EVALUATION OF METEOROLOGICAL INDICES FOR DROUGHT MONITORING IN CHENGALPATTU DISTRICT, TAMILNADU, INDIA

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ABSTRACT: Drought indices are widely used for monitoring the drought condition. The study is aimed to estimate the performance of composite indices for monitoring the severity condition of drought in Chengalpattu District, Tamilnadu, India. Indices such as Standardized Precipitation Index (SPI), Decile Indicator (DI), Effective Drought Index (EDI), Percent of Normal Indicator (PNI) and Rainfall Anomaly Index (RAI) were evaluated for monitoring the condition of drought. These indices were calculated with the help of 30 years' rainfall data from 1989 to 2018. Rainfall plays a prominent role in the identification and monitoring of drought condition, prevailing in a region. The drought condition was categorized from extremely dry to extremely wet based on the values computed by different indices. Based on the results, the most frequent category of SPI was below normal to moderately dry condition and that of PNI was moderate drought condition. The deciles indicated 1 to 3 which shows a much below normal precipitation, the frequent category of EDI was moderate to severely dry and RAI indicated extreme to severely dry condition. By the evaluation of different meteorological indices, the drought is monitored and it is evident that the selected region is under moderate to severe drought condition.

1. INTRODUCTION

Water is a vital commodity for the survival of human and other living beings and the sustainability depends mainly on it. When there is plenty of water, there will not be any problem for the utilization but during scarcity, life will become miserable. Drought and flood are the result of an extreme water event which should be managed properly to benefit the future by meeting the demand when there is any shortage (Zekai Sen 2015). Drought is a kind of disaster which has a slow onset and its impact on human will be more, since it affects the groundwater. Drought indices can replicate the impacts exactly which are experienced during the drought. Drought monitoring has different aspects in the hydrologic cycle and requires various indices/indicators. Precipitation, temperature, groundwater, streamflow and soil moisture which are considered as the indicators of drought, helps in identifying the drought condition. Drought indices are normally the calculated mathematical representations of severity condition of drought, which are evaluated using climatic, hydrological and meteorological inputs. Meteorological drought can be identified early and it is considered as the obvious event in the process of incidence and development of different drought conditions (Smakhtin and Hughes, 2007; M. Naresh Kumar et al. 2009). The meteorological indices play an important role in the preliminary stage of drought monitoring which uses the rainfall data as the source. Some of the indices which used only the precipitation data for the identification and monitoring of drought are Standardized Precipitation Index (SPI), Decile Indicator (DI), Effective Drought Index (EDI), Percent of Normal Indicator (PNI) and Rainfall Anomaly Index (RAI). These indices are evaluated for monitoring the drought condition in the selected study region. In the recent past, the district was exposed to the onset of drought in different years with deviations in their intensities. These resulted in the emergence of meteorological drought which leads slowly to hydrological drought (Esther Metilda J et al. 2020). The region experienced a massive flood in the year 2015 and most of the surrounding area was affected due to the unexpected flood. The effect of flood event on water quality in the part of Kancheepuram District (includes Chengalpattu region) was studied by Kamalanandhini. M et al. 2019. Even after the flood happening in the region, there is a scarcity of water due to lack of rainfall till date and also due to the poor water management practice in the region. All these factors drives to the onset of drought in the region and with proper monitoring and preventive measures, this situation can be modified and the area can be rescued from the future flood/drought events.

2. ANALYSIS OF DATA

2.1 Study Area

The study was conducted in Chengalpattu district, Tamilnadu, India which has more agricultural area and the major water supply for the locality is the Palar river. The district has many lakes and one of the important and largest lakes among them is the Maduranthagam lake which is also the second largest lake in Tamilnadu. There are many rainfall stations contained inside the study area boundary which measures the rainfall at different locations. The district after bifurcation from Kancheepuram district has five taluks namely Tambaram, Chengalpattu, Thirukazhukundram, Maduranthagam and Cheyyur **(Figure 1)**. The average annual temperature of Chengalpattu district is 28.4°C and the annual rainfall is 1160mm. Since the Palar river in the region is mostly dry, the district mainly depends on the seasonal rainfall. The region is situated at the North Eastern Agro climatic zone with different soil types such as red sandy loam, clay loam and saline coastal alluvium. Many crops such as rice, sugarcane, groundnut, paddy, maize, cotton etc., are cultivated in this region. Maduranthagam, Cheyyur and Thirukazhukundram taluks are major rice producers of the district. There are a number of manufacturing industries and IT parks situated inside the district boundary. The district is connected with good transportation facilities such as roadways and railways.

