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Assessment of meteorological drought in western central table land agro-climatic zone of Odisha, India

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Abstract

In this paper, assessment of meteorological drought has been carried out by standardized precipitation index (SPI) for Western Central Table Land Agro-climatic Zone covering six districts of Odisha, India. Monthly rainfall data of 115 years (1901-2015) for all the six districts of this agro-climatic zone of Odisha were analyzed using SPI on different time scales of 1, 3, 6, 9, and 12-month. Results indicate that mild drought events have the highest frequencies of occurrence followed by moderate drought events for all timescales under analysis in all the districts. The average total frequency of drought of all intensities are observed to be 54.10% out of which mild, moderate, severe and extreme drought will occur with frequencies of 35.5, 9.5, 6.25 and 2.85%, respectively. 49.25% areas of this agro-climatic zone in the state are affected by drought of various intensities out of which the share of mild, moderate, severe and extreme drought is 28.40, 13.28, 5.05 and 2.52%, respectively.

Keywords: Agro-climatic zone, meteorological drought, standardized precipitation index, western central table land zone

Introduction

Drought is a natural hazard which is caused due to low precipitation than the normal. Its extent over a longer period of time affects human activities and the environment. Its occurrence is uncertain and it cannot be visualized. Difficulty in accurate prediction of its onset and uncertainty about its spread and severity render this phenomenon more harmful. Therefore, the study of drought and preparation of contingency plan based on its characteristics is very important for mankind in general and for government in particular (Dash *et al.* 2013; Panigrahi and Panda 2001) [7, 17]. Identification and classification of drought severity are some of the most difficult aspects of drought management.

Drought indices are used to monitor and assess severity of drought for effective crop and water resources planning. They are helpful to study the impact of climate change and its variability and various anomalies study related to climate change (Wilhite *et al.* 2000; Tsakiris *et al.* 2007) [23, 20]. Moreover, drought indices are helpful to identify and locate places suffering from deficit of available water resources which may affect the effective use of crop production and productivity (Tsakiris *et al.* 2007) [20].

A number of researchers have studied on identification and quantification of drought indices. Most of these drought indices are based either on meteorological or hydrological variables. As reported by Buttafuoco *et al.* (2015) [3] some important indices include the Surface Water Supply Index (SWSI; Shafer and Dezman 1982) [19], the National Rainfall Index (RI; Gommers and Petrassi 1994) [10] and the Standardized Precipitation Index (SPI; McKee *et al.* 1993) [14]. Vicente-Serrano *et al.* (2010) [22] proposed the Standardized Precipitation Evapotranspiration Index (SPEI) which is based on precipitation and temperature data Gocic and Trajkovic (2014) [9] analysed monthly precipitation data from 29 synoptic stations using a number of different multivariate statistical analysis methods to investigate the spatial variability and temporal patterns of precipitation across Serbia. They identified three distinct sub-regions by applying the agglomerative hierarchical cluster analysis to the two component scores.

As reported by Wilhite *et al.* (2000) [23], Bordi and Sutura (2001, 2002) [1, 2] and Livada and Assimakopoulos (2007) [13], standardized precipitation index (SPI) is widely used for drought assessment in many countries of the world. The advantage of using SPI as an effective drought index is that it can be calculated for different time-scales and can be used to analyse different drought categories (Capra and Scicolone 2012) [5]. SPI is easier to calculate than more complex indices as it is based on a single data *i.e.* precipitation alone (Vicente-Serrano 2006; Wu *et al.* 2005) [21, 25].

Drought is a recurring feature of Indian climate. The drought history of India suggests that India is highly vulnerable to drought due to its monsoonal climate and the inherent spatial and temporal variability of rainfall associated with the monsoons. Failure of monsoon rain is the principal cause of drought in India. The monsoon rains are highly erratic and unevenly distributed both in space and time, which results in serious hydrological imbalance. Odisha has less experience of coping with droughts, in comparison to floods, resulting in poor preparedness. Hence, the impact of drought events may be more severe in the state. A systematic analysis of the meteorological drought pattern in Odisha would help in identifying drought scenario and provide an aid to drought management (Panigrahi *et al.* 2002) [18].

