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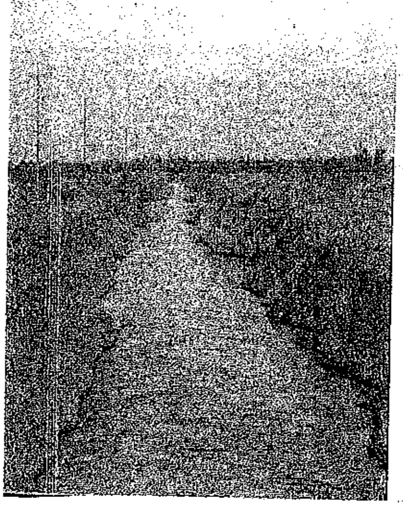

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Drought Assessment of Bundelkhand in Central India based on Drought Index Suited for Climate Change

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ABSTRACT

Droughts are regional phenomena caused due to the lack of precipitation events in a region over a period of time with its severity depending on the degree of moisture deficiency, its duration and its aerial extent. The assessment of drought characteristics is generally based on a wide variety of drought indices. The applicability of the Reconnaissance Drought Index (RDI) which incorporates both precipitation and potential evapotranspiration and useful in regions with changing climate, has been explored to study the hydro-meteorological drought characteristics including severity, duration and intensity based on the monthly climatic time series. The drought frequency varies between 1 in 3 years to 1 in 5 years. The spatial and temporal variation of the drought characteristics has been studied based on the analysis in GIS environment, which helps to identify the progression and withdrawal of droughts. During the widespread drought of 2007-08 about 95% of the Bundelkhand region was reeling under drought of varying severities.

Keywords: *Reconnaissance Drought Index, Bundelkhand, Spatio-Temporal Variation, Climate*

INTRODUCTION

Droughts significantly impact the ecosystems, socio-economic environment and agricultural areas which calls for proper drought assessments and effective drought monitoring mechanisms. Droughts cause major economic losses and human sufferings, affecting hundreds of millions of people, and several studies have highlighted the need for development of drought prevention and mitigation plans [1]. It develops slowly and imperceptibly and may remain unnoticed for a long time unlike other natural hazards [2]. Due to their large spatial extent and long durations, droughts have significant economic, social, and environmental impacts. Drought can be classified as meteorological, agricultural or hydrological, based on the different components of the hydrological cycle affected by it. Although its impact does not come through sudden events, such as floods and storms, drought is the world's costliest natural disaster, causing an average \$6- \$8 billion in global damages annually and collectively affecting more people than any other form of natural disaster [3].

Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, although other climatic factors such as high temperatures, strong wind and low relative humidity are often associated with it. Drought severity is dependent not only on the duration, intensity, and spatial extent of a specific drought episode, but also on water supply demands. Spatial aspects of the drought including area covered by it and total deficit are the important characteristics, as the size of the affected area provides a measure of the severity of the event. The spatial variation of droughts has been studied extensively [4]. According to a recent drought study there is an increasing trend in drought extent and population affected by drought, which makes drought research and management a pressing issue [5]. It is not possible to avoid meteorological droughts but it can be monitored and analysed by which their adverse impacts can be alleviated, the success of which depends on how well the droughts are defined and drought characteristics quantified.

STUDY AREA

Bundelkhand is a cultural-geographic region in Central India bounded by Vindhyan Plateau in south, Yamuna river in north, Ken river in east and rivers Betwa and Pahuj in west and remains administratively divided between the seven districts in Uttar Pradesh (U.P.) viz., Jhansi, Lalitpur, Jalaun, Hamirpur, Banda, Mahoba and Chitrakoot and six districts in Madhya Pradesh (M.P.) viz., Sagar, Damoh, Chhatarpur, Tikamgarh, Panna and Datia. It extends between 23° 08′ N to 26° 30′ N latitude and 78° 11′ E to 81° 30′ E longitude with a total area of 71619 sq. km. The region receives average annual rainfall varying between 514.4 mm to 1260.1 mm, 90% of which occurs during the south-west monsoon from mid-June to early-October and the rainfall pattern is highly erratic and uncertain with very high variability. The principal rivers draining the region are Sindh, Betwa, Ken, and Dhasan with elevation ranging from 600 m above mean sea level (amsl) in southern part to 150 m amsl near the Yamuna.