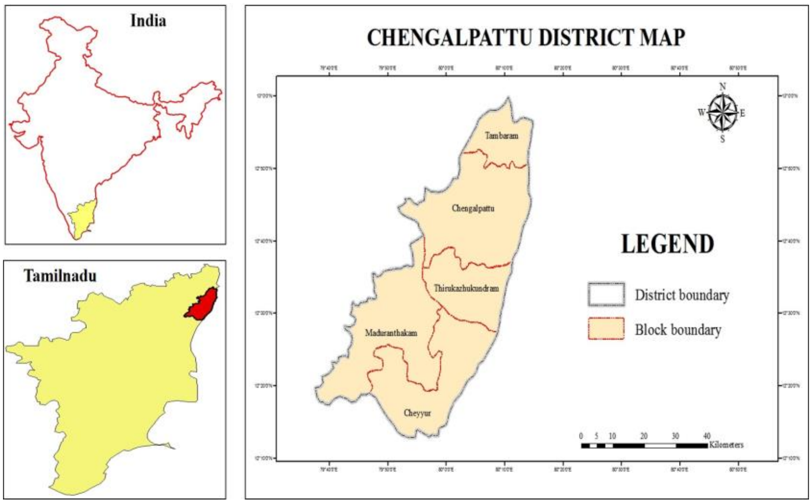

Figure 1 Location map of study area

2.2 Analysis of Meteorological Indices

Rainfall data is used for the analysis of Meteorological Indices. 30 years' rainfall data from 1989-2018 have been used for the analysis of various indices. With the help of rainfall data, the meteorological indices are evaluated to identify the drought condition prevailing in the region. Meteorological indices such as Standardized Precipitation Index (SPI), Decile Indicator (DI), Effective Drought Index (EDI), Percent of Normal Indicator (PNI) and Rainfall Anomaly Index (RAI) were evaluated to identify and monitor the drought severity of the region of interest.

2.2.1 Standardized Precipitation Index (SPI)

Standardized Precipitation Index is obtained by finding the difference in the precipitation and mean precipitation for a specified time divided by its standard deviation. SPI is a normal distribution curve, which indicates that it can monitor both dry and wet periods (Thomas B. McKee et al. 1993). When SPI is represented in different time scales, it assesses the effects of deficit in the precipitation on different components of water (Saeid Morid et al. 2006). The SPI values ranges from extremely dry to extremely wet condition with a value ranging from -2 to 2 respectively. The SPI is calculated from the following probability density function:

$$\mathrm{g(x)} = \frac{1}{\beta^{\alpha}\gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \tag{1}$$

where $\gamma(\alpha)$ is the gamma function; α is the shape parameter, x is the amount of precipitation in mm, β is the scale parameter and (x>0), (α>0) and (β>0) (Nasrin Salehnia et al. 2017; Dogan Selim et al. 2012).

2.2.2 Decile Indicator (DI)

The sum of monthly precipitation from a continuous record are graded from highest to lowest to make a cumulative frequency distribution and then it is divided into 10 parts. By comparing the total precipitation in a month with the cumulative frequency distribution in that period, the drought severity can be identified. The deciles are divided into five categories, and there are two deciles for each category. In the first decile, precipitation value is less than 40% (deciles 0 to 1) of all precipitation values and it is grouped in much below normal category. The second decile is between 40 to 55% (deciles 1 to 2) which indicates below normal precipitation and the third decile is between 55 to 80% (deciles 2 to 3) which indicates near normal precipitation. The fourth decile is from 80 to 100% (deciles 3 to 4) which indicates above normal precipitation and the fifth decile is more than 100% (deciles 5 and above) indicate much above normal precipitation (Saeid Morid et al. 2006).

