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Meteorological drought assessment using standardized precipitation index for different agro-climatic zones of Odisha

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सार – इस शोधपत्र में भारत के एक पूर्वी राज्य, ओडिशा में 10 कृषि-जलवायविक क्षेत्रों सहित सभी 30 जिलों में मौसम संबंधी सूखे का आकलन करने के लिए मानकीकृत वर्षण सूचकांक (एस.पी.आई.) का उपयोग किया गया है। ओडिशा के सभी 30 जिलों के 115 वर्षों (1901-2015) के मासिक वर्षा के आंकड़ों का विश्लेषण 1, 3, 6, 9 और 12 महीने के समय-मानों पर मानकीकृत वर्षण सूचकांक का उपयोग करके किया गया है। ये समयमान विभिन्न जल संसाधनों की उपलब्धता पर सूखे के प्रभाव को दर्शाते हैं। परिणाम बताते हैं कि ओडिशा के सभी कृषि-जलवायविक क्षेत्रों में, हल्के सूखे की घटनाओं की आवृत्ति उच्चतम होती है, जिसके बाद विभिन्न समय पैमानों पर लिए मध्यम सूखे की घटनाएं होती हैं। हल्के और मध्यम सूखे की तुलना में प्रचंड और चरम सूखे की आवृत्तियाँ कम हैं। मानकीकृत वर्षण सूचकांक विश्लेषण से पता चलता है कि ओडिशा के विभिन्न कृषि-जलवायविक क्षेत्रों के 115 वर्षों के अध्ययन काल के दौरान 32-46 वर्ष हल्के सूखे से प्रभावित हैं, 4-16 वर्ष मध्यम सूखे से प्रभावित हैं, 1-9 वर्ष गंभीर सूखे से प्रभावित हैं और 1-5 वर्ष अत्यधिक सूखे से प्रभावित हैं। यह देखा गया है कि राज्य में 50.3% क्षेत्र जून में सूखे से प्रभावित होते हैं, जिनमें से हल्के सूखे की घटना की संभावना अधिकतम (28.7%) होती है। जुलाई, अगस्त और सितंबर के महीनों में, 51.7, 48.5 और 46.1% क्षेत्र सूखे से प्रभावित होते हैं। औसतन पूरे राज्य के 49.15% क्षेत्र विभिन्न तीव्रता के सूखे से प्रभावित हैं, जिनमें से हल्के, मध्यम, भीषण और चरम सूखे का प्रतिशत क्रमशः 28.38, 13.28, 5.06 और 2.43% है।

ABSTRACT. In this paper standardized precipitation index (SPI) is used to assess meteorological drought for all 30 districts covering 10 agro-climatic zones in an eastern Indian state, Odisha. Monthly rainfall data of 115 years (1901-2015) for all 30 districts of Odisha are analyzed using SPI on 1, 3, 6, 9 and 12-month timescale. These timescales reflect the impact of drought on the availability of different water resources. Results indicate that in all the agro-climatic zones of Odisha, mild drought events have the highest frequencies of occurrence followed by moderate drought events for different timescales. Severe and extreme drought frequencies are comparatively lesser than mild and moderate drought frequencies. SPI analysis shows that 32-46 years are affected by mild drought, 4-16 years affected by moderate drought, 1-9 years are affected by severe drought and 1-5 years are affected by extreme drought during study period of 115 years in different agro-climatic zones of Odisha. It is observed 50.3% areas in the state are affected by drought in June out of which chances of occurrence of mild drought is maximum (28.7%). In the months of July, August and September, 51.7, 48.5 and 46.1% areas are affected by droughts. On average 49.15% areas of the entire state is affected by drought of various intensities out of which the share of mild, moderate, severe and extreme drought is 28.38, 13.28, 5.06 and 2.43%, respectively.

Key words – Drought, Meteorological drought, Standardized precipitation index, Agro-climatic zones, Odisha.

1. Introductions

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. Indeterminacy regarding its onset and uncertainty about its spread and severity rendered this phenomenon more harmful. Therefore, study about drought characteristics and to be ready by contingency plan is more important for mankind in general and for government in particular. 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). 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).

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) some important indices include the Palmer Drought Severity Index (PDSI; Palmer, 1965), the Rainfall Anomaly Index (RAI; Van Rooy, 1965), the Rainfall deciles (Gibbs and Maher, 1967), the Crop Moisture Index (CMI; Palmer, 1968), the Bhalme and Mooley Drought Index (BMDI; Bhalme and Mooley, 1980), the Surface Water Supply Index (SWSI; Shafer and Dezman, 1982), the National Rainfall Index (RI; Gommes and Petrassi, 1994) and the Standardized Precipitation Index (SPI; McKee *et al.*, 1993).

Vicente-Serrano *et al.* (2010) proposed Standardized Precipitation Evapotranspiration Index (SPEI) which is based on precipitation and temperature data and has the advantage of combining a multi-scalar character with the capacity to include the effects of temperature variability on drought assessment. Tsakiris (2004) proposed the Reconnaissance Drought Index (RDI) that is based on the ratio between cumulative values of precipitation and evapotranspiration. Tsakiris *et al*. (2007) stated that although the Reconnaissance Drought Index (RDI) generally responds in a similar fashion to the SPI it is more sensitive and suitable in cases of a changing environment. Gocic and Trajkovic (2014) analysed monthly precipitation data from 29 synoptic stations for the period 1946-2012 using a number of different multivariate statistical analysis methods to investigate the spatial variability and temporal patterns of precipitation across Serbia. R-mode principal component analysis was used to study the spatial variability of the precipitation and 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); Bordi and Sutera (2001, 2002) and Livada and Assimakopoulos (2006), 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). 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). As reported by Buttafuoco *et al*. (2015); Guttman (1998) compared the SPI with PDSI and concluded that the SPI has statistical consistency advantages and can describe both short-term and long-term drought impacts through different time scales of precipitation anomalies.

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. About 68% of the area is susceptible to drought in varying degrees. Of the entire area, 35% of the area, which receives precipitation between 750 mm and 1,125 mm, is considered drought-prone, whereas another 33%, which receives less than 750 mm of precipitation, is called chronically drought-prone. 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.