The topography of the region is highly undulating with rocky outcrops and boulder-strewn plains with a rugged looking landscape. The prominent crops are wheat, gram, bajra, and sorghum. Citrus fruits are cultivated and tomato and brinjal are main vegetables. Bundelkhand is prominently comprised of Vindhyan rocks in southern part and Granites with alluvium soils on top mixed with rocky and boulder outcrops at few places. The soils comprise of red sandy soils, mix of black and red soils, shallow black soils and alluvial soils. The region has been facing recurrent and continuos droughts in the last decade causing severe hardships for the local population leading to large-scale out-migration from the region. The index map showing the Bundelkhand region is given as Figure 1.

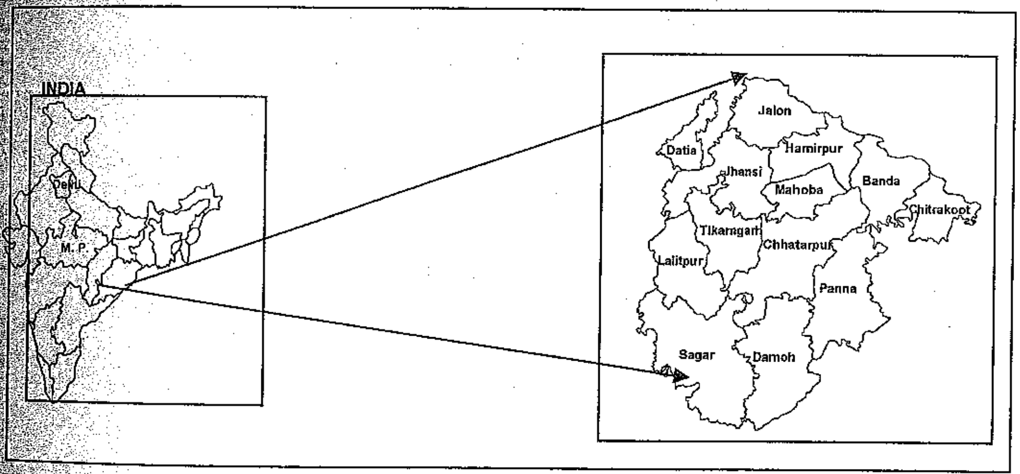

Figure 1: Index Map of Bundelkhand Region

MATERIALS AND METHODS

DATA AVAILABILITY

The detailed drought analysis which has been carried out at the scale of development blocks, requires considerable long-term data pertaining to the various aspects of interest. The data used in the analysis include long-term rainfall data, climatic data like minimum and maximum temperatures, wind speed, sunshine hours, and relative humidity at daily frequency. Extensive field visits were carried in all the thirteen districts of Bundelkhand region falling in M.P. and U.P. and the requisite data collected from the Revenue Department and Water Resources Department. Daily rainfall data for few districts where sufficient length of data record were not available has been procured from India Meteorological Department, Pune.

Estimation of Potential Evapotranspiration

The various methods available for the estimation of reference evapotranspiration include Blaney-Criddle method, Thornthwaite method, Hargreaves method, Modified Penman method, Priestly-Taylor method and Peman-Montieth method. Penman-Monteith method has strong likelihood of correctly predicting reference evapotranspiration (ET_o) in a wide range of locations and climates and has a provision for application in data short situation (FAO, 1998). FAO Penman-Monteith method is now recommended as the sole standard method for definition and computation of reference evapotranspiration using weather data such as radiation, air temperature, air humidity and wind speed [6]. The FAO Penman-Monteith method to estimate reference evapotranspiration (ET_o) is given as,

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where, ET_o =reference evapotranspiration [mm day^{-1}], R_n =net radiation at the crop surface [MJ m^{-2} day^{-1}], G =soil heat flux density [MJ m^{-2} day^{-1}], T=mean daily air temperature at 2 m height [°C], u_2 =wind speed at 2 m height [m s^{-1}], e_s =saturation vapor pressure [kPa], e_a =actual vapor pressure [kPa], e_s - e_a=saturation vapor pressure=slope vapor pressure curve [kPa °C^{-1} deficit [kPa], $^{-1}$=], psychometric constant [kPa °C^{-1}]

Reconnaissance Drought Index

The Reconnaissance Drought Index (RDI) can be characterized as a general meteorological index for drought assessment [7], [8] & [9]. The RDI deviates substantially from Standardised Precipitation Index (SPI) providing a more sound representation of the drought conditions and may be considered as a more suitable index for studying drought conditions under climate change, since it incorporates precipitation and potential evapotranspiration, both of which are directly affected by climate change. Also a strong advantage of RDI is that it offers a rational comparison of drought conditions between areas with different climatic characteristics.

