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Drought spells identification with indices for Almora district of Uttarakhand, India

Arvind Singh Tomar, Bhawana Negi and Lokendra Singh
Department of Irrigation & Drainage Engineering, College of Technology,
Govind Ballabh Pant University of Agriculture & Technology, Pantnagar (Uttarakhand) 263145, INDIA

***Abstract**: In this study, 91 years (1923-2013) monthly rainfall dataset of Almora district of Uttarakhand was analyzed with the help of different drought indices namely, Dependable Precipitation Index (DPI), Precipitation Departure Index (PDI), Standard Index of Anomaly Precipitation (SIAP) and Standardized Precipitation Index (SPI). In addition to this, the occurrence of monthly and yearly drought spells was also calculated by the criterion given by researchers. From the study, it was found that with DPI, 14 dry, 51 wet and 26 normal years were obtained, whereas, with PDI, 46 years were found to have more than average rainfall of 1113.78 mm. The SIAP values showed that 18 extreme wet, 10 wet, 35 normal, 16 drought and 12 extreme drought years were observed at Almora during 91 years period. The SPI values at different timescales showed that maximum numbers of months near normal condition category were observed at all the timescales. Drought severity calculated by using IMD method showed that the study area experienced 32.10%, 12.67%, 15.25% and 39.78% months as severe, moderate, mild and no-drought, whereas, with revised IMD method, they were obtained as 6.41%, 8.33%, 30.68%, and 46.61% respectively. Further, on the basis of monthly and yearly drought investigation, it was found that 3.86 drought months per year may come into existence and there is possibility that one drought year in every seven years may occur in this district.*

***Keywords**: Drought, DPI, PDI, SIAP, IMD method, Revised IMD method.*

I. Introduction

Drought is one of the main natural hazards which affect the economy and environment of large areas. They cause crop losses, water supply shortages, degradation, desertification, forest fire, famine, displacement of people, homelessness, ill health, social disorder and in advanced stages, deaths as well [1]. Drought is a temporary aberration within the natural variability and may be regarded as an underhand hazard of nature. However, a precise, unambiguous definition of drought remains elusive. A drought is an extended period when a region notes a deficiency in its water supply [2]. Generally, this occurs when a region receives consistently below average precipitation. It can have a substantial impact on the ecosystem and agriculture of affected region. Although droughts can persist for several years, even a short, intense drought can cause significant damage. It is not possible to avoid drought but drought preparedness can be developed and drought impacts can be managed. The success of these both depends amongst others on how well the droughts are defined and their characteristics are quantified [3].

Drought can be considered to be essentially a climatic phenomenon related to an abnormal decrease in precipitation and it occurs when moisture supply is abnormally below average for periods of up to two years. Drought distresses large areas, lasts for long periods of time and affects most climates. As one of the most important parts of a proactive drought management system, drought indicators characterize drought conditions and help to guide appropriate responses to reduce impacts [4]. There is no universal drought indicator measuring all types of drought effectively [5]. Numerous specialized indices have been proposed to measure drought in different ways and extensive listings of drought indices are available [6-8]. Some studies explore the effectiveness of drought indices to measure drought on a global scale [9] and other rank drought indices in terms of usefulness for the assessment of drought severity. Drought is a naturally reoccurring climatic variability. With a changing climate, droughts are likely to become more severe and occur more often. Drought, in contrast to aridity, affects almost all climates in the world [10].

There is no universal definition of drought [5], however, a common theme in defining drought is a deficit in normal precipitation for a region over a period of time sufficient to cause impacts. Based on impacts, the WMO defines four major drought types as meteorological, agricultural, hydrological and socio-economic. All droughts originate from a deficiency of precipitation and begin as meteorological drought. Other types of drought and their impacts cascade from meteorological drought to other types [10]. All types of drought have distinctive characteristics that vary across different locations, climate types, populations and economic vulnerabilities.

In view of above, the present study was undertaken with objectives for Almora district of Uttarakhand as (i) to identify drought spells by using different indices namely, Dependable Precipitation Index (DPI), Precipitation Departure Index (PDI), Standard Index of Anomaly Precipitation (SIAP) and Standardized Precipitation Index (SPI); and (ii) to determine the occurrence of drought spells on monthly and yearly basis.

II. Materials and Methods

Data collection and analysis: The monthly rainfall dataset of 91 years (1923-2013) for Almora district (longitude 79˚30'E, latitude 29˚36'N) was used to identify occurrence of drought spells.