Agriculture in the state of Odisha, India is mainly rain-fed, as only 35% of the cultivated area of 62 lakh hectares has irrigation facilities from various sources (OSDMA, 2016). The state’s population of 45 million resides mainly in rural areas (85%), with a large population of marginal farmers; indicating high level of dependence on agriculture. The monsoonal behaviour across the state holds the key to agricultural productivity and consequent food security. Nearly, 86% of the annual rainfall in the state 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; Panigrahi and Panda, 2001; Panigrahi, 2013).

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. 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 covering all the 10 agro-climatic zones of Odisha.

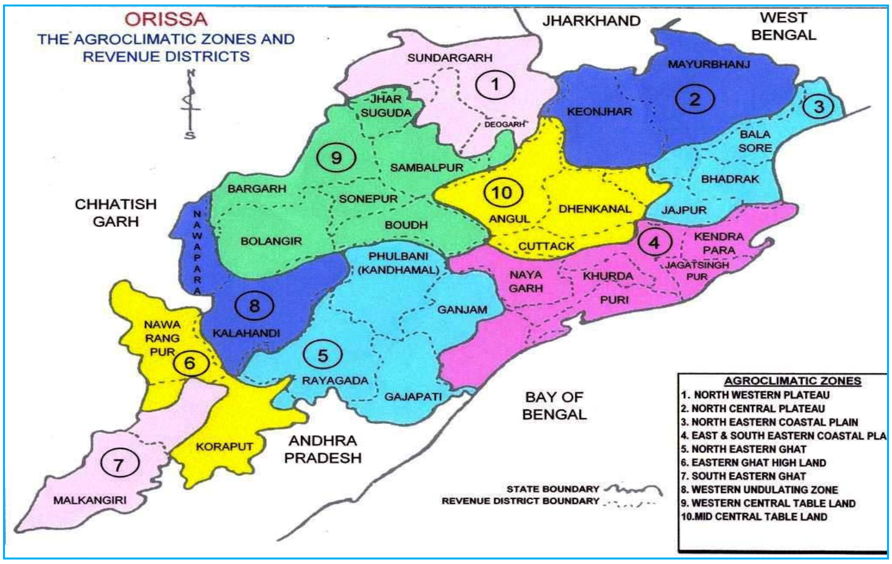

Fig. 1. Map showing districts covering various agro-climatic zones of Odisha (OMEGA, 2014)

2. Materials and method

2.1. *Study area*

Odisha is 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. It spreads over an area of 155,707 square kilometres accounting for about 4.87% of the total area of India. Odisha is the eleventh most populous state in India with about 45 million people contributing 3.47% to the total population of India. The climate is represented by tropical monsoon weather. Southwest monsoon arrives in the state by early June and departs by the middle of October. Rainfall is the main source of water in Odisha and the annual value varies from 1200 to 1700 mm across the state with average of 1482 mm. About 76% of rainfall is received during the monsoon season/ rainy season from 1st June to end of September and the remaining 24% is received throughout the year (Panigrahi, 1998).

Kharif is the main cropping season and rice (*Oryza sativa)* is the principal crop during this season. Cropping during *rabi* season (winter season) is mainly confined to irrigated areas and areas with residual moisture.

The state of Odisha has been divided into 30 districts covering 10 agro-climatic zones (ACZs) based on the basis of soil structure, humidity, elevation, topography, vegetation, rainfall and other agro-climatic factors. Fig. 1 shows view of different ACZs of Odisha.

2.2. *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 30 districts of Odisha.

2.3. *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) originally calculated the SPI for 1, 3, 6, 12, 24 and 48-month timescales.

As suggested by Edwards and McKee (1997) 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) used the classification system shown in the SPI value in Table 1

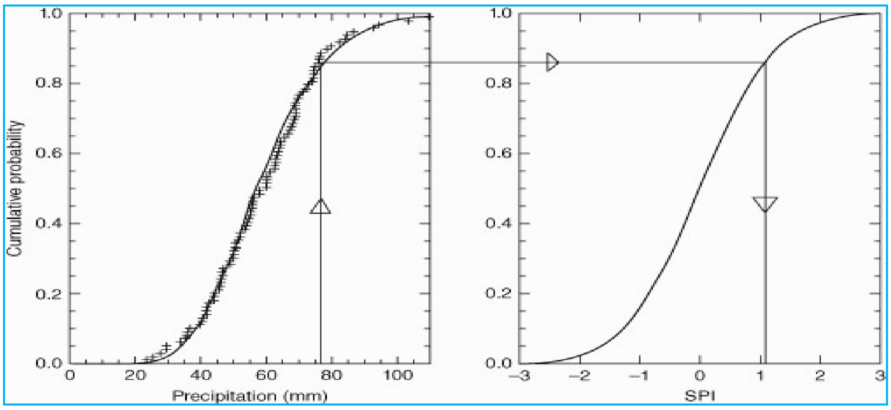

Fig. 2. Transformation from cumulative probability distribution into standardized normal distribution

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)

to define drought intensities resulting from the SPI. They also defined the criteria for a drought event for any of the timescales. When a drought event occurs at any time, 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:

Step 1 : 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.

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

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

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

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

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 Abramowitz and Stegun (1970); Edwards and McKee (1997); McKee *et al.* (1993); Caloiero *et al.* (2018) and Kumar *et al.* (2009), cumulative probability distribution suggested for use is by Gamma distribution which is as follows:

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

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 zero events in the data series.

