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

Pranav B. MISTRY [1], Tallavajhala M. V. SURYANARAYANA [2]

[1]The Maharaja Sayajirao University of Baroda, Faculty of Technology and Engineering , Water Resources Engineering and Management Institute Samiala, /INDIA
pranav.mistry-wremi@msubaroda.ac.in, ORCID: 0000-0002-2029-4283
[2]The Maharaja Sayajirao University of Baroda, Faculty of Technology and Engineering, Water Resources Engineering and Management Institute Samiala, /INDIA
drsurya-wremi@msubaroda.ac.in, ORCID: 0000-0002-6201-5676

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Corresponding Author/İletişim yazarı: Pranav B. MISTRY
E-mail: pranav.mistry-wremi@msubaroda.ac.in
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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^{o} 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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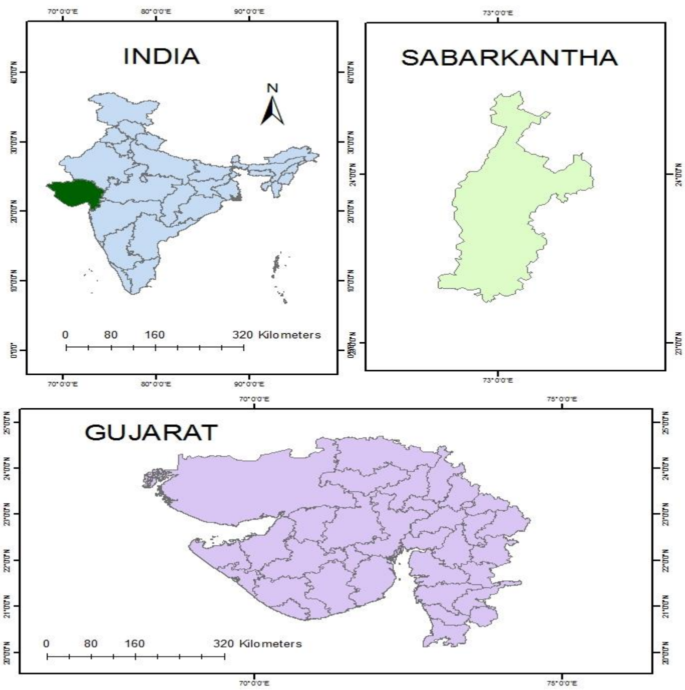

Figure 1. Location Map of Study Area

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).

$$\mathrm{D_i} = \mathrm{P_i} - \mathrm{PET_i}$$

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. 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.

