Development of a Drought Management plan for Bearma basin in Bundelkhand region of Central India

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Abstract: Droughts are one of the most hazardous causes of human misery that cannot be avoided and it also claims most of the victims annually. Climate change which is one of the most serious challenges facing the mankind today is expected to exacerbate the extreme events including heat waves and drought in various regions of the world. Recent findings point out to the fact the land degradation is the next biggest challenge after climate change which is expected to have long term impacts on the sustainable management of natural resources worldwide. The climate change and the increased occurrences of droughts are expected to increase the land degradation which in-turn will induce and intensify climate change. The increased variability in the climate has led to the change in weather pattern with lesser number of rainy days, higher intensity rainfall, longer duration and frequent dry spells, and regular droughts. The Bundelkhand region in Central India is facing an increased drought frequency from 1 in 16 years in the last century to 1 in 3 years during the last few decades. Persistent drought in Bundelkhand region has resulted in loss of agricultural livelihood, food crisis, depletion of surface and ground water resources, reduction in crop yield, land degradation and increased poverty. Even though droughts cannot be avoided, it can be managed if appropriate drought management plans (DMP) are devised. A methodology has been tested to develop an action-linked DMP for a pilot basin viz., Bearma basin in Bundelkhand. The DMP is based on drought triggers developed using multiple drought indicators, for evaluating the various types of drought including meteorological, hydrological and groundwater drought. Similar to the flood levels used in flood forecasts, five stages of drought levels were suggested based on the drought triggers, which have been fine-tuned based on the actual drought conditions prevailing in the basin. An action plan has also been linked with these drought levels and the suggested actions may be initiated based on the prevailing drought level for the specific month. This method can be up-scaled to the other river basins in the Bundelkhand region and adopted by decision makers for better drought management.

Keywords: drought management, drought indicators, drought levels, SPI, Bundelkhand

1. Introduction

Drought regularly affects large areas worldwide and has serious impacts on society, environment and economy and is still one of the least understood phenomena (Rossi et al., 1992; Obasi, 1994). Drought impacts are usually first apparent in agriculture but gradually move to other water-dependent sectors. Nearly 50% of the world's agricultural areas are susceptible to droughts. Drought is one of the significant natural hazards responsible for the socio-economic imbalance in several parts of India on a cyclic basis. Four types of inter-related droughts are meteorological drought, hydrological drought, agricultural drought and socio-economic drought. The climatic variables namely, precipitation and its anomalies including the duration of the dry period defines the meteorological drought whereas the effects of meteorological drought on surface or sub-surface water supplies related to stream flow, reservoir, lake levels, and ground water defines the hydrological drought. Recovery time for water stored in surface and subsurface systems can be quite long under severe drought conditions. The agricultural drought however, links impacts of meteorological drought to agriculture, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, and crop failure whereas the socio-economic drought occurs when the demand for economic goods exceeds supply as a result of a weather-related shortfall in water supply.

The IPCC report and other climate model predictions indicate that the global change is likely to increase the vulnerability of tropical countries to drought, more so in South Asia [IPCC 1996, 2001]. IPCC 2007 suggests that the climate change will have its implications on the duration and magnitude of droughts. As a result of the climate change, the reduction in precipitation and increase in temperature and evapotranspiration is expected to affect the frequency and severity of droughts. Understanding the spatio-temporal variability of the various types of drought events and assessment of their trends under the future climate change scenarios are fundamental for formulation of sound adaptation mechanisms. The water resources planning and management under drought conditions necessitates the characterization of drought including the risk and vulnerability. The water resource systems have been planned and are operating on the assumption that future climate features might be similar to those observed in the past years. However this may not be true owing to the impacts of climate change expected on the water resources sector.

2. Objectives

The regular and continuous droughts in Bundelkhand has resulted in loss of agricultural livelihood, food crisis, depletion of surface and ground water resources, reduction in crop yield and increased poverty. The scientifically devised drought management plan will help to address the issues and manage the drought as well as the scarce water resources during drought years. This study has been carried out with the following objectives.

