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Meteorological drought trend analysis by standardized precipitation index (SPI) and reconnaissance drought index (RDI): a case study of Gajapati District

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Abstract

Drought is taken into account as a natural hazard, which might be characterized mainly by its severity, duration, and areal extent. Among the above three dimensions, drought severity is that the main factor through which drought analysis was done. The paper aims at presenting the overall meteorological drought analysis of Gajapati District of Odisha by Reconnaissance Drought Index (RDI) and Standard Precipitation Index (SPI), through DrinC software using SPI-3, SPI-6, SPI-9 & SPI-12, and RDI-3, RDI-6, RDI-9 & RDI 12 which were computed at multiple time steps (3, 6, 9 and 12-month) for the period 1967-2002. The 12-month SPI and RDI series shows well-defined wet periods and dry periods compared to other months. It has been discussed, for identifying dry/wet periods, SPI 12 and RDI 12 shows greater utility than SPI 3 and RDI 3. The analysis of RDI-12 shows that, there was a Moderate drought recorded during 1967-68, 1973-74, 1984-85, 1987-88. In the Gajapati region drought index, by SPI & RDI method showed that extremely affected by drought among 35 years was 1972-73 and severe drought occurred in 1979-80. Overall, there was a moderate drought situation within the Gajapati district.

Keywords: Drought, standard precipitation Index (SPI), reconnaissance drought index (RDI), dry period

1. Introduction

Drought is characterized by deficit supply of moisture resulting from subnormal rainfall over the large areas causing below normal natural availability of water over long periods of time. Drought has been increased gradually in number and intensity in various parts of the globe. Drought could be a decrease in water availability during a particular period and over a specific area.

The escalating impacts of droughts have increasingly drawn the eye of scientists, planners, and society. The vulnerability to drought is in reference to the increasing needs of the growing population has become some extent of great concern, especially on the food front. In spite of technological developments in providing the improved crop varieties and good management practices, in India, agriculture has been considered as important as agricultural productivity is usually influenced by vagaries of the monsoon.

Drought phenomenon could be a hydrological extreme like floods and could be a natural disaster. However, unlike floods the droughts are of the creeping kind; they develop in a very region over a length of your time and sometimes may reach continental scale. The implications of droughts on agricultural production, hydropower generation, and also the regional economy, in general, are well-known.

Drought time slow-onset of natural disaster also an insidious and creeping phenomenon that mostly occurs in virtually all the climatic regimes. Drought is additionally being associated with the timing and effectiveness of rains; thus, every drought year is exclusive in its climatic characteristic and impact.

Drought may also be described by the three characteristics: intensity, duration, and spatial coverage. Intensity refers to the degree of precipitation shortfall and is extremely closely linked to the duration within the determination of its impacts.

To some extent, drought occurs with uncertainty at a micro-scale, and drought occurrence sites vary from time to time while studying spatial distributions of drought (Wang and Wei, 1998).

Many classifications of droughts are available within the literature. In India commission of agriculture (1976) has categorized the drought into three types, viz., meteorological drought, hydrological drought, and agricultural drought supported the concept of its utilization. To a meteorologist, drought is that the absence of rain while to the agriculturist it's the deficiency of soil moisture within the crop root zone to assist in crop growth and productivity. A drought could be a complex event that will impair social, agricultural, economic, and other activities of the society. it's a chronic, abnormally dry period when there's a shortage of water for normal needs. it's temporary also sometimes recurring natural disaster, which originates because of an absence of precipitation and brings significant economic losses.

Meteorological drought

It is a situation where there's over 25% decrease in precipitation from normal over a region.

Hydrological drought

Meteorological drought, if lengthens, leads to the hydrological drought with significant depletion of surface water and groundwater. the implications are the desiccation of tanks, reservoirs, streams and rivers, cessation of springs and fall within the geological formation.