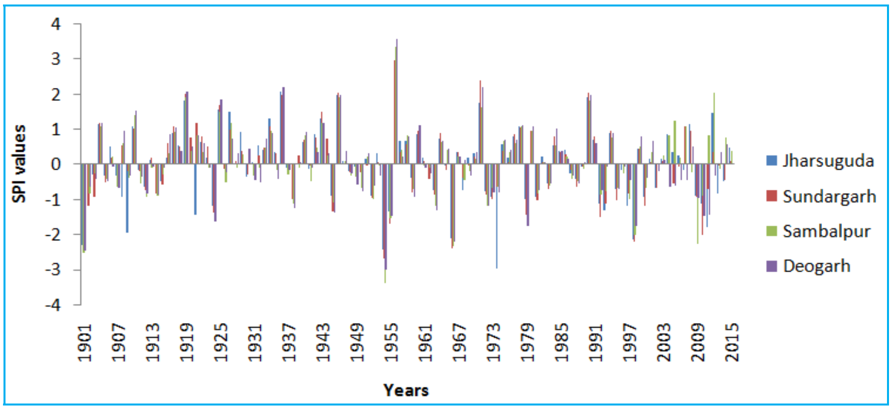

Fig. 3. 3-month SPI values for North Western Plateau Zone of August

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) 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).

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

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

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

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

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.

3. Results and discussion

3.1. *North western plateau zone*

The North Western Plateau consists of Sundargarh, parts of Deogarh, Sambalpur and Jharsuguda. Even though only parts of Deogarh, Sambalpur, Sundargarh and Jharsuguda fall under this ACZ, for analysis purpose whole districts are taken into account. The result shows that the majority of drought events fall under mild drought (73%) and only 6% are under the category of severe drought for the north western plateau. The 1-month SPI value shows the highest SPI value in the year 1954 for Deogarh, Sundargarh and Sambalpur while 1974 shows the highest single drought in 1974. The highest SPI value was found to be -3.03 in Deogarh, -2.99 in Jharsuguda, -2.69 in Sundargarh and -3.38 in Sambalpur districts for 3-month SPI. The 3, 6, 9 and 12 months SPI values for all 4 districts are also calculated for all the months but only 3-month SPI for the month of August is represented in graphical form as shown in Fig. 3 (graphical presentations of other time scales for rest of the 11 months are not shown in this manuscript to reduce the length of manuscript although they have been studied).

Attempt was also made to find out the number of drought years and its frequency of occurrence during the study period (Table 2). Deogarh has the highest mild drought years (39.4% frequency) followed by Sambalpur (38.5% frequency), Sundargarh (36.8% frequency) and then Jharsuguda (36.6% frequency). The years 1901, 1954, 1966 fall under extreme drought years for Deogarh. The years 1901, 1954, 1966, 1998, 2009 and 2010 fall under extreme drought conditions in Sundargarh and Sambalpur districts. The years 1901, 1954, 1966, 1998 and 1974 are extreme drought years in Jharsuguda.

TABLE 2

Frequency (percentage) of occurrence of drought in SPI series of 1, 3, 6, 9 and 12 months in different districts of Odisha

Districts	1 month				3 month				6 month				9 month				12 month			
	Mil	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext	Mild	Mod	Sev	Ext
Sundargarh	36.8	9.34	3.1	0.72	32.7	8.47	3.91	2.9	33.5	8.55	3.1	2.8	36.0	7.39	2.7	3.40	32.3	7.89	3.11	3.18
Deogarh	34.6	8.04	4.42	1.23	32.5	8.33	4.85	2.7	35.1	7.17	3.8	3.0	29.5	6.6	3.7	3.04	39.4	6.44	2.39	3.76
Keonjhar	34.3	6.23	2.17	1.52	32.9	8.04	3.40	2.4	35.8	7.97	3.3	2.5	39.4	7.39	3.7	1.95	40.9	7.39	3.69	1.95
Mayurbhnj	33.6	7.17	3.47	1.59	32.9	8.69	3.98	2.6	35.3	7.82	4.1	2.7	38.9	8.40	3.2	2.10	41.1	8.84	2.53	1.73
Balasore	34.0	9.0	4.2	2.53	32.0	8.26	4.42	2.9	32.0	8.47	4.1	3.1	36.6	7.68	3.7	2.55	35.3	9.6	4.05	1.88
Bhadrak	35.1	8.76	4.34	2.02	33.9	7.75	4.27	2.8	34.2	7.39	3.6	3.2	35.9	8.26	3.1	2.39	37.3	9.56	3.04	1.95
Jajpur	32.4	9.78	3.40	2.17	32.5	8.76	4.27	2.9	32.7	9.20	2.6	3.3	36.9	8.91	2.7	2.46	34.8	9.49	3.47	2.02
Kendrapada	37.6	8.98	3.40	1.23	32.7	8.76	4.20	2.7	34.5	7.89	3.0	3.5	35.6	8.62	2.5	2.68	36.9	7.31	2.97	2.53
Jagatsigpur	37.4	11.2	3.62	1.15	33.9	8.62	4.56	2.5	35.4	8.69	3.5	3.0	38.5	8.33	2.3	2.68	40.3	7.89	2.53	2.17
Khorda	33.7	7.68	2.89	1.66	33.3	7.46	5.22	2.6	34.8	7.25	3.8	3.1	38.2	8.04	2.2	2.75	41.3	7.75	1.88	2.46
Puri	39.8	6.95	3.18	1.08	34.6	8.91	3.98	2.4	36.3	8.33	3.4	2.5	39.9	8.91	2.0	2.18	42.5	8.98	1.59	1.95
Nayagarh	36.4	6.16	3.04	1.38	33.9	9.13	4.06	2.4	36.0	6.67	3.8	2.9	38.4	7.25	3.3	2.40	40.4	8.77	2.83	2.03
Kandhamal	37.2	6.01	2.75	1.08	34.3	8.40	4.05	2.2	37.3	7.39	3.2	2.6	39.9	6.52	3.5	2.07	42.2	6.88	3.11	1.37
Ganjam	35.8	10.8	3.76	1.01	31.9	9.42	4.56	2.5	34.6	7.10	4.2	2.9	37.5	6.52	3.5	2.78	37.9	7.75	3.11	2.24
Rayagada	35.1	7.61	2.25	1.52	32.2	10.1	4.35	1.9	31.2	9.13	3.7	3.0	32.4	8.70	4.4	2.78	34.2	8.62	4.49	2.17
Gajapati	35.9	8.55	4.56	1.08	33.9	8.41	4.78	2.4	34.2	8.18	4.2	2.6	35.8	7.61	4.1	2.58	34.3	9.34	3.55	2.10
Nawarnpur	37.5	4.78	3.04	1.01	34.5	9.20	4.20	1.7	36.6	8.55	4.4	1.8	38.0	7.53	4.9	1.95	40.3	6.73	3.84	2.31
Koraput	40.6	5.72	2.68	1.15	34.9	9.20	3.33	1.9	35.2	9.49	3.7	1.6	37.8	9.05	4.0	1.09	39.2	9.71	3.69	1.89
Malkangiri	32.2	6.73	1.95	1.45	35.2	10.1	3.47	1.5	37.5	9.27	3.5	1.4	40.0	8.62	3.3	1.22	42.7	8.91	2.54	1.74
Naupada	37.8	4.85	2.68	1.15	33.7	8.62	4.70	2.5	34.5	8.11	4.3	2.5	33.5	9.05	4.4	2.45	33.8	8.47	4.64	2.10
Kalahandi	37.2	5.36	2.61	1.37	33.3	9.13	4.34	1.9	35.5	8.11	4.2	2.4	34.8	7.75	5.1	2.24	36.5	6.95	4.92	2.31
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	3.48	38.5	7.97	1.88	3.26
Jharsuguda	36.6	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
Anugul	35.0	10.0	7.0	2.0	34.3	7.97	3.76	2.5	34.8	7.54	3.1	3.2	35.6	7.60	3.8	2.88	38.0	6.73	3.62	2.31
Dhenkanal	35.1	8.84	4.05	1.95	33.7	8.69	4.42	2.5	34.5	8.40	3.2	3.2	37.0	8.26	3.2	2.31	36.8	9.28	3.04	2.10
Cuttack	32.0	7.82	4.05	1.44	35.6	7.97	4.63	2.0	33.5	6.88	2.9	1.6	45.9	5.86	1.8	1.37	51.2	4.92	1.52	1.02