Agriculture in the Western Central Table Land Zone in the state of Odisha is mainly rain-fed, as only 42% of the cultivated area has irrigation facilities from various sources. A large chunk of the state's population of 45 million resides mainly in rural areas (81%) in this zone, with a large population of marginal farmers; indicating high level of dependence on agriculture. Nearly, 86% of the annual rainfall is contributed by the southwest monsoon. A delayed/untimely monsoon, and/or less precipitation during the season are indicative of poor crop yield and drought situation, resulting in damaging consequences and reduced coping capacities (CGWB 1999; OMEGA 2014; Panigrahi and Panda 2001) [6, 15, 17].

Drought indices are used to trigger drought relief program and quantify deficit water resources to access drought severity in various regions. Drought places enormous demand on water resources of urban and rural areas and also immense burden on agricultural and energy production. Therefore, timely determination of the level of drought will help in effective decision making process in mitigating environmental, social and costly economic impacts of drought. With this in mind, the study was conducted with the objective of meteorological drought assessment using standardized precipitation index for

different districts in the Western Central Table Land Agro-Climatic Zone of Odisha.

Materials and Methods

Study area

Odisha is a state on the eastern seaboard of India, located between 17°49' and 22°34' North latitudes and between 81°27' and 87°29' East longitudes. It is bounded by the Bay of Bengal on the east; Madhya Pradesh on the west and Andhra Pradesh on the south. Western Central Table Land Zone is one of the biggest agro-climatic zone of Odisha. It is bounded in north by North Western Plateau Zone, in south by Western Undulating Zone, in east by North Eastern Ghat and Mid Central Table Land Zone and in west by the state of Chhattisgarh. The climate is represented by tropical monsoon weather. By early June, the southwest monsoon announces its arrival in the state and departs by the middle of October. Rainfall is the main source of water in this ACZ and the annual value varies from 1200 to 1700 mm across the districts in this ACZ with average of 1480 mm. About 78% of rainfall is received during the monsoon season/rainy season from 1st June to end of September and the remaining 22% is received throughout the year. The soil is light to medium texture and red soils. *Kharif* is the main cropping season and rice is the principal crop during this season. Cropping during *rabi* season is mainly confined to irrigated areas and areas with residual moisture. Other important crops produced in the zone are pulses, oil seeds, fibres (Jute, Mesta, Cotton), sugarcane and vegetables. Mango, Banana, Coconut and Cashew nut are the main horticultural crops of the state. The state of Odisha has been divided into 30 districts covering 10 Agro-Climatic Zones (ACZs). Western Central Table Land Agro-Climatic Zone lies in the western part of the state. It covers six districts namely Bargarh, Bolangir, Boudh, Sonapur and parts of Sambalpur and Jharsuguda. Fig 1 shows view of different ACZs of Odisha including Western Central Table Land Agro-Climatic Zone.

