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Assessment of Drought Using Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI): A Case Study of Amreli District

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Abstract: ***Drought is a natural phenomenon which affects the human beings as well as animals. It also affects on the world's economy, environment, industries and the community. therefore, drought hydrology has been receiving much attention. Assessment of droughts can be helpful to implement drought mitigation strategies and measures, before they occur again. A wide variety of concepts are applied for drought assessment. In present study, SPI and RDI were developed for assessment of the drought for Amreli district. The SPI considers rainfall data as only variable, where RDI considers two hydro-meteorological variables (i.e., rainfall and potential evapotranspiration) that affect the droughts. For the assessment of drought, rainfall and PET data of 35 years (i.e., 1965-2000) were used of Amreli station. For calculating the indices "DrinC" software tool was used. Wet and dry period were compared using trend analysis of SPI-3, SPI-6, SPI-9 & SPI-12 and RDI-3, RDI-6, RDI-9 & RDI 12. it is better to use SPI and RDI of 12 months' index for analysis of drought for this study. Overall, there was moderate drought situation in Amreli but the duration and intensity was above normal.***

Keywords: Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Rainfall, Potential Evapotranspiration, DrinC.

1. Introduction

Drought is one of the world's costliest natural disasters, causing an average US $6–8 billion in global damages annually, and affecting more people than any other form of natural catastrophe. In India, around 68% of the country is prone to drought in varying degrees. 35% which receives rainfall between 750 mm and 1125 mm is considered drought prone while 33% receiving less than 750 mm is chronically drought prone. It is a temporary, recurring natural disaster, which originates from the lack of precipitation and brings significant economic loss. It is not possible to avoid droughts. But drought preparedness can be developed and drought impacts can be managed. In the most general sense, drought originates from a deficiency of precipitation over an extended period of time, usually a season or more, resulting in a water shortage for some activity, group, or environmental sector. A drought can last for months or years, or may be declared after as few as 15 days. Generally, this occurs when a region receives consistently below average precipitation. Technically, drought is a temporary condition, even though it may last for long periods of time.

1.1 Drought

In general, drought means different things to different people. To a meteorologist it is the absence of rain while to the agriculturist it is the deficiency of soil moisture in the crop root zone to support crop growth and productivity. To the hydrologist it is the lowering of water levels in lakes, reservoirs, etc., while for the city management it may mean the shortage of drinking water availability Thus, it is unrealistic to expect a universal definition of drought for all fields of activity.

1.1.1 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. 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.

An objective of assessment of drought conditions in a

particular region is to plan the water resources in order to prevent and mitigate the occurrence of the drought in further years. In this paper, SPI index was used for assessment of drought.

Khadr et al. (2013) Worked to detect the changes in drought frequency, persistence and severity in the Ruhr river basin. The frequency of drought events was calculated using the Standardized Precipitation Index (SPI). Used data are daily precipitation records from seven meteorological stations covering the period 1961-2007. The main benefit of the application of this index is its versatility, only rainfall data is required to deliver five major dimensions of a drought: duration, intensity, severity, magnitude, and frequency. Furthermore, drought can be calculated in different time steps. In this study SPI was calculated for 1, 3, 6, 9, 12, and 24 months. Several drought events were detected in the covered period, these events contain mild, moderate and severe droughts. Also positive and negative trends in the SPI values were observed.

Tsakiris and Vangelis (2005) Introduced A new general drought index, which is proposed for the assessment of meteorological drought severity. The new index called Reconnaissance Drought Index, RDI, is based on cumulative values of precipitation and potential evapotranspiration. Three expressions of RDI are given: the initial, the normalised and the standardised. The standardised RDI can be directly compared to the Standardised Precipitation Index (SPI) which is widely used. The new index has certain advantages when compared to SPI since it is more representative of the deficient water balance conditions than an index based only on precipitation.

Tigkas et al. (2014) Presented the overall design and the implementation of the DrinC (Drought Indices Calculator) software along with the utilization of various approaches for drought analysis. DrinC can be used for the calculation of two recently developed indices, the Reconnaissance Drought Index (RDI) and the Streamflow Drought Index (SDI), as well as two widely known indices, the Standardized Precipitation Index (SPI) and the Precipitation Deciles (PD). Moreover, the software includes a module for the estimation of potential evapotranspiration (PET) through temperature based methods, useful for the calculation of RDI. The software may be used in a variety of applications, such as drought monitoring, assessment of the spatial distribution of drought, investigation of climatic and drought scenarios, etc. The applications of DrinC in several locations, especially in arid and semi-arid regions, show that it is gaining ground as a useful research and operational tool for drought analysis.

