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Drought Assessment using Standardized Precipitation Index and Normalized Difference Vegetation Index

Aishwarya Panda*, Narayan Sahoo, Balram Panigrahi and Dwarika Mohan Das

Department of Soil and Water Conservation Engineering, CAET, OUAT, Bhubaneswar, Odisha, India

**Corresponding author*

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A B S T R A C T

The present study was carried out to assess the meteorological drought using Standardized Precipitation Index (SPI), agricultural drought using Normalized Difference Vegetation Index (NDVI) in Nuapada district of Odisha. SPI is a popular meteorological drought index which is designed to quantify the precipitation deficit for multiple time scales. NDVI is a vegetation index to represent agricultural drought based on remote sensing data. Comparison between SPI and NDVI was made to assess the potentiality of these indices to predict the actual drought condition a better way. The results indicated that there were mismatches between SPI and Odisha State Disaster Management Authority (OSDMA) drought information whereas the drought risk assessment based on NDVI values was much better correlated with the actually observed drought on ground. Hence, NDVI is found to be more suitable for effective agricultural drought prediction.

Introduction

A drought is an event caused due to the prolonged shortages in the water supply. It mostly occurs when an area or region experiences below-normal precipitation. The lack of adequate precipitation, either rain or snow, can cause reduced soil moisture or groundwater, diminished stream flow, crop damage, and a general water shortage. Conditions of drought appear primarily, though not solely; on account of substantial rainfall deviation from the normal and the skewed nature of the spatial or temporal distribution to a degree that inflicts an adverse impact on crops over an agricultural season or successive seasons. As an unpleasant climatic phenomenon the drought directly affects societies through the limiting access to water resources; drought is also followed by some huge economic, social and environmental degradation costs (Goddard *et al*., 2003). This phenomenon is also affected by rainfall, temperature, evaporation and transpiration, the moisture content in accessible soil and the condition of underground water (Shahabfar *et al*., 2012).

Drought monitoring through satellite based information has been popularly accepted in recent years for its low cost, synoptic view, repetition of data acquisition and reliability (Dutta *et al*., 2015). In addition to the advantages mentioned as above, the NDVI has been accepted globally for identifying agricultural drought in different regions with varying ecological conditions (Barati *et al*., 2011; Dutta *et al*., 2015).

The variability in the occurrence of active-break spells of South-West monsoon rainfall is a major concern for sustainable agricultural production in rainfed regions (Chandrasekar *etal*.,2010).Delay in the onset of monsoon defers sowing operations in these regions. The crop condition is dependent on periods of adequate soil moisture availability driven by the probability of wet spell – dry spell and total amount of rainfall during a growing season. Therefore, periodic accounting of rainfall and crop vigour is necessary for agricultural drought assessment.

World Bank report (2008), estimated that about 75% of cultivated area in the state is rainfall dependent. Thus, 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 South-West monsoon (CGWB, 2013). A delayed or 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.

Drought seems to be a consistent phenomenon in the state of Odisha and every year some or the other parts of the state are affected by it. Looking at the frequency and geographical spread of drought, the districts such as undivided Nuapada, Kalahandi, Balangir and especially the western part of Odisha are more vulnerable. Nuapada being a prominent part of Western Odisha, has been the most vulnerable district facing drought in every alternate year.

There is a need to study the comparison between meteorological and agricultural droughts of Nuapada district of Odisha for better interpretation of drought phenomena to arrive at a feasible solution. Keeping all these things in mind, the objectives decided are; to compute Standardized Precipitation Index (SPI) for meteorological drought assessment, to compute Normalised Difference Vegetation Index (NDVI) through remote sensing and GIS for agricultural drought assessment and to compare and critically interpret the values of Standardized Precipitation Index (SPI) with that of Normalised Difference Vegetation Index (NDVI) for better drought assessment.