Agricultural drought

This occurs when the moisture of soil and rainfall are less during the **season to boost** the healthy crop growth to maturity. **there'll** be extreme crop stress and wilt conditions.

1.1.1 Meteorological drought

The India Meteorological Department (IMD) has adopted the subsequent criteria for sub-classification of meteorological droughts. A meteorological sub-division is taken into account to be stricken by drought if it receives a complete seasonal rainfall but that of 75% of the conventional value. Also, the drought is assessed as moderate if the seasonal deficiency is between 26% and 50%. The drought is claimed to be severe if the deficiency is above 50% of the conventional value. Further, a year is taken into account to be a drought year just in case the world stricken by moderate or severe drought either individually or collectively is over 20% of the overall area of the country.

If the drought occurs in a district with a probability $0.2 \leq P \leq 0.4$, the world is assessed as drought prone area, if the probability of occurrence of drought at an area is bigger than 0.4, such a district is termed as chronically drought prone area. Further, in India the meteorological drought is normally associated with the onset, breaks and withdrawal times of monsoon within the region. As such, the prediction of the occurrence of drought in an exceedingly region within the country is closely associated with the forecast of deficient monsoon season and its distribution. Accurate forecast of drought, unfortunately, remains uphill.

1.1.2 Hydrological drought

From a hydrologist's point of view drought means below average values of stream flow, contents in tanks and reservoirs, groundwater and soil moisture. Such a hydrological drought has four components:

- Magnitude (= amount of deficiency)
- Duration
- Severity (= cumulative amount of deficiency)
- Frequency of occurrence

The beginning of a drought is very difficult to work out as drought could be a creeping phenomenon. However, the top of the drought is comparatively easy to work out when adequate rainfall saturates the soil mass and restores the stream flow and reservoir contents to normal values.

In the studies on hydrological drought different techniques should be adopted for study of (i) surface water deficit, and (ii) groundwater deficit. The surface water aspect of drought study is expounded to the stream and therefore the following techniques are commonly adopted:

- Low-flow duration curve
- Low-flow frequency analysis and
- Stream flow modeling.

Such studies are particularly important in reference to the look and operation of reservoirs, diversion of stream flow for irrigation, power and water needs; and all told activities associated with water quality.

1.1.3 Agricultural drought

Deficiency of rainfall has been the principal criteria for outlining agricultural drought. However, counting on whether the study is at regional level, crop level or plant level there are a range of definitions. Considering the assorted phases of growth of a crop and its corresponding water requirements, the duration for water deficiency in agricultural drought will should be much smaller than in hydrological drought studies. Further, these are going to be not only regional specific but also crop and soil specific.

An aridity index (AI) is defined as

$$AI = \frac{AET - PET}{PET} \times 100$$

Where, PET = Potential evapotranspiration and
AET = Actual evapotranspiration

In this AI calculation, AET is calculated in step with Thornthwaite's water balance technique PET, actual rainfall and cubature unit of the soil. it's common to calculate the AI on weekly or bi-weekly basis. AI is usually used as an indicator of moisture stress experienced by crops. The departure of AI from its normal value, called AI anomaly, represents the moisture shortage. supported AI anomaly, the intensity of the agricultural drought is assessed as follows:

Table 1: Intensity of agricultural drought.

AI anomaly	Severity class
Zero or negative	Non-arid
1 –25	Mild arid
26 –50	Moderate arid
> 50	Severe arid

In addition to the AI index, there are other indices rather like the Palmer index (PI) and also the Moisture availability index (MAI) which are aware of characterize agricultural drought. IMD produces aridity index (AI) anomaly maps of India on a bi-weekly basis supported data from 210 stations representing different agro-climatic zones within the country. These are useful in planning and management of agricultural operations especially within the drought-prone areas. Keeping insight, the analysis of drought indices within the districts of Gajapati,

the current study is undertaken with the subsequent objectives:

1. To evaluate the drought indices.
2. To analyze the severity of drought in study area.

2. Material and methods

The present study was to compute the drought indices SPI and RDI, values for various time using the most and minimum temperature, Precipitation of Gajapati District, (ODISHA) state of INDIA.