1.2 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. In the international publications different indices have been discussed and applied. Among those we mention:

1) Standardized Precipitation Index (SPI)
2) Reconnaissance Drought Index (RDI)

1.2.1 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) to serve as a ~~–v~~ersatile tool in drought monitoring and analysis". The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). SPI is calculated by taking the difference of the precipitation from the mean for a particular time scale, then dividing it by the standard deviation:

$$SPI = (X_{ik} — X_i)/ \sigma_i \quad \textbf{(1)}$$

Where,
σ_i = Standardized deviation for the i^{th} station
X_{ik} = Precipitation for the i^{th} station and k^{th} observation
X_i = Mean precipitation for the i^{th} station
The gamma distribution is defined by its probability density function as

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad for\ x > 0 \quad \textbf{(2)}$$

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \quad \textbf{(3)}$$

Fitting the distribution to the data requires that a and b be estimated. For this Edwards and McKee (1997) suggested a method using the approximation of Thom (1958) for maximum likelihood as follows:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad \textbf{(4)}$$

$$\hat{\beta} = \frac{x}{\hat{\alpha}} \quad \textbf{(5)}$$

Where,

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad \textbf{(6)}$$

for n observations

Accumulated values of the SPI can be used to analyze drought severity. The SPI is usually calculated for monthly periods and therefore uses monthly data. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Since SPI is normalized, wetter and drier climates can be represented in the same way. Although, SPI can monitor wet periods, it is typically used to assess the length and magnitude of drought events.

Table 1: Classification of SPI

SPI	*Classification*
2.00 >	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
0 to 0.99	Near Normal
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought

1.2.2 Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) (**Tsakiris and Vangelis, 2005; Tsakiris et al., 2007b**) can be characterized as a general meteorological index for drought assessment. The RDI can be expressed with three forms: the initial value αk, the normalized RDI (RDIn) and the standardized RDI (RDIst). In this paper we will focus on αk and RDIst.

The initial value (αk) is presented in an aggregated form using a monthly time step and may be calculated on monthly, seasonal (3-month, 4-month, etc.) or annual basis. The αk for the year i and a time basis k (months) is calculated as:

$$\alpha_0^{(i)} = \frac{\sum_{j=1}^{N} P_{ij}}{\sum_{j=1}^{N} PET_{ij}} \quad (7)$$

In which P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the j^{th} month of the i^{th} year and N is the total number of years of the available data.

A second expression, the Normalized RDI (RD_{In}) 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 α_o values calculated for the N years of data.

$$RDI_n^{(i)} = \frac{\alpha_o^{(i)}}{\bar{\alpha_0}} - 1 \quad (8)$$

The third expression, the Standardized RDI (RDI_{st}), is computed following a similar procedure to the one that is used for the calculation of the SPI: The expression for the Standardized RDI is:

$$RDI_{st(k)}^{(i)} = \frac{y_k^{(i)} - \bar{y_k}}{\widehat{\sigma_{yk}}} \quad (9)$$

In which y_i is the ln ($\alpha_0^{(i)}$), y_k is its arithmetic mean and $\bar{\alpha_{yk}}$ is its standard deviation.

The Reconnaissance Drought Index (RDI) was developed to approach the water deficit in a more accurate way, as a sort of balance between input and output in a water system. It is based both on cumulative precipitation (P) and potential evapotranspiration (PET), which are one measured (P) and one calculated (PET) determinant. Positive values of RDI_{st} indicate wet periods, while negative values indicate dry periods compared with the normal conditions of the area. The Table 2 shows the classification of RDI as shown below.

Table 2: Classification of RDI

Values of RDI_{st}	*Description of State*
−0.5 to −1.0	Mild
−1.0 to −1.5	Moderate
−1.5 to −2.0	Severe
< −2.0	Extreme

2. Study Area & Data Collection

The Amreli District is selected as study area for assessment and forecasting of drought in this study. It includes meteorological and topographical information related to Amreli district. Amreli city is governed by Municipal Corporation which comes under Amreli Metropolitan Region. The Amreli city is located in Gujarat state of India. This Chapter also includes the brief of collected data of rainfall and potential evapotranspiration which will be used for study.

Amreli district covers an area of 7397 Sq. km., lies in the south Central part of the Saurashtra Peninsula and is one of the most important district of the Saurashtra. Amreli district is situated between north latitudes 20°45' & 22°05' and east longitude 70°40' & 71°45'. It is bounded by Rajkot district in the north Junagarh district in the west and south west Bhavnagar district in the east and Arabian sea in the south as shown in Figure 1.

