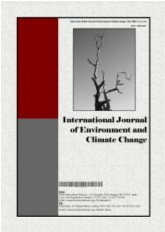

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Effective Drought Index Based Analysis of Drought Characteristics and Its Propagation for the Subtropical Climatic Region in Vindhyan Range

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Drought is a disastrous natural phenomenon that significantly impacts socio-economic, agricultural, and environmental spheres. It is considered as the primary factor of uncertainty that continues to haunt Indian agriculture and its economy. In this context, the drought scenario in the Mirzapur and Sonbhadra districts of the Vindhyan range motivates the investigation of drought characteristics through an index called Effective Drought Index (EDI). The analysis revealed that the region faced drought during 1989, 1992, 1998, 2005, 2007, 2009, 2010, 2014, and 2018. Maximum extreme drought events occurred in Citynagar block (21 events) followed by Kon block (20 events) in Mirzapur district, while blocks located in Sonbhadra district of the study area face 1 to 6 extreme drought events. Haliya block (28 events) in Mirzapur district and Myorpur block (26 events) in Sonbhadra district faces maximum severe drought events. Chhanvey block in Mirzapur district faces 25 severe drought events, while the rest of the block of the study area faces severe drought conditions that vary between 6 to 22 events. The severity of extreme drought is maximum in Citynagar block (-47.46) followed by Kon block (-44.87) in Mirzapur district. Maximum drought severity based on EDI computation used to prevails in Chopan block (-170.48) in Sonbhadra block followed by Haliya block (-171.12) in Mirzapur district. Maximum drought events of varying severity classes used to prevail in Robertsganj block (172 events) in Sonbhadra district. The analysis exposed the characteristics of drought that prevail in the region and through a thorough inspection suitable strategy can be synthesis that renders the impact of drought.

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Keywords: Drought; Effective Drought Index (EDI); Vindhyan range; drought characteristics.

1. INTRODUCTION

Drought is the imbalance in hydro-meteorological parameters due to the appreciable deficit in rainfall (less than 75% from normal) and combined episodes of dry spells [1]. Lack of sufficient precipitation causes meteorological drought, which is subsequently converted to agricultural and hydrological drought if the rainfall is inadequate to replenish the amount of moisture depleted due to evapotranspiration and absorption by plants [2,3]. Since drought is the consequence of natural and manmade activities and the circumstances created induce to classify drought based on its impacts, drought is classified as meteorological, agricultural, hydrological, and socioeconomic [4].

Meteorological drought is defined as the deficit in the rainfall amount. It is the leading elucidation for other categories of drought events. When meteorological drought causes a significant reduction in the environmental flows which helps to thrive river and stream then resulting effect converted to hydrological drought. Inadequate soil moisture and perseverance of meteorological drought over a continuous period of time result to cause agricultural drought. Drought with varying degrees of severity and intensity globally causes a significant loss which is equivalent to more than 6–8 billion US$ annually [5].

Studies and extensive research highlighted the difficulty in detecting and investigating drought and its complexes hence developing different drought indices that are area-specific and region-oriented. Most of the drought indices have their own advantages and disadvantages. Thus, indices requiring less cumbersome data that are readily available and less complicating are pretty extensively used. One such index is the Effective Drought Index (EDI), which has been used in the present study to detect drought on a monthly basis. The proposed index defined drought as the objective measure of daily water accumulation based on the weight of the current and antecedent rainfall [6].

The EDI concept was considered in following recent researches on droughts [7,8,9,10,11]. The main strength of this drought indicator is its ability to detect the onset and end of the drought and drought conditions before the other indices [12,13]. Most of the current indices use normalized statistical metrics to analyze the deficit periods [1,14], while their multi-scale drought characterization ranges from the month (smallest time scale) to longer periods [15]. These indices are not considered the daily consecutive or accumulated stress of drought [6]. Drought severity is mostly calculated from the climatological mean of water deficiency for some predefined duration without considering the diminishing water resources over time.