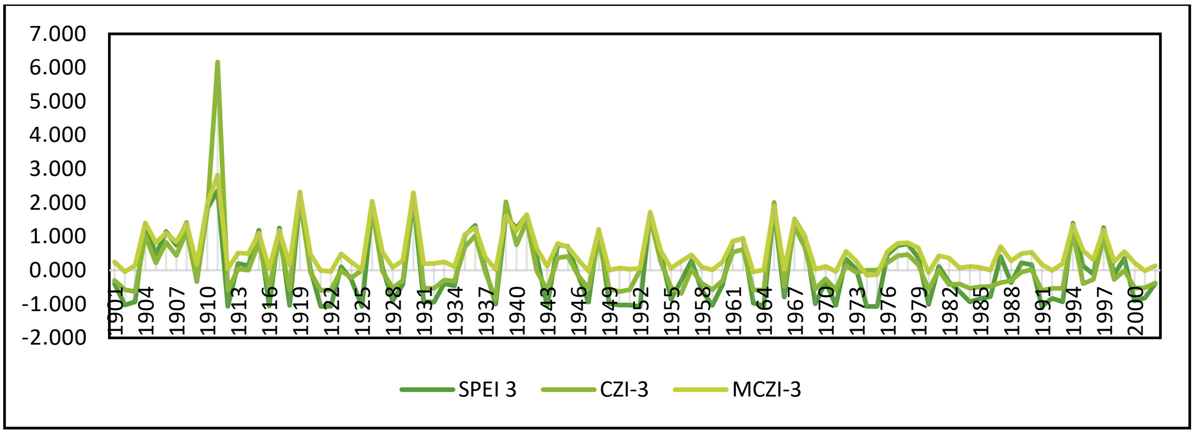

Figure 2: Comparisons of SPEI, CZI and MCZI for 3 Month Time Scale

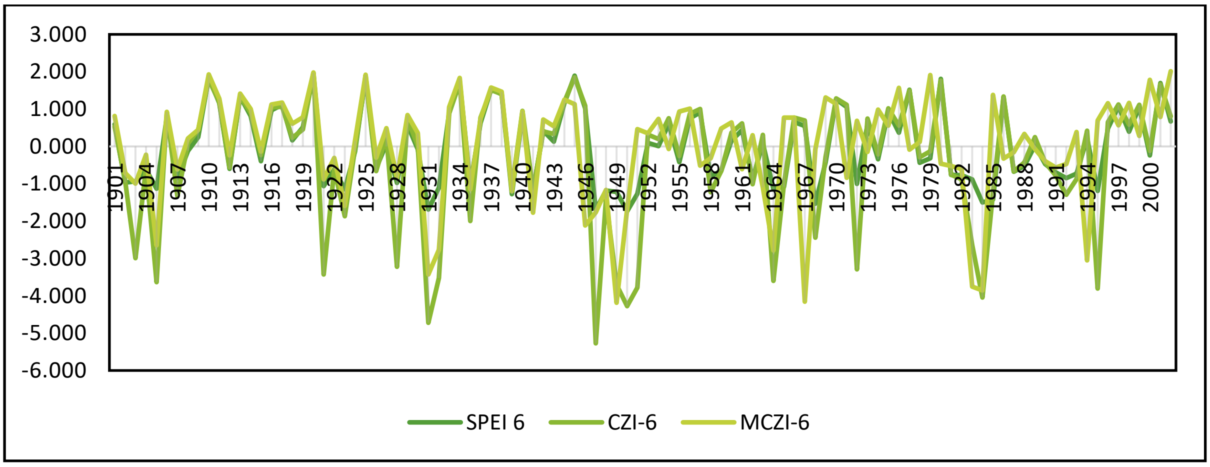

Figure 3: Comparisons of SPEI, CZI and MCZI for 6 Month Time Scale

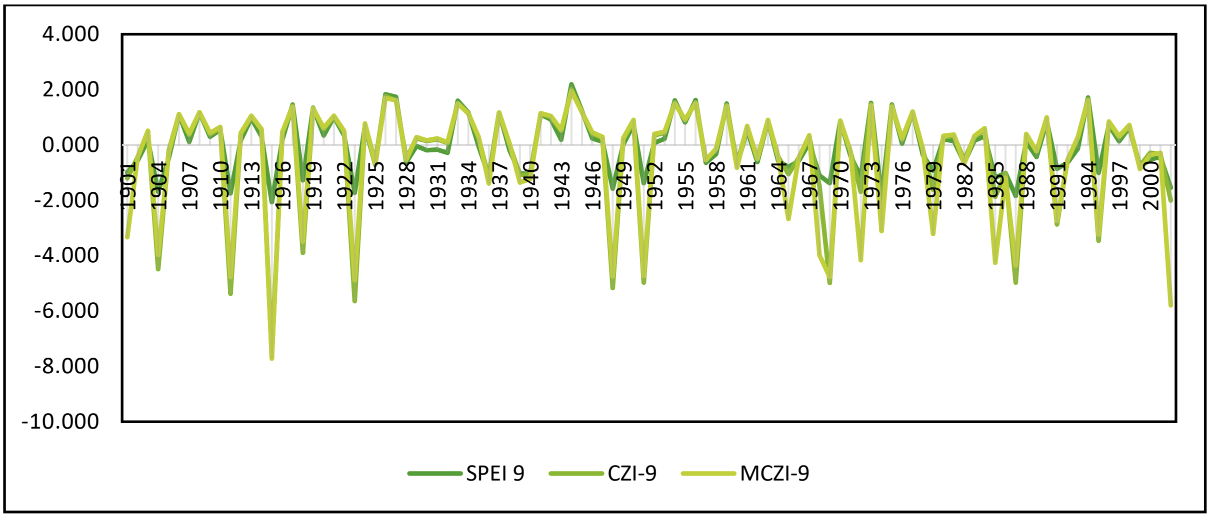

Figure 4: Comparisons of SPEI, CZI and MCZI for 9 Month Time Scale

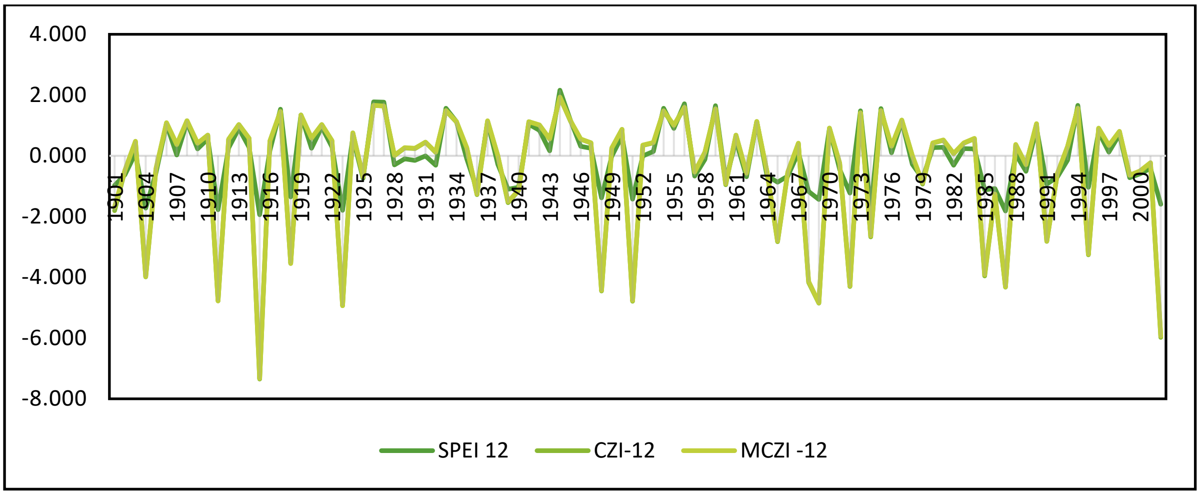

Figure 5: Comparisons of SPEI, CZI and MCZI for 12 Month Time Scale

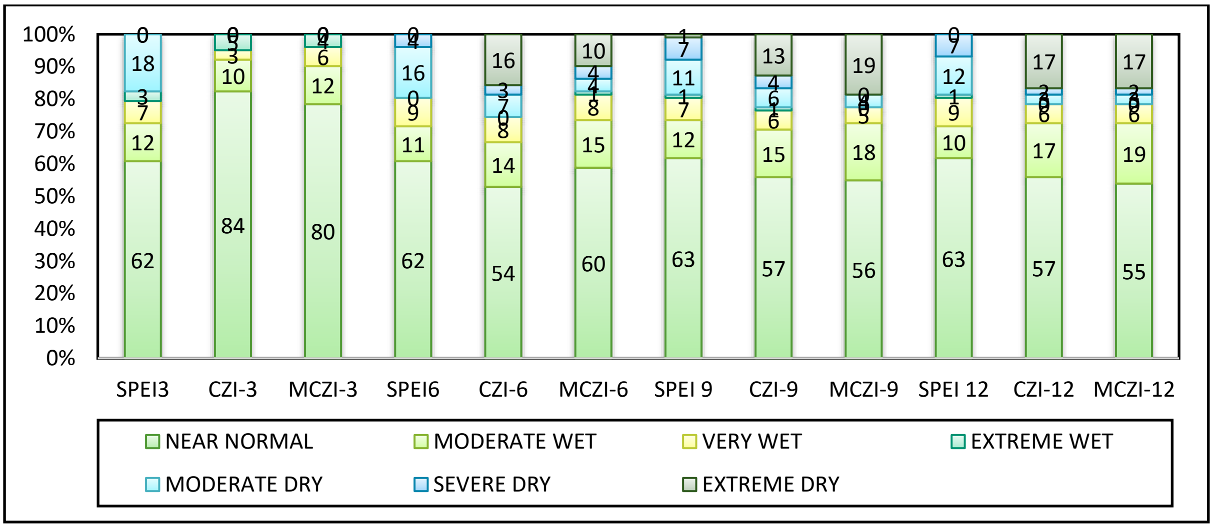