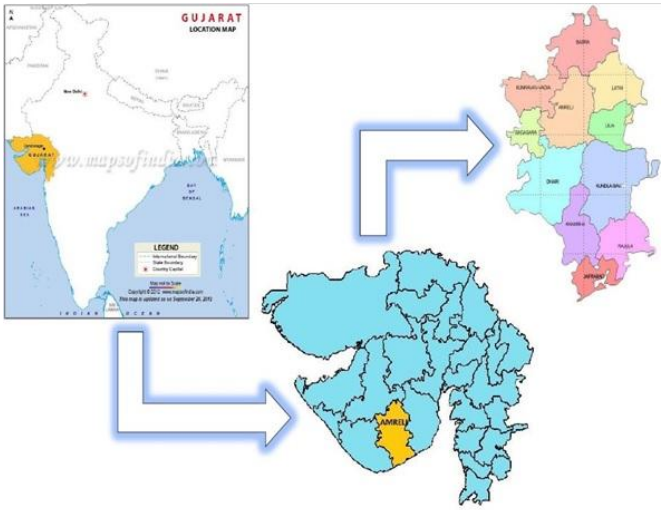

Figure 1: Location of Amreli District in Gujarat

Administratively the district is divided into eleven talukas, i.e. Amreli, Dhari, Rajula, Khamba, Jagrabad, Kunkavav, Babra, Lathi, Lilia and Kundla. Amreli is the district headquarters. There are 616 villages in the district. This study required minimum 30-years of precipitation data. Rainfall and PET Data of 1965 to 2000 has been collected from the **Indian Meteorological department (IMD)** of Amreli district. Collected data was in monthly basis. Data of 35 years was used in this study.

3. Methodology

In this study, SPI and RDI has been used for assessment of the drought for Amreli District. For the assessment of drought, precipitation and potential evapo-transpiration data

of Ajmer district was used. Wet and dry periods have been compared using the SPI-3, SPI-6, SPI-9 and SPI-12 & RDI-3, RDI-6, RDI-9, and RDI-12. In this study Drought Index (DI) was calculated using ―DrinC" software.

The SPI and RDI were calculated for 3, 6, 9 and 12 months, as in India, generally a monsoon season is between June to September or June to October and sometime it happens till October and November.

SPI/RDI - 3 = SPI/RDI value calculated from Jun to Aug
SPI/RDI - 4 = SPI/RDI value calculated from Jun to Sep
SPI/RDI - 5 = SPI/RDI value calculated from Jun to Oct
SPI/RDI - 6 = SPI/RDI value calculated from Jun to Nov

Monthly rainfall values of year 1973 to 2008 were used for calculation of SPI. DrinC gives the ability to formulate a drought analysis that suits better the needs or the purpose of this study. The results for each drought index may be presented per month or per period that allows a direct comparison of drought severity for specific periods of the year. As an input, series of at least 30 years' period of data must be required in order to produce reliable results for drought characterization.

4. Results and Analysis

4.1 Drought Period & Trend Analysis Using SPI Values

Analyzing SPI-3 value, the moderate drought occurred in 1966-67,1971-1973,1984-85,1986-87,1988-90,1991-92 and 1994-95 in Amreli District. There was no severe or extreme drought occurred. And there was extremely wet period recorded in year 1979-80 as Shown in the Figure 2.

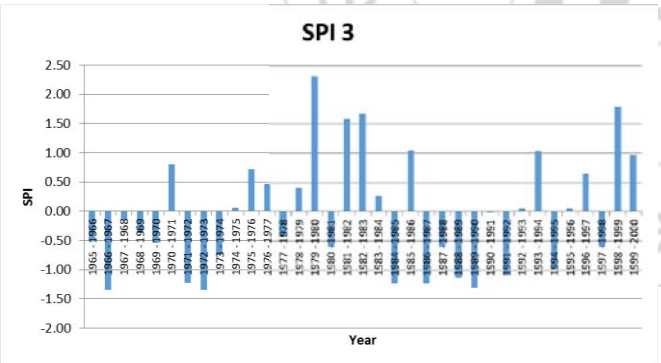

Figure 2: SPI-3 of Amreli District

Similarly, Analysis of SPI-6 value shows that, the moderate drought occurred in 1972-73,1984-85,1986-87, 1988-89, 1991-92 and 1994-95 in Amreli District. There was no severe or extreme drought occurred but extremely wet period was recorded in year 1979-80 as shown in Figure 3.