Materials and Methods

Study area

The present study was conducted for assessment of drought in Nuapada district of Odisha (Fig.1). The district is located in the western part of Odisha. It lies between 20°15′55.88″ N to 20°56′31.92″ N latitude and 82°32′57.34″ E to 82°38′49.10″ E longitude. Average elevation of Nuapada district with respect to mean sea level is 1200 m. The boundaries of Nuapada district extends in the North, West and South to Raipur district of Chhattisgarh and in the East to Bargarh, Balangir and Kalahandi Districts of Odisha. This district is spread over an area of 3852 km². The administrative headquarters of the district is located at Nuapada itself. The district of Nuapada was a part of undivided Kalahandi district till early March 1993, but for the administrative convenience, Kalahandi district was divided into two parts i.e. Kalahandi and Nuapada. Presently Nuapada district comprises of one sub-division (Nuapada), five Tahsils (Nuapada, Khariar, Komna, Boden and Sinapali) and five blocks (Khariar, Sinapalli, Boden, Nuapada and Komna).

The South-West monsoon is the principal source of rainfall in the district. Average annual rainfall of the district is 1378.2 mm (CGWB, Odisha). About 75% of the total rainfall is received during the period from June-September. The erratic distribution of rainfall in Boden block of Nuapada district from 1998 to 2018 is presented in Fig.2. Droughts are quite common in the whole of the district. As the district falls in the rain shadow region, the rainfall is very erratic (Fig-1 and Fig-2).