Two expressions to be evaluated are, the initial α_k and the standardized RDI, $RDI_{st(k)}$. The initial α_k is presented in an aggregated form using a monthly time step and may be calculated on a monthly, seasonal or annual basis. The α_k for the year i and a reference period of k (months) is calculated as:

$$\alpha_k^i = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}} \; i=1, N \text{ and } j=1,\ldots,12 \quad (2)$$

Where, P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of month j of year i, starting from June, which is the onset of the hydrological year in the Bundelkhand region and N is the total number of years of the available data. A second expression, the Normalized RDI (RDI_n) is computed for each year, in which the parameter $\overline{\alpha_k}$ is the arithmetic mean of $\alpha_k$values calculated for the N years of data.

$$RDI_n^{(i)} = \frac{\alpha_k^i}{\overline{\alpha_k}} - 1 \quad (3)$$

The calculation of the standardized form of RDI_{st} is performed by fitting a log-normal probability density function to the given frequency distribution of α_k similar to the procedure used for SPI. The expression for the Standardized RDI is given by,

(4)

...ln (α_k^i); $\bar{y}_k$ is the arithmetic mean and σ_{y_k} is its standard deviation.

...expression is based on the assumption that α_k values follow a lognormal ...amma distribution can also be fitted instead of a log-normal distribution. In the ...out during the establishment of the RDI, the goodness of fit tests confirmed that ...distribution fits the data satisfactorily. The positive values of RDI_{st} indicate wet ...negative values indicate dry periods compared with the normal conditions of the ...rity of drought events increases when RDI_{st} values decrease. Drought severity can be ...mild, moderate, severe and extreme, with corresponding thresholds of RDI_{st} (-0.5), ...nd (-2.0), respectively. The initial expression of RDI for is estimated for four different ...riods (time scales) of 3, 6, 9 and 12 months. The P/PET ratio, for the given time scales, ...based on the assumption that both quantities P and PET separately and jointly follow a ...ibution.

...AND DISCUSSIONS

...nce evapotranspiration have been computed at all the district headquarters and varies ...9 mm/day in December to 6.87 mm/day in May at Sagar. The RDI has been estimated ...lock in all the thirteen districts in Bundelkhand region in Central India. The temporal ...in RDI at Tikamgarh block is given in Figure 1 and the summary of the drought ...stics in Sagar and Chhatarpur districts is given in Table 1. It can be observed from Figure ...the droughts have become more predominant since 2002 with continuos droughts in few ...Similar drought conditions prevailed in the other blocks of various districts falling in the ...delkhand region in M.P. with substantial variations in drought characteristics. Widespread ...ghts were experienced in 2002-03 and 2007-08 in the last decade with continuos droughts from ...4-2007.