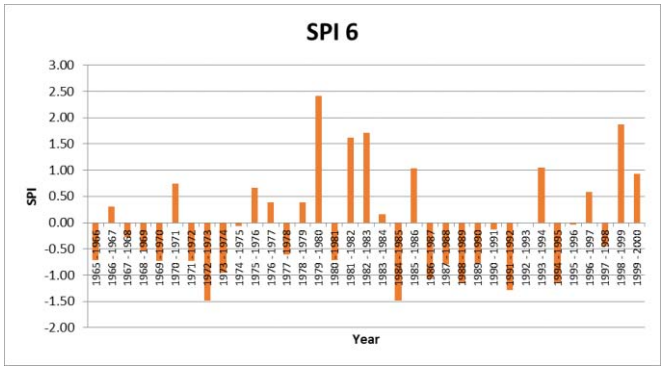

Figure 3: SPI-6 of Amreli District

According to Figure 4 shown below, the moderate drought years were recorded in 1967-68, 1973-74, 1984-85, 1986 to 1988 and 1990 to 1993, severe drought in year 1984-85 and 1994-95 and extremely wet period was recorded in year 1979-80 and 1982-83 in Amreli station as per SPI-9.

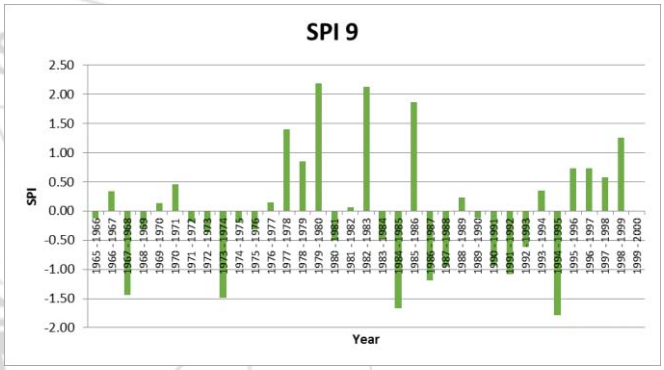

Figure 4: SPI-9 of Amreli District

Analyzing SPI-12, the moderately dry years were recorded in 1965-66, 1968-69, 1971-72, 1973 to 1976, 1984-85 and 1994-95, extremely dry period was recorded in 1986-87 and there was extremely wet period recorded in year 1979-80 and 1982-83 as shown in Figure 5.

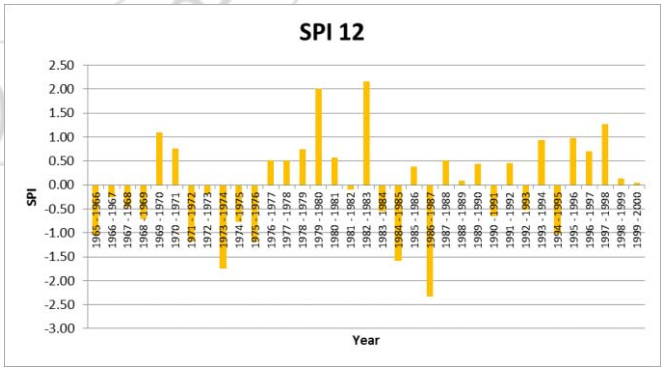

Figure 5: SPI-12 of Amreli District

According to SPI values of 3, 6, 9 and 12 months, the drought severity of the Amreli district has been categorizes by three classes. i.e., Moderate, Severe and Extreme drought.

Table 3: Drought Severity using SPI-3, SPI-6, SPI-9 and SPI-12 as per Mackee's Classification Table

SPI	*Severity*	*Months*	*Years*
3 Month	Moderate	Jun – Aug	1966-67, 1971-1973, 1984-85, 1986-87, 1988-90, 1991-92, 1994-95
	Severe	Jun – Aug	-
	Extreme	Jun – Aug	-
6 Month	Moderate	Jun – Nov	1972-73, 1984-85, 1986-87, 1988-89, 1991-92, 1994-95
	Severe	Jun – Nov	-
	Extreme	Jun – Nov	-
9 Month	Moderate	Jun – Feb	1967-68, 1973-74, 1986-87, 1991-92
	Severe	Jun – Feb	1984-85, 1994-95
	Extreme	Jun – Feb	-
12 Month	Moderate	Jun – May	1971-72, 1975-76, 1994-95
	Severe	Jun – May	1973-74, 1984-85
	Extreme	Jun – May	1986-87

As shown in Figure 6 and Figure 7, there is increasing trend in Graph of SPI-3 and SPI-6 from year 1965 to 2000. Also, it can be seen that, from 1966 to 1986 there was drought period. And after that, from 1987 to 2000 there was wet period in Amreli district.