2.1 Study areas

Gajapati is a district of Odisha, India. Covering an area of 3850 sq. km, Gajapati District lies between 18° 6' to 19° 39' North Latitude and 83° 48' to 84° 08' East Longitude.

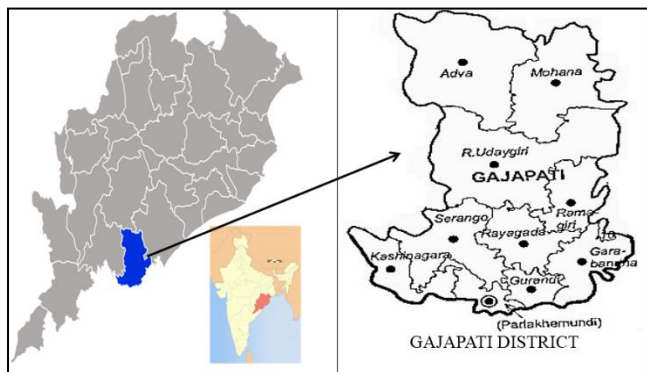


Fig 1: District Map of GAJAPATI

2.1.1. Climate, Location and Soil

The climatic condition within the Gajapati District varies from 16 to 45 °C and therefore the normal rainfall received is 1403.30 mm. The District is being surrounded by Ganjam District in its East, state in its South, Rayagada in its West, and Kandhamal in its North. The soil and therefore the climate is very suitable for plantation of crops and there's the great potential of horticulture development within the District. over hr of the lands are located within the hilly terrain and high lands, mainly suitable for horticulture. The ratio ranges from 45 to 85% and is high during NE monsoon. Red Loamy soils, Laterite Soils, Black soils represent my study area. Red sandy loam deep soil is found to be most typical during this district.

2.2 Data Acquisition

2.2.1 Meteorological and hydrological data

The meteorological data required for the study were collected from the Indian Meteorological Department (IMD) website (Gajapati district). the information includes the most and minimum temperature, precipitation, and also daily streamflow data of 35 years from 1967-2002 respectively. The hydrological data required for the study were collected from India-Wris, at Kashinagar, the station of the Banshadhara basin.

2.3 Software used

2.3.1 DrinC

DrinC (Drought Indices Calculator) accustomed provide a user-friendly tool for the estimation of several drought indices. the most objective in its design was the widest possible applicability for several styles of drought (meteorological, hydrological, agricultural) and different locations. it had been also taken under consideration that

drought studies are particularly essential in arid and semi-arid regions, where data availability is typically limited.

2.3.2 Drought indices overview

A short description supported the severity of the drought; the drought indices is given below. The key objectives for the choice of indices were: a) to own a comparatively low data requirement, which permits applying the software in several regions and b) the results must be clear for the interpretation of direct and efficient operational use. Based on these criteria, two newly developed and two more widely known indices were included within the DrinC: The Precipitation Deciles (PD), the Standardized Precipitation Index (SPI), the Reconnaissance Drought Index (RDI) and therefore the Streamflow Drought Index (SDI). For easy understanding, SPI, RDI, and PD check with the meteorological drought during which precipitation was used because of the main determinant (and additionally the potential evapotranspiration for RDI only).

2.3.3 Standard Precipitation Index (SPI)

for the SPI calculation, the long-term precipitation record for the specified period was fitted to a probability distribution, which was then transformed into a standard distribution so the mean SPI for the situation and desired period is zero (McKee *et al.* 1993; Edwards and McKee 1997). Positive SPI values indicate greater than median precipitation, and negative values indicates less than median precipitation. Since SPI is normalized, wetter and drier climates can be represented in the same way.