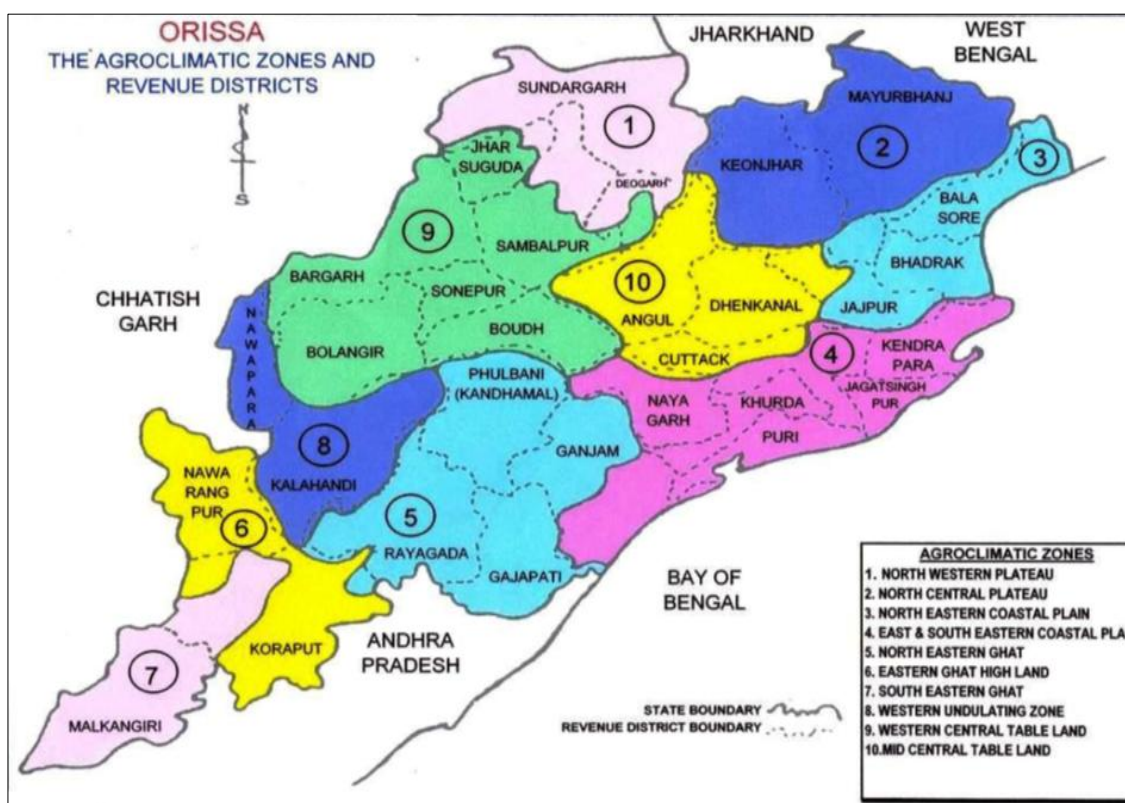


Fig 1: Agro-climatic Zones of Odisha

Data Collection

Meteorological data (rainfall) required for this study were collected from India Meteorological Station (IMD) and Indian Water Portal for a period of 115 years (1901-2015) for all the six districts of Odisha.

Standardized Precipitation Index

In the present study standardized precipitation index (SPI) is used to quantify the deficit of precipitation in various time scales in order to study the severity of drought and their characteristic in different districts and agro climatic zones. These timescales include both short and long term precipitation anomalies. Short term anomalies are generally used in soil moisture study whereas long term anomalies are used for groundwater, stream flow and reservoir storage studies. For these reasons, McKee *et al.* (1993) [14] originally

calculated the SPI for 1, 3, 6, 12, 24 and 48-month timescales. As suggested by Edwards and McKee (1997) [8] for any location, long term precipitation over a desired period is used to compute SPI. This long-term record is then 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. Positive SPI values indicate greater than median precipitation whereas negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way; thus, wet periods can also be monitored using the SPI. McKee *et al.* (1993) [14] used the classification system shown in the SPI value in Table 1 to define drought intensities resulting from the SPI. They also defined the criteria for a drought event for any of the timescales.

Table 1: SPI classification and their values

Category	SPI range
Extremely wet	2.00 or more
Severely wet	1.50 to 1.99
Moderately wet	1.00 to 1.49
Mildly wet	0 to 0.99
Mildly dry	0 to -0.99
Moderately dry	-1.00 to -1.49
Severely dry	-1.5 to -1.99
Extremely dry	-2.00 or less

Source: World Meteorological Organization 2012) [24].

A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues.

Calculation of SPI involves the following steps:

Step1: Calculation of the mean for the normalized precipitation values of the log-normal (ln) rainfall series and compute the shape and scale parameter β and α , respectively by Eqns. (1) to (4). The transformation from cumulative probability distribution into standardized normal distribution is shown in Fig 2.

$$\text{Log mean: } \bar{X}_{ln} = \frac{\sum \ln X}{N} \quad (1)$$

$$\text{Shape parameter: } \beta = \frac{1}{4U} \left[1 + \sqrt{\frac{4U}{3}} \right] \quad (2)$$

$$\text{Scale parameter: } \alpha = \frac{\bar{x}}{\beta} \quad (3)$$

$$\text{where } U \text{ is the constant, } U = \ln \bar{X} - \bar{X}_{ln} \quad (4)$$

Step 2: The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station. As suggested by Edwards and McKee (1997) [8], McKee *et al.* (1993) [14], Caloiero *et al.* (2018) [4], Kumar *et al.* (2009) [11] and Liansangpui *et al.* (2019) [12], cumulative probability distribution suggested