Mod = Moderate, Sev = Severe, Ext = Extreme

TABLE 3

Average values of frequency of drought (percentage) of various intensities in different ACZs in rainy months at 1 month time scale

ACZs → / Month ↓	Frequency of drought (percentage)										
	North Western Plateau	North Central Plateau	North Eastern Coastal Plain	East & South Eastern Plain	North Eastern Ghat	Eastern Ghat High-Land	South Eastern Ghat	Western Undulating Zone	Western Central Table Land	Mid Central Table Land	Odisha
June											
Mild	36.5	35.5	38.4	33.9	35.0	34.9	35.8	36.5	35.0	37.8	35.93
Moderate	9.9	10.1	11.3	8.2	8.9	8.5	9.9	10.0	9.2	10.3	9.63
Severe	6.5	6.6	7.3	6.1	7.2	6.3	7.0	6.6	6.3	7.2	6.71
Extreme	2.9	3.0	3.1	2.7	3.0	2.8	2.7	2.8	2.9	3.1	2.9
Total Drought	55.8	55.2	60.1	50.9	54.1	52.5	55.4	55.9	53.4	58.4	55.17
July											
Mild	35.8	36.4	36.8	34.7	35.3	34.8	36.3	36.5	34.9	36.6	35.81
Moderate	8.9	8.9	11.7	8.5	8.8	8.7	8.9	9.2	10.4	11.1	9.51
Severe	6.3	6.2	6.6	6.0	6.3	6.5	6.4	6.0	6.3	6.6	6.32
Extreme	2.8	2.9	3.3	2.9	2.9	2.9	3.1	2.8	2.9	3.1	2.96
Total Drought	53.8	54.4	58.4	52.1	53.3	52.9	54.7	54.5	54.5	57.4	54.6
August											
Mild	34.3	36.8	32.3	36.8	36.1	36.7	35.8	36.4	36.3	32.0	35.35
Moderate	8.1	8.0	7.1	10.2	8.9	10.0	9.6	8.3	10.1	6.8	8.71
Severe	5.8	6.2	5.3	6.1	6.3	6.0	7.3	6.2	5.6	5.4	6.02
Extreme	3.0	2.9	2.8	3.0	3.0	2.9	2.4	2.6	3.0	2.7	2.83
Total Drought	51.2	53.9	47.5	56.1	54.3	55.6	55.1	53.5	55.0	46.9	52.91
September											
Mild	34.8	35.0	37.8	34.7	35.0	34.9	35.0	35.3	35.8	36.9	35.52
Moderate	8.3	8.5	9.5	8.0	9.2	8.3	9.1	8.5	8.3	9.5	8.72
Severe	6.4	6.4	6.7	6.2	6.4	6.3	6.3	7.6	6.8	6.6	6.57
Extreme	2.7	2.6	2.8	2.3	2.6	2.5	2.6	2.7	2.6	2.7	2.61
Total Drought	52.2	52.5	56.8	51.2	53.2	52.0	53.0	54.1	53.5	55.7	53.42

3.2. *North central plateau zone*

12-months SPI indicates highest frequency of drought months for the studied period. 40.94% frequency of mild drought months occurs in Keonjhar while Mayurbhanj gives a slightly higher frequency of mild drought months of 41.15%. From Table 2 we can see that North Central Plateau Zone experiences maximum mild drought events (ranging from 32.9 to 41.1% frequency) followed by moderate drought events (ranging from 6.23 to 8.14% frequency) for all the different timescale under analysis. Severe and extreme drought frequencies are comparatively lesser as compared to mild and moderate drought frequency. The 3, 6, 9 and 12 months SPI values for all 2 districts are calculated for all the months to identify the drought affected years. The 3-month time scale for the month of August is presented in Fig. 4 which shows that Keonjhar has more drought years compared to Mayurbhanj. The years 1901, 1954, 1966, 1945 and 2010 fall under extreme drought years for the North Central Plateau Zone. It can be seen from the results that there is temporal and spatial variations in the occurrence of drought events. Taking into consideration the year 2015, Keonjhar shows mild drought years while on the other hand Mayurbhanj lies in the mildly wet categories.