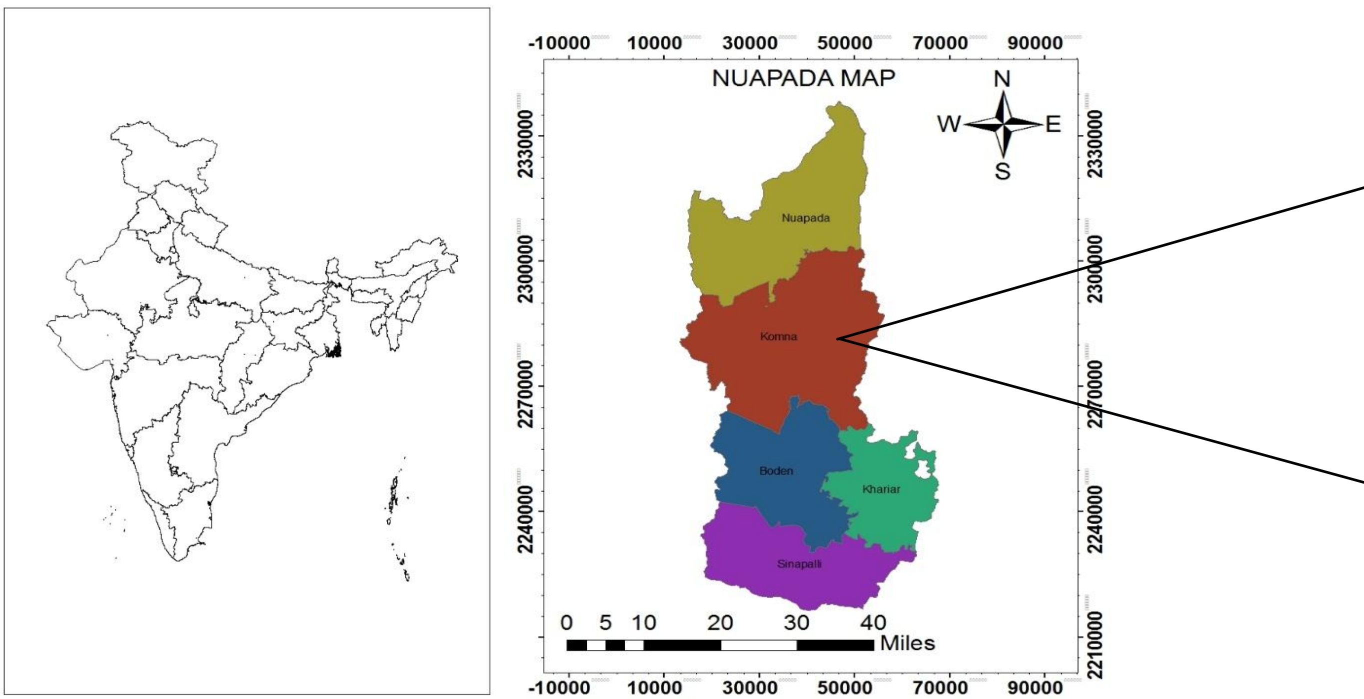

Fig.1 Map showing the location of Nuapada

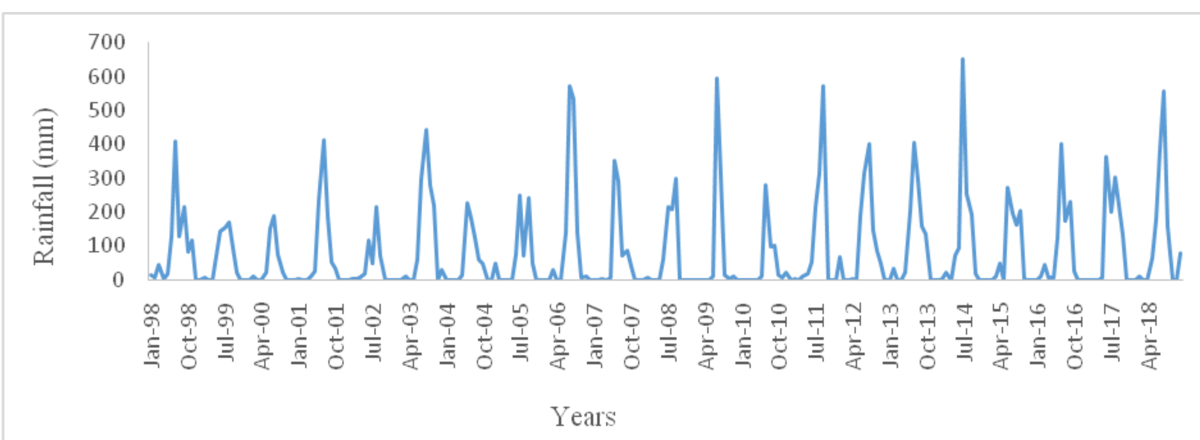

Fig.2 Erratic distribution of rainfall in one of the blocks (Boden) of Nuapada district

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (McKee *et al*., 1993) is a widely used index to characterize meteorological drought on a range of timescales which is solely based on precipitation data. The SPI can be compared across regions with markedly different climates. The SPI can be created for differing periods of 1-to-36 months, using monthly input precipitation data. The SPI calculation for any location is based on the long-term precipitation record that is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero.

Normalized Difference Vegetation Index (NDVI)

NDVI is one of the most well-known herbal indices widely used in most research works and satellite studies for determining vegetation health and density which is explained through the Eq. (1).

$$\mathrm{NDVI} = \frac{\mathrm{NIR-RED}}{\mathrm{NIR+RED}} \ldots\ldots\ldots\ (1)$$

Where:

NIR = Reflection of the light in NIR bands and RED = Reflection of the light in red bands

In this formula, NIR is near infrared band and R is red band. NDVI value varies between -1.0 to +1.0. Negative values of NDVI, i.e. values approaching -1 correspond to deep water and positive values, i.e. +1 indicates very good and dense vegetation. NDVI provides an estimate of vegetation health and a means of monitoring changes in vegetation over time.

Data collection

Block wise monthly rainfall data of Nuapada district was collected from Special Relief Commissioner, Odisha, for a period of 20 years (1998-2018). Land use land cover map of the district for the year 2015 was collected from Odisha Watershed Development Mission, Bhubaneswar. Drought information of Nuapada district occurred in last 20 years was collected from Odisha State Disaster Mitigation Authority (OSDMA), Bhubaneswar. LANDSAT images covering the entire district were downloaded from USGS Earth Explorer for the drought and non-drought years.