Studies have confirmed that EDI is more efficient than the SPI in assessing both short term (e.g. Daily, weekly and monthly) and long-term (e.g. Seasonal and annual) droughts [16,17,18]. Byun and Kim [16,17] compared the EDI with the SPI, and their analysis indicates that EDI detects short term/long term drought that cannot be detected by the long term/short term SPIs, respectively. EDI considers any rainfall amount and rainfall day, one single value for the day or period, long memory of rainfall (365 days) and therefore the consecutive weight of rainfall; confirming that EDI is superior to SPI in measuring the drought severity [16,17]. Moreover, Morid et al. [19], cited in Deo et al. [15], indicates that EDI is best for detecting the beginning and end of drought than the percent of normal, SPI, China Z index and therefore the Z score. EDI are often used due to its self-defined time step, which is free from fixing time step problem [6,15,12]. Kar et al., [20] studied the drought severity using EDI for the Bundelkhand region and found a gradually increasing severity in the region. Kumar et al., [10] characterized meteorological drought using effective drought index for Banswara district, Rajasthan.

The area under consideration is completely rain-fed; variation in rainfall amount during the monsoon period severely affects crop growth. Vindhyan range located in Mirzapur district is one of the seven most drought prone and among the 17 back ward districts of U.P. (https://mirzapur.kvk4.in/mandate.html).
Vindhyan range located in Mirzapur district is one of the seven most drought-prone and among the 17 backward districts of U.P. (https://mirzapur.kvk4.in/mandate.html). Also, there was a demand to consider the district located in the Vindhyan range with the seven backward districts of Bundelkhand which are highly water-stressed regions. (https://www.hindustantimes.com/lucknow/three-east-up-districts-may-get-bundelkhand-package-benefits/story-SP6ZXjyk0B713g8eIA6yPL.html).

Several studies by Yadav et al., [21], Yadav et al., [22], and Gond et al., [23] also highlighted the instability resulting due to increased drought frequency and intensity in the region. Due to the wide application of Effective Drought Index (EDI), it has been used in this research paper to assess the meteorological drought characteristics in the Vindhyan range with the aim the results obtained helps to identify the worst affected blocks as well as for drought investigation and drought monitoring which will helps for adaptation of suitable mitigation strategy during water stress conditions in the region.

2. METHODOLOGY

2.1 Study Area

The Vindhyan range in Mirzapur and Sonbhadra district of Uttar Pradesh lies between 82° to 83°23' E longitude and 22°45' to 24°34' N latitude. The region has an area of 11,309 sq km with an average elevation of 298 m. The region has a relatively subtropical climate with high variation in temperatures during summer (avg. 32°C- 42°C) and winter season (avg. 2°C-15°C). The average annual rainfall in the area is 935 mm, about 90% of which occurs between June and September (monsoon period). Surplus runoff water flows through ephemeral creeks and streams during the monsoon season, ultimately meeting to river Ganges. Due to its hilly topographic features, the surface runoff is mostly not harvested in the study area. Winds are generally strong in the area, increasing force during summer and southwest monsoon season. The mean wind velocity is 4 kmph and average potential evapotranspiration rate is 1456.7 mm. In the region, primarily alluvial soil is found. Districts in the Vindhyan range viz., Sonbhadra and Mirzapur comprise Archaean to Neoproterozoic rocks and Quaternary flood plain/ alluvial deposits. The location map of the study area is given in Fig. 1.

