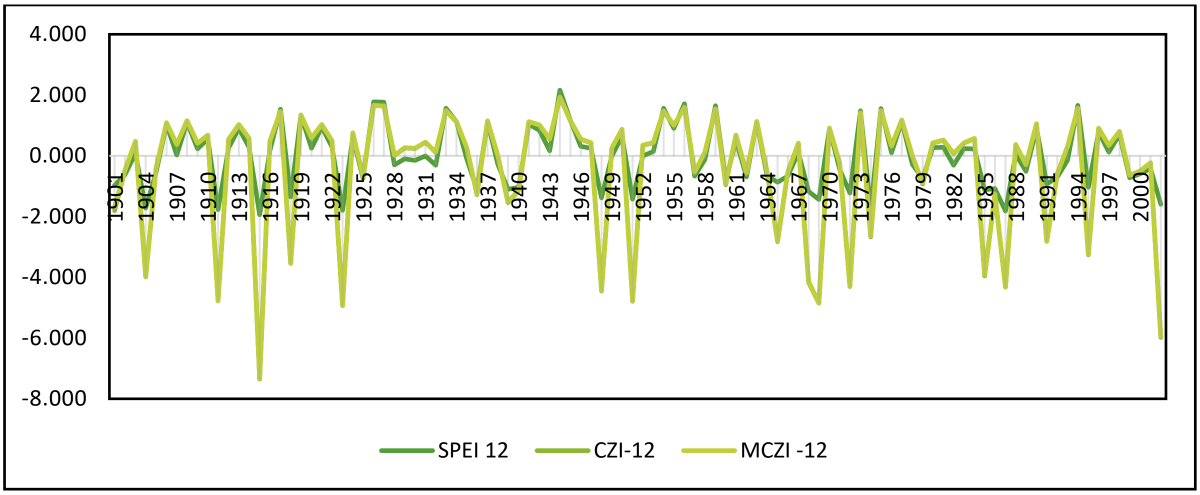

Figure 5: Comparisons of SPEI, CZI and MCZI for 12 Month Time Scale

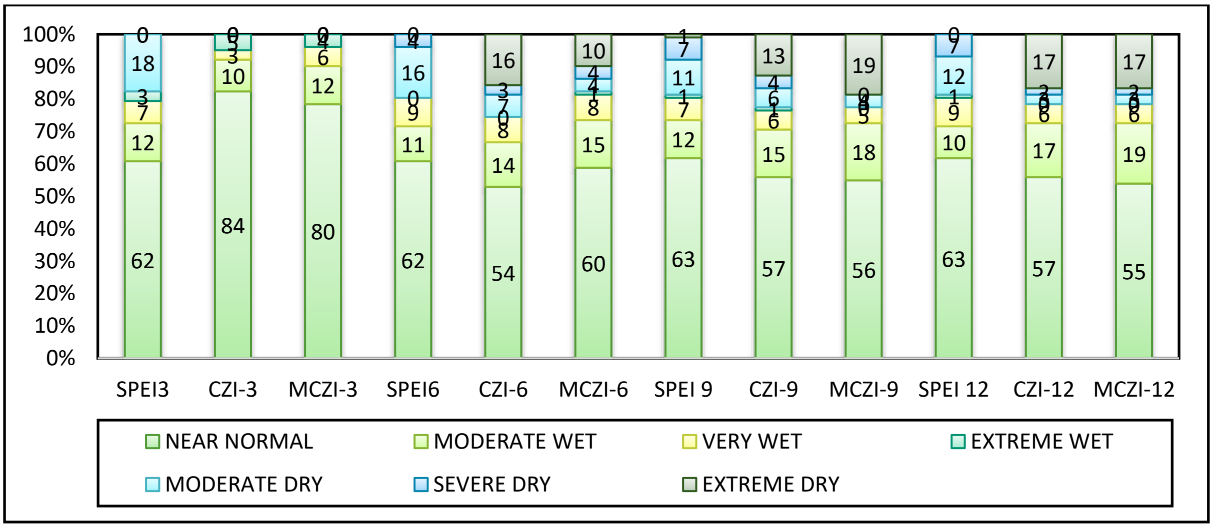

Figure 6: Drought Frequency as per Various Indices for Different Time Scales

The annual average rainfall of Sabarkantha district is 812.83mm for 102 years.SPEI 12 index shows severe dry years as 1904, 1911, 1915, 1923, 1974, 1987, 2002 with annual rainfall 352.89 mm. while moderate dry years as 1918, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1985, 1986, 1995 with annual rainfall 507.89 mm. Similarly, CZI 12 and MCZI 12 index extreme dry years as 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995, 2002 with average rainfall 445.31 mm and severe dry year as 1901, 1939 with average annual rainfall 551.11 mm.