Thom (1958) found the gamma distribution to fit well to the climatological precipitation time series. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}, \text{ for } x = 0$$

In which α and β are the form and scale parameters respectively, x is that the precipitation amount and $\Gamma(\alpha)$ is that the gamma function. Parameters α and β of the gamma pdf are estimated for every station and for every continuance of interest (1, 3, 6, 9, 12 months, etc.). Maximum likelihood estimations of α and β are:

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \beta = \frac{\hat{x}}{a} \text{ where } A = \ln(\hat{x}) - \frac{\sum \ln(x)}{n}$$

and n is that the number of observations. The resulting parameters are then went to find the cumulative probability of an observed precipitation event for the given month and continuance for the placement in question. Since the gamma function isn't defined for $x=0$ and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q) G(x)$$

in which q is that the probability of zero precipitation and $G(x)$ is that the cumulative probability of the unfinished gamma function. If m is that the number of zeros during a precipitation statistic, then q is often estimated by m/n . The cumulative probability $H(x)$, is then transformed to the quality normal stochastic variable z with mean zero and variance of 1 (Abramovitz and Stegun 1965), which is that the value of the SPI. According to the SPI, a drought spell occurs when the

index value continuously reaches an intensity of -1.0 or less. The spell ends when the SPI becomes positive. Each drought spell, therefore, incorporates a duration defined by its beginning and end, and intensity for each month that the event continues. Drought magnitude is that the positive sum of the SPI for each month during the drought event (Hayes *et al.* 2007). Generally, monthly precipitation isn't normally distributed so a change is performed such the derived SPI values follow a typical distribution. The SPI is that the number of ordinary deviations that the observed value would deviate from the long-term mean, for a normally distributed variant. One interpretation of the resultant values is presented in Table (Tsakiris and Vangelis 2004).

Table 2: Classification of drought conditions according to the SPI

SPI values	Classification
2.0 or more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 or less	Extremely dry

2.3.4 Reconnaissance drought index (RDI)

The Reconnaissance Drought Index (RDI) was developed to know the water deficit during a more accurate way, as a form of balance between input and output during a water system (Tsakiris and Vangelis 2005; Tsakiris *et al.* 2007c). RDI is based both on cumulative precipitation (P) and potential

evapotranspiration (PET), which is one measured (P) and other one calculated (PET) determinant. The value (α_k) of RDI is calculated for the i -th year during on the basis of time of k (months) as follows

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^k P(i,j)}{\sum_{j=1}^k PET_{ij}}, i = 1(1)N \wedge j = 1(1)k$$

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. The values of α_k follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested (Tigkas 2008; Tsakiris *et al.* 2008). By assuming that the lognormal distribution is applied, the following equation can be used for the calculation of RDIst:

$$RDIst^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}_y}$$

in which $y^{(i)}$ is the $\ln(\alpha_k(i))$, \bar{y} is its arithmetic mean and $\hat{\sigma}_y$ is its standard deviation.

In case the gamma distribution is applied, the RDIst can be calculated by fitting the gamma probability density function (pdf) to the given frequency distribution of α_k (Tsakiris *et al.* 2008; Tigkas 2008).

Positive values of RDIst indicate wet periods, while negative values indicate dry period compared with the conventional conditions of the realm.

Table 3: Classification of drought conditions according to the RDI

State	Description	Criterion
01	mild	-0.5 to -1.0
02	moderate	-1.0 to -1.5
03	severe	-1.5 to -2.0
04	extreme	< -2.0

2.4 Methodology

Potential evapotranspiration is calculated by using meteorological data like maximum and minimum temperature by the Hargreaves method. RDI and SPI confer with the meteorological drought, whose key determinant is precipitation. RDI will be used for agricultural drought analysis, adequately describe the water balance, and useful for development stages of crop.