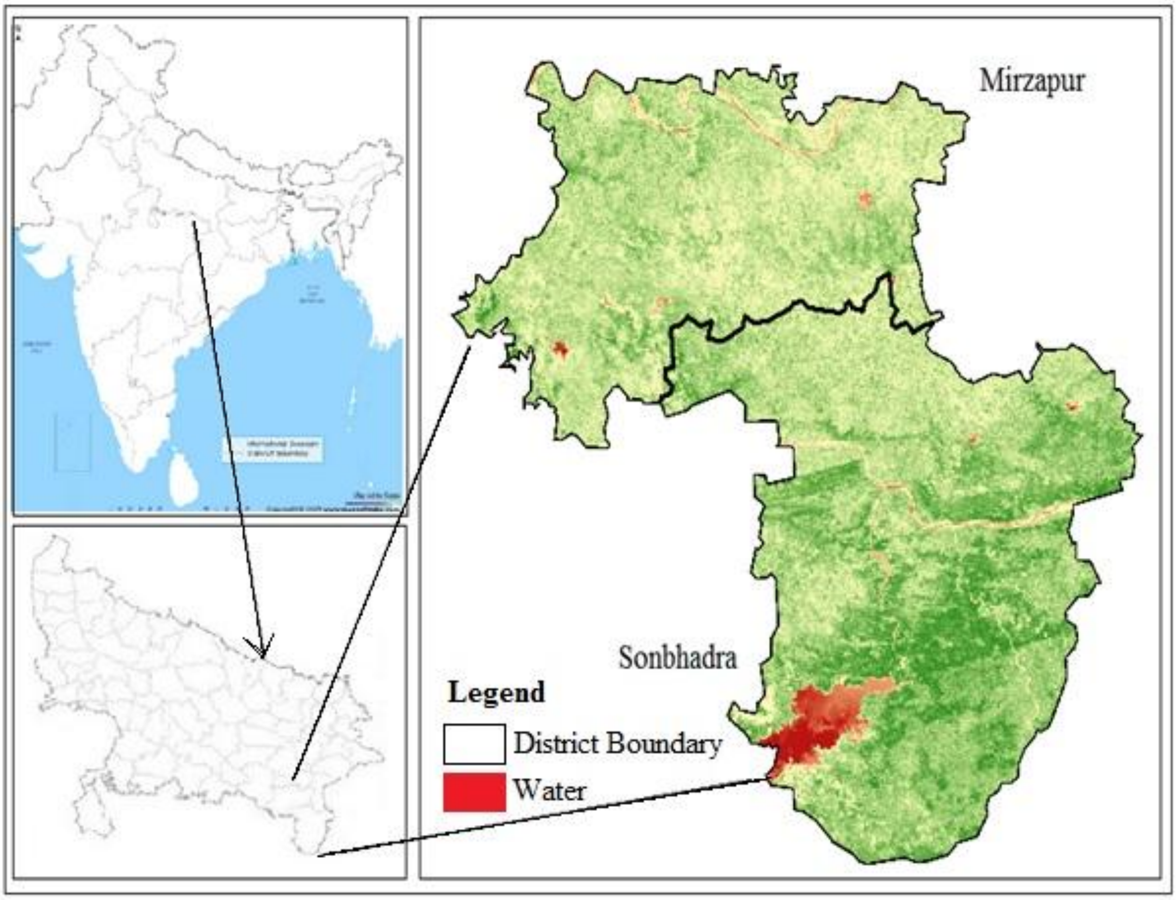

Fig. 1. Location map of the study area

2.2 Data Availability

Gridded daily rainfall data has been used to investigate drought and its characteristics, which was obtained from Indian Meteorological Department (IMD), Pune. The data consists of 40 years period from 1980 to 2019. ArcGIS 10.4 software has been utilized for delineating drainage map within the district located in Vindhyan range and is given in Fig. 2a. Land use and Land cover map of the region was obtained from Decadal map of India, which was available online and LULC map of Vindhyan range is shown in Fig. 2b. In the Vindhyan range, 8 blocks are lying Sonbhadra district, and 12 blocks are lying in the Mirzapur district as per district profile, whose locations are shown in Fig. 2c and names are mentioned in Table 1 with their average annual rainfall.

Table 1. Location of blocks in Mirzapur and Sonbhadra district of Vindhyan range

District Name	Block	Lat	Long	Avg. Rainfall (mm)
Mirzapur	Chhanvey	25.17	82.37	900.09
	Citynagar	24.91	82.56	916.57
	Haliya	24.8	82.3	1003.26
	Jamalpur	25.16	83.08	863.34
	Kon	25.2	82.53	900.78
	Lalganj	24.99	82.38	923.56
	Madihaon	24.92	82.57	941.89
	Majhawan	25.22	82.7	973.13
	Narainpur	25.13	82.95	871.46
	Pahari	25.07	82.68	907.45
	Rajgarh	24.98	82.86	893.09
	Sikhdi	25.15	82.79	959.42
Sonbhadra	Babhani	23.95	83.1	962.31
	Chatra	24.66	83.24	974.89
	Chopan	24.45	82.99	968.17
	Dudhi	24.22	83.23	943.02
	Ghorawal	24.75	82.81	976.82
	Myorpur	24.14	82.88	901.63
	Nagwa	24.62	83.4	943.93
	Robertsganj	24.69	83.06	970.36