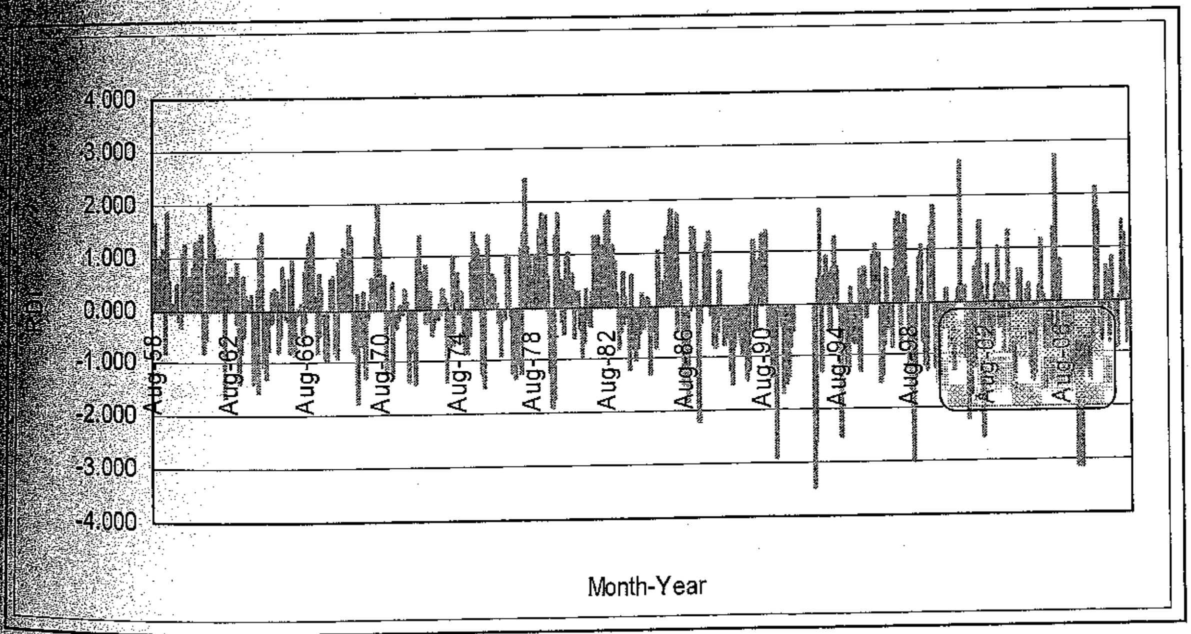

Figure 2: Temporal Variation of RDI at Tikamgarh Block

Table 1: RDI based Drought Charactersitics in Sagar and Chhatarpur Districts

S. No.	Name of Block	Number of Drought Events	Total Drought Duration	Total Drought Severitys	Average Drought Intensity
			Sagar District		
1.	Sagar	49	129	-297.3	-2.30
2.	Khurai	48	132	-147.42	-1.12
3	Banda	44	129	-132.77	-1.03
4.	Rehli	48	150	-153.53	-1.02
5.	Deori	47	152	-158.33	-1.04
6.	Malthone	38	125	-111.99	-0.90
7.	Jaisinagar	37	109	-90.15	-0.83
8.	Bina	52	70	-71.18	-1.02
9.	Rahatgarh	32	90	-96.27	-1.07
10.	Kesli	32	80	-75.95	-0.95
11.	Shahgarh	32	79	-71.61	-0.91
12.	Garhkota	27	79	-77.98	-0.99
			Chhatarpur District		
1.	Chhatarpur	60	148	-174.82	-1.18
2.	Laundi	64	146	-173.68	-1.19
3.	Bijawar	60	150	-176.81	-1.18
4.	Buxwaha	56	144	-154.98	-1.08
5.	Nowgong	36	104	-102.07	-0.98
6.	Rajnagar	41	118	-119.99	-1.02
7.	Badamalhera	41	111	-109.21	-0.98
8.	Gaurihar	37	92	-101.2	-1.10

The drought characteristics in the various districts show distinct variations. During the period of analysis spanning between 1976 and 2008, it is observed that the drought intensity varies between -0.91 at Shahgarh to -2.30 at Sagar in Sagar district. In Sagar district, maximum 49 drought events with cumulative duration of 129 months occurred at Sagar block whereas Garhakota experienced minimum 27 drought events with cumulative duration of 79 months. However all the blocks in Chhatarpur district faced higher number of drought events with higher durations and severity as compared to Sagar district. Similar scenario has been observed in Tikamgarh and Panna districts. The maximum number of 60 drought events occurred at Chhatarpur block with cumulative duration of 148 months and average drought intensity of -1.18 whereas 81 and 66 drought events occurred at Tikamgarh and Panna respectively with cumulative duration of 211 and 157 months respectively.

Once the normalized RDI and the standardized RDI is estimated for a particular area, subsequently a relation can be developed between α_k and the standardized RDI for getting a quick idea of the drought severity solely based on α_k, which is the ratio of the rainfall to the potential evapotranspiration, for that particular reference period. This can avoid the computation of standardized RDI in future by the field agencies for quick appraisal of drought severities. The developed relationship can be used to evaluate the ranges of α_k such that it coincides with the RDI classification of various drought classes. An example for development of the α_k *vs RDI* relationship and fixing of ranges for drought classes is illustrated for Garhakota block in Sagar district. The relationship between α_k and RDI at Garhakota is given in Figure 3. The relationship developed can be expressed by:

$$RDI = 3.5208Ln(\alpha_k) + 1.6142 \quad (5)$$

... relationship, the levels of drought have been fixed based on α_k for Garhakota block ... in Table 2. Similar analysis has been carried out for all the blocks in Bundel khand

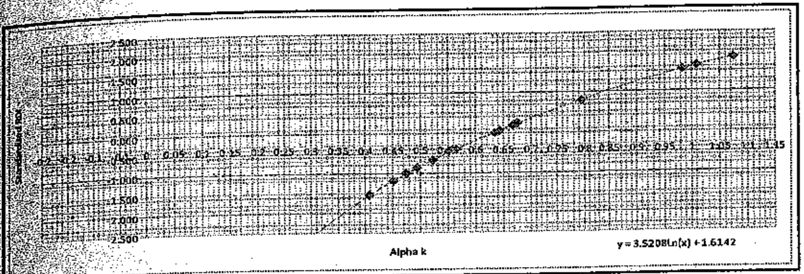

Figure 3: Establishment of Levels of Drought for α_k at Sagar

Table 2: Establishment of Drought Levels based on α_k at Garhakota Block

Drought State	Range of _RDI	Range of α_k
Extreme Drought	< -2.00	< 0.358
Severe Drought	-1.50 to -2.00	0.358 to 0.413
Moderate Drought	- 1.00 to -1.50	0.413 to 0.476
Mild Drought	-0.50 to -1.00	0.476 to 0.549
No drought	> -0.50	> 0.549

