Krishi Netra

Multi-Indicator Approach for Comprehensive Drought Assessment: Integrating Rainfall Deviation with Vegetation, Soil Moisture, and Hydrological Indices

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Abstract

Drought, being a complex hazard poses significant challenges for accurate and timely prediction as well as management. No single indicator can fully capture its complexity, necessitating an integrated monitoring approach. As the complexity of drought cannot be captured with the aid of a single indicator, therefore many drought indices categorised as mandatory and impact indicator are used combinedly for monitoring purpose. Drought monitoring proposes combining mandatory meteorological indicators such as Rainfall Deviation (RFdev) and dry spells with key impact indicators: Vegetation Condition Index (VCI) derived from NDVI, Percent Available Soil Moisture (PASM), and Groundwater Drought Index (GWDI). Drought severity (normal, moderate, or severe) is determined by the consensus of at least three impact indicators, with final validation requiring ground-level verification by authorities. Despite challenges posed by data irregularity and spatial-temporal variability, this multi-indicator framework supported by regular field checks and region-specific contingency plans enables reliable early warnings and targeted mitigation, thereby enhancing agricultural resilience in drought-prone areas.

Keywords: Drought, Rainfall, Dry spell, VCI, GWDI

Introduction

The Indian subcontinent is highly vulnerable to natural disasters such as droughts and floods, particularly during the monsoon season. Unlike other natural hazards, drought is a severe phenomenon marked by its gradual onset and its indefinite commencement and termination. It has significant impact on agricultural, socio-economic and environmental sphere but is difficult to accurately quantify since its definition is spatially variant and context dependent (Quiring, 2009a).

Drought is additionally described as a climatic irregularity marked by inadequate moisture supply, arising from below-average rainfall, irregular rainfall patterns, increased water demand, or a combination of these factors. The primary categories of drought include: (a) meteorological drought, (b) hydrological drought, and (c) agricultural drought.

Meteorological drought is the first observation of drought condition caused by deviation in rainfall amount from its normal. Meteorological droughts lead to soil moisture deficits (Wang *et al.* 2009), which in result affect plant growth, and hampers the overall quantity and quality of crops produced (Mishra and Cherkauer 2010). Due to prolonged meteorological drought, hydrological drought situation arises where there is unavailability of water in surface and sub- surface levels. Then comes the agricultural drought which is a situation when rainfall and soil moisture are inadequate during the crop season to support the timely cultural practices and healthy crop growth. Soil moisture depletion below the permanent wilting point results in crop

mortality, putting the food security of the region at risk.

No single drought index can comprehensively capture the multifaceted, multi-scale, and multi-impact characteristics of this complex phenomenon. Accurate evaluation of drought occurrence, extent, and severity requires a precise understanding of the spatial and temporal patterns of critical variables, including meteorological, hydrological, and surface variables. Consequently, numerous drought indices have been developed to monitor drought conditions (Quiring, 2009b). Each index employs distinct data inputs and methodological approaches to quantify drought.

1. Rainfall based indices

1.1 Rainfall deviation : Rainfall deviation from normal long term mean, is the most commonly used indicator for drought monitoring. Percent deviation of rainfall (RFdev) is expressed as RFdev $=\times 100$

Where RFi is current rainfall (in mm) in time period 'i' and RFn is normal rainfall (in mm) average of at least 30 years

Table 1: IMD classification of rainfall deviation

Deviation from normal rainfall (%)	Category of rainfall
> + 19	Excess
+19 to -19	Normal
+19 to - 19	Normal
-20 to -39	Deficient
-40 to -59	Severe Deficient
< - 60	Scanty

Source: Manual for Drought Management, 2016

1.2 Dry Spell

A dry spell is a short period, usually 4 weeks (up to 3 weeks in case of light soils), of low rainfall or no rainfall. Thus, consecutive 3/4 weeks after the due date for the onset of monsoon with rainfall less than 50% of the normal in each of the weeks is defined as a dry spell. The weekly rainfall data of each block was analysed to calculate the number of dry spell occurred in the respective month.

$$\text{Percentage of rainfall} = \times 100$$

Step 2:- Impact indicators from Agriculture based indices, Remote sensing based vegetation indices Soil moisture based indices and Hydrological indices are considered to assess the severity of drought condition in the area.

2. Agriculture based indices

2.1 Crop sown area

Drought conditions could said to be exist if the total sown area under kharif crop is less than 85% of the total normal sown area by the end of July / August, depending upon the schedule for sowing in individual

states due to failure of rains or very late arrival of monsoon. In such situations, even if rainfall revives in the subsequent months, there is a little possibility of full recovery and the agricultural production is likely to take a substantial hit. However, the conditions will indicate portents for drought of a 'severe' nature, if the area under crop falls to 75% of the normal by the end of July / August.

