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Drought Assessment in Tel River Basin using Multiple Time Scaled Indices and GIS

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Abstract : India is amongst the most vulnerable drought prone countries in the world, where a drought has been reported at least once in every three years in the last five decades. In this paper, an attempt has been made to provide a comprehensive idea of drought through interpretation and correlation of various drought causative parameters. The Tel watershed covering an area of 2756 km^2 and lies between 19° 17′ and 20° 00′ N latitude and 82° 30′ and 82° 59′E longitude near Bhawanipatna region of Kalahandi district of Odisha, India was selected as the study area. Spatiotemporal variation of seasonal drought patterns and drought severity in the Tel watershed was analyzed by the Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). The analysis shows that drought assessment by watershed approach and the combination of various parameters can offer better understanding and better monitoring of drought conditions.

Key words : Drought, SPI, NDVI, NDWI, GIS

INTRODUCTION

Drought can be defined as a temporary and recurring meteorological event, which stems from a deficiency of precipitation over an extended period of time compared to some long term average conditions. Drought is quite common in India. According to Government of India reports, about 68% of the country is prone to drought in varying degrees. Odisha is one of the chronically drought affected states of India. The single important factor, which has contributed to the severe drought in the state, has been the erratic distribution of rainfall over the state. Historical data reveals that the first drought of severe nature that struck the state was in 1866 & ever since this till now; drought of moderate to severe nature has been experienced 17 times. This Indicates that drought of moderate to severe nature occurs in Odisha once in almost 8 years duration on an average that leads to crop losses, large-scale migration in search of alternative livelihoods, loss of human life due to stress, suicide, starvation or unhygienic conditions, and increased social conflict in this state.

Over the past decades, many studies have been carried out on the reasons for drought occurrences in Odisha as in [2], and its impact on crop yield and livelihood [1], using rainfall analysis [7], [10], [11]. However only rainfall analysis cannot depict a clear picture of drought in an area unless it is correlated with the rate of plant growth, vegetation water content, leaf area index, crop yield etc.

The present study aims to analyze the effects of precipitation on the vegetation of a region. Standardized Precipitation Index (SPI) has been used to monitor meteorological drought as SPI offers a quick, handy, simple approach with minimal data requirements [4]. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) have been employed to assess the impact of precipitation deficiency on vegetation and to analyze the spatio-temporal variation of drought conditions.

METHODOLOGY

Analysis of meteorological drought is the most fundamental requirement of any investigation as it gives us idea about the previous year's drought situation in the basin. A number of different indices have been developed to quantify drought based on precipitation, each with its own strengths and weaknesses. However the SPI has an advantage over the other indices because it is spatially invariant in its interpretation, and probabilistic, so it can be used in risk and decision analysis [8]. SPI is more representative of short-term precipitation than PDSI and thus is a better indicator for soil moisture variation and soil wetness [3]. SPI is a better predictor of crop production, as it represents the moisture state of soil better [9]. SPI also provides a better spatial standardization than does PDSI with respect to extreme drought events [5]. In this study, the identification and assessment of drought severity were done using the SPI at 1, 2, 3 time scales as agricultural activities can be best explained by SPI at short term time scales. The SPI is calculated using the following equation, written as

$$SPI = (Xij - Xim)/\sigma \qquad (1)$$

where, Xij is the seasonal precipitation at the ith rain-gauge station and jth observation, Xim is its long-term seasonal mean and σ is its standard deviation. Drought intensities and corresponding SPI values are shown in table 1.

Table 1. Drought intensities using SPI [6].

SPI values	Drought category
0 to – 0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.0 or more	Extreme drought

SPI has been computed separately for each of the 5 rain-gauge stations falling within the study area for a period of 44 years i.e. 1965-2008. Since drought is a regional phenomenon, SPI values of the rain-gauge stations have been interpolated using Inverse Distance Weighted interpolation technique in Arc GIS 9.3 to demarcate its spatial extent.

Though SPI at short time scales like 1, 2, 3 months can be used for agricultural drought assessment, only SPI cannot depict a clear picture of agricultural drought unless it is correlated with the rate of plant growth, vegetation water content, leaf area index crop yield etc. Hence, in this study the NDVI and NDWI were used for drought vulnerability analysis along with SPI. That is why the NDVI and NDWI were also generated In this study using the multi-date LANDSAT ETM+ satellite images as mentioned below.