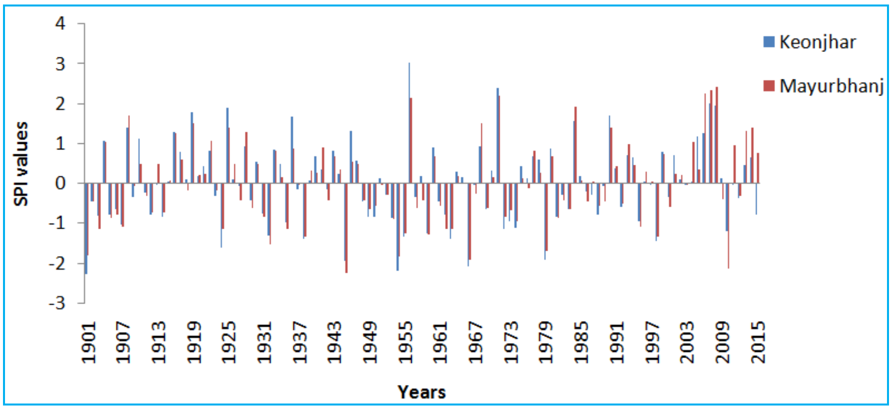

Fig. 4. 3-month SPI values for North Central Plateau Zone of August

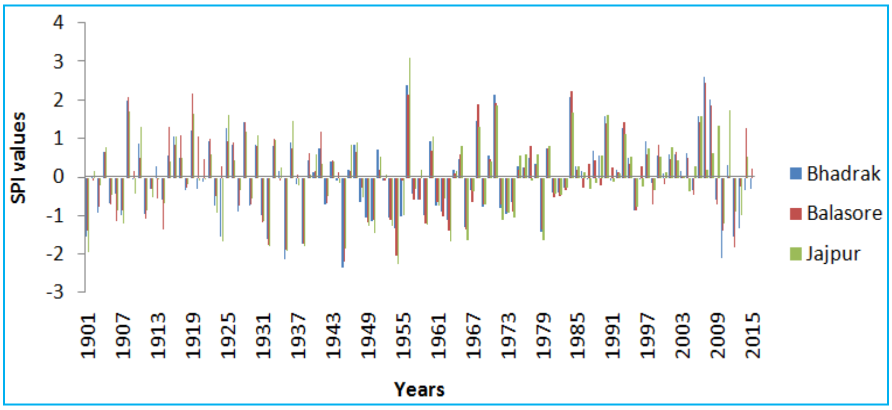

Fig. 5. 3-month SPI values for North Eastern Coastal Plain of August

3.3. *North eastern coastal plain zone*

Bhadrak, Balasore, Jajpur and Anandapur sub-division of Keonjhar districts come under North Eastern Coastal Plain agro-climatic zone (ACZ). Since only one division of Keonjhar falls under this ACZ, only the first three districts are taken for assessment of drought. The highest frequency of drought occurrence was found in Bhadrak (37.31% at 12 month time scale) under mild drought condition for the north eastern coastal plain (Table 2). Balasore has the highest frequency of drought of 9.56% at 12 month time scale under moderately drought conditions. As for severe drought, Bhadrak gives the highest frequency of 4.34% and Jajpur gives the highest frequency (3.33%) under extreme drought category. The 1-month SPI result shows that the highest drought intensity occurred in 1954 with Jajpur having SPI value of -3.33. The 3-months SPI result shows that the highest drought intensity occurred in 1945 with Bhadrak giving SPI value of -2.35 (Fig. 5). The 6-month SPI result shows that the highest drought intensity occurred in 1935 with Bhadrak having SPI value of -2.92. The 9 and 12-months SPI result shows that the highest drought intensity occurred in 1908 with Jajpur giving value of -2.75 and -2.96, respectively. Bhadrak has the highest number of drought years (60 out of 115) followed by Jajpur ((58 out of 115) and then Balasore (57 out of 115).

3.4. *East and south eastern coastal plain zone*

Kendrapada, Khorda, Jagatsinghpur, Puri, Nayagarh, a part of Ganjam and Cuttack come under East and South Eastern Coastal Plain. Since small part of Ganjam and Cuttack comes under this zone, they are excluded from this zone. The long term analysis (12-month) SPI gives the highest mild drought frequency for each timescale except Kendrapada in which 1-month SPI gives the highest frequency (37.60%) The 1-month results show that Jagatsindhpur has the highest number of drought frequency under moderate (11.2% frequency) and severe category (3.62% frequency) and Khorda shows the highest frequency under extreme condition (1.66% frequency).