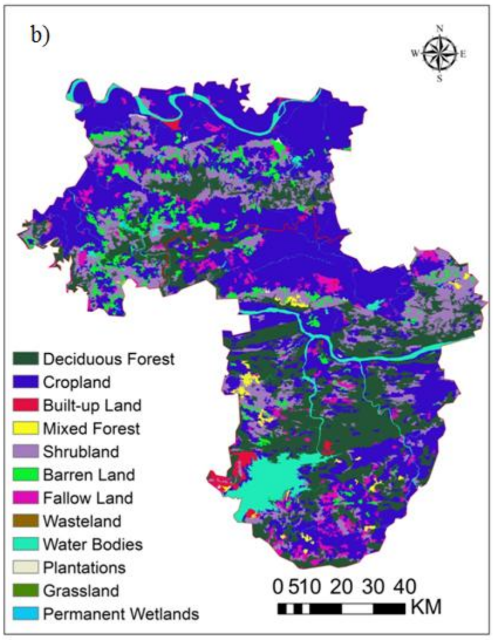

Fig. 2a): Drainage Map; 2b): Land use and Land cover map

Fig. 2c): Block Map

2.3 Effective Drought Index (EDI)

Byun and Wilhite [6] proposed Effective Drought Index (EDI) and stated that it can deal with all of the limitations of SPI. Morid *et al.*, 2006 used seven rainfall based indicator and suggested that EDI was more responsive to the initiation of a drought as compared to EDI. Pandey et al., 2008 also showed that EDI performed better as compared to other drought indicator while investigating drought severity. Byun and Kim, 2010 compared the performance EDI with SPI at different time scale 1-, 3-, 6-, 9-, 12-, and 24-month using drought monitoring data accumulated over the 200-year from 1807 to 2006 for Seoul, Korea to select a underlying drought index. The results confirmed that the EDI was more efficient than the SPIs in assessing both short and long-term droughts. Kamruzzaman et al., [24] showed with his investigation the efficiency of EDI as compared to SPI over Bangladesh. In order to investigate drought in Vindhyan range EDI can be considered as an effective drought indicator that can helps to provides more information regarding the duration and severity of rainfall deficit and the start and end of the drought period. Effective precipitation helps to represent daily depletion of water [19]. The original form of EDI is computed with a daily time step using daily rainfall data. Smakhtin and Hughes [25] modified his algorithm to be tested with monthly data.

Byun and Wilhite [6] suggested the following equation for EP:

$$\mathrm{EPi} = \sum_{n=1}^{i} \frac{\sum_{m=1}^{n} \mathrm{Pm}}{n} \quad (1)$$

Where, EPi = valid effective precipitation, Pm = daily precipitation, m = number of days before a specific day, i = the number of days of the time window, n = running from 1 till i [26].

$$DEP = EP / MEP \quad (2)$$

Where, EP = effective precipitation for 365 days counting from a specific day, MEP = the mean of effective precipitation, DEP = deviation of EP from MEP.

EDI is calculated as,

$$EDI = DEP / SD (EP) \quad (3)$$

SD (EP) = the standard deviation of each day's EP.

Ranks of EDI reflect drought conditions [6] indicate: extreme drought (EDI ≤ –2.0), severe drought (–1.99 ≤ EDI ≤ –1.5), moderate drought (–1.49 ≤ EDI ≤ –1.0) and near normal conditions (–0.99 ≤ EDI ≤ 0.99).

3. RESULT AND DISCUSSION

3.1 Evaluation of Drought Characteristics Based on Effective Drought Index (EDI)

The drought over the Vindhyan range was analysed using the EDI method using monthly rainfall time-series data (1980–2019). While evaluating drought based on EDI, the drought severity classification criterion was considered for the evaluation of the results. Temporal variations of drought characteristics are of great significance for understanding the drought pattern in the region. Figs. 3 to 6 depicts the temporal variation of drought severity for different blocks of Mirzapur and Sonbhadra district of the Vindhyan range.

Temporal variation of EDI indicates that the region faced severe drought conditions during 1989, 1992, 1998, 2005, 2007, 2009, 2010, 2014, and 2018. Similar results were obtained by Gond et al., 2019. Table 2 represents drought events evaluated based on EDI. A maximum