NDVI = (Band 4-Band 3) / (Band 4+Band 3)……………(2)
NDWI = (Band 4-Band 5) / (Band4+Band5)…………….(3)

Where band 3 (0.63 µm -0.69 µm), band 4 (0.77 µm -0.90 µm) and band 5 (1.55 µm -1.75µm) are the reflectance of red, near infrared and short wave infrared bands respectively. To take advantages of information contained in RED, NIR and SWIR channels both the NDVI and NDWI maps were overlaid using the weighed overlay analysis technique in Arc GIS 9.3 software.

RESULTS AND DISCUSSION

SPI

In this study, the standardized precipitation index (SPI) was used for the spatio-temporal analysis of meteorological drought in the Tel river basin. SPI indices were determined using monthly total precipitation series at the five meteorological stations and results are discussed for May-October months. Since negligible rainfall occurred during November to April months, results of these months are not discussed here. The analysis showed that in 1-month scale, extreme drought was experienced in Junagarh with an SPI value of -2.5 in the month of July 2007. July was the most critical month, experiencing maximum number of extreme and severe droughts in the 5 meteorological stations. May followed July in experiencing severe drought and moderate drought in 9.78% and 13.63% of the total 44 years, respectively. Drought magnitude was increased with 2-month scale as compared to the 1-month scale. The highest magnitude observed was -2.74 in the month of July in Dharamgarh during 2002. Analysis showed that 2002 rainy season was affected by severe drought with all the months having negative SPI value (Figure 2). The lowest extreme drought event was experienced during May, with the value of -2.02 in Junagarh in a 3-month time scale. May was found to be the most critical month, with 43.15% of severe drought and 25% of moderate drought of the total area (Figure 3), while October was the least critical month with 25% of moderate drought, 11.36% severe drought and only 2.27% extreme drought during the investigation period. The maximum number of observed drought events occurred in May, followed by July and August.

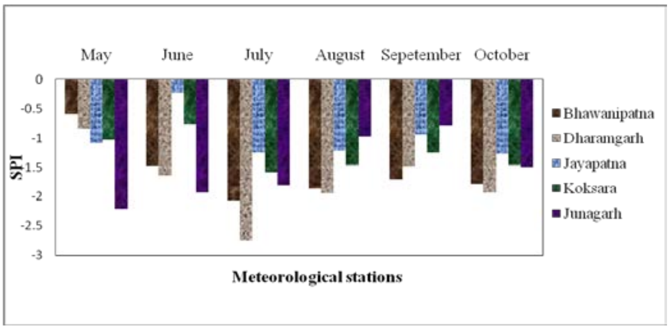

Fig. 2. SPI values in all meteorological stations in the year 2002 in 2-month time scale

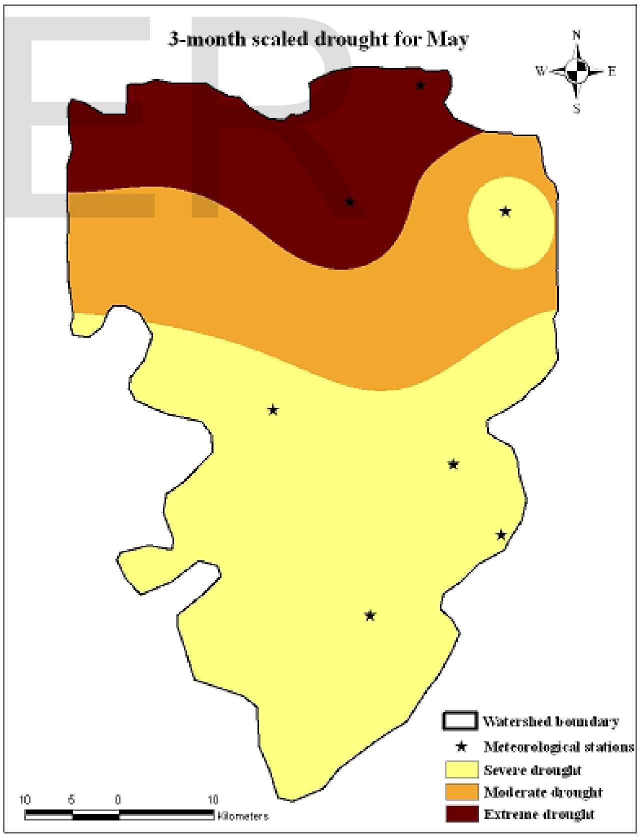

Fig. 3 Spatial distribution of 3 month scaled droughts in May in the study area.