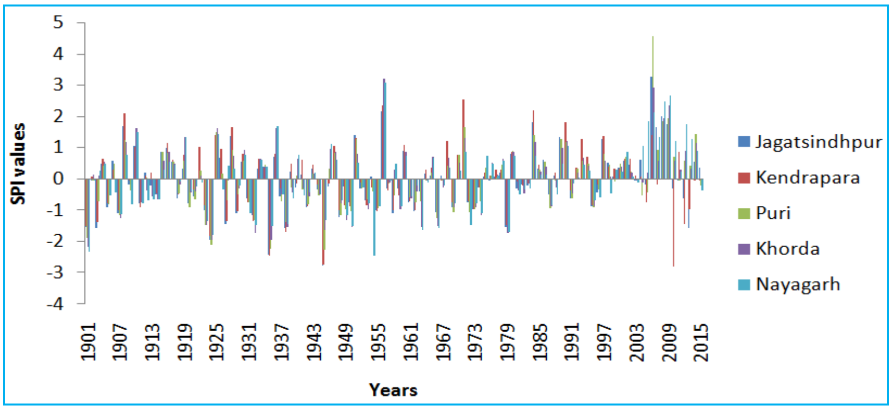

Fig. 6. 3-month SPI values of East and South Eastern Coastal Plain of August

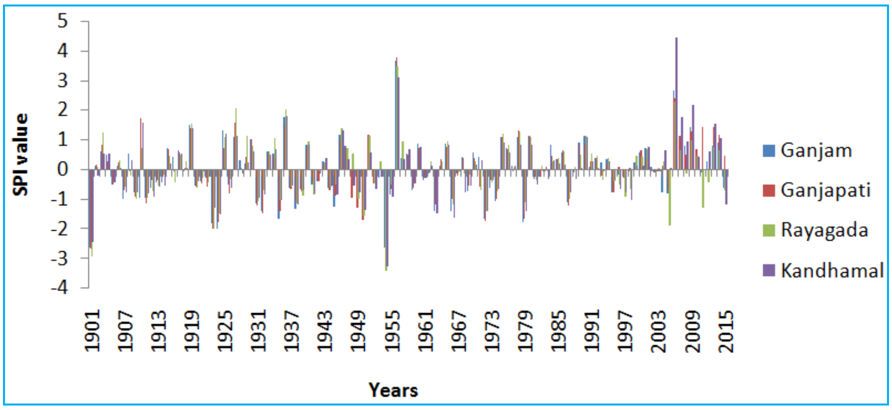

Fig. 7. 3-month SPI values for North Eastern Ghats of August

The 3-month SPI analysis (Fig. 6) shows that Nayagarh is affected the most by moderate drought (9.13% of time) with 5.22% frequency being the highest value in severe conditions which is found in Khorda district. The highest value of frequency of extreme conditions is found in Kendrapada (2.75% at 9 month time scale). The 6-month SPI gives the highest moderate drought frequency of 8.69% in Khorda district, severe drought of 3.84% frequency in Nayagarh and extreme drought frequency of 3.55% in Kendrapada. For 6-month SPI analysis, the result shows that highest frequency of moderate, extreme and severe drought are found in Puri (8.91%), Nayagarh (3.33%) and Khorda (2.75%) respectively. 12-month SPI results also gives highest frequency of drought in the moderate category for Puri district (8.91%). Like the 9-month SPI, the highest number of severe and extreme drought is found in Kendrapada district having value of 2.97% and 2.53% respectively. It can be seen from the Fig. 6 (which represent the 3-month SPI for the month of August) that the years 1901, 1924, 1935, 1945 and 1954 were affected by severe drought during the period of 1901-2015.

3.5. *North eastern ghats zone*

Kandhamal, Rayagada, Gajapati, Ganjam and a small patch of Koraput come under North Eastern Ghat ACZ. Results for the short-term analysis (1, 3 and 6-month) shows that 6-month SPI for Kandhamal gives the highest frequency of 37.31%. The 3-month SPI value of Rayagada district shows the highest frequency of 10.14% under moderate drought category. 4.78% frequency under 3-month SPI is the highest value under the severe drought category which occurred in Ganjapati district. Rayagada has the highest frequency of 3.04% under 6-month SPI for extreme category. Long term SPI values (9 and 12-month) show the highest frequency of 42.24% for Kandhamal district under 12-month SPI timescale. Ganjapati have the highest number of drought months which is obtained under 12-month SPI analysis. Severe drought frequency is found to be the highest for Rayagada. Ganjam and Rayagada show same value of severe drought frequency under 9-month SPI timescale (Table 2).

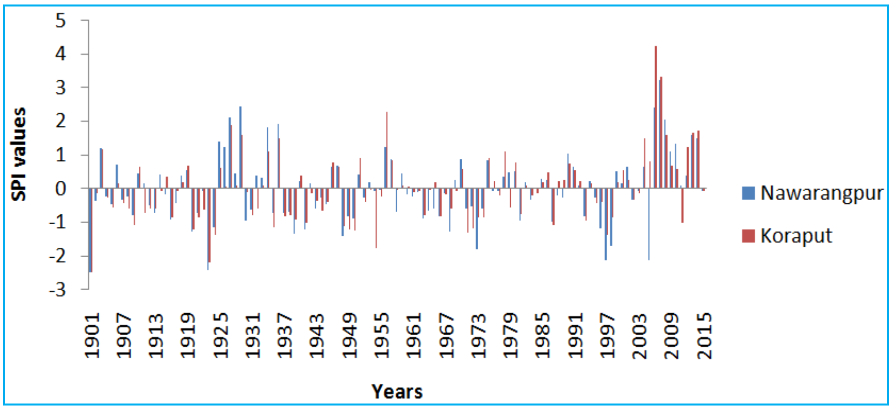

Fig. 8. 3-month SPI values of Eastern Ghat Highland of August

The years 1901, 1908 and 1954 are found to be severe drought affected years during the study period. The highest number of mild drought year (43 years) is found in Kandhamal district whereas the lowest number of mild drought year (39 years) occurred in Ganjapati. Nine to ten years are affected by moderate drought years for North Eastern Ghat. Two to six years fall under extreme drought intensity. Fig. 7 represents the 3-month SPI values for North Eastern Ghats for the month of August.

3.6. *Eastern ghat highland zone*

The Eastern Ghat Highland Agro-Climatic Zone covers major parts of Koraput and Nawarangpur. The highest frequency of drought occurrence was found in Koraput under mild and moderate drought condition for Eastern Ghat Highland while higher frequency of extreme and severe drought was found in Nawarangpur (Table 2). The 1-month SPI result shows that the highest drought intensity occurred in 1973 in Nawarangpur having SPI value of -3.27. The 3-months SPI results show that the highest drought intensity having SPI value of -2.49 occurred in 1901 in Koraput district (Fig. 8), while 6-month SPI result shows that the highest drought intensity occurred in 1923 with Bhadrak having SPI value of -2.15. The 9 and 12-months SPI result shows that the highest drought intensity occurred in 1903 with Nawaranrgpur giving SPI value of -2.13 and -2.32, respectively.

Forty years fall under mild drought years for Nawarangpur while Koraput has forty-three years under the same category. The analysis shows that even though Koraput has lesser mild drought years it is affected more by moderate drought. Severe and extreme drought occurred in Nawarangpur from time to time but the result shows that Koraput does not have much extreme condition as compared to Nawarangpur.