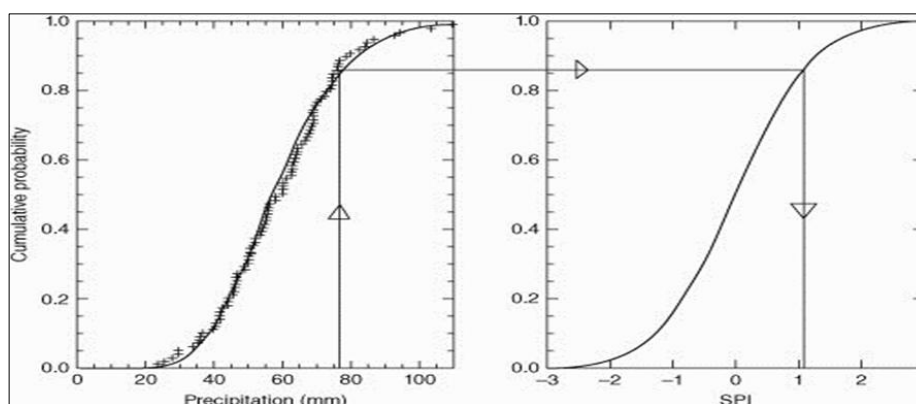


Fig 2: Transformation from cumulative probability distribution into standardized normal distribution

for use is by Gamma distribution which is as follows:

$$G(x) = \frac{1}{\alpha^\beta \Gamma(\beta)} \int_0^x t^{\beta-1} e^{-t/\alpha} dt \quad (5)$$

Letting $t = \frac{x}{\alpha}$, this equation becomes the incomplete gamma function;

$$G(x) = \frac{1}{\Gamma(\beta)} \int_0^{t^\alpha} t^{\beta-1} e^{-t} dt \quad (6)$$

Since the gamma function is undefined for $x=0$ and a precipitation distribution may contain zero, the cumulative probability becomes,

$$H(x) = q + (1 - q).G(x) \quad (7)$$

Where, q is the probability of a zero.

If m is the number of zeros in a precipitation time series, than q can be estimated by m/N . Tables of the incomplete gamma function can be used to determine the cumulative probability $G(x)$. McKee *et al.* (1993) [14] used an analytic method to determine the cumulative probability. The cumulative probability, $H(x)$, is then transformed to the standard normal random variable "Z" with mean zero and variance one, which is the value of the SPI. The Z or SPI values is more easily obtained computationally using an approximation that converts cumulative probability to the standard normal random variable Z (Eqns. 8 to 11).

$$Z = SPI = -\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{ for } 0 < H(x) \leq 0 \quad (8)$$

$$Z = SPI = +\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{ for } 0.5 < H(x) \leq 1.0 \quad (9)$$

$$\text{Where, } t = \sqrt{\frac{1}{(H(x))^2}} \text{ for } 0 < H(x) \leq 0.5 \quad (10)$$

$$t = \sqrt{\frac{1}{(1.0 - H(x))^2}} \text{ for } 0.5 < H(x) \leq 1.0 \quad (11)$$

Where, $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$ and $d_3 = 0.001308$.

In this study, the SPI_SL_6 program developed by the National Drought Mitigation Centre, University of Nebraska-Lincoln has been used to compute time series of drought indices (SPI) for the selected station and for each month of the year at different time scales.

Results and Discussions

Frequency of Occurrence of Drought in Different Time Scales

The Western Central Table Land Agro Climatic Zone has six districts under it. These districts are Bargarh, Bolangir, Boudh, Sonapur and parts of Sambalpur and Jharsuguda. Attempt was made to find out the number of drought years

