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Drought characterization by using UNEP Aridity Index

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ABSTRACT: UNEP Aridity Index (UNEP AI) methods was used to identify meteorological drought for long term (1990-2019) in Bundelkhand region of India. The percentage of drought occurrence were obtained by taking the ratio of drought occurrences to the total drought occurrences for particular time and particular drought category. The drought occurrence probabilities were calculated by using each drought event for all stations in each district in Bundelkhand region based on UNEP AI. Time relative frequency of drought occurrence in different classes viz. Hyper arid, arid and semi-arid were categorized based on UNEP aridity index values. The highest probability of occurrence for extreme drought (3.33 %) was monitored in three districts Chhatarpur, Damoh and Lalitpur. The highest percentage was observed at Jalaun district as 8.00 % for severe drought and of the moderate drought as 11.33 % at Jhansi district. The highest probability of occurrence for hyper arid (9.33 %) was monitored in Datia district and for arid category in same district as 14.00 %. The highest percentage of occurrence of probability for semi-arid category was detected as 22.67 % at Jalaun and Tikamgarh districts. In most of the districts semi-arid class contributed maximum followed by arid class and hyper arid class. By increasing frequency of irrigation and their proper management, impact of drought may be minimized.

Keywords: Drought, UNEP aridity index, Hyper arid, probability of occurrence, time relative frequency.

INTRODUCTION

Drought is a phenomenon that exists when precipitation is significantly below normal, causing serious hydrological imbalances and which adversely affects land resource production systems. Drought is a natural phenomenon that results from a deficiency of rainfall from expected rainfall or normal rainfall and which may exist over a season or for longer time period and is insufficient to satisfy the need of water for human activities and the environment (Wilhite and Buchanan-Smith, 2005). It's a short-lived aberration within the natural variability and may be considered an insidious hazard of nature; it differs from aridity which may be a long-term, average feature of climate. Drought may be a period of drier-than-normal conditions that leads to water-related problems. It's the amount when rainfall is a smaller amount than normal for several weeks, months or years (Nagarajan, 2009). Drought is not permanent situation but it is temporary dry period, in comparison to the permanent aridity in arid areas (Dai, 2010). Impact of drought was analyzed in terms of spatiotemporal characteristics and risk assessment was completed for agricultural drought during the winter wheat-growing season in the Huang-Huai-Hai Plain, China and was found that there was variation in drought frequency in different years (Hu *et al.,* 2020).

Bundelkhand region has faced a no. of times drought which has made the life of the people worst. Repeating droughts have resulted in scarcity of food grains and have increased struggle for life in them. Mostly here agriculture is rainfed which is very risky and vulnerable. A number of the widely used drought indices include Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), Crop Moisture Index (CMI), UNEP Aridity Index and Surface water system Index (SWSI). By using the climatological standards, like precipitation and evaporation, grades of injury caused by drought to agricultural production was evaluated. Risk and impact of drought to crop yield actually determined by a number of approaches like climatic indices which may include precipitation and evaporation and crop simulation models. Risk and impact of drought to crop yield actually determined by a no. of approaches like climatic indices which may include precipitation and loss of water through evapotranspiration and crop models. So, risk assessment of drought was tried to evaluate by using different parameters responsible for risk. Probable damage or loss of yield due to drought was tried to assessed was derived by combined effect of different parameters like frequency, coverage of area affected by drought and its severe effect and also capability of the region or society to minimize the impact of drought on crop production.

MATERIALS AND METHODS

A. Study area and meteorological data

The Bundelkhand region consists of thirteen districts:

seven in Uttar Pradesh- Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda and Chitrakoot, and six in Madhya Pradesh - Datia, Tikamgarh, Chattarpur, Damoh, Sagar and Panna. This is situated just below the Indo-Gangetic plain and is extending to the north with the undulating Vindhyan range spread across the northwest to the south. It is situated between 23°20′ and 26°20′ N latitude and 78°20′ and 81°40′E longitude.