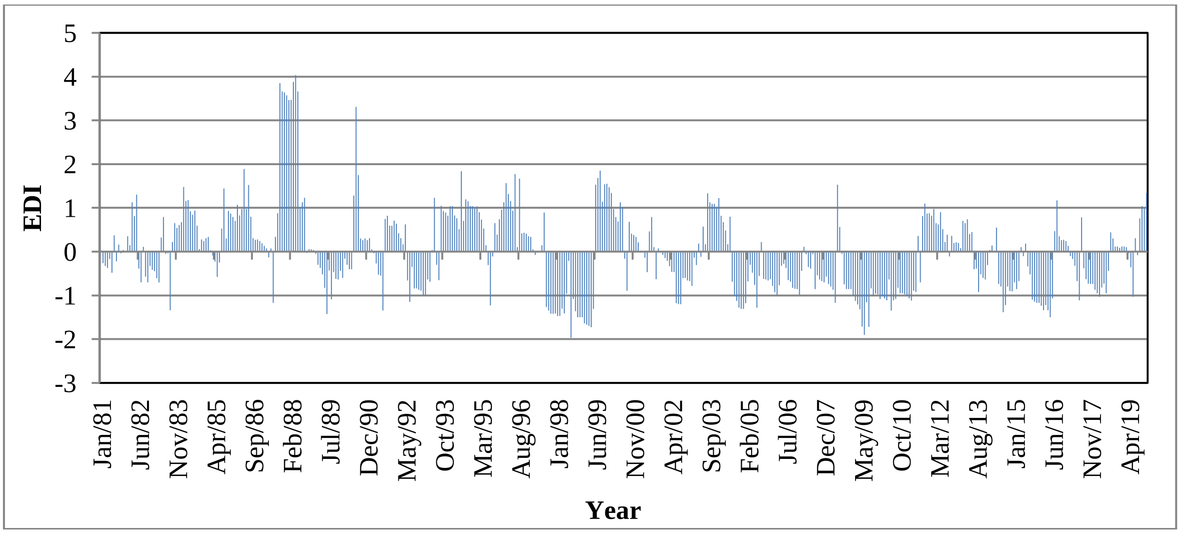

Fig. 3. Temporal variation of EDI in Jmalpur block in Mirzapur district

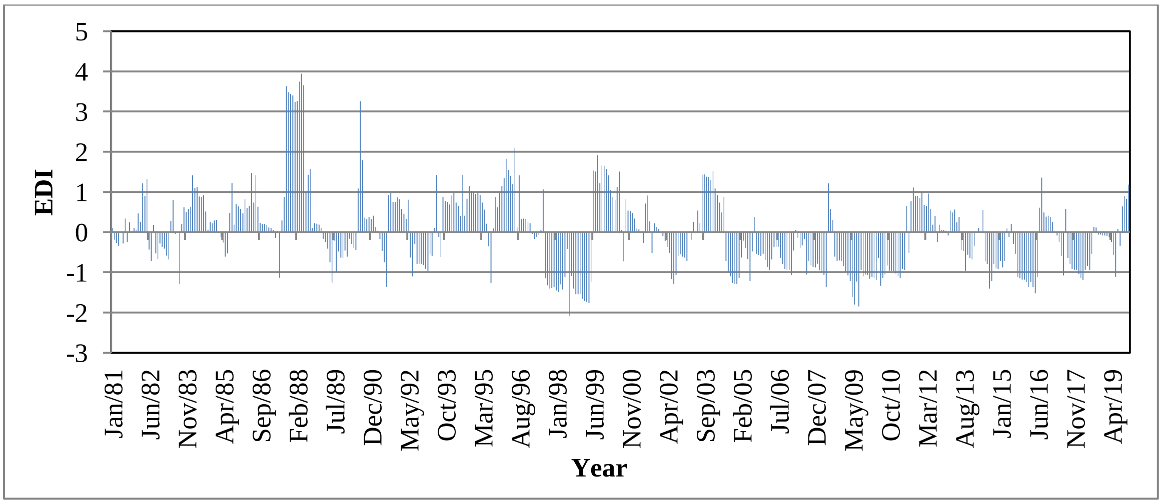

Fig. 4. Temporal variation of EDI in Narainpur block in Mirzapur district

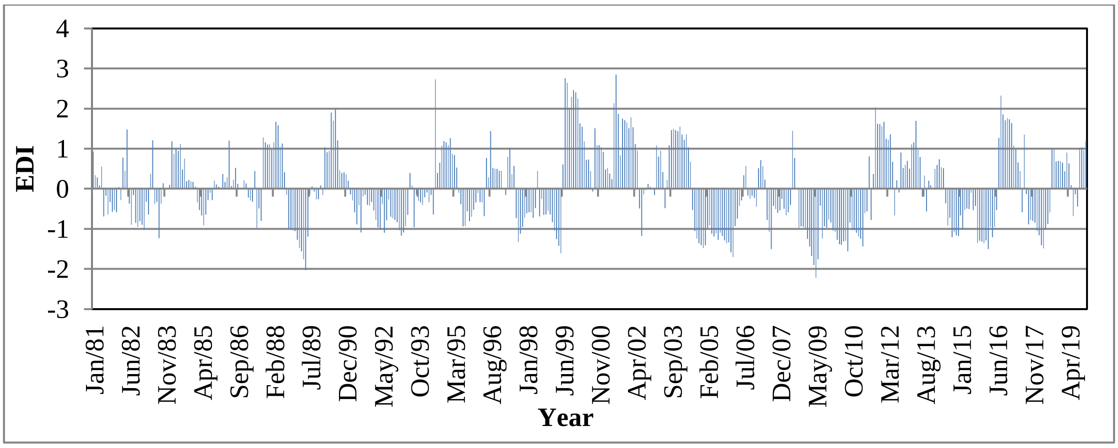

Fig. 5. Temporal variation of EDI in Robertsganj block in Sonbhadra district

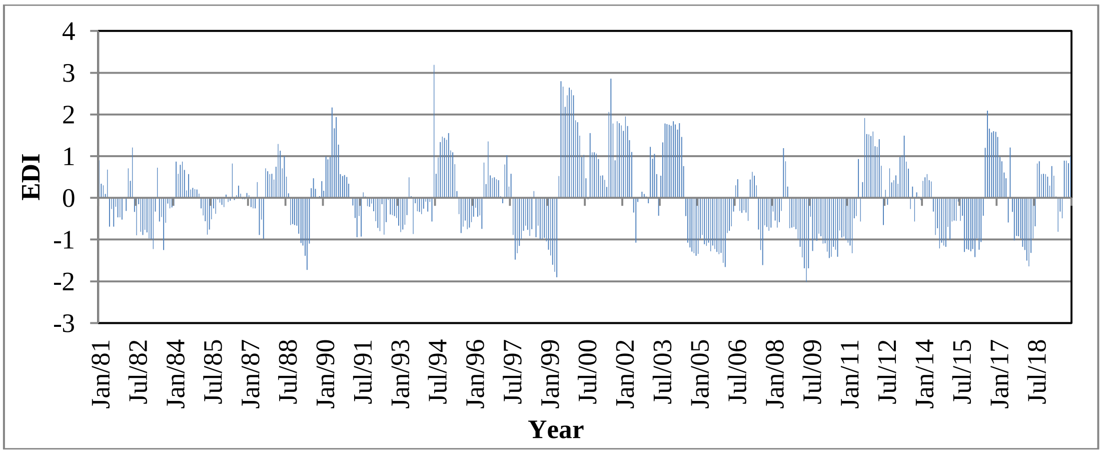

Fig. 6. Temporal variation of EDI in Ghorawal block in Sonbhadra district

Table 2. Drought events evaluated based on EDI

District Name	Block	Extreme	Severe	Moderate	Mild	Total Drought Events
Mirzapur	Chhanvey	14	25	39	54	132
	Citynagar	21	15	39	62	137
	Haliya	4	28	57	59	148
	Jamalpur	0	8	60	94	162
	Kon	20	17	37	63	137
	Lalganj	15	26	37	56	134
	Madihaon	10	19	49	68	146
	Majhawan	9	13	55	70	147
	Narainpur	1	11	64	92	168
	Pahari	9	6	58	88	161
	Rajgarh	5	8	64	81	158
	Sikhdi	6	12	57	81	156
Sonbhadra	Robertsganj	2	9	69	92	172
	Ghorawal	1	10	60	97	168
	Chatra	1	16	55	85	157
	Nagwa	0	9	63	83	155
	Chopan	1	22	58	84	165
	Babhani	6	22	43	67	138
	Myorpur	3	26	58	60	147
	Dudhi	1	20	59	65	145