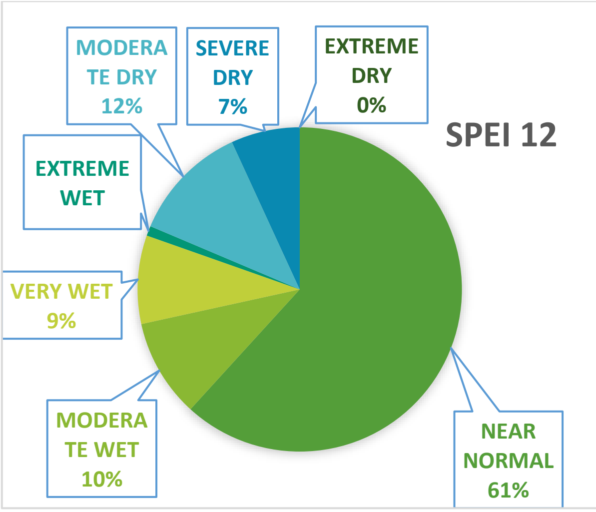

Figure 7: Distribution of Wet and Dry Periods as per SPEI 12

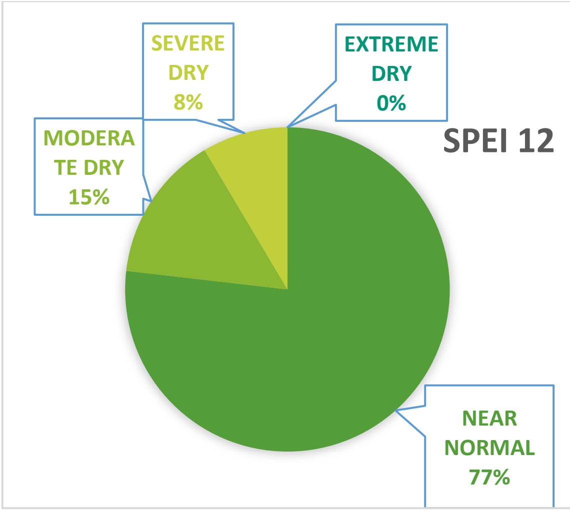

Figure 8: Frequency of Drought conditions as per SPEI 12

Figure 7 shows distribution of wet and dry periods of SPEI 12 indicator, whereas Figure 8 shows only frequency of drought years. From the Figure 7, it is shown that only 1% year is obtained as the extreme wet conditions in the last 102 years, because the average annual rainfall of Sabarkantha is only 790 mm. From the Figure 8, it reveals that out of the drought years, 23% years are categorised into moderate to extreme drought years, which includes 15% Moderate dry, 8% severe dry years.

5. CONCLUSİONS

The highest average rainfall in Sabarkantha 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 time period of 102 years. The months of March, November and December have 79, 77 and 80 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 09 and 13 respectively. From the results and analysis of SPEI, CZI and MCZI it was concluded that Severe dry years as 1904, 1911, 1915, 1923, 1974, 1987, 2002 and Moderate dry years as 1918, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1985, 1986, 1995. It is shown that only 1% year is obtained as the extreme wet conditions in the last 102 years, because the average annual rainfall of Sabarkantha is only 790 mm. It also reveals that out of the drought years, 23% years are categorised into moderate to extreme drought years, which includes 15% Moderate dry, 8% severe dry years. Overall, the SPEI is more suitable than the CZI and MCZI for applications examining characteristics of climate change and drought variation in present area because it considers both precipitation and evapotranspiration data. This study was limited to historical meteorological drought indices. The findings would be more beneficial if hydrologic, agricultural, and socioeconomic droughts are considered in future studies.

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