The daily climatic data (maximum temperature, minimum temperature, mean temperature and rainfall) for the amount of 1990 to 2019 were downloaded and were extracted by R environment with Python from gridded data of India Meteorological Department, Pune, India (Pai *et al.,* 2014; Srivastava *et al*., 2009). Monthly mean, maximum and minimum temperature and monthly rainfall were estimated for all 13 districts (Banda, Chhatarpur, Chitrakoot, Damoh, Datia, Hamirpur, Jalaun, Jhansi, Lalitpur, Panna, Sagar and Tikamgarh) of Bundelkhand region for duration 1990–2019.

Estimation of UNEP Aridity Index. Aridity index (AI) based on UNEP (1992) to quantify the drought occurrence at each study location was used. This index is derived from two important climatic elements for agriculture and reflects both the atmospheric supply (rainfall) and atmospheric demand (evapotranspiration), i.e. two important factors affecting the water budget of land surface (Zhuguo and Congbin, 2003). Unlike other drought indices, the use of UNEP AI serves the probabilistic nature of the present DRI model since the index is in the form of a ratio. The reference evapotranspiration (ETo) was calculated by using temperature method given by Hargreaves and Samani (1985) and modified by Hargreaves *et al*., (1985). This index defines six climatic zones (drought categories), assigning a selected score to every as described within the Table 1. As per the UNCCD definition, area which are sensitive to drought are often divided into the three categories, namely arid, semi-arid, dry sub-humid. This classification was applied in the study to categorize different drought condition. When the ratio exceeds the upper threshold value, drought doesn't advance. Drought occurrences were examined based upon the frequencies of events for every drought category for various time steps for all 13 districts coming under this region. The percentage of drought occurrence were obtained by taking the ratio of drought occurrences to the total drought occurrences for particular time and particular drought category (Sonmez *et al.,* 2005). The drought occurrence probabilities were calculated by using each drought event for all stations in each district in Bundelkhand region.

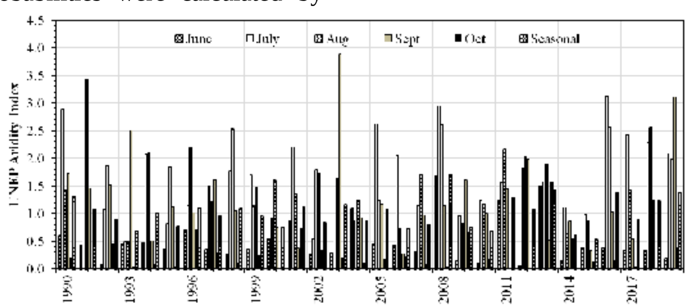
Table 1: Drought category according to drought index (UNEP AI) (FAO, 1977).

Drought Category	UNEP AI
Per humid	>0.75
Humid	(0.65) – (0.75)
Dry sub-humid	(0.5) – (0.65)
Semi-arid	(0.2) – (0.5)
Arid	(0.05) - (0.2)
Hyper arid	< 0.05

RESULTS AND DISCUSSION

A. Drought monitoring using UNEP Aridity Index (UNEP AI)

In case of UNEP AI, if this index is less than 0.5 then dry condition occurs in the area. In Banda district Chhatarpur and Chitrakoot districts, in most of the years in the month of June, October and in whole season, there was dry condition as indicated by Fig. 1. In Chitrakoot district, there was more severe condition and cases of hyper arid and arid condition was also more in comparison to these other two districts. In the districts, Damoh, Datia and Hamirpur, Hamirpur was more affected by dry condition and there were more cases of hyper arid condition. In Datia also there were more cases of dry condition but arid condition was more prevailing than hyper arid and number of cases were lesser than Datia (Fig. 2). In Jalaun, Jhansi and Lalitpur, all the districts were affected by dry condition mostly in the months of June and October months. But in whole season, the condition was little bit better than individual months. In Jhansi district, dry condition was in more no. of years in comparison to other two districts (Fig. 3). In Mahoba, Panna and Sagar, Mahoba was more affected than other two districts. Hyper arid to arid condion was more in June and October months in comparison to other three months. In season, there was some dry condition but condition was better (Fig. 4). In Tikamgarh, hyper arid condition was more in no. in the month of October followed by June month. Arid condition was also more in these months in comparison to other three months (Fig. 5). Among all 13 districts, Datia and Jhansi were more affected and aridity index was very less in June and October months in comparison to other 11 districts. The monthly and seasonal aridity indices showed the variability of rainfall and their adverse effects that could be seen in the form of crop failures.