1. Drought characterization using the drought indicator based approach.
2. Development of an indicator based drought management plan.

3. Study Area

The Bundelkhand region comprises of 6 districts of Madhya Pradesh viz., Sagar, Damoh, Chhatarpur, Tikamgarh, Panna and Datia and 7 districts of Uttar Pradesh in India viz., Jhansi, Lalitpur, Jalaun, Hamirpur, Banda, Mahoba and Chitrakoot. The topography comprises of gently-sloping uplands, distinguished by barren hilly terrain and lies between 23° 8′ N to 26° 30′ N latitude and 78° 11′ E to 81° 30′ E longitude with a total area of 71,619 sq. km. with a semi-arid to sub-tropical climate. The rainfall pattern of this region is erratic and uncertain with very high variability. About 82% of the population is dependent on agriculture. Sonar, Bearma, Dhasan, Ken, Betwa, Bewas, Kopra, Jamuni are some of the important rivers traversing the region. The topography of the region is highly undulating with rocky outcrops and boulder-strewn plains with a rugged looking landscape. The soils comprise of red sandy soils, mix of black and red soils, shallow black soils and alluvial soils. The location of the study area is given in Figure 1. The Bearma basin a tributary of Ken river basin has been selected as a pilot basin for the preparation of drought management plan. The river originates from Bandra Reserved Forest in Narsinghpur district and travels through Sagar and Damoh district before its confluence with Sonar river, which is another major tributary of the Ken river system.