Figure 6: Trend Analysis of Amreli District Using SPI-3

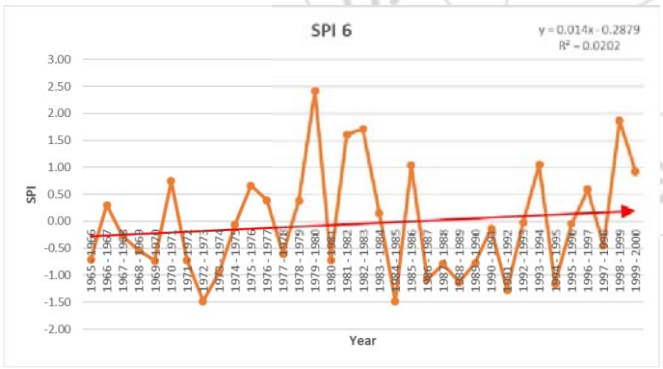

Figure 7: Trend Analysis of Amreli District Using SPI-6

According to Figure 8, it can be seen that, from 1966 to 1985 there was dry period and from 1986 to 2000 wet period is recorded. Also the Graph shows increasing trend for SPI-9.

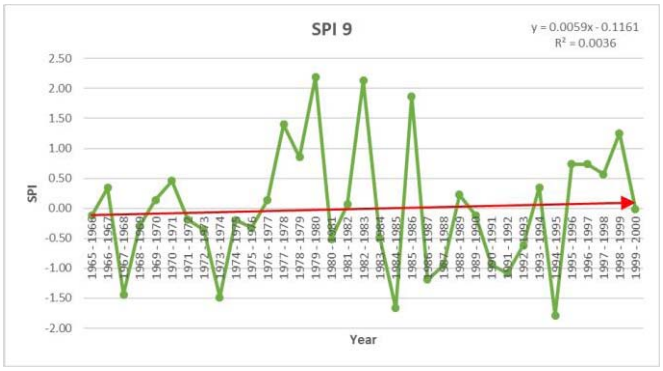

Figure 8: Trend Analysis of Amreli District Using SPI-9

According to Figure 9, it can be seen that, from 1966 to 1985 there was dry period and from 1986 to 2000 wet period is recorded. Also the Graph shows increasing trend for SPI-12.

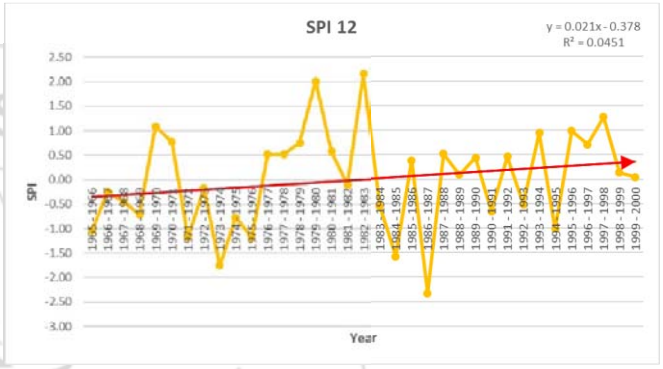

Figure 9: Trend Analysis of Amreli District Using SPI-12

Figure 6, Figure 7, Figure 8 and Figure 9 shows the trend analysis of SPI 3, SPI 6 and SPI 9 and SPI 12 respectively of Amreli district. Graphs shows that, SPI index is following increasing trend which indicates that severity of draught is decreasing and region is moving toward wet condition.

4.2 Drought Period & Trend Analysis Using RDI Values

After analyzing Figure 10, the 3 month RDI value shows that, moderate drought occurred in Amreli during 1966-67, 1971-1973, 1984-85, 1986-87, 1988-1990 and 1991-92 and there was no severe or extreme drought occurred. But there was an extremely wet period recorded in the year 1979-80.