NDVI and NDWI

In this study both the NDVI and NDWI indices were generated in ERDAS 9.3 software to monitor agricultural drought in Tel river basin. As the NDVI or NDWI image is a single band continuous data, only one value per pixel in each

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image, the differences in data can be evaluated and pixels having similar values can be assigned to a single class. Hence, the NDVI and NDWI values were reclassified into 7 classes using the spatial analyst tool of Arc GIS 9.3 software. The new classes were then assigned NDVI or NDWI values with reference to the land use/land cover map of the study area. The fig. 4 shows the reclassified NDVI image of the Tel watershed. The color scale at the bottom of the fig indicates that the NDVI values increases from -0.13 (blue color) from the top to 0.69 (Dark green color) in the bottom of the watershed. The areas in Yellow and dark brown correspond to the crop areas with different reflectance and the areas in red color indicate deep water bodies. The area with light green color is the shrubs and areas with white color represent the alluvial deposits along the rivers with the lowest NDVI value.

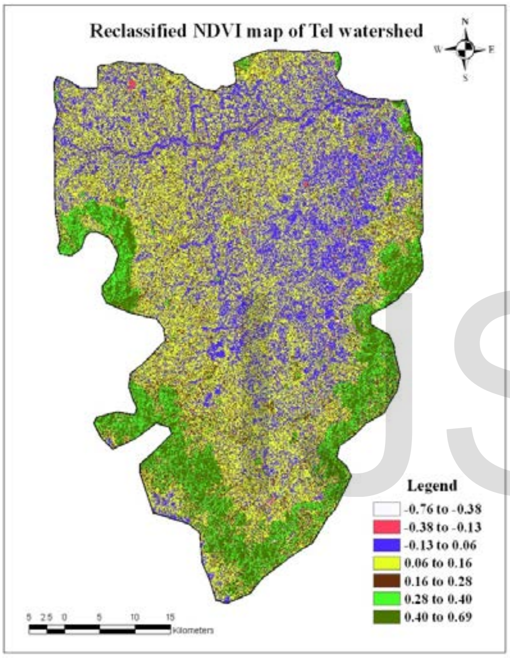

Fig.4. NDVI map showing different landuse features.

The NDWI values varied from -0.44 to 0.97 in the entire watershed. As the NDWI indicates both the water content (In the absence of vegetation cover) and the vegetation canopy water content in plants, the reflectance of different land use features are quite different than that of NDVI. The fig. 5 shows the reclassified NDWI image of the Tel Watershed. Large areas in blue color corresponding to NDWI values between -0.13 to -0.028 indicated low moisture content in crop canopies in the cultivated areas. The areas in light green correspond to NDWI values -0.45 to -0.12 indicates the dryness of some parts of streams and the main river. The areas in red and white with lowest positive NDWI values indicate the presence of water in the Tel river and some of the tributaries and also in surface water bodies like tanks and reservoirs. Yellow and dark green color with higher positive NDWI values ranging from 0.24-0.96 indicates the high canopy water content shrubs and dense forests as well as the increased depth of water in the rivers and streams.

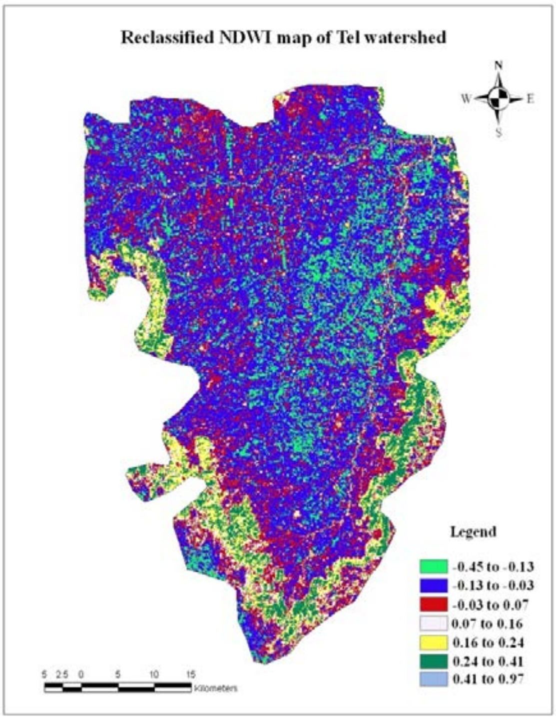

Fig.5. NDWI map showing different landuse features.