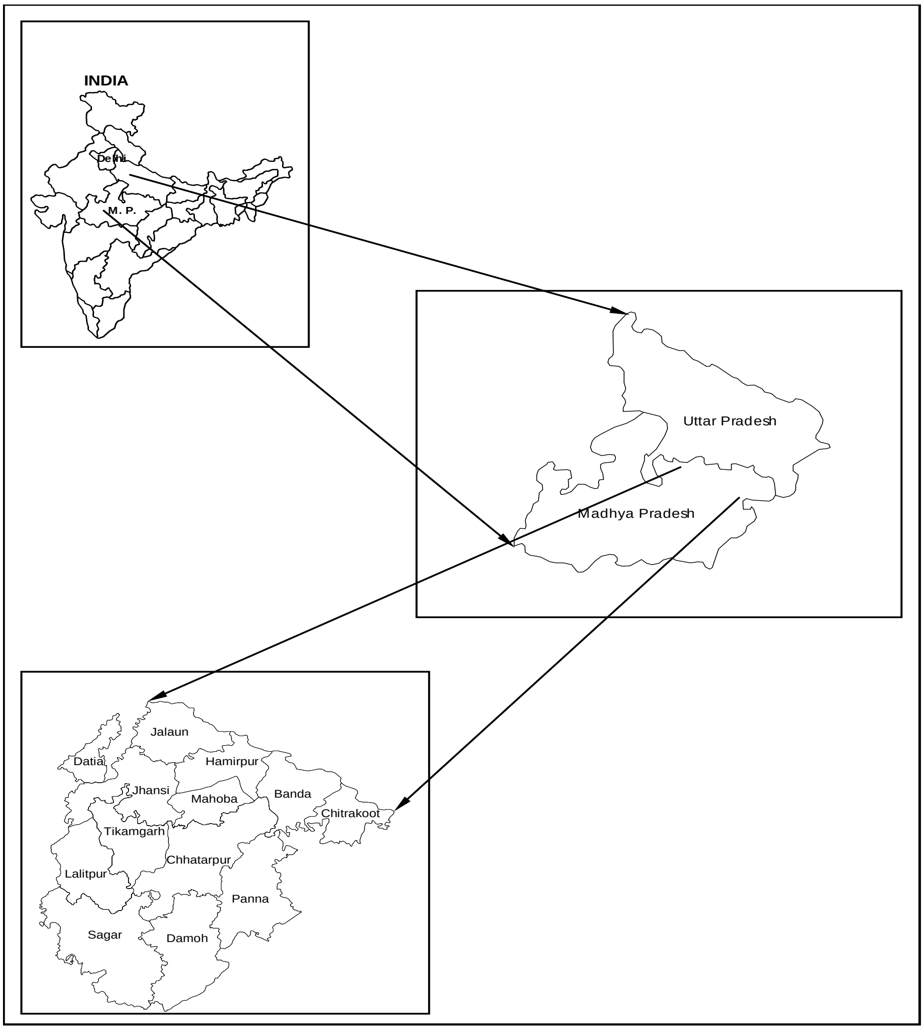

Fig. 1: Index map of the study area

4. Materials and Methods

4.1 Data Availability

The detailed drought analysis requires considerable long-term data pertaining to rainfall, stream flow, ground water level and other climatic variables at the district or block level. The data used in the analysis includes rainfall, maximum and minimum temperature, relative humidity, wind speed, solar radiation. The processing and analysis of all the data have been carried out before initiating the comprehensive drought analysis. The daily rainfall at the developmental blocks viz., Deori, Rehli in Sagar district and Jabera, Damoh, Hatta in Damoh district falling in and around the Bearma basin has been used for the evaluation of meteorological drought characteristics.

4.2 Standardized Precipitation Index

The Standardized Precipitation Index (SPI) has been applied by a large number of researchers widespread application (McKee et al., 1993; Heim, 2000; Wilhite et al., 2000; Rossi and Cancelliere, 2002) due it its advantages of statistical consistency, and its ability to describe both short-term and long-term drought impacts through the different time scales of precipitation anomalies. Guttmann, 1999 suggested that SPI can be used for drought risk analysis due to its intrinsic probabilistic nature. Due to its standardization, it can be used to compare drought conditions among different time periods and regions with different climatic conditions (Bonaccorso et al., 2003).

SPI is based on an equiprobability transformation of aggregated monthly precipitation into a standard normal variable. The SPI computation requires fitting a probability distribution to aggregated monthly precipitation series for k = 1, 3, 6, 12, or/and 24 months and then computing the non-exceedance probability related to such aggregated values and thereafter defining the corresponding standard normal quantile as the SPI. McKee et al. (1993) assumed the aggregated precipitation to be gamma distributed and used a maximum likelihood method to estimate the parameters of the distribution. However, the distribution can be considered based on the actual distribution of the time series. Among users there is a general consensus about the fact that the SPI on shorter time scales of 3 month describes agricultural drought events while on the longer time scales of 6 month describes stream flow drought. The 12-month SPI or 24-month SPI describes the groundwater drought. As such it has been observed that the SPI is more suitable for water resources management purposes.

The computation of the SPI is carried out as described viz., i) computation of the mean of the log-normal (ln) aggregated rainfall series, ii) fitting a gamma probability density function to a given frequency distribution of the aggregated rainfall and iii) computation of shape and scale parameters β and α, of the gamma distribution for specific time scale of interest namely, 1 month, 3 month, 6 month or/and 12 month, respectively as giben below in Equation 1 to Equation 4.

$$\bar{X}_{ln} = \frac{\sum ln\, X}{N} \tag{1}$$

$$\beta = \frac{1}{4U}\left[1 + \sqrt{\frac{4U}{3}}\right] \tag{2}$$

$$\alpha = \frac{\bar{X}}{\beta} \tag{3}$$

$$U = ln(\overline{X}) - \bar{X}_{ln} \tag{4}$$

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. The cumulative probability as given by Gamma distribution,

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

Letting t = $\frac{-x}{\alpha}$, this equation becomes the incomplete gamma function;

$$G(x) = \frac{1}{\Gamma\beta}\int_0^{t\alpha} t^{\beta-1}e^{-t}\ dt \tag{6}$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zero, the cumulative probability becomes,

$$H(x) = q + (1-q)G(x) \tag{7}$$

where, 'q' is the probability of a zero.