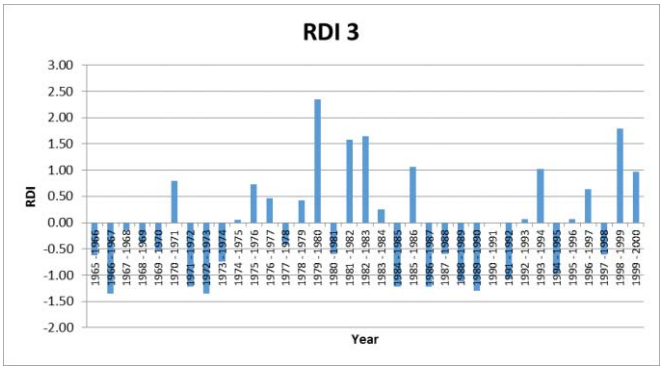

Figure 10: RDI-3 of Amreli District

RDI 6 value shows that, the moderate drought was occurred in 1972-73, 1984-85, 1986-87, 1988-89, 1991-92 and 1994-95 in Amreli District and there was no severe or extreme

drought occurred. But there was an extremely wet period recorded in the year 1979-80 as shown in Figure 11.

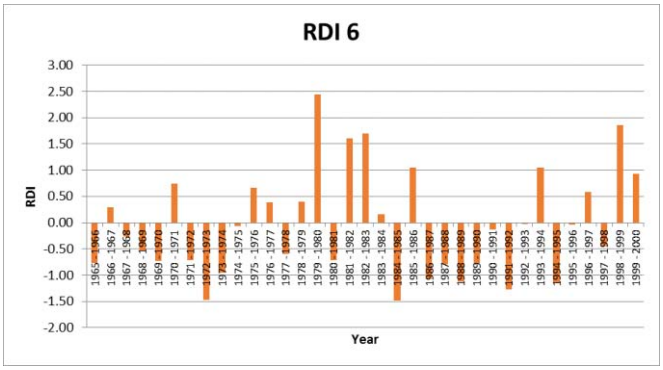

Figure 11: RDI-6 of Amreli District

RDI value shows that, during 1984-85 and 1994-95 there has been severe drought conditions in Amreli district. There is no extreme drought found in Amreli in any year between 1966-2000. But there were two extremely wet years occurred in year 1979-80 and 1982-83 as shown in Figure 12.

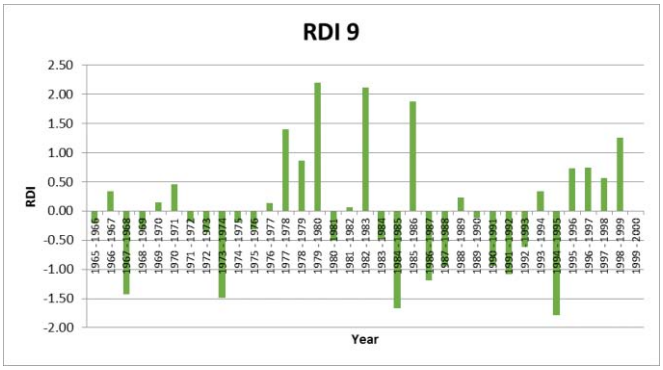

Figure 12: RDI-9 of Amreli District

After analyzing Figure 13 the 12 month RDI value shows that, there were severe drought conditions in Amreli district during 1973-74 and 1984-85. Also it shows an extreme drought during 1986-87. And during 1982-83 there was extreme wet situation.

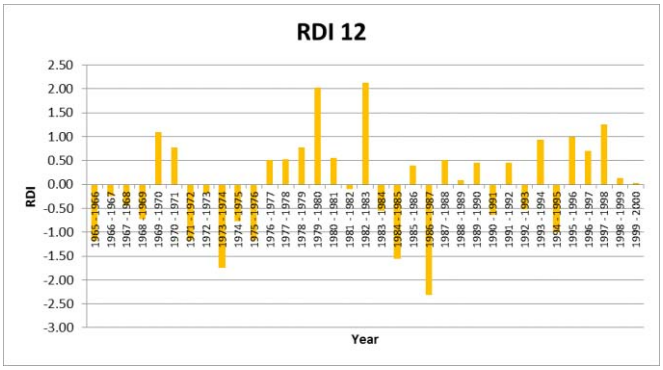

Figure 13: RDI-12 of Amreli District

According to RDI value the drought severity years of the Amreli district have been categories by three classes. i.e., Moderate, severe and extreme drought, which is as shown below in the Table 4. In this study the RDI value is found out at 3, 6, 9 and 12 months.