Dependable precipitation index (DPI): The DPI is a meteorological drought index and is calculated by using equation:

$$\mathrm{DPI} = 0.8 \times \sqrt[n]{P_1 \times P_2 \times P_3 \times \dots \dots \dots P_n} \quad (1)$$

where DPI is dependable precipitation index, P is years rainfall (mm), n is number of observations and 0.8 is constant coefficient.

With the help of DPI, the drought intensity can be obtained on the basis of variation in rainfall intensity in terms of normal rainfall (NR), dry-year threshold (D) and wet-year threshold (W), given as:

Classification	Range
Normal year	DPI≤P≥GM
Dry year	P<DPI
Wet year	P>GM

where P is years rainfall (mm) and GM is geometric mean of rainfall values observed during study period.

Precipitation Departure Index (PDI): It is a meteorological drought index and is defined as measure of annual variability and long term trends can be achieved by plotting rainfall departure from arithmetic mean for the period of record taken into consideration.

$$\mathrm{PDI} = \frac{P_i - \overline{P}}{100} \quad (2)$$

where P_i is annual rainfall in i^{th} year (mm) and $\overline{P}$ is average rainfall (mm).

Standard Index of Annual Precipitation (SIAP): The values of SIAP can be computed by using equation:

$$\mathrm{SIAP} = \frac{P_i - \overline{P}}{\mathrm{PSD}} \quad (3)$$

where P_i is annual rainfall in i^{th} year (mm), $\overline{P}$ is average rainfall (mm); and PSD is standard deviation of rainfall during the study period. The trend of drought and wet years can be ascertained on the following basis:

Classification	SIAP value
Extremely wet	≥ 0.84
Wet	0.52 to 0.84
Normal	- 0.52 to 0.52
Drought	- 0.84 to - 0.52
Extreme drought	≤ - 0.84

Standard Precipitation Index (SPI): The SPI, a meteorological drought index was designed to quantify precipitation deficits for multiple timescales. The SPI calculation for any location is based on the long-term precipitation record for a desired period. Its standardization allows determination or frequency of a current level of drought, as well as probability of precipitation necessary to end the current drought. For these reasons, SPI was originally calculated SPI for 3-, 6-, 12-, 24- and 48- month timescale [11]. The use of different timescales allows assessing the effect of a precipitation deficit on different water resource components (groundwater, reservoir storage, soil moisture, streamflow etc.). The index ranges from negative to positive values and measures dry and wet conditions.

The SPI is a simple, powerful and flexible rainfall index based on probability of rainfall for any timescale. In order to calculate this index, rainfall data series is fitted to gamma distribution function (pdf), given as:

$$\mathbf{f_{(x)}} = \frac{\mathbf{x^{(a-1)} e^{\left(-\frac{x}{b}\right)}}}{\mathbf{b^a\, \Gamma(a)}} \quad (4)$$

where "a" and "b" (both greater than 0) are shape and scale parameters and $\boldsymbol{\Gamma(a)}$ is gamma function. The aim to fitting distribution to data is to estimate parameters "a" and "b". By integrating pdf with respect to "x" and inserting estimated values of "a" and "b", the gamma cumulative distribution function is computed at each value of "x" which is then transformed into standard normal distribution to yield SPI values. The drought intensities resulting from SPI classifies drought events as:

Classification	Range
Extremely wet	≥ 2.00
Very wet	1.50 to 1.99
Moderately wet	1.00 to 1.49
Near normal	-0.99 to 0.99
Moderately dry	-1.49 to -1.00
Severely dry	-1.99 to -1.49
Extremely dry	≤ -2.00

IMD Method: With this method, the drought can be assessed on the basis of percentage deviation of rainfall (D_i) from long-term average rainfall (PM), expressed mathematically as:

$$D_i = \frac{P_i - PM}{PM} \times 100 \quad (5)$$

where P_i is rainfall (mm) in time period "i" (month or year) and PM is long-term average rainfall (mm).
The values of D_i and categorisation of drought prescribed by IMD, Pune are given hereunder as:

Percentage deviation	Category
> 0	No drought
0 to -25	Mild
-25 to -50	Moderate
< -50	Severe

Revised IMD Method: With this method, the drought can be assessed [12] on the basis of percent deviation of cumulative long-term average rainfall (CD_i), expressed mathematically as:

$$CD_i = \frac{PC_i - PCM_i}{PM} \times 100 \quad (6)$$

where PC_i is cumulative actual rainfall (mm), PCM_i is cumulative long-term average rainfall (mm) and PM is long-term average rainfall.
The variation of drought on the monthly and yearly basis was evaluated by considering criterion proposed [13-14] mentioned below as:

- Normal month: if actual rainfall lies in between 50% and 200% of average monthly rainfall;
- Abnormal month: any month receiving rains more than twice of average monthly rainfall;
- Drought month: if actual rainfall is less than 50% of average monthly rainfall;
- Normal year: if year receiving rainfall in between (P_{av}-SD) and (P_{av}+SD);
- Abnormal year: if year receiving rainfall more than or equal to (P_{av}+SD); and
- Drought year: if year receiving rainfall less than or equal to (P_{av}-SD).

where P_{av} is average annual rainfall (mm) and SD is standard deviation of annual rainfall.