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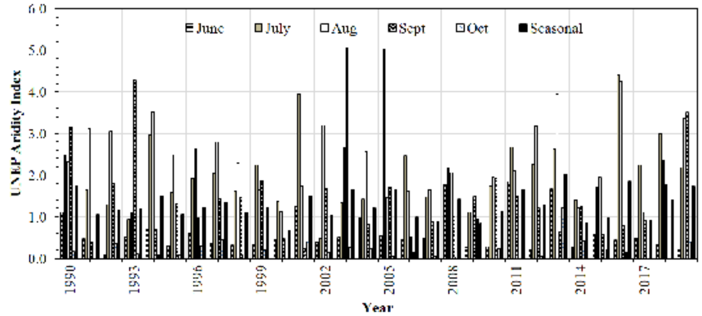

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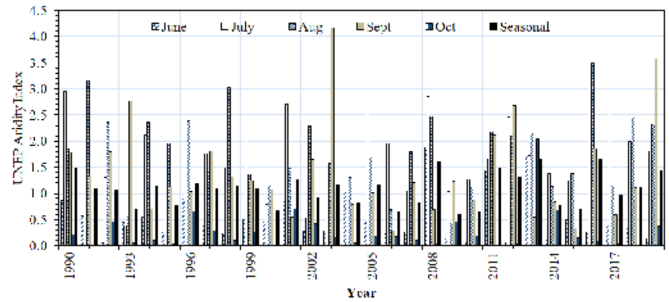

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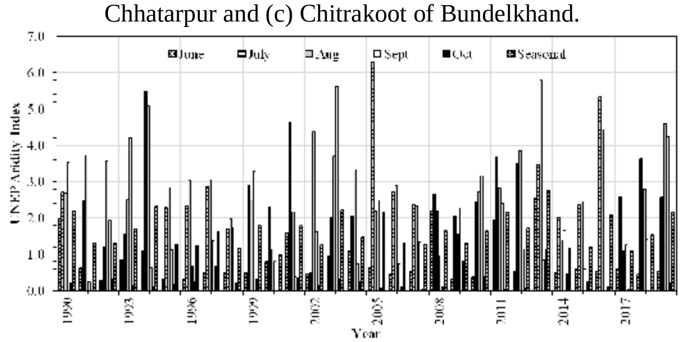
Fig. 1. Temporal variation in the UNEP Aridity Index for the growing season (June-October) for (a) Banda (b) Chhatarpur and (c) Chitrakoot of Bundelkhand.



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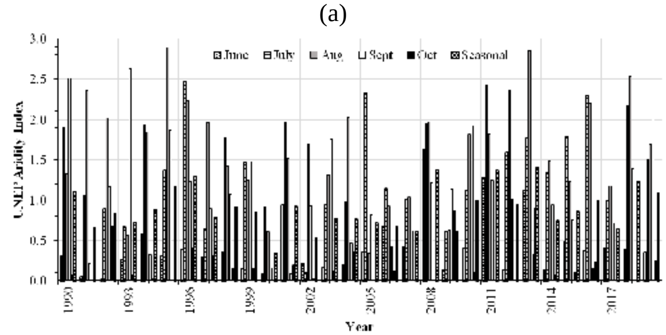

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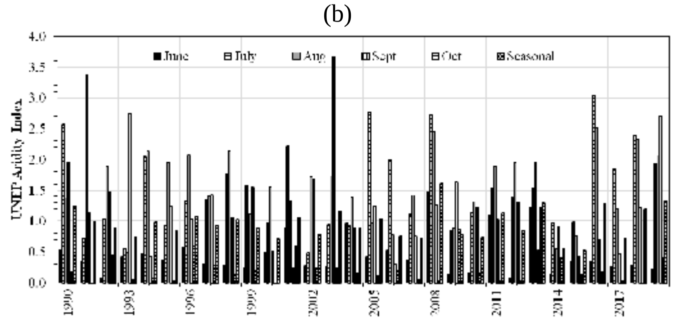