and its frequency of occurrence during the study period for different time scales of 1, 3, 6, 9 and 12 months (Table 2). The methodology used for assessment of drought by SPI method has been presented earlier in the section Materials and Methods. Based on the range of values of SPI, the drought has been characterised as mild, moderate, severe and extreme (Table 1). Higher mild dryness month were found under long term analysis (9 and 12-month SPI) compared to short term analysis (1, 3 and 6-month SPI) (Table 2). Under the long term analysis, the district Boudh gave the highest frequency (42.10%) for mild drought category while highest frequency of 8.91% of moderate category was found in Bargarh district. Bolangir has the highest severe drought frequency (5.20%) and the highest extreme drought frequency of 3.58% occurred for the district Sambalpur. Boudh district has the highest number of drought in the mild, moderate and severe category under the short term analysis. The frequency for this district is found to be 37.10% for mild dryness, 11.16% for moderate dryness and 5.58% for severe dryness. The highest frequency of 3.19% under extreme dryness is found in Sambalpur. The variation of mild drought in the agro climatic zone ranges from 30.6 to 37.0%, 32.6 to 35.4%, 31.8 to 37.1%, 32.0 to 37.5% and 32.1 to 42.1% for 1, 3, 6, 9 and 12 month time scales. The variation of moderate drought ranges from 8.04 to 11.2%, 6.96 to 9.06%, 7.10 to 8.84%, 6.96 to 8.48% and 7.03 to 8.91% for 1, 3, 6, 9 and 12 month time scales (Table 2).

The different values obtained from the analysis under the concerned timescale were obtained and the 1-month SPI values of Western Central Table Land for the rainy months of June, July, August and September are represented in Figs. 3 to 6 in serial. Similar patterns of graphs/figures for other time scales and all other months were also obtained but for the sake of not lengthening the paper, they are not presented in this paper. Since drought studies at 1 month time scale is very important for agricultural planning, we have represented the 1 month time scale SPI values of 4 rainy months (June to September) of all the districts of this agro climatic zone. An investigation of drought year according to value of SPI shows that Boudh district has the highest number of drought years for the Western Central Table Land Agro Climatic Zone. Jharsuguda district has the least number of drought years. The years 1901, 1954, 1966, 1974 and 1998 are the common years affected by severe drought. The 2009 is also found to be under severe dryness for Sambalpur. The dryness in the 2000's fall under mild condition and a few years under extreme condition.

Table 2: Frequency (percentage) of occurrence of drought in SPI series of 1, 3, 6, 9 and 12 months in different districts of Western Central Table Land Zone, Odisha

Districts	1 month				3month				6 month				9 month				12 month			
	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext
Bolangir	34.3	10.1	3.33	1.45	32.7	9.06	4.86	2.3	34.1	8.12	4.6	2.5	33.5	7.46	5.2	2.03	36.5	8.04	4.57	2.17
Baragarh	37.0	9.42	3.91	0.80	32.6	7.90	4.93	2.5	33.0	8.84	3.7	2.8	33.8	8.48	3.8	2.90	35.0	8.91	2.61	3.12
Sonepur	35.4	8.55	2.83	1.01	34.4	7.46	5.36	1.8	35.9	7.39	4.3	2.2	37.5	7.54	3.8	2.25	38.0	8.41	4.20	1.59
Boudh	35.4	11.2	3.26	1.09	35.4	7.97	5.58	1.5	37.1	7.10	2.8	2.9	34.6	8.04	2.7	3.21	42.1	7.03	2.25	2.54
Sambalpur	30.6	8.04	1.81	1.16	34.0	6.96	4.42	2.6	34.6	8.04	2.7	3.2	36.5	6.96	2.5	3.58	38.5	7.97	1.88	3.26
Jharsuguda	36.9	8.91	2.39	1.74	32.8	7.25	4.57	2.6	31.8	8.48	3.6	2.9	32.0	7.68	3.9	3.04	32.1	7.46	4.06	3.12