2.2.3 Effective Drought Index (EDI)

Effective Drought Index values are also standardized as of SPI, which assess the drought severity at the location. The EDI value varies from −2 to 2 i.e., from extremely dry to extremely wet condition similar to the SPI values (Saeid Morid et al. 2006). EP_i is calculated from the following equation:

$$EP_i = \sum_{n=1}^{i} \left(\frac{\sum_{m=1}^{n} P_m}{n} \right) \tag{2}$$

where EP_i (mm), is the effective precipitation which denotes accumulation of precipitation; P_m (mm), is the precipitation over the former m days and n (day), is the duration of the former period (Nasrin Salehnia et al. 2017). The deviation from the mean (DEP) is calculated by subtracting the standard deviation and mean ($\overline{EP}$).

$$\mathrm{DEP} = \mathrm{EP} - \overline{EP} \tag{3}$$

The precipitation needed for the return to normal condition (PRN) is determined using the DEP

$$PRN = \frac{DEP}{\sum_{i=1}^{N} \frac{1}{i}} \tag{4}$$

Finally, EDI is calculated as below:

$$EDI = \frac{PRN}{\sigma_{PRN}} \tag{5}$$

where σ_{PRN} is the standard deviation of the relevant month's PRN values (Dogan Selim et al. 2012).

2.2.4 Percent of Normal Indicator (PNI)

The Percent of Normal Indicator measures the deviation in rainfall from its long-term mean. The above normal value of is considered as 100% which may be calculated for a month or a year or for a season (Saeid Morid et al. 2006). When the normal indicator value is less than 40, there is an extreme dry condition and when it is between 40 to 55, it is in a severely dry condition. The value of normal indicator between 55 to 80 represents the moderate dry condition and between 80 to 100 indicates a normal condition. For a good amount of rainfall, the PNI value will always be more than 100 when there is a wet to extremely wet condition prevailing in the region.

$$\text{PNI} = \frac{P_i}{P} \text{ x } 100 \tag{6}$$

where Pi (mm), is the precipitation in time increment 'i' and P (mm) is the normal precipitation for the study period (Nasrin Salehnia et al. 2017).

2.2.5 Rainfall Anomaly Index (RAI)

The Rainfall Anomaly Index uses the standardized precipitation values centered to the Raingauge station of a particular location. The comparison of current year with the previous years' produces the output in a historical perception. RAI mainly focusses on the droughts that affect the agricultural stretch, water resources and other divisions, as it is flexible for different timescale analysis (M. Svoboda and B.A. Fuchs 2016). The positive and negative anomaly threshold can be calculated from the formula 7 and 8 shown below.

$$RAI = 3\ X \left[\frac{(p-\bar{p})}{(\bar{m}-\bar{p})}\right] \tag{7}$$

$$RAI = -3\ X \left[\frac{(p-\bar{p})}{(\bar{m}-\bar{p})}\right] \tag{8}$$

where p (mm), is the actual precipitation for each year; $\bar{p}$ (mm), is the long-term average precipitation and $\bar{m}$ is the mean of the ten highest and ten lowest values of p for the positive and negative anomaly respectively (Nasrin Salehnia et al. 2017).

3. RESULTS AND DISCUSSION

Rainfall event determines the amount of recharge of the groundwater in a region. When there is a scarcity in rainfall it affects the groundwater potential and in turn lowers the groundwater table if the extraction of water is more due to human activities. The meteorological drought condition can be identified using different indices and these indices are named as meteorological indices since they use only the precipitation data for the analysis. Meteorological indices represent the dry and wet conditions of the region with the help of rainfall recorded in the previous years. After the analysis of rainfall, various categories are framed from extremely wet to extremely dry condition with a range of values for each index. A graphical plot between the years and the index value can be made to identify the drought condition of a particular year and also the variation between different years. It can be arrived at a conclusion that, if a particular year was having sufficient rainfall, it will fall in the extremely wet category and if there is no sufficient rainfall, it comes under dry to extremely dry condition. **Table 1** shows the different categories of meteorological indices and their respective value ranges (Saeid Morid et al. 2006; Juliana Alcantara Costa and Glauber Pontes Rodrigues 2017).