RDI is based upon cumulative precipitation (P) and potential evapotranspiration (PET) in which P is measured and PET was calculated. The first reference base in DrinC is that the hydrological year (October- September), therefore the default calculation period starts from October, and also the main calculation steps are 3-months, 6-months, 9-months and annual. This flexibility is also useful for several real-world applications; for example, the study of drought effects on specific crops should coincide with the crop growth period. Calculation of drought indices like Reconnaissance Drought Index (RDI) and Standard Precipitation Index (SPI), was discovered. DrinC facilitates the above indices calculation supported the log-normal method and gamma method both with a period of annual and monthly.

3. Results and Discussion

In this study, DrinC software was accustomed calculate the drought indices SPI and RDI, within the Gajapati district. Both the indices of drought discussed below with graphs.

within the study we've got used meteorological data of 35 years (1967-2002).

3.1 Drought analysis of Gajapati

3.1.1 Drought Period analysis by SPI for Gajapati district:

Analyzing SPI-3 value, the moderate drought occurred in 1970-71, 1988-90, and 2000-01 in Gajapati District and extreme drought occurred in 1967-68, 1981-82, and 1984-85. There was no severe drought occurred. as shown in Figure 2.

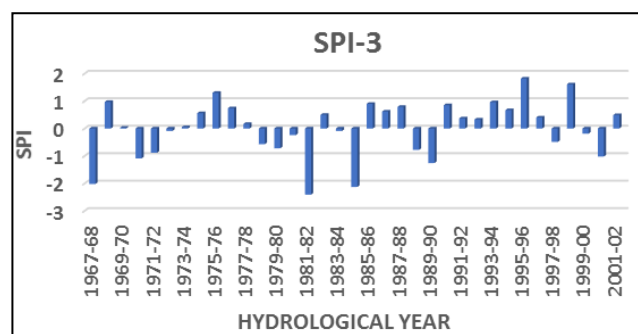


Fig 2: Drought index by SPI for Gajapati district

Similarly, the Analysis of SPI-6 value shows that, the moderate drought occurred in 1967-68, 1988-89 and 2000-01 in Gajapati District. There was no severe drought occurred but

the extremely dry period was recorded in the year 1981-82, 1984-85, 1989-90 as shown in Figure 3.

There was a extreme drought in 1967-68,1981-82 and 1984-85, there was no severe drought occurred.

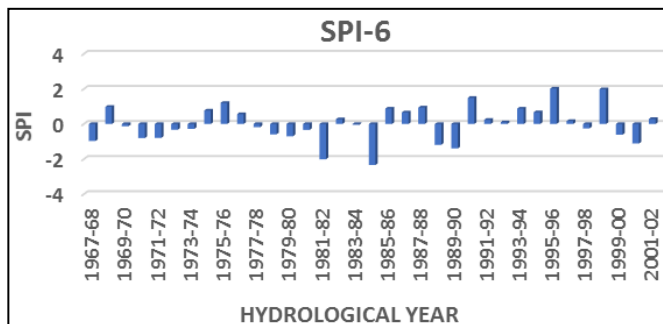


Fig 3: Drought index by SPI for Gajapati district

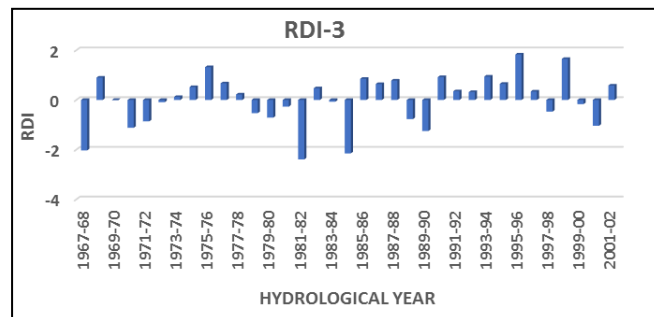


Fig 6: Drought index by RDI for Gajapati district

According to Figure 4 shown below, the moderate drought years were recorded in 1967-68, 1973-74, 1989-90, 1997-98, severe drought in year 1988-89 and extremely dry period was recorded in year 1972-73 and 1981-82 in Gajapati district as per SPI-9