Mod = Moderate, Sev = Severe, Ext = Extreme

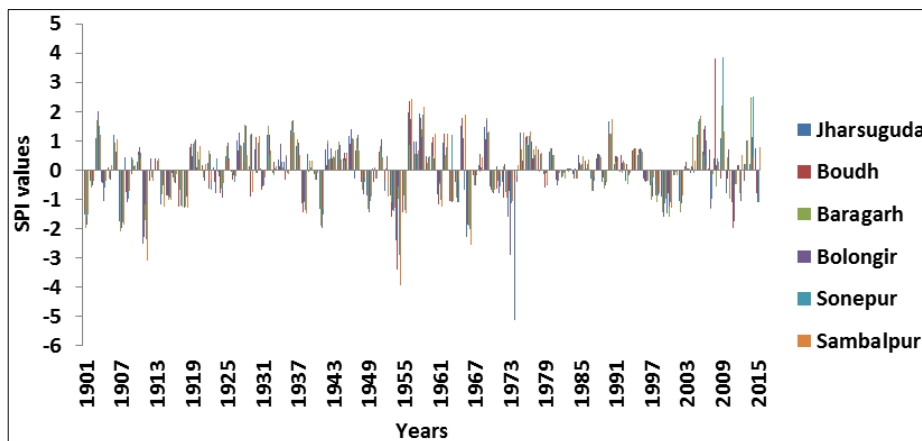


Fig 3: 1-month SPI values of Western Central Table Land for the month of June

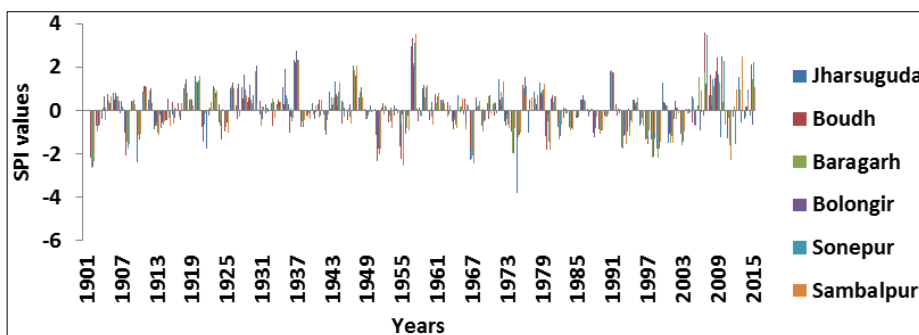


Fig 4: 1-month SPI values of Western Central Table Land for the month of July

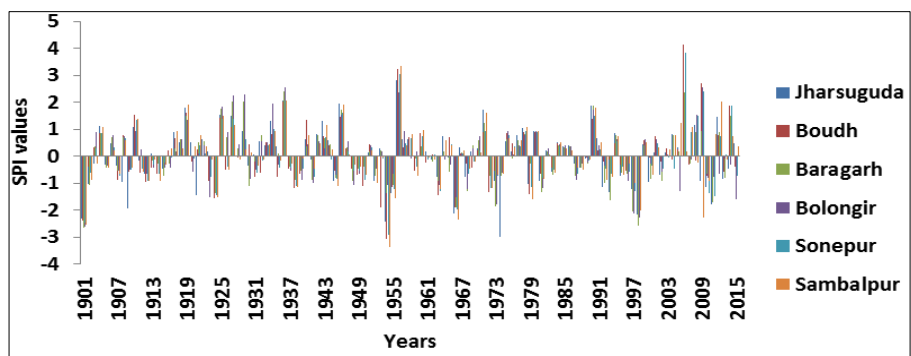


Fig 5: 1-month SPI values of Western Central Table Land for the month of August

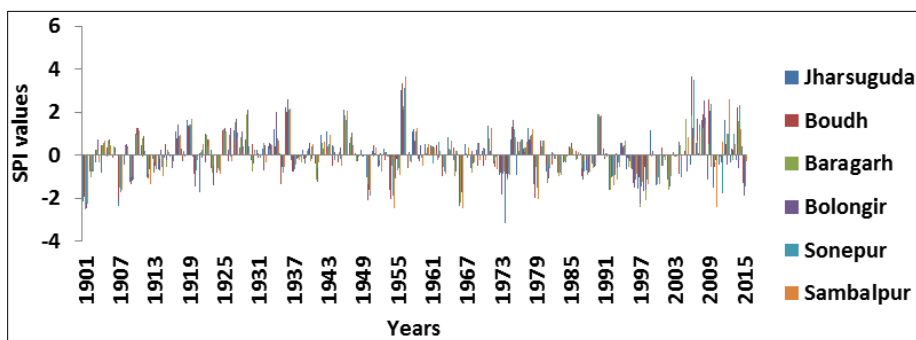


Fig 6: 1-month SPI values of Western Central Table Land for the month of September

Drought Frequency in Rainy Season

Rainy season of India and Odisha comprises 4 months starting from June to September. This season is crucial in Indian agriculture especially in rainfed regions like Odisha where the agricultural production mostly depends on rainfall. The study relating to the drought analysis and its consequential effect on agricultural production are mainly focussed on nature and variation of rainfall causing drought of various intensities. As

stated earlier, SPI analysis of 1-month time scale is generally adopted for crop planning and agricultural production. So, in this research we have studied the frequency of occurrence of drought of various intensities in different months (June-September) for 1-month time scale (Table 3). It is seen from Table 3 that the region experiences highest frequencies of mild droughts ranging from 34.9 to 36.3% in the rainy season from June to September. The month August experiences the

highest frequency of 36.3% drought followed by September (35.8%).