Table 1 Categories of SPI, PNI, DI, EDI and RAI values

<table>
<tr><th>Value</th><th>Category</th><th>SPI</th><th>PNI</th><th>DI</th><th>EDI</th><th>RAI</th></tr>
<tr><td>3</td><td>Extremely Wet</td><td>≥ 2</td><td rowspan="3">≥ 100</td><td rowspan="2">4</td><td>≥ 2</td><td>≥ 3</td></tr>
<tr><td>2</td><td>Very Wet</td><td>1.5 to 1.99</td><td>1.5 to 1.99</td><td>2.1 to 3</td></tr>
<tr><td>1</td><td>Moderately Wet</td><td>1.0 to 1.49</td><td>3</td><td>1.0 to 1.49</td><td>0.3 to 2.1</td></tr>
<tr><td>0</td><td>Normal</td><td>-0.99 to 0.99</td><td>80 to 100</td><td>≥ 5</td><td>-0.99 to 0.99</td><td>0 to 0.3</td></tr>
<tr><td>-1</td><td>Moderately Dry</td><td>-1.0 to -1.49</td><td>55 to 80</td><td rowspan="2">2</td><td>-1.0 to -1.49</td><td>0.3 to -2.1</td></tr>
<tr><td>-2</td><td>Severely Dry</td><td>- 1.5 to -1.99</td><td>40 to 55</td><td>- 1.5 to -1.99</td><td>-2.1 to -3</td></tr>
<tr><td>-3</td><td>Extremely Dry</td><td>≤ -2</td><td>≤ 40</td><td>1</td><td>≤ -2</td><td>≤ -3</td></tr>
</table>

From the SPI plot **(Figure 2)** obtained using the precipitation data of 30 years, it is evident that the year 1989 was under moderately dry condition and 1997 was under extremely dry condition. Most of the years were below normal range, which will lead to occurrence of drought in the region.

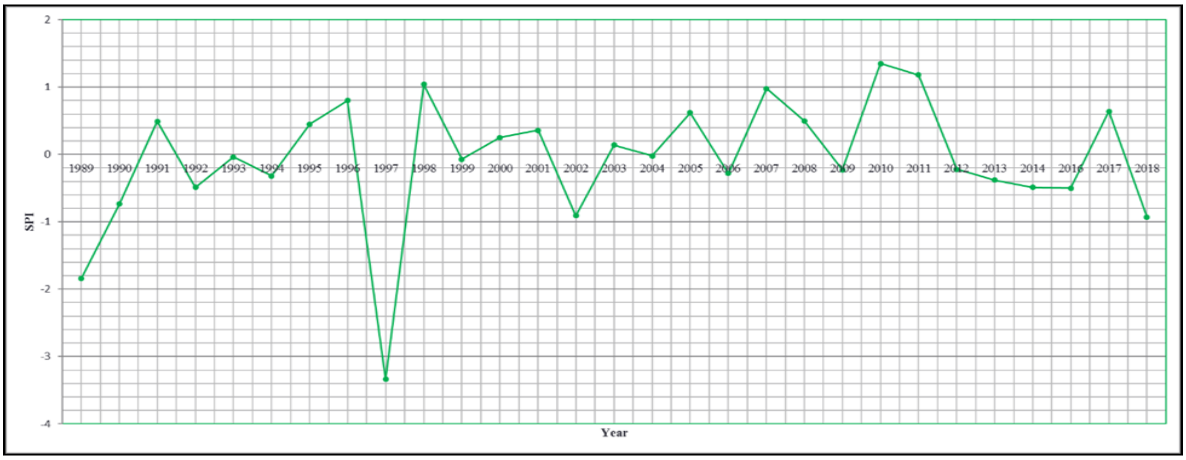

Figure 2 SPI plot from 1989-2018

The Decile Indicator **(Figure 3)** showed a value range from (0 to 2) which was extreme to severe drought condition and from 2 to 4 which was severe to weak drought condition in most of the years. During the year of flood i.e., in 2015 the indicator value was more than 5 which was having a no drought condition. There was a drastic drop from 2017 to 2018 based on the DI value observed in these years i.e., from no drought condition to a severe drought condition and this might be due to the lack of precipitation in 2018.