III. Results and Discussion

Dependable Precipitation Index (DPI): The value of DPI calculated with long-term annual rainfall data series of 91 years (1923-2013) reveals that the study area experienced 14, 51 and 26 years as dry, wet and normal respectively.

Precipitation Departure Index (PDI): From variation in PDI values, it is clear that during the study period, Almora district received an average annual rainfall of 1113.78 mm and had experienced higher than average rainfall during 46 years and during 45 years, it received less than average annual rainfall.

Standard Index of Annual Precipitation (SIAP): The variation in SIAP values reveals that the study area experienced 18 years as extreme wet, 10 years as wet, 35 years as normal, 16 years as drought and 12 years as extreme drought.

Standard Precipitation Index (SPI): The value of SPI on 1-, 3-, 6-, 9-, 12- and 24- month timescale for the study area is presented in Table 1.

IMD Method: The severity of drought on monthly basis (Table 2) reveals that with IMD method, about 32.10, 12.67, 15.25 and 39.78% months were observed as Severe (S), Moderate (Mod), Mild (Mi) and No drought (ND) respectively. During *rabi* (November to March) seasons 17.48, 3.84, 4.65 and 15.63% months were observed as S, Mod, Mi and ND respectively, whereas, values of these drought months during *kharif* (July to October) season were obtained as 7.95, 5.2,6.49 and 13.64% respectively. It is also found that severe droughts were occurred maximum during November, moderate in August, mild in July and no drought was observed in the month of August during the study period of 91 years (1923-2013).

Revised IMD Method: With revised IMD method (Table 2), about 6.41, 8.33, 30.68 and 46.61% months were observed as Severe (S), Moderate (Mod), Mild (Mi) and no drought (ND) respectively. During *rabi* (November to March) seasons 5.22, 2.38, 11.07 and 18.95% months were observed as S, Mod, Mi and ND respectively, whereas, values of these drought months during *kharif* (July to October) season were obtained as 0.45, 3.66,

12.54 and 16.20% respectively. It is also found that severe droughts were occurred maximum during January, moderate in July, mild in July and no-drought was observed during month of September.

Drought Investigation on Monthly and Yearly Basis: By following the criterion given by [13] and [14] for drought (D), abnormal (A) and normal (N) conditions, the drought analysis on monthly and yearly basis was conducted and pertinent results are presented as:

(a) Monthly rainfall investigation: Rainfall based criteria for drought, abnormal and normal months and their distribution pattern is presented in Table 3. The average monthly rainfall varied in the range from 4.48 mm (November) to 316.19 mm (August). From Table 3, it is clear that least number of drought months (8 times) were observed in the months of July and August, whereas, it occurred maximum in November (54 times), followed by 46 times during October. From analysis, it is also clear that 32.15, 11.17 and 56.68% drought, abnormal and normal months were observed and thus, 3.86 drought months / year is expected to occur at Almora district. From analysis, it has been found that during October-May, 82.62% drought months were observed, whereas, it was only 17.38% during Monsoon (June-September) season. During *kharif* (July-October) and *rabi* (November-March) seasons, 24.78% and 54.41% drought months were observed at Almora district.

(b) Yearly rainfall investigation: The value for average precipitation (P_{av}) and standard deviation (SD) of annual rainfall during study period were calculated as 1113.79 mm and 261.55 mm respectively. Thus, as per the above-mentioned criteria, any year which receives rainfall less than and equal to 852.24 mm ($P_{av} - SD$) will be considered as drought year, whereas, years receiving rainfall equal to or greater than 1375.34 mm ($P_{av} + SD$) will be designated as abnormal year while year experiencing rains in between 852.24 mm and 1375.34 mm will be considered as normal year.