Table 3. Drought characteristics evaluated based on EDI

District Name	Block	Drought severity				Total drought severity	Drought intensity
		Extreme	Severe	Moderate	Mild		
Mirzapur	Chhanvey	-32.1	-44.73	-47.11	-39.52	-163.46	-1.24
	Citynagar	-47.46	-25.46	-48.28	-45.19	-166.39	-1.21
	Haliya	-8.72	-46.38	-71.79	-44.23	-171.12	-1.16
	Jamalpur	0	-14.04	-72.72	-70.36	-157.12	-0.97
	Kon	-44.87	-29.12	-46.3	-47.9	-168.19	-1.23
	Lalganj	-35.13	-46.01	-43.5	-39.47	-164.11	-1.22
	Madihaon	-22.61	-33.38	-61.7	-49.45	-167.14	-1.14
	Majhawan	-19.94	-22.21	-66.15	-52.88	-161.18	-1.1
	Narainpur	-2.09	-18.29	-77.12	-68.36	-165.86	-0.99
	Pahari	-19.77	-9.97	-69.8	-66.6	-166.14	-1.03
	Rajgarh	-11.01	-14.41	-78.36	-64.14	-167.92	-1.06
	Sikhdi	-13.37	-21.76	-70.15	-60.11	-165.39	-1.06
Sonbhadra	Robertsganj	-4.25	-15.11	-83.5	-68.01	-170.87	-0.99
	Ghorawal	-2.02	-16.85	-73.63	-73.33	-165.83	-0.99
	Chatra	-2.01	-26.36	-68.68	-63.5	-160.55	-1.02
	Nagwa	0	-14.16	-78.96	-63.95	-157.07	-1.01
	Chopan	-2.21	-37.05	-72.66	-60.56	-172.48	-1.05
	Babhani	-13.04	-37.92	-51.94	-48.05	-150.95	-1.09
	Myorpur	-6.77	-43.92	-71.83	-45.61	-168.13	-1.14
	Dudhi	-2.35	-33.01	-74.34	-46.19	-155.89	-1.08

number of extreme drought conditions occurred in Citynagar block (21 events) followed by Kon block (20 events) in Mirzapur district. Block namely Lalganj, Chhanvey, Madihaon in Mirzapur district faces 15, 14, and 10 extreme drought events, respectively. Most of the blocks located in Sonbhadra district of the study area face 1 to 6 extreme drought events over the span of 40 years. Haliya block in Mirzapur district faces maximum severe drought events (28 events) followed by Lalganj block in Mirzapur district and Myorpur block (26 events) in Sonbhadra district. Chhanvey block in Mirzapur district faces 25 severe drought events while rest of block of the study area faces severe drought condition that varies between 6 to 22 events. Maximum moderate drought events occurred in Robertsganj block (69 events) in Sonbhadra district followed by Narainpur and Rajgarh block (64 events) in Sonbhadra district of the study area. Occurrence of mild drought events in the study area are frequent i.e., once in every two years.

Table 3 showed drought characteristics based on EDI. Drought severity is computed as a summation of a particular type of drought whereas drought intensity is calculated as total severity divided by drought duration. Severity of extreme drought is maximum in Citynagar block (-47.46) followed by Kon block (-44.87) in Mirzapur district whereas in Sonbhadra district Babhani block (-13.04) has maximum extreme drought severity. Maximum severe drought severity prevails in Haliya and Lalganj block (approx. -46) in Mirzapur district. Moderate drought severity is maximum in Nagwa block (-78.96) in Sonbhadra district followed by Rajgarh block (-78.36) in Mirzapur district. Severity of mild drought events was maximum in Ghorawal block (-73.33) in Sonbhadra district followed by Jmalpur block (-70.36) in Mirzapur district. Maximum drought severity based on EDI computation used to prevails in Chopan block (-170.48) in Sonbhadra block followed by Haliya block (-171.12) in Mirzapur district. Maximum drought events of varying severity class used to prevails in Robertsganj block (172 events) in Sonbhadra district. Drought intensity, which was computed as the ratio of total drought severity to the study period, suggested that Chhanvey Kon and Lalganj block have the highest drought intensity compared to other blocks in the study area.

4. CONCLUSION

Changes in the climatic phenomenon that occurred due to human-induced activities over a period of time exacerbated the consequences especially concerning drought. The situation has been extensively devastating for India, which has an agrarian economy. The Vindhyan range where agriculture flourishes has been severely affected due to frequent drought occurrence of various severity classes. The present study highlight that in Mirzapur district the Citynagar block face the maximum number of extreme drought events whereas Babhani block in Sonbhadra district. Maximum drought events occurred in the Robertsganj block of Sonbhadra district and minimum drought events occurred in the Chhanvey district of Mirzapur district. The overall occurrence of drought events in Sonbhadra district (155 events) of Vindhyan range is more as compared to Mirzapur district (149 events) whereas average drought severity in Mirzapur district (-166) is more as compared to Sonbhadra district (-162.5). Therefore, it can be concluded that both the district lying in the Vindhyan range is critical to drought, thus suggesting adaptation of suitable mitigation strategies that can reduce the impact of drought.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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