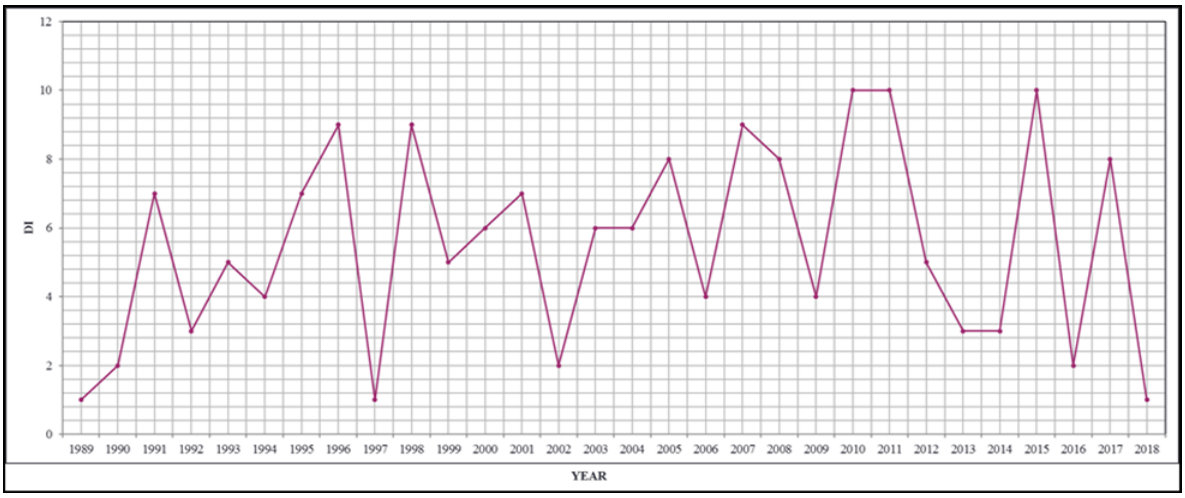

Figure 3 DI plot from 1989-2018

The EDI results **(Figure 4)** shows that, the years 1989, 1990, 1992, 1997, 2002, 2014, 2016, 2018 were under extremely dry condition. Most of the years were under moderate to severely dry condition in the region. Some of the years which received good rainfall were under moderate to extremely wet condition.

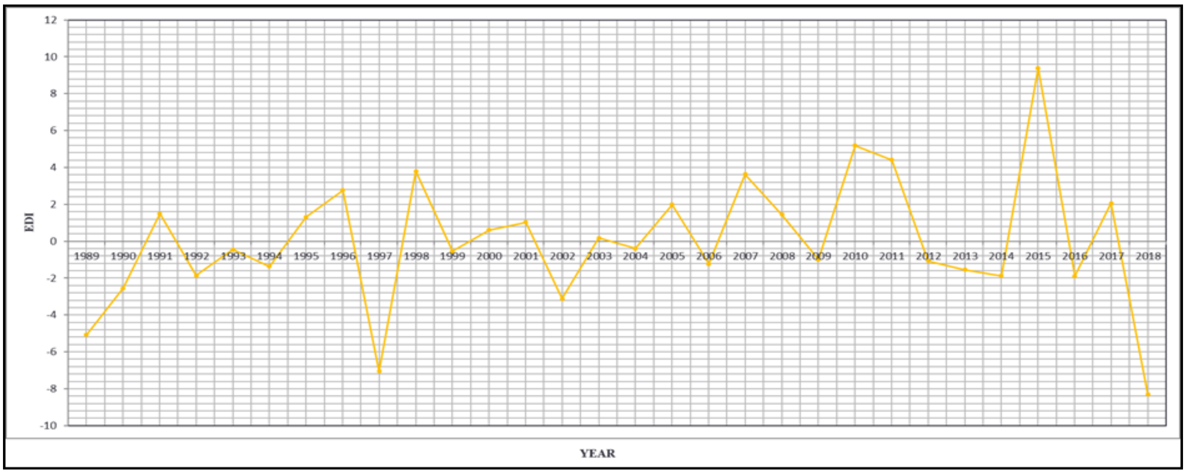

Figure 4 EDI plot from 1989-2018

The PNI ranges **(Figure 5)** were below 40 percent in the year 1989 and 1997 which indicates extreme drought condition. PNI values ranged between 55 to 80 percent in most of the years which indicates moderate drought condition in the region. In the year 2015, the PNI value was more than 100 percent which was during the flood that happened in the region. From RAI results **(Figure 6)**, it is clear that, in most of the years the RAI values were showing moderate to extremely dry condition based on the anomaly observed with the rainfall in the study area.