Satellite data acquisition

The images of LANDSAT 8, LANDSAT 7 and LANDSAT 4-5 were downloaded from USGS Earth Explorer website. According to the drought information provided by OSDMA, the drought years that were studied here are 2002, 2008, 2009, 2011, 2015 and 2018 in which all the 5 blocks of Nuapada district were affected. For the ease of comparison of NDVI between drought and non-drought years, the non-drought years that were taken for study were 2006 and 2016. The images of October month were taken into account for all the years as the sky remains cloud free and hence clear NDVI can be obtained. Another reason for taking the October month in this study is that, the vegetation condition and greenness of crop can be easily studied in this month as it is the peak growing period for kharif paddy. For calculation of NDVI, Arc GIS 10.1 software was used.

Rainfall analysis

Rainfall analysis is used to predict drought. For rainfall analysis, minimum 20 years of rainfall data is needed. In this study, rainfall data from 1998-2018 were used for the analysis. If the rainfall deviation with respect to normal rainfall is 25% or below, then it is classified as normal drought, if it lies between 25 to 50%, then it is called moderate drought and if it is above 50% then the drought appears as severe (Subramanya, 2018).

Assessment of meteorological drought

In this study, meteorological drought is assessed by computing SPI. For calculation of SPI, 20 years of rainfall data were used. The SPI was designed to quantify the precipitation deficit for multiple timescales of 1 month, 3 months, 6 months, 9 months and 12 months. These timescales reflect the impact of drought on the availability of different water resources.

Classification of meteorological drought

McKee *et al.*, (1993) used the classification system for categorization of droughts based on SPI values, which was provided by World Meteorological Organization, in 2012 and is presented in Table 1. They also defined the criteria for a drought event for any of the timescales. A drought event occurs any time where the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive (Table-1).

Table.1 SPI classification and their values

Category	SPI range
Extreme drought	-2.00 or more
Severe drought	-1.50 to -1.99
Moderate drought	-1.00 to -1.49
Normal drought	-0.99 to 0.99
Very wet	1.99 to 1.5
Extremely wet	2.0 or more

(Source: World Meteorological Organization, 2012)

Computation of SPI

1-month SPI

A 1-month SPI map is very similar to a map displaying the percentage of normal precipitation for a 30-day period. For example, a 1-month SPI at the end of November compares the 1-month precipitation total for November in that particular year with the November precipitation totals of all the years on record.

3-month SPI

The 3-month SPI provides a comparison of the precipitation over a specific 3-month period with the precipitation totals from the same 3-months period for all the years included in the historical record.

6-month SPI

The 6-month SPI compares the precipitation for that period with the same 6-months period over the historical record. For example, a 6-month SPI at the end of September compares the precipitation total from the month of April–September with all the past totals for that same period.

9-month SPI

The 9-month SPI provides an indication of inter-seasonal precipitation patterns over a medium timescale duration. Droughts usually take a season or more to develop. SPI values below -1.5 for these timescales are usually a good indication that dryness is having a significant impact on agriculture and may be affecting other sectors as well. This time period begins to bridge a short-term seasonal drought to those longer-term droughts that may become hydrological, or multi-year, in nature.

12-month up to 24-month SPI

A 12-month SPI is a comparison of the precipitation for 12 consecutive months with that recorded in the same 12 consecutive months in all previous years of available data.

SPI calculator

The monthly block wise rainfall data of 20 years (1998-2018) of Nuapada district has been used to obtain block wise SPI values for 1, 3, 6, 9 and 12 months timescale, using a software named as SPI calculator, SPI_SL_6exe, developed by the United States National Drought Mitigation Centre (WMO, 2012).

Classification of meteorological drought based on SPI values

Meteorological drought for the 5 blocks of Nuapada district was classified based on the ranges of SPI values. The 20 years of precipitation data along with SPI values were analyzed for the classification. The SPI values were classified as extreme, severe, moderate, normal and no drought.