RDI-6 value shows that, the mild drought occurred in 1967-68, 1970-71, 1971-72, 1979-80, and 1999-00 in Gajapati District, a moderate drought occurred in 1988-89, 1989-90, and 2000-01. There was a severe or extreme drought that occurred in 1981-82 and 1984-85 respectively as shown in Figure 7

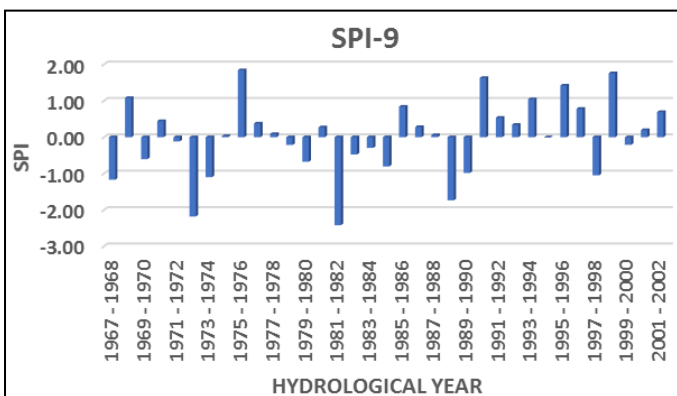


Fig 4: Drought index by SPI for Gajapati district

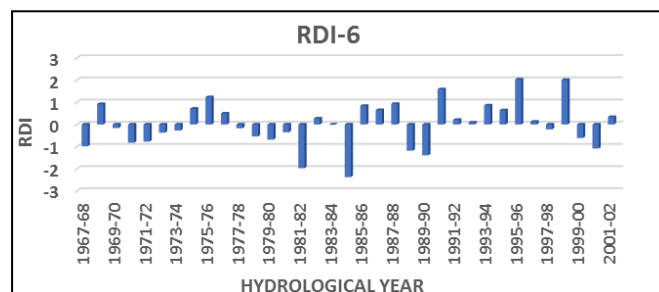


Fig 7: Drought index by RDI for Gajapati district

Analyzing SPI-12, the moderately dry years were recorded in 1967-68, 1973-74, 1984-85, 1987-88, the severely dry period was recorded in 1979-80 and there was extremely dry period recorded in the year 1972-73 as shown in Figure 5.

RDI-9 value shows that, the mild drought occurred in 1969-70, 1982-83, 1989-90, and 1997-98 in Gajapati District, a moderate drought occurred in 1967-68, 1973-74, 1979-80, and 1984-85. There was a severe drought that occurred in 1988-89 and extreme drought occurred in 1972-73 and 1981-82 as shown in Figure 8.