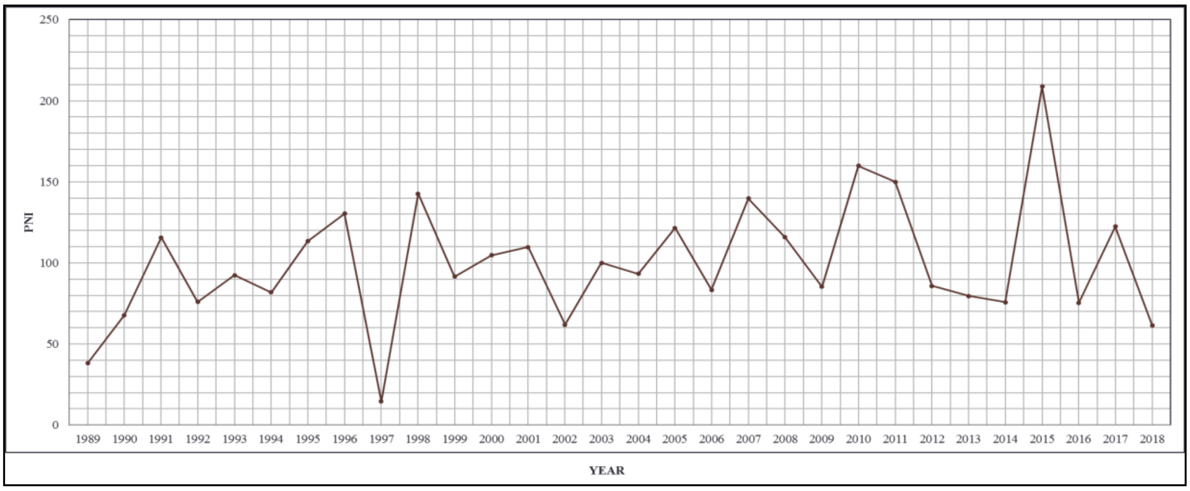

Figure 5 PNI plot from 1989-2018

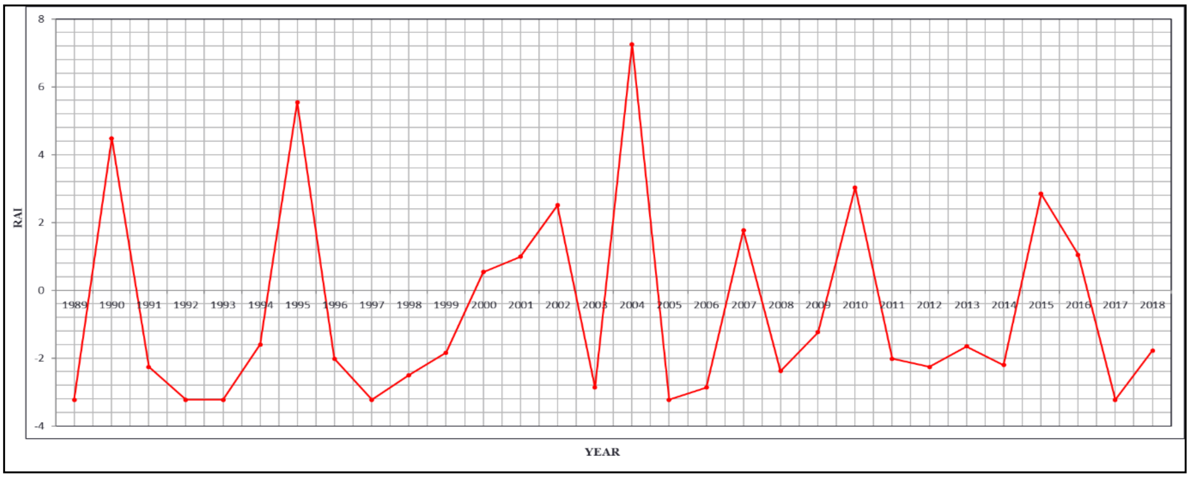

Figure 6 RAI plot from 1989-2018

4. CONCLUSION

The evaluation of meteorological indices such as Standardized Precipitation Index, Decile Indicator, Effective Drought Index, Percent of Normal Indicator and Rainfall Anomaly Index for monitoring the drought condition based on the rainfall data of a region proves to be an effective and easier method. The mean precipitation, deviation in the rainfall and the standardized rainfall values helps to calculate these indices. The result of SPI represented a moderate to extremely dry condition of drought. The deciles were from 2 to 4 which showed a severe to weak drought condition in the study area. The EDI ranges were indicating moderate to severe dry condition in the district. The Percent of Normal indicator range was below 40 percent which falls under extreme drought condition. From the result of RAI, it is evident that the region is under moderate to extremely dry condition. From the results obtained after evaluation of all these indices, the region is found to be under a moderate to severely dry condition of meteorological drought in compliance with the past rainfall events. Further study can be extended to identify the other driving factors for the occurrence of the major drought event.

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