3. Remote sensing based vegetation indices

3.1 Vegetation Condition Index (VCI)

NDVI was developed by Rouse *et al.,* (1973) and is based on the fact that internal mesophyll structure of healthy green leaves reflects Near-infrared (NIR)radiation whereas the leaf chlorophyll and other pigments absorb a large proportion of the red visible (RED) radiation. The current period values of NDVI can be compared with long-term data (at last ten years) for computing Vegetation Condition Index (VCI) which compares the observed NDVI to the range of values observed for the same period in previous years. The VCI is expressed in percentage (%) and gives an idea where the current value is placed within the extreme value (minimum and maximum) in the historical dataset normalized to a scale of 0-100% (Table 2). Lower and higher values indicate bad and good vegetation state conditions, respectively. VCI is computed as:

$$VCI (NDVI) = \times 100$$

Where the subscript 'curr' refers to current period value, 'min' and 'max' refer to minimum and maximum values of NDVI in historical dataset for the same period and same location.

Table 2: VCI representing different drought classes

VCI Values (%)	Vegetation Condition
60 - 100	Normal
40 - 60	Moderate
0 - 40	Severe

Source: Manual for Drought Management, 2016

4. Soil moisture based drought indices

4.1 Percent Available Soil Moisture (PASM)

PASM (Table 3) is derived from observed moisture sensor data or sample soil-water balance model following the 'bucket approach' and using the following formula: $PASM = \times 100$

Where, SM_w = weekly calculated volumetric soil moisture (vol/vol) for the current week

FC= Field capacity of soil (vol/vol)

PWP= Permanent wilting point of soil (vol/vol)

Table 3: Drought classification based on PASM

PASM (%)	Agricultural drought classes
76 – 100	No drought
51-75	Moderate drought
0 – 50	Severe drought

Source: Manual for Drought Management, 2016

5. Hydrological drought indices

5.1 Groundwater Drought Index (GWDI)

Ground water drought index derived from the ground water level which is measured quarterly (January, April, August and November) in a year by the Central Ground Water Board (CGWB). Ground water drought is a distinctive class of drought resulting from the decrease in ground water recharge and the decrease in ground water storage and discharge (Bloomfield *et al.* 2015).

The computation procedure for Ground Water Drought Index (Table 4) is as follows:

$$GWDI_{ij} = \text{ Where, } GWDi_j= \text{Ground water drought index for month and year.}$$

$MGWD_j$ = Mean depth to ground water table below surface (in meter)

$GWDi_j$ = Depth to ground water table in month and year (in meter)

$GWDi_{max}$ = Maximum depth to ground water table in ith month in available data set for n number of years (in meter)

Table 4: Ground Water deficit class

Ground Water Drought Index (GWDI)	Ground Water deficit class
>-0.15	Normal
-0.16 to -0.30	Mild
-0.31 to -0.45	Moderate
-0.46 to -0.60	Severe
< -0.60	Extreme

Source: Manual for Drought Management, 2016

6. Assessment of drought severity

The severity of the drought will be contingent upon the values of at least three out of four impact indicators viz. Agriculture, Remote sensing, Soil moisture and Hydrology in the following manner:

- Severe drought: If at least two of the selected 3 impact indicators are in 'severe' category and one is 'moderate' category, then the area is considered to be in severe drought.

- Moderate drought: If at least two of the selected 3 impact indicators are on 'moderate' category then

the area is considered to be in moderate drought.

- For all other cases the area is considered to be in normal condition.

Conclusion

The integrated multi-indicator approach presented herein offers a robust framework for comprehensive drought monitoring and assessment, addressing the inherent limitations of single-index methods in capturing the multifaceted nature of this slow-onset hazard. By synergistically combining mandatory meteorological indicators, such as rainfall deviation (RFdev) and dry spells, with impact-oriented indices including crop sown area, Vegetation Condition Index (VCI) derived from NDVI, Percent Available Soil Moisture (PASM), and Groundwater Drought Index (GWDI) this methodology enables a more accurate delineation of drought onset, extent, and severity across meteorological, agricultural, and hydrological dimensions. Drought classification based on the consensus of at least three impact indicators, supplemented by mandatory ground-level verification, enhances the reliability of early warnings and facilitates targeted, region-specific interventions.

Despite persistent challenges, related to data irregularity, spatial heterogeneity, and temporal variability in observation frequencies, the adoption of consistent, high-quality datasets coupled with field validation and contingency planning such as Odisha's annual Crop Contingency Plan promotes proactive mitigation strategies, including the deployment of drought-resistant varieties and adaptive cropping practices. Ultimately, this integrated framework strengthens agricultural resilience in drought-prone regions, supporting sustainable food security and informed policy responses in the face of escalating climatic risks.

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