If m is the number of zeros in a precipitation time series, Thom (1966) states that q can be estimated by m/N. He used the tables of the incomplete gamma function to determine the cumulative probability G(x). McKee et al., (1993) used an analytic method to determine the cumulative probability. SPI is then obtained by transforming the cumulative probability H(x), to the standard normal random variable (Z) with mean zero and variance one. The *Z* or SPI values is more easily obtained computationally using an approximation provided by Abramowitz and Stegun, (1965) that converts cumulative probability to the standard normal random variable *Z*.

$$Z = SPI = -\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right] \quad \text{for } 0 < H(x) \le 0.5 \tag{8}$$

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

where,

$$t = \sqrt{ln\left\{\frac{1}{(H(x))^2}\right\}} \quad \text{for } 0 < H(x) \le 0.5 \text{ and} \tag{10}$$

$$t = \sqrt{ln\left\{\frac{1}{(1.0 - H(x))^2}\right\}} \quad \text{for } 0.5 < H(x) \le 1.0 \tag{11}$$

$c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$ and $d_3 = 0.001308$

The SPI classification (Hayes et al., 1999) used at the National Drought Mitigation Center (NDMC) is given in Table 1. A drought event occurs when SPI is continuously negative and reaches an intensity of -1.0 or less and ends when the SPI becomes positive. The positive sum of the SPI for all the months within a drought event is termed as drought magnitude and the division of drought magnitude by its duration gives the drought intensity for that particular duration. As the SPI is normally distributed, it can also be used to identify the wet event. SPI allocates a single numeric value to the precipitation between -3 to 3, which can be compared across regions with different climates. A SPI of 2 or more happens about 2.3% of the time and a mild drought (SPI between 0 and -0.99) happens 34.1 % of the time. SPI and its corresponding cumulative probability are given in Table 9.2.

Table 1: Standard ranges of SPI values and their classification

S. No.	SPI range	Classification	Occurrence probability (%)
1.	2.0 ≥	Extremely wet	2.3
2.	1.5 to 1.99	Very wet	4.4
3.	1.0 to 1.49	Moderately wet	9.2
4.	0.0 to 0.99	Mild wet	34.1
5.	0.0 to -0.99	Mild drought	34.1
6.	-1.0 to -1.49	Moderate drought	9.2
7.	-1.5 to-1.99	Severe drought	4.4

8.	-2.0 ≤	Extreme drought	2.3

Table 2: Cumulative probability of SPI

S. No.	SPI	Cumulative probability	S. No.	SPI	Cumulative probability
1.	-3.0	0.0014	7.	0.0	0.5000
2.	-2.5	0.0062	8.	+0.5	0.6915
3.	-2.0	0.0228	9.	+1.0	0.8413
4.	-1.5	0.0668	10.	+1.5	0.9332
5.	-1.0	0.1587	11.	+2.0	0.9772
6.	-0.5	0.3085	12.	+2.5	0.9938

5.0 Results and Discussions

The temporal variation of the 3-month SPI is given in Figure 2. It can be observed that droughts have been occurring regularly but the severity and the frequency of droughts have increased during the last two decades. The moderate droughts and severe droughts have increased in the last few decades in the study area. Similar conditions have been observed in the 3-month SPI for the remaining blocks falling in the study area.