Table 4: Drought Severity using RDI-3, RDI-6, RDI-9 and RDI-12 as per Tsakiris' Classification Table

RDI	*Severity*	*Months*	*Years*
3 Month	Moderate	Jun – Aug	1966-67, 1971-1973, 1984-85,
	Severe	Jun – Aug	1986-87, 1988-1990, 1991-92
	Extreme	Jun – Aug	-
6 Month	Moderate	Jun – Nov	-
	Severe	Jun – Nov	1972-73, 1984-85, 1986-87,
	Extreme	Jun – Nov	1988-89, 1991-92, 1994-95
9 Month	Moderate	Jun – Feb	-
	Severe	Jun – Feb	-
	Extreme	Jun – Feb	1967-68, 1973-74, 1986-87, 1991-92
12 Month	Moderate	Jun – May	1984-85, 1994-95
	Severe	Jun – May	-
	Extreme	Jun – May	1965-66, 1971-72, 1975-76, 1994-95

As shown in Figure 14 and Figure 15, the trend analysis of RDI-3 and RDI-6 respectively. It can be seen that the Graph is following increasing trend during 1965 to 2000. According to RDI trend analysis, during 1965-66 to 1982-83 there was Dry period in Amreli. Likewise, from 1983-84 to 2000 Amreli station was under wet period. Also the drought period was varied from normal to moderate.

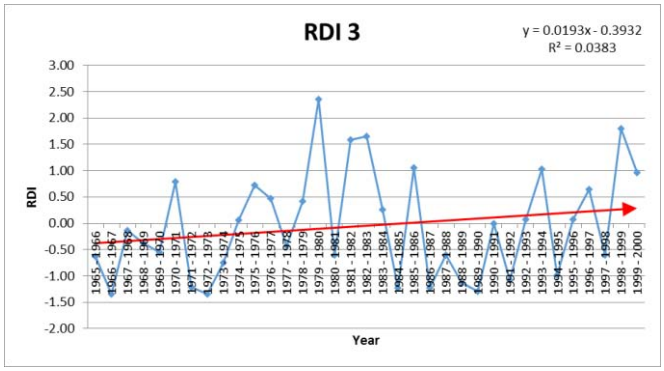

Figure 14: Trend Analysis of Amreli District Using RDI-3

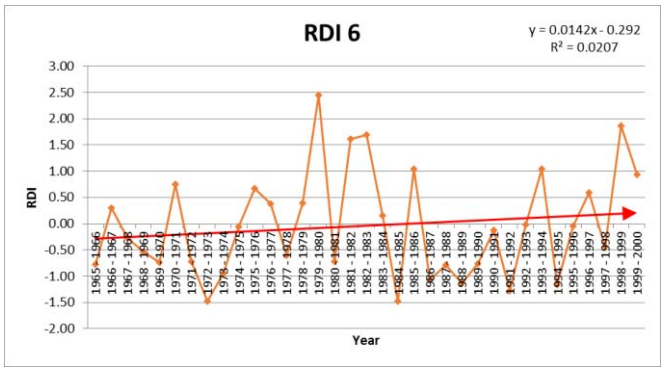

Figure 15: Trend Analysis of Amreli District Using RDI-6

As shown in Figure 16, the trend analysis of RDI-9 shows that the Graph is following increasing trend during 1965 to 2000. And during 1965-66 to 1982-83 there was Dry period in Amreli. Likewise, from 1983-84 to 2000 Amreli station was under wet period.

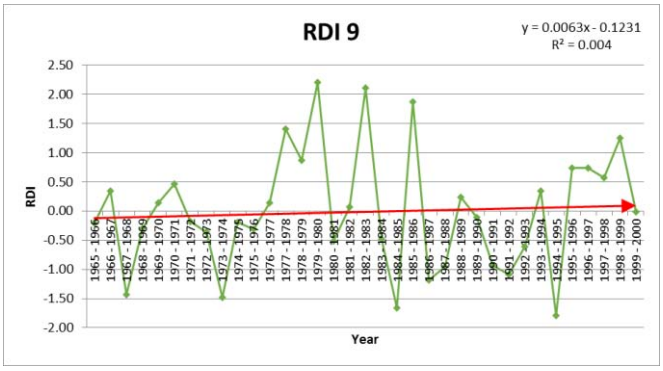

Figure 16: Trend Analysis of Amreli District Using RDI-9

As shown in Figure 17, It can be seen that the Graph is following increasing trend during 1965 to 2000. According to RDI-12 trend analysis, during 1965-66 to 1982-83 there was Dry period in Amreli. Likewise, from 1983-84 to 2000 Amreli station was under wet period.