... the spatial variation of drought characteristics based on the RDI has been carried out by ... interpolation of the RDI at various blocks during the various months of monsoon season. ... showing the spatial and temporal variation of drought during 2007-08 is given in Figure ... analysis has been carried out in GIS using ILWIS 3.6. The progression of the drought can be ... understood by comparison of the RDI maps in June, July, August and September 2007. The ... of the classified map of RDI for 2007-08 is given in Table 3.

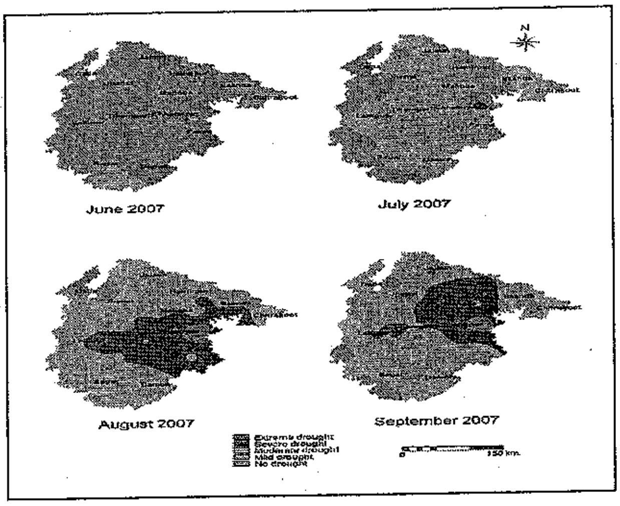

Figure 4: RDI Variation in Bundelkhand During 2007–08

Table 3: Spatial and Temporal Variation of RDI During 2007–08 in Bundelkhand

S.No	Drought Severity	Percentage of Area (%)			
		Jun-07	Jul-07	Aug-07	Sep-07
1.	Extreme	0.00	0.06	2.37	2.04
2.	Severe	0.00	0.53	28.86	23.30
3.	Moderate	0.09	18.76	43.89	42.17
4.	Mild	5.51	59.68	20.40	25.65
5.	No drought	94.39	20.95	4.64	6.83

It is observed that during June 2007, only 5.5% area was under mild drought mostly at the southern tip of Bundelkhand comprising of Kesli and Deori in Sagar district and more than 94% of the area was under near normal conditions. However in July 2007, the area affected by various classes of droughts increased and only 20.95% area was under near normal conditions. The area under mild droughts increased from 5.5% in June to 59.7% in July and new areas were affected by severe droughts (28.86%) in August. Mild droughts covered the various blocks in the districts of Sagar, Damoh, Lalitpur, Tikamgarh, Mahoba, Jhansi, Banda and Chitrakoot. Moderate drought conditions persisted in parts of Hamirpur, Panna, Lalitpur and Chhatarpur districts. However in August 2007, the severity of droughts intensified and about 95.4% of the area was under various classes of drought namely, extreme (2.37%), severe (28.86%), moderate (43.89%) and mild (20.40%). The situation in September 2007 was similar to the previous month with only 94.2% under drought conditions. However, it is to be noted that the area under severe drought changed and Hamirpur, Mahoba and some parts of Jalaun too faced severe droughts. The number of pockets under extreme drought increased in September 2007.

CONCLUSION

The meteorological drought analysis has been carried out in Bundelkhand based on the RDI which is a relatively new technique in evaluating the drought characteristics particularly under a changing climate, so the drought mitigation activities can be planned and prioritized accordingly. The Bundelkhand region has been in the limelight due to the recurrent droughts in last few years. The analysis indicates that the frequency of occurrence of drought varies between 1 in 3 years to 1 in 5 years and requires meticulous planning to solve the problems of the region. There is considerable variation in the drought severities and drought durations in various blocks of the study area. The study of the spatial and temporal variation of the drought during various drought years revealed that each drought event has its own distinct footprints. The progression and withdrawal of the drought give a clear understanding of the problematic areas under a prevailing drought and efforts can be channelized towards those areas to provide the much required relief to the affected areas. The analysis clearly indicates that rain-fed agriculture in the basin is virtually impossible without provision for adequate supplementary irrigation and a proactive drought management strategy is required to cope up with the frequent drought scenario.

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