IV. Conclusions

The present study was carried out for Almora district of Uttarakhand state on the basis of monthly rainfall dataset of 91 years (1923-2013) each to identify drought spells with the help of different indices and standard criterion given by researchers. On the basis of finding of this study, following conclusions were drawn:

- On the basis of Dependable precipitation index, it was found that the study area has experienced 14, 51 and 26 years as dry, wet and normal years respectively.
- With precipitation departure index, 46 years were found to have more than average rainfall of 1113.78 mm.
- The SIAP values for extreme wet years were obtained as 18, wet condition 10 years, normal condition 35 years, drought condition 16 years, whereas, 12 extreme drought years were observed.
- The SPI values at different timescales (1-, 3-, 6-, 9-, 12- and 24- months) showed that maximum numbers of months near normal condition category were observed at all the timescales.
- The drought severity calculated by using IMD method showed that 32.10%, 12.67%, 15.25% and 39.78% months were observed as severe, moderate, mild and no-drought.
- By using revised IMD method, it was found that Almora experienced 6.41% severe, 8.33% moderate, 30.68% mild and 46.61% no-drought months.
- 3.86 drought months per year may come into existence and there is possibility that one drought year in every seven years may occur in this district.

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Table 1: Details about observed SPI values

S. No.	Category	Total numbers observed during Months					
		1	3	6	9	12	24
1	Extremely wet (EW)	23 (2.11)	20 (1.83)	24 (2.20)	24 (2.20)	25 (2.29)	28 (2.56)
2	Very wet (VW)	45 (4.12)	41 (3.75)	27 (2.47)	23 (2.11)	13 (1.19)	34 (3.11)
3	Moderately wet (MW)	109 (9.98)	109 (9.98)	85 (7.78)	82 (7.51)	82 (7.51)	57 (5.22)
4	Near normal (NN)	761 (69.69)	752 (68.86)	773 (70.80)	774 (70.80)	777 (71.10)	794 (72.71)
5	Moderately dry (MD)	83 (7.60)	91 (8.33)	107 (9.80)	98 (8.97)	104 (9.52)	80 (7.33)
6	Severely dry (SD)	52 (4.76)	43 (3.94)	37 (3.39)	46 (4.21)	34 (3.11)	32 (2.93)
7	Extremely dry (ED)	19 (1.74)	36 (3.34)	39 (3.57)	45 (4.12)	57 (5.22)	67 (6.14)
	Total	1092 (100.00)	1092 (100.00)	1092 (100.00)	1092 (100.00)	1092 (100.00)	1092 (100.00)

Figures in parenthesis shows percent of total number of months.

Table 2: Monthly drought severity observed with IMD and revised IMD methods

Month	IMD method				Revised IMD method			
	S	Mod	Mi	ND	S	Mod	Mi	ND
Jan	2.93	0.64	1.09	3.66	2.93	0.64	1.10	3.66
Feb	2.93	0.73	1.28	3.38	1.28	1.28	1.83	3.39
Mar	2.56	1.37	1.37	3.02	1.01	0.46	2.01	3.57
Apr	2.56	1.00	1.19	3.57	0.37	0.55	2.84	3.39
May	2.28	1.28	1.28	3.47	0.18	0.46	2.01	4.21
Jun	1.83	1.37	1.64	3.47	0.18	1.28	2.20	3.85
Jul	0.73	1.46	2.47	3.67	0.27	1.74	3.39	3.57
Aug	0.73	1.64	2.19	3.75	0.18	1.10	3.02	4.21
Sep	2.28	1.46	1.28	3.29	0.00	0.64	3.02	4.30
Oct	4.21	0.64	0.55	2.93	0.00	0.18	3.11	4.12
Nov	4.94	0.37	0.18	2.83	0.00	0.00	3.11	4.12
Dec	4.12	0.73	0.73	2.74	0.00	0.00	3.02	4.21
Total	32.10	12.67	15.25	39.78	6.41	8.33	30.68	46.61

S = severe; Mod = moderate; Mi = mild; ND = no drought.

Table 3: Drought, abnormal and normal months

Month	Average rains (mm)	For drought month (mm)	Number of months		
			Drought	Abnormal	Normal
Jan	25.71	<12.86	32	12	47
Feb	28.27	<14.14	32	11	48
Mar	22.32	<11.11	28	12	51
Apr	16.60	<8.30	28	7	56
May	34.17	<17.09	25	11	55
Jun	133.40	<66.70	20	6	65
Jul	312.35	<156.18	8	2	81
Aug	316.19	<158.09	8	0	83
Sep	174.63	<87.31	25	9	57
Oct	35.15	<17.57	46	15	30
Nov	4.48	<2.24	54	22	15
Dec	10.60	<5.30	45	15	31
		Total	351	122	619