Figure 6: Drought Frequency as per Various Indices for Different Time Scales

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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.

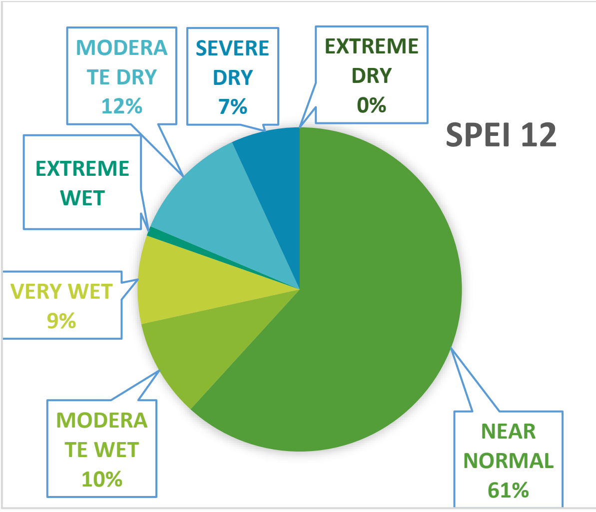

Figure 7: Distribution of Wet and Dry Periods as per SPEI 12

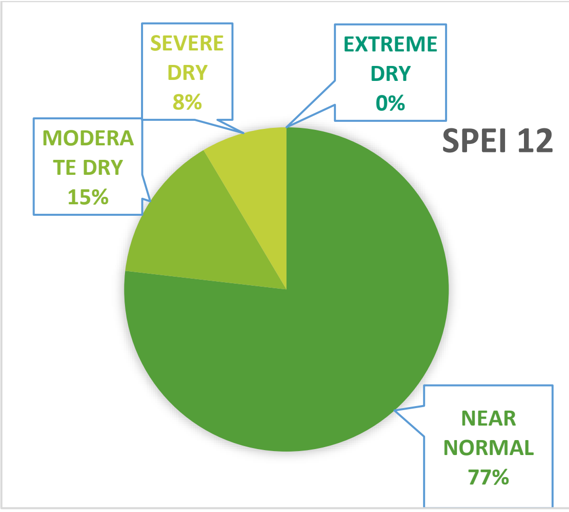

Figure 8: Frequency of Drought conditions as per SPEI 12

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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