3.7. *South eastern ghat zone*

The South Eastern Ghat agro-climatic zone covers Malkangiri and part of Koraput. A small part of Koraput comes under this zone. Because of this and since result of Koraput is already presented in Eastern Ghat Highland ACZ, only Malkangiri is presented under South Eastern Ghat ACZ. Malkangiri follows the common trend which is found in the different agro climatic zones in which the result shows the highest drought frequency under mild dryness (42.7%) followed by moderate dryness (10.1%), then severe dryness (3.5%) and lastly extreme dryness (1.74%). Table 2 shows that the highest frequency under mild drought condition was found under 12- month timescale (42.7%). The 3-month timescale give the highest frequency of drought occurrence under the remaining category *i.e.*, moderate (10.1%), severe dryness (3.47%) and extreme (1.5%). Fig. 9 represents the computed value SPI values against chronological years under consideration. From Fig. 9 it can be interpreted that Malkangiri district has a high wet condition from the year 2005 onwards. However under 1-month time scale, the district experiences mild drought condition for the year 2008, 2009 and 2015. This clearly indicates that this agro climatic region faces only short term dryness during the last decade. But it should be noted that agricultural practices are affected by short term dryness. So utmost care should still be taken for mitigating drought to improve the productivity from agriculture. Continuous drought of various intensity seems to occur from 1901-1925. The highest single drought intensity is observed under 12-month SPI timescale having a value -2.45 (Table 2).

3.8. *Western undulating zone*

Western Undulating agro-climatic zone comprises of two districts *i.e.*, Kalahadi and Naupada. The 1-month SPI indicates highest frequency of drought months for the

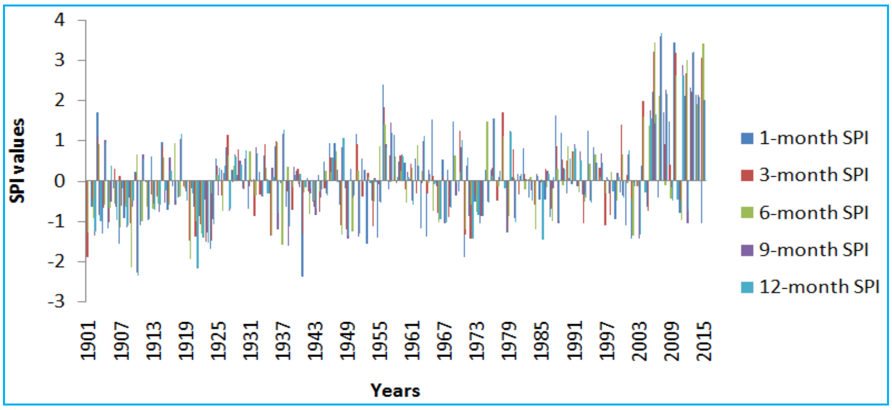

Fig. 9. SPI values for Malkangiri (South Eastern Ghat) of August

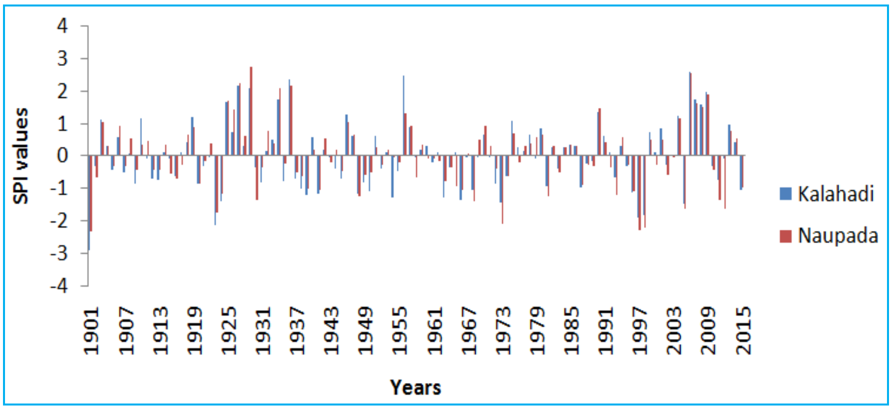

Fig. 10. 3-month SPI values of Western Undulating Zone of August

studied period. 37.2% frequency of mild drought months occurs in Kalahadi while Naupada gives a slightly higher frequency of mild drought months of 37.82%. From Table 2 we can see that western undulating zone experiences maximum mild drought events (37.8% frequency) followed by moderate drought events (9.13% frequency) for all the different timescale under analysis. Severe and extreme drought frequency is comparatively lesser as compared to mild and moderate drought frequency. Fig. 10 represents 3-month SPI values of Western Undulating Zone for the month of August. The 12- month SPI values give the highest number of drought years under extreme and severe category while most of the drought years fall under mild and moderate category in 1 and 3-month timescale.

3.9. *Western central table land zone*

The western table land agro climatic zone has six districts under it. These districts are Bargarh, Bolangir, Boudh, Sonepur and parts of Sambalpur and Jharsuguda. 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 gives the highest frequency (42.10%) for mild drought category while highest frequency of 8.91% was found in Bargarh district. Bolangir has the highest severe drought frequency (5.22%) amongst all the districts. However, 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 different values obtained from the analysis under the concerned timescale were obtained and the 3-month SPI values of Western Central Table Land Zone and for the month of August is represented in Fig. 11. An investigation of drought year according to value of SPI