All 7 classes of the NDVI and the NDWI maps were assigned some weightage depending upon its vulnerability to drought and considering the NDVI and NDWI values. The weighted overlay technique was applied to integrate the NDVI and NDWI values to derive the final drought vulnerability map. An area is considered to be vulnerable to drought if NDVI<0.5 and NDWI<0.3 and similarly if NDVI>0.5 and NDWI>0.3, then non drought conditions occur in an area. In this study, the NDVI and NDWI values were classified separately to define various drought intensities and were divided into 4 drought categories. The overlaid map was also divided into 4 drought categories after clubbing up the NDVI and NDWI values together. The comparisons of the percentage of drought areas under different drought categories in the NDVI, NDWI and the overlaid map are shown in table 2 and the spatial variation of agricultural drought in the Tel river basin is shown in fig. 6. The table indicates that non-drought conditions occurred in 16.58% of the total study area as per the NDVI analysis where as it is 11.2% in NDWI analysis. When both the NDVI and NDWI values are summed up in the overlaid map, the result was quite low for the non-drought categories i.e 7.36%. This shows that the NDWI values exhibited a quicker response than NDVI and the overlaid map was even quicker in response due to the combined effect of the visible, near infrared and shortwave infrared channels.

Table 2. Comparison of areas under different drought categories

Drought classes	NDVI	NDWI	Overlaid map
No drought	16.58%	11.20%	7.36%
Mild drought	37.71%	27.80%	17.86%
Moderate drought	23.55%	15.60%	34.55%
Severe drought	21.78%	24.80%	27.66%
Extreme drought	0.38%	20.60%	12.57%

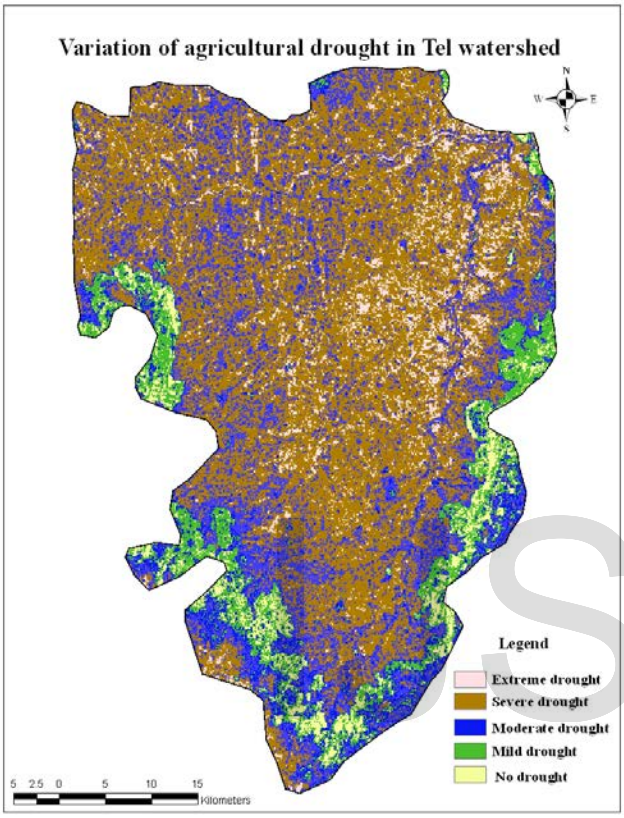

Fig 6 Spatial variation of agricultural drought in Tel watershed

CONCLUSION

The present study concerned the assessment of drought in a chronically drought affected region of Odisha, India. Meteorological as well as remotely sensed vegetation indices are used to study the correlation of rainfall with vegetation vigor and plant growth. An analysis of the variation of drought scenario in different places of the watershed on different time scales show that the study area was facing severe and extreme drought conditions in July month in almost all the years under observation. Dharamgarh was the worst affected among all meteorological stations having highest SPI values while other stations were facing extreme droughts of lower magnitude. The years 1966, 1972, 1979, 1987 and 2002 were the most drought-affected years during the investigation period. The NDVI values of the study area varied from -0.13 to 0.69 and the NDWI values varied from -0.44 to 0.97. NDWI values decreased more in response to drought conditions than NDVI, indicating that NDWI was more sensitive than NDVI to the onset of drought conditions. The weighted overlay technique was applied to integrate the NDVI and NDWI values to study the spatial extension of agricultural drought. The analysis showed that the NDWI values exhibited a quicker response than NDVI and the overlaid map was even quicker in response due to the combined effect of the visible, near infrared and shortwave infrared channels. It was also observed from the analysis that combination of meteorological indices and vegetation indices helped in better understanding of the drought occurrences in this region.

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