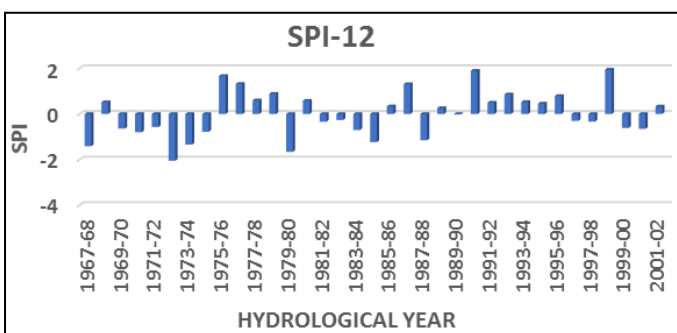


Fig 5: Drought index by SPI for Gajapati district

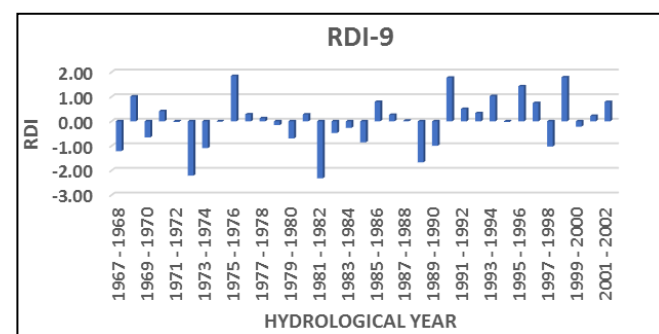


Fig 8: Drought index by RDI for Gajapati district

3.1.2 Drought index by RDI for Gajapati district:

After analyzing Figure 6, the 3-month RDI value shows that, a mild drought occurred in Gajapati during 1988-89, a moderate drought occurred in 1970-71, 1989-90 and 2000-01.

After analyzing Figure 9 the 12-month RDI value shows that, the mild drought occurred in 1969-70, 1970-72, 1974-75, 1983-84, 1999-00, and 2000-01 in Gajapati District, a moderate drought occurred in 1967-68, 1973-74, 1984-85 and 1987-88. There was a severe drought that occurred in 1979-80 and extreme drought occurred in 1972-73.

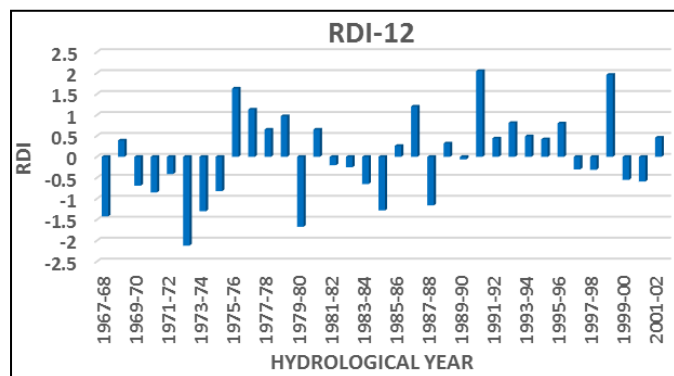


Fig 9: Drought index by RDI for Gajapati district

4. Summary and 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 Gajapati District.

The RDI (standardized) shows advantages over SPI by including PET as 2nd parameter in addition to rainfall. But the results for Gajapati district shows that there is 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. The main findings of the study are as follows:

- In Gajapati region drought index, by SPI & RDI method it showed that extremely affected by drought among 35 was 1972-73 and severe drought occurred in 1979-80
- The above analysis showed that the SPI and RDI are undoubtedly co-related and predict the yearly RDI index, even if first three months rainfall data is available.
- In this paper, SPI-3, SPI-6, SPI-9, and SPI-12 are calculated for the aim of drought assessment. The analysis of assorted graphs shows that the 12-month indices are more accurate as compared to the other three. The analysis of SPI-12 shows that there was Moderate drought was recorded during 1967-68, 1973-74, 1984-85, 1987-88, and severe drought was during the year 1979-80. In 1972-73 extreme drought was recorded within the year span of 1967-2002. Similarly, RDI-3, RDI-6, RDI-9, and RDI-12 were calculated for the purpose of drought assessment. The analysis of RDI-12 shows that, there was a Moderate drought was recorded during 1967-68, 1973-74, 1984-85, 1987-88, and severe drought was during the years 1979-80 and 1984-85. In 1972-73 extreme drought was recorded in the year span of 1967-2002. Here The results showed that RDI and SPI are significantly correlated. At shorter time scales (i.e., 3 months), the SPI and RDI values are fluctuated frequently dry or wet period. The 12-month SPI and RDI series shows well-defined wet periods and dry periods compared to three months. It has been discussed, for identifying dry/wet periods, SPI 12 and RDI 12 shows greater utility than SPI 3 and RDI 3. Thus, it's better to use SPI and RDI of 12 months' index for analysis of drought for this study. Overall, there was a moderate drought situation within the Gajapati district.

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