Assessment of agricultural drought

In this study, agricultural drought assessment was done by calculating NDVI which is the simplest, efficient and universally used index (Liu and Huete, 1995). For computing NDVI, LANDSAT information was used which was downloaded from USGS Earth Explorer.

Extraction of agricultural area from NDVI maps

The shape file of the *kharif* crop area of Nuapada district was collected from the land use land cover map of Odisha supplied by National Remote Sensing Centre (NRSC), Hyderabad and the kharif crop area was extracted from the NDVI maps of every drought and non-drought year taken for study. After extracting, the zonal statistics of NDVI (mean NDVI) was noted down block wise for drought and non-drought years.

Classification of agricultural drought

Agricultural drought was classified based on the formula as stated below:

$$\text{NDVI dev}(\%) = \frac{\text{NDVI}_i - \text{NDVIn}}{\text{NDVIn}} \times 100 \quad .(2)$$

The above Eq (2) is available in the drought management manual, 2016, published by Govt. of India.

Where:

$NDVI_i$= Current value of NDVI and NDVIn = Normal value of NDVI

If the NDVI deviation is -20% or more, then it is classified as normal drought, if it lies between -20% to -30%, then it goes for moderate drought condition and if the deviation is -30% or less then it called as severe drought (Manual for Drought Management, 2016).

A comparison was made between the meteorological drought index and agricultural drought index for better interpretation of drought and to analyse the index which is more accurately predicting the drought. After the classification of meteorological and agricultural drought for the drought years, the rainfall deviations with respect to meteorological and agricultural drought index were compared for better drought assessment.

Results and Discussion

Rainfall analysis

Rainfall analysis of 5 blocks of Nuapada district was made based on eight years of rainfall data, out of which, six years are drought years and two years are non-drought years.

The drought information collected from OSDMA, Bhubaneswar, revealed that in the year 2002 and 2015, there was severe drought in Nuapada district where all the 5 blocks were affected. Most of the agricultural area was affected and the crop yield was drastically reduced. But the drought analysis for the 5 blocks (Boden, Khariar, Komna, Nuapada and Sinapali) of Nuapada district showed that in most of the drought years, the blocks were normally affected by drought which is reflected in (Table-2).

Table.2 Drought analysis for Boden block of Nuapada district

Year	Annual rainfall(mm)	Average annual Rainfall (mm)	Deviation (%)	Classification
2002	816.0	1209.25	-32.52	moderate drought
2006	1352.0	1209.25	11.80	no drought
2008	1091.0	1209.25	-9.77	normal drought
2009	1002.0	1209.25	-17.13	normal drought
2011	1018.0	1209.25	-15.82	normal drought
2015	916.0	1209.25	-24.25	normal drought
2016	1387.0	1209.25	14.70	no drought
2018	1156.0	1209.25	-4.40	normal drought

Assessment of Meteorological Drought Index (SPI)

The SPIs with 5 timescales i.e. 1 month, 3 month, 6 month, 9 month and 12 month time period were computed for the 5 blocks of Nuapada district based on 20 years of rainfall record as specified earlier. It was observed that the 9-month SPI time lag had better correlation with the observed agricultural drought (Table-3 and Table-4).

The classification of meteorological drought was done for the 5 blocks of Nuapada district. But, here only the classification of meteorological drought based on 9 month SPIs for different drought years in the Boden block of Nuapada district is presented in Table.4 to avoid repetition for other four blocks of Nuapada district (Fig-3).

Generally meteorological drought is noticed on the onset, breaks and withdrawal times of monsoon in the district. However, maximum numbers of drought event were observed in the month of September in all the 5 blocks of the district, as it was evidenced from Fig.3 developed for the Boden block. Here the sum of 9-month SPI values (preferably negative values) was closely matched with the breaking and the withdrawal of monsoon in that district. The better correlation of sum of 9-month SPIs for all the drought years was found to be established with the month of September. Because the sum of monthly SPI values (negative values) are very high in the month of September for all the six drought years leading to severe drought, which was followed by moderate droughts in the month of July and August.