Table 3: Average values of frequency of drought (percentage) of various intensities in rainy months at 1 month time scale

Month	Drought intensities at time scale				Total
	Mild	Moderate	Severe	Extreme	
June	35.0	9.2	6.3	2.9	53.4
July	34.9	10.4	6.3	2.9	54.5
August	36.3	10.1	5.6	3.0	55.0
September	35.8	8.3	6.8	2.6	53.5
Average	35.5	9.5	6.25	2.85	54.10

The percentage of occurrence of moderate drought is found to be 9.2, 10.4, 10.1 and 8.3, respectively in the months of June, July, August and September, respectively. The percentage of occurrence of severe drought is found to be 6.3, 6.3, 5.6 and 6.8, respectively in the months of June, July, August and September, respectively. Extreme drought events are very less in different months. The occurrence of extreme drought events in different rainy months ranges from 2.6 to 3.0%. The frequency of occurrence of droughts of all categories are observed to be 53.4, 54.5, 55.0 and 53.5% in June, July, August and September, respectively. Western Central Table Land ACZ occupies 15.4% cultivated areas in the state which are affected by droughts more frequently. The average (average of all 4 months) total frequency of drought of all intensities are observed to be 54.10% out of which mild, moderate, severe and extreme drought will occur with frequencies of 35.5, 9.5, 6.25 and 2.85%, respectively (Table 3). Thus, the study reveals that in the region, out of 100 years, there will be 54 years drought which necessitates initiation of proper drought mitigation plan and arrangement of supplemental irrigation for crop production.

Area Affected by Drought in Rainy Season

Area affected by drought of various intensities in different months (June-September) in all 115 years (1901-2015) of various districts under the Western Central Table Land zone are collected (OSDMA 2016)^[16] from which percentage of areas affected by drought are computed. The average values of 115 years of percentage area affected by drought of each drought intensity are calculated for different months which were used to calculate the total percentage area affected by drought in various months in the agro-climatic zone as a whole (Table 4).

Table 4: Area (percentage) affected by various intensities of drought in rainy months

Drought intensity	Month				Average
	June	July	August	September	
Mild	26.7	30.5	29.0	27.5	28.40
Moderate	12.6	15.2	14.3	11.0	13.28
Severe	5.6	5.0	5.5	3.5	5.05
Extreme	2.7	2.7	2.3	2.0	2.52
Total	47.6	53.4	51.1	44.0	49.25

It is observed that in June 47.6% areas will be affected by drought of all intensities out of which, 26.7, 12.6, 5.6 and 2.7% of areas will be affected by mild, moderate, severe and extreme drought. In the months of July, August and September, total 53.4, 51.1 and 44.0% areas will be affected by droughts of various intensities. 49.25% areas of the region will be affected by drought of various intensities out of which

the share of mild, moderate, severe and extreme drought is 28.40, 13.28, 5.05 and 2.52%, respectively (Table 4).

Conclusion

The study reveals that mild drought events have the highest frequencies of occurrence followed by moderate drought events for all the different timescale under analysis for Western Central Table Land Agro-Climatic Zones of Odisha. Severe and extreme drought frequencies are comparatively lesser than mild and moderate drought frequencies. On an average frequency of drought events are found to have values of 37, 8, 3 and 2% for mild, moderate, severe and extreme cases across all districts in this agroclimatic zone of Odisha. The frequencies of occurrence of droughts of all categories are observed to be 53.4, 54.5, 55.0 and 53.5% in June, July, August and September, respectively. The average (average of all 4 months) total frequency of drought of all intensities are observed to be 54.10% out of which mild, moderate, severe and extreme drought will occur with frequencies of 35.5, 9.5, 6.25 and 2.85%, respectively. 49.25% areas of the region will be affected by drought of various intensities out of which the share of mild, moderate, severe and extreme drought is 28.40, 13.28, 5.05 and 2.52%, respectively.

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