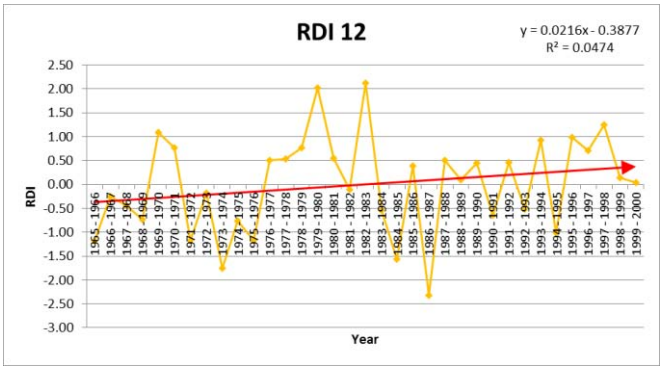

Figure 17: Trend Analysis of Amreli District Using RDI-12

As per Figure 14, Figure 15, Figure 16 & Figure 17 the trend analysis of RDI 3, RDI 6 and RDI 9 and RDI 12 respectively of Amreli district. Graphs shows that, RDI Index is following increasing trend which indicates that severity of draught is decreasing and region is moving toward wet condition.

5. Conclusions

The frequency of drought events was calculated using the Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) and it is also used to detect the changes in duration and severity of drought in Amreli District.

As per this study, the main benefit of SPI is its versatility, because only rainfall data is required to identify duration, intensity, severity, and frequency of drought. Furthermore, drought can be calculated in different time steps.

The RDI (standardized) shows advantages over SPI by including PET as 2nd parameter in addition to rainfall. But the results for Amreli district shows that there in not much difference in the values of RDI and SPI. Although RDI seems to be a little more accurate than SPI due to use of an extra parameter in calculation.

In this paper, SPI-3, SPI-6, SPI-9 and SPI-12 have been calculated for the purpose of drought assessment. The analysis of various graphs shows that the 12 month indices is more accurate in compare of other three. The analysis of SPI-12 shows that, there was dry period during 1966 to 1983 and wet period during 1984 to 2000 following an increasing trend. Moderate drought was recorded during 1971-72, 1975-76, 1994-95 and severe drought was during year 1973-74 and 1984-85. In 1986-87 extreme drought was recorded in year span of 1965-2000.

Similarly, RDI-3, RDI-6, RDI-9 and RDI-12 was calculated for the purpose of drought assessment. The analysis of RDI-12 shows that, there was dry period during 1965 to 1983 and wet period during 1984 to 2000. Moderate drought was recorded during 1965-66, 1971-72, 1975-76, 1994-95 and severe drought was during year 1973-74 and 1984-85. In 1986-87 extreme drought was recorded in year span of 1965-2000. Here RDI proves to be more precise in detecting drought as it shows more number of drought years in compare of SPI.

As per trend analysis of SPI and RDI (3, 6, 9 and 12 months), there was no significant and continuous trend observed but dry and wet periods can be distinguished. Drought period was observed from 1965-66 to 1981-82. Severity of drought is decreasing from 1982-83 to 1999-2000.

At shorter time scales (i.e., 3 months), the SPI and RDI values are fluctuated frequently above and below the zero line, and there was no extended dry or wet period. The 12 month SPI and RDI series shows well-defined wet periods and dry periods compared to 3 months. The performance of indices at various time scales in representing individual drought and flood events appears different from identifying dry/wet periods. As has been discussed, for identifying dry/wet periods, SPI 12 and RDI 12 shows greater utility than SPI 3 and RDI 3. Thus, it is better to use SPI and RDI of 12 months' index for analysis of drought for this study. Overall, there was moderate drought situation in Amreli but the duration and intensity was above normal.

References

[1] Edwards, D.C. and McKee, T.B., "Characteristics of 20th century drought in the united states at multiple time scales," Atmospheric Science Paper No. 634, pp 1-129, 1997.
[2] Khadr, M., Morgenschweis, G. and Schlenkhoff, A., "Analysis of Meteorological Drought in the Ruhr Basin by Using the Standardized Precipitation Index," International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:3, pp 291-300, 2013.
[3] McKee, T. B., Doesken, N.J. and Kleist, J., "The relationship of drought frequency and duration to time scales," Eighth Conference on Applied Climatology, Anaheim, CA, pp 179-184, 1993.
[4] Tigkas, D., Vangelis, H. and Tsakiris, G., "DrinC: a software for drought analysis based on drought indices," Earth Science Inform (8), pp 697–709, 2014.
[5] Tsakiris, G., and Vangelis, H., "Establishing a Drought Index Incorporating Evapotranspiration," European Water (9/10), pp 3-11, 2005.

[6] Tsakiris, G., Pangalou, D. and Vangelis, H., –Regional Drought Assessment Based on the Reconnaissance Drought Index (RDI),” Water Resources Management (21), pp 821–833, 2006.

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