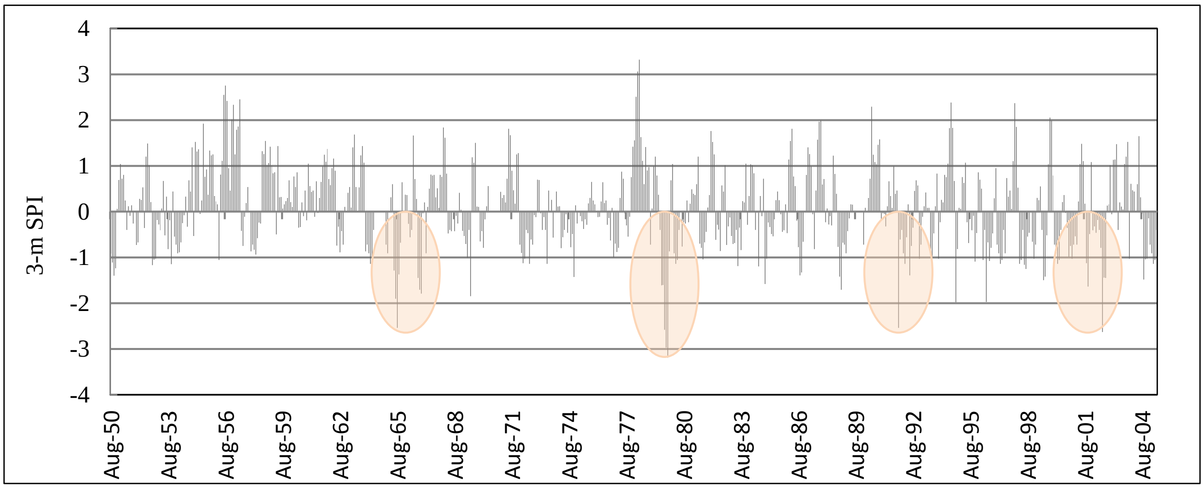

Fig. 2: Temporal variation of 3m-SPI at Damoh block in Damoh district

The 6-month SPI and 12-month SPI have also been evaluated. With the changes in the time scale, the drought duration and the drought frequency also changes. On longer time scales, drought becomes less frequent but lasts longer. As the time scale increases, the index responds more slowly which indicates that each new month has less impact on the total, which is indicative of fewer droughts of longer duration. Both the cases, i.e. more number of droughts of shorter duration and fewer number of droughts of longer duration can be interpreted differently for different types of water resources. The soil moisture in the study area is more sensitive to a 3-m drought that may lead to water stress and crop failures, whereas it may take more time to see the effect of drought on the surface water resources as given by the 6-m SPI and still more time to observe the effect of drought on the underground water resources of the region given by the 12-month SPI. Therefore the 3-month SPI, 6-month SPI and the 12-month SPI has been considered to represent the soil moisture drought, surface water drought and groundwater drought respectively. The frequency of the meteorological drought alongwith the total severity and total duration for the various time scales for the blocks falling in the basin is given in Table 2.

Table 2: Time scale based drought charactersitics in Bearma basin

S. No	Time scale (months)	Frequency of drought events (number)	Total drought duration (months)	Total drought severity	Average drought intensity
Damoh					
1.	3-month	45	71	-101.78	-1.43
2.	6-month	41	91	-138.41	-1.52
3.	12-month	22	63	-104.86	-1.66
Hatta mo					
1.	3-month	18	26	-41.46	-1.59
2.	6-month	31	64	-100.19	-1.56
3.	12-month	23	82	-134.54	-1.64
Jabera					
1.	3-month	23	41	-167.73	-4.09
2.	6-month	30	65	-96.58	-1.48
3.	12-month	21	79	-117.96	-1.49
Deori					
1.	3-month	19	27	-42.84	-1.58
2.	6-month	24	51	-72.79	-1.42
3.	12-month	18	74	-102.01	-1.37
Rehli					
1.	3-month	20	29	-40.92	-1.41
2.	6-month	30	52	-70.38	-1.35
3.	12-month	19	67	-85.63	-1.27

The maximum total severity based on the 3-month SPI occurred at Jabera block with severity of -167.73 whereas the minimum total severity occurred at Hardua Morar block with severity of -30.43 whereas based on the 12-m SPI, Hatta and Mala blocks experienced the maximum and minimum total severities respectively.

The drought management plan has been prepared based on the drought triggering mechanism which has been developed based on the fitted probability distribution of the SPI for these time scales representing the soil moisture drought, surface water drought and groundwater drought. Based on the fitted distribution, the four stages (levels) of drought have been considered namely, Drought Level 0 representing the normal conditions with associated probability <0.10; Drought Level 1 representing the drought watch with associated probability ranging between 0.10 and 0.20; Drought Level 2 representing the drought warning with associated probability ranging between 0.20 and 0.35 and Drought Level 3 representing the drought emergency with associated probability > 0.35. These probability levels have been fine-tuned with the actual drought conditions prevailing in the basin during the drought years. The drought levels have been evaluated for each of the influencing blocks falling in the study area based on the monthly rainfall at these influencing stations. The spatial variation of the drought levels have been captures by interpolating the drought levels prevailing for a particular month at these blocks. The temporal variation of the drought levels have been evaluated based on the variation of the drought levels during each month of the drought year. The spatio-temporal variation of the drought levels in Bearma basin during October 2002 to January 2003 is given in Figure 3. It can be observed that during November 2002, drought watch level was prevailing the northern parts of the basin whereas drought warning levels was prevailing in the southern parts of the basin. However during Decembers 2002, the conditions improved and the entire basin was under normal condition. However