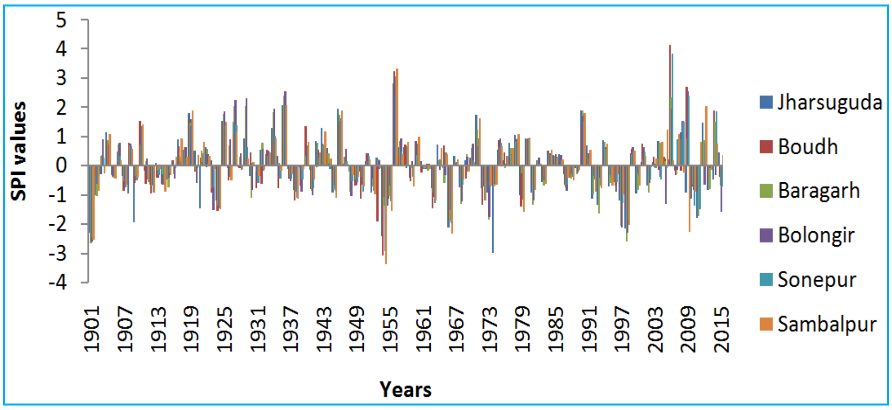

Fig. 11. 3-month SPI values of Western Central Table Land of August

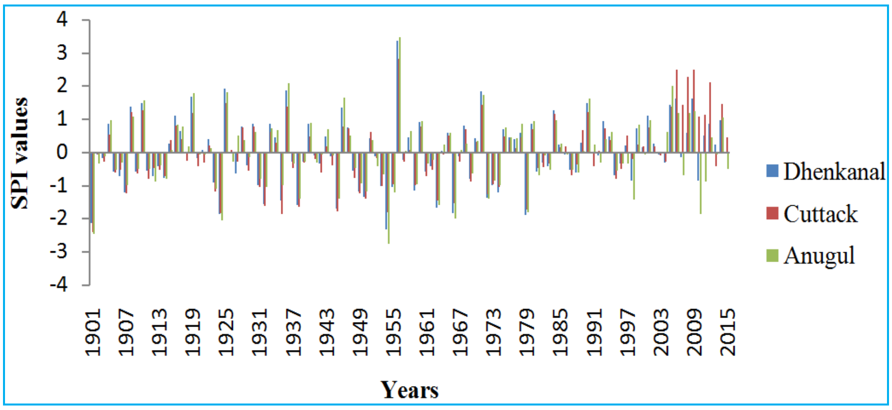

Fig. 12. 3-month SPI values of Mid Central Table Land of August

shows that Boudh district has the highest number of drought years for the western table land agro climatic zones. 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.

3.10. *Mid central table land zone*

Dhenkanal, Anugul and Cuttack come under Mid Central Table Land ACZ. The study reveals that Anugul has the highest frequency of 38.04% under mild dryness, 10% under moderate dryness, 7% under severe dryness and 3.18% under extreme dryness condition. 36.81% frequency under 12-month SPI is the highest under mild drought category for Dhenkanal district, 9.28% frequency under moderate dryness, 4.42% frequency under severe dryness and 3.26% frequency under extreme dryness different timescale under analysis. Cuttack shows the highest frequency of 51.23% under mild drought category at 12 month time scale in the Mid Central Table Land zone. The 3-month SPI shows the highest frequency for moderate, severe and extreme dryness for Cuttack district.

The 1-month analysis give the highest single drought magnitude of -3.58 for Dhenkanal, -3.58 value of SPI for Cuttack and -3.85 magnitude for Anugul. For 3-month SPI analysis, the highest single drought magnitude is found to be -2.76 for district of Anugul in the year 1954 (Fig. 12). 1907 show the highest magnitude of single drought for the three district of mid central table land zone under 6-month SPI analysis. 1908 show the highest magnitude of single drought for the three district of mid central table land zone under 9-month SPI and 12-month SPI analysis.

3.11. *Drought frequency in rainy season*

Rainy season of India and Odisha comprises 4 months starting from June to September. This season is

TABLE 4

Area (percentage) affected by various intensities of drought in different rainy months in Odisha

Drought intensity	Month				
	June	July	August	September	Average
Mild	28.7	29.5	28.0	27.3	28.38
Moderate	13.6	14.2	13.3	12.0	13.28
Severe	5.5	5.1	5.0	4	5.06
Extreme	2.5	2.9	2.2	2.1	2.43
Total	50.3	51.7	48.5	46.1	49.15

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) in all the 10 ACZs for 1-month time scale (Table 3).

It is seen from Table 3 that North Eastern Coastal Plain ACZ experiences highest frequencies of droughts of various intensities in June, July and September followed by Mid Central Table Land ACZ. In June, out of 60.1% frequency, occurrence of mild, moderate, severe and extreme droughts are 38.4, 11.3, 7.3 and 3.1%, respectively. Frequency of occurrence of droughts of all intensities in this ACZ in July, August and September are 58.4, 47.5 and 56.8%, respectively. North Eastern Coastal Plain ACZ occupies 11.4% cultivated areas in the state which are affected by droughts more frequently. Frequency of occurrence of drought of different intensities are the least in East and South Eastern Plain followed by Eastern Ghat Highland ACZ in the months of June, July and September. The total frequency of drought of all intensities are observed to be 50.9% out of which mild, moderate, severe and extreme drought will occur with frequencies of 33.9, 8.2, 6.1 and 2.7%, respectively. In the entire state, the frequency of occurrence of total droughts of all intensities varies from 52.91 to 55.17% in different months in rainy season with an average (average of 4 months) frequency of occurrence of 54.02% out of which the share of mild, moderate, severe and extreme droughts are 35.65, 9.14, 6.40 and 2.83%, respectively (Table 3). Thus, the study reveals that in the state, 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.

3.12. *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 all 10 ACZs are collected (OSDMA, 2016) 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 and for different ACZs which were used to calculate the total percentage area affected by drought in various months in the state as a whole (Table 4). It is observed 50.3% areas in the state will be affected by drought of all intensities in June out of which, 28.7, 13.6, 5.5 and 2.5% of areas will be affected by mild, moderate, severe and extreme drought. In the months of July, August and September, total 51.7, 48.5 and 46.1% areas will be affected by droughts of various intensities. 49.15% areas of the state will be affected by drought of various intensities out of which the share of mild, moderate, severe and extreme drought is 28.38, 13.28, 5.06 and 2.43%, respectively (Table 4).

4. Conclusions

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 different 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 ACZs of Odisha. The SPI analysis shows that 32-46 years are affected by mild drought, 4-16 years are affected by moderate drought, 1-9 years are affected by severe drought and 1-5 years are affected by extreme drought during the study period of 115 years in different agro-climatic zones of Odisha. North Eastern Coastal Plan ACZ will face frequent occurrence of all types of droughts with highest frequency values ranging from 47.5 to 60.1% in different months whereas East and South Eastern Plain ACZ will face least occurrence of drought varying from 50.9 to 56.1%. In the state as a whole, the frequency of occurrence of all forms of droughts will vary from 52.91 to 55.17% in different months in rainy season with an average monthly value of 54.02%. 49.15% areas of the entire state will be affected by drought of various intensities out of which the share of mild, moderate, severe and extreme drought is 28.38, 13.28, 5.06 and 2.43%, respectively.

Acknowledgements

The contents & views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organisations they belong to.

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