Table.3 9-month SPI showing better correlation for the drought year 2002 in Boden block of Nuapada district

Year	Month	1MSPI	1MSPI	1MSPI	1MSPI	1MSPI	Drought classification				
2002	1	1.31	0.38	-1.3	1.12	1.09	no drought	no drought	moderate	no drought	no drought
2002	2	0.71	0.52	-1.92	0.99	1.1	no drought	no drought	severe	no drought	no drought
2002	3	0.76	0.63	-1.03	0.17	1.16	no drought	no drought	moderate	no drought	no drought
2002	4	0.71	0.68	0.22	-1.23	1.16	no drought	no drought	no drought	moderate	no drought
2002	5	0.02	0.32	0.3	-1.49	0.98	no drought	no drought	no drought	normal	no drought
2002	6	-0.16	-0.14	-0.12	-0.55	0.05	normal	normal	normal	normal	no drought
2002	7	-0.65	-0.58	-0.49	-0.48	-1.32	normal	normal	normal	normal	moderate
2002	8	-0.18	-0.6	-0.52	-0.49	-1.24	normal	normal	normal	normal	moderate
2002	9	-0.66	-0.98	-0.88	**-1.87**	-1.07	normal	normal	normal	**severe**	moderate
2002	10	0.14	-0.72	-0.94	-0.87	-0.86	no drought	normal	normal	normal	normal
2002	11	0.57	-0.65	-0.96	-0.91	-0.89	no drought	normal	normal	normal	normal
2002	12	1.07	-0.12	-1.02	-0.95	-0.94	no drought	normal	moderate	normal	normal

Table.4 Classification of meteorological drought based on 9 month SPIs for different drought years in Boden block of Nuapada district

Years	9-month SPI	Classification
2002	-0.67	normal drought
2008	-0.24	normal drought
2009	-0.35	normal drought
2011	-0.02	normal drought
2015	-1.49	moderate drought
2018	-0.57	normal drought

Table.5 Agricultural drought classification for Boden block of Nuapada district

Years	NDVI deviation (%)	Classification
2002	-59.48	severe drought
2008	-13.31	normal drought
2009	-13.02	normal drought
2011	-13.55	normal drought
2015	-41.96	severe drought
2018	-3.62	normal drought

Table.6 Comparison of meteorological and agricultural drought for Boden of Nuapada district

Drought years	Ground truthing (OSDMA)	Rainfall analysis	SPI	NDVI
2002	severe	moderate	normal	severe
2008	normal	normal	normal	normal
2009	normal	normal	normal	normal
2011	normal	normal	normal	normal
2015	severe	normal	moderate	severe
2018	normal	normal	normal	normal

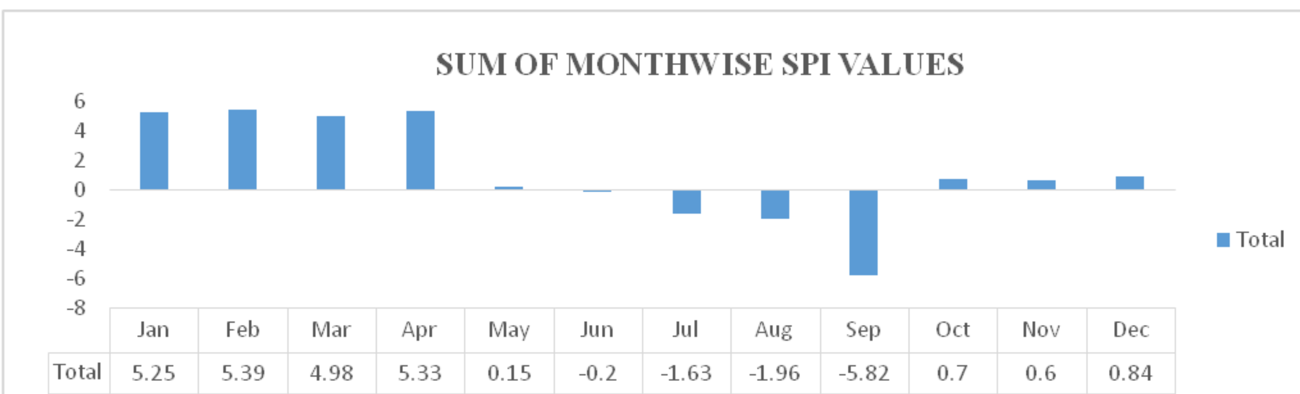

Fig.3 Sum of month wise SPI values of all the six drought years in Boden block of Nuapada district