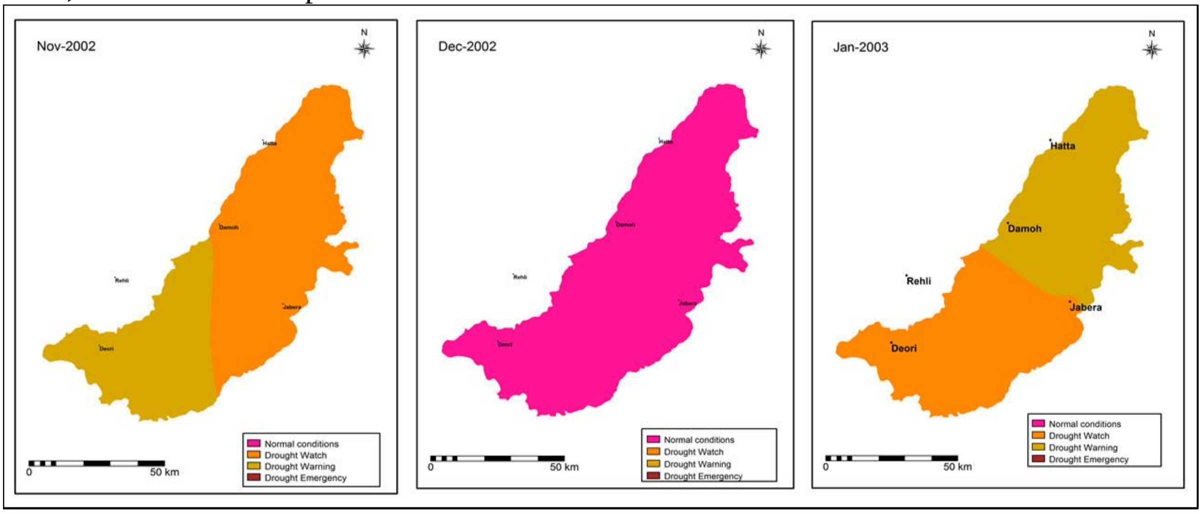

Fig. 3: Spatio-temporal variation of drought levels in during Nov 2002 to Jan 2003

During January 2002the southern parts of the basin was under drought watch level whereas the northern parts of the basin was under the drought warning levels. This type of information can be used to develop management plans for the study area. Specific tasks to be taken up during each of these four drought levels have been devised to address the prevailing drought in various parts of the basin and during each month of the drought year. Going forward, drought levels can be developed based on the real time monitoring of the rainfall, streamflow and groundwater levels accumulated over a monthly time frame and this information can be used for issuing drought alerts for the real time management of drought during the drought years.

6.0 Conclusions

The Bundelkhand region in Central India now regularly face drought particularly since the last two decades. There is lot of distress during the drought years which need scientific planning and research for the management of the precious water resources during the droughts as well as management of the drought. A proactive approach is needed to address this situation as there are many constraints in Bundelkhand as the groundwater is limited due to the prevalent aquifer systems and geology of the region. The drought frequency is one in three years of-late and therefore a drought management plan is necessary. The Bearma basin has been selected as a pilot basin and the meteorological, surface water and groundwater drought characteristics have been evaluated. However since the frequency of the monitoring of the rainfall, streamflow and groundwater levels are different, it is necessary to have a continuous monitoring of these variables at the same frequency (daily) and also the real time monitoring of these variables should be initiated as early as possible. This will help in applying this technique of drought levels developed using the various drought indicators and probability based drought triggers for the development of real time monitoring of drought and linking it with appropriate action plans.

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