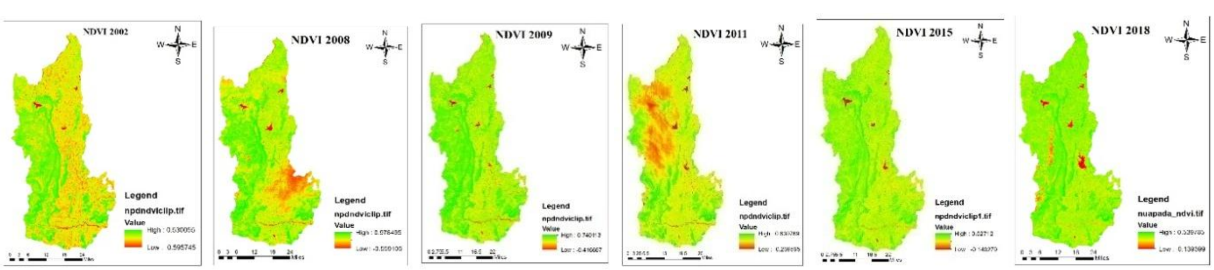

Fig.4 Temporal pattern of NDVI of Nuapada district for different drought years

As per the drought information collected from OSDMA, Bhubaneswar, in the year 2002 and 2015, there was severe drought in Nuapada district where all the 5 blocks were affected but the analysis of meteorological drought had a clear mismatch with the information collected from OSDMA which can be seen in the Table.3.

Assessment of Agricultural Drought Index (NDVI)

The temporal pattern of NDVI of different drought years showed the variation in the condition of vegetation. The NDVI values were found to be very low in 2002 and 2015 drought years (FIG-4).

Interpretation of mean NDVI values

The mean NDVI values indicated the status of crop with the highest accuracy as compared to the maximum and minimum values of the NDVI.

From the observation of the 5 blocks of Nuapada district, it was found that the average of mean NDVI values of the drought years varied from 0.23 to 0.27 for the kharif crop area. For non-drought years, the average of mean NDVI varied from 0.42 to 0.44 which indicates that for non drought years the NDVI goes above 0.4 for crop area and for drought years the NDVI lies between 0.23 and 0.27 for crop area.

Classification of agricultural drought

In order to classify the agricultural drought, NDVI deviation was found out. Based on the deviation, the drought years were classified as normal, moderate and severe (Table-5).

The classification of agricultural drought was made for all the 5 blocks which was based on recommendation of the Manual designed for drought management, 2016. As per the information collected from OSDMA, during the year 2002 and 2015, all the blocks of Nuapada district were severely affected by drought. The analysis of agricultural drought based on NDVI values for all the blocks evidenced that the droughts occurred in the 5 blocks are nearly matching with the information provided by OSDMA, Bhubaneswar. The NDVI information extracted from the satellite imageries is more realistic and more accurate than OSDMA information extracted from the area statistics based on rough estimation (i.e. if 33% of total sown area is suffered from crop loss, then it is declared as drought) for better drought assessment.

Comparison of meteorological drought and agricultural drought

The comparison was made for the 5 blocks of Nuapada district which showed in some cases that the drought categories based on SPI, matched with the drought categories based on NDVI and also with drought categories based on rainfall information. The droughts based on SPI and rainfall information were found contradictory with OSDMA information. (TABLE-6)

The 9-month SPI values of all the drought years for each block were critically compared with the mean NDVI values of all the drought years for the respective blocks. From the observation, it was found out that the results obtained from the 9-month SPI values had a mismatch with the ground truth information supplied by OSDMA while the results obtained from NDVI values had a clear-cut match with the ground truth information. Hence it was concluded that NDVI showed better results in comparison to SPI and can be used for effective agricultural drought assessment.

In conclusions, drought assessment was made using SPI and NDVI information. The SPI on

5 different timescales i.e. 1, 3, 6, 9 and 12-months were calculated but the 9-month SPI value was only considered in the study so as to establish the better correlation with NDVI value and the 9 month SPI is also coinciding with the harvesting season of *kharif* crop. It was observed that 9-month SPI was better in representing the drought conditions in comparison to other SPIs in the 5 blocks of Nuapada district as it is the cumulative value of rainfall of 9 months starting from January to September. The drought years that were taken for study had negative SPI values and were classified as normal, moderate and severe drought years among which, on an average, 4 out of the 6 drought years were normally affected. Assessment of agricultural drought indicated that the drought years had lower NDVI values in comparison to the observed non-drought years. For the drought years, the mean NDVI of the cropped area lies between 0.23 and 0.27 whereas the mean NDVI for the non-drought years of the cropped area lies between 0.42 and 0.45 for the 5 blocks of Nuapada district. The SPI values revealed that there are drought risks in the five blocks of Nuapada district. But in many occasions, there were deviations between SPI and OSDMA information, which discouraged the use of SPI values for effective drought prediction .The drought risk assessment based on NDVI values was much better than SPI values as in many cases there was very little deviation between NDVI and OSDMA information, which is treated as ground truthing parameter. Hence, NDVI method of drought prediction is the most suitable method in comparison to SPI method.

References

Barati F. Clevers J. and Steven M.D. (2011). The robustness of canopy gap fraction estimations from red and near-infrared reflectances. Journal of *Remote Sensing of Environment* 54 (3): 14–151.

Chandrashekhar G, Gopal S, Macomber S, Martens S, Woodcock C, and Franklin J. (2010). A Neural Network Method for Efficient Vegetation Mapping. Journal of *Remote Sensing of Environment*, 70:326–338.

Dutta R, Skidmore, Andrew., Atzberger, Clement., Wieren, Sip van. (2015). Estimation of vegetation LAI from hyperspectral reflectance data: Effects of soil type and plant architecture. *International Journal of Applied Earth Observation and Geoinformation* 10: 358–373.

Goddard, S., Harms, S., Reichenbach, S., Tadesse, T and Waltman, W.J. (2003). Geospatial decision support for drought risk management. Communication of the ACM 46(1): 35–37.

Ground water information booklet for Kalahandi district, 2013 CGWB, Ministry of Water Resources, Govt. of India, New Delhi.

Liu, H.Q. and Huete, A.A. (1995) Feedback Based Modification of the NDVI to Minimize Canopy Background and Atmospheric Noise. IEEE Transaction on Geoscience and Remote Sensing, 33, 457-465.

Manual for drought management (2016) Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare Government of India New Delhi.

McKee, T.B., Doesken, N.J. and Kleist, J. (1993). The relationship of drought frequency duration to time scales. Preprints, 8th Conference on Applied Climatology, pp. 179–184

Shahabfar I., Rasmussen, K., Andersen, J. (2012). A simple interpretation of the surface Temperature vegetation index space for assessment of surface moisture status. *Journal of Remote Sensing of Environment*, 79: 213-224.

Rural Livelihoods Project (English)., World

Bank Report. 2008, World Bank, Washington, DC. http://documents.worldbank.org/curated/en/741531468051855319/India-Orissa-Rural-Livelihoods-Project

SPI User guide, (2012) WMO-No. 1090, © World Meteorological Organization, Geneva 2, Switzerland.

Subramanya, K. (2018). Engineering Hydrology 4th Edition, Tata McGraw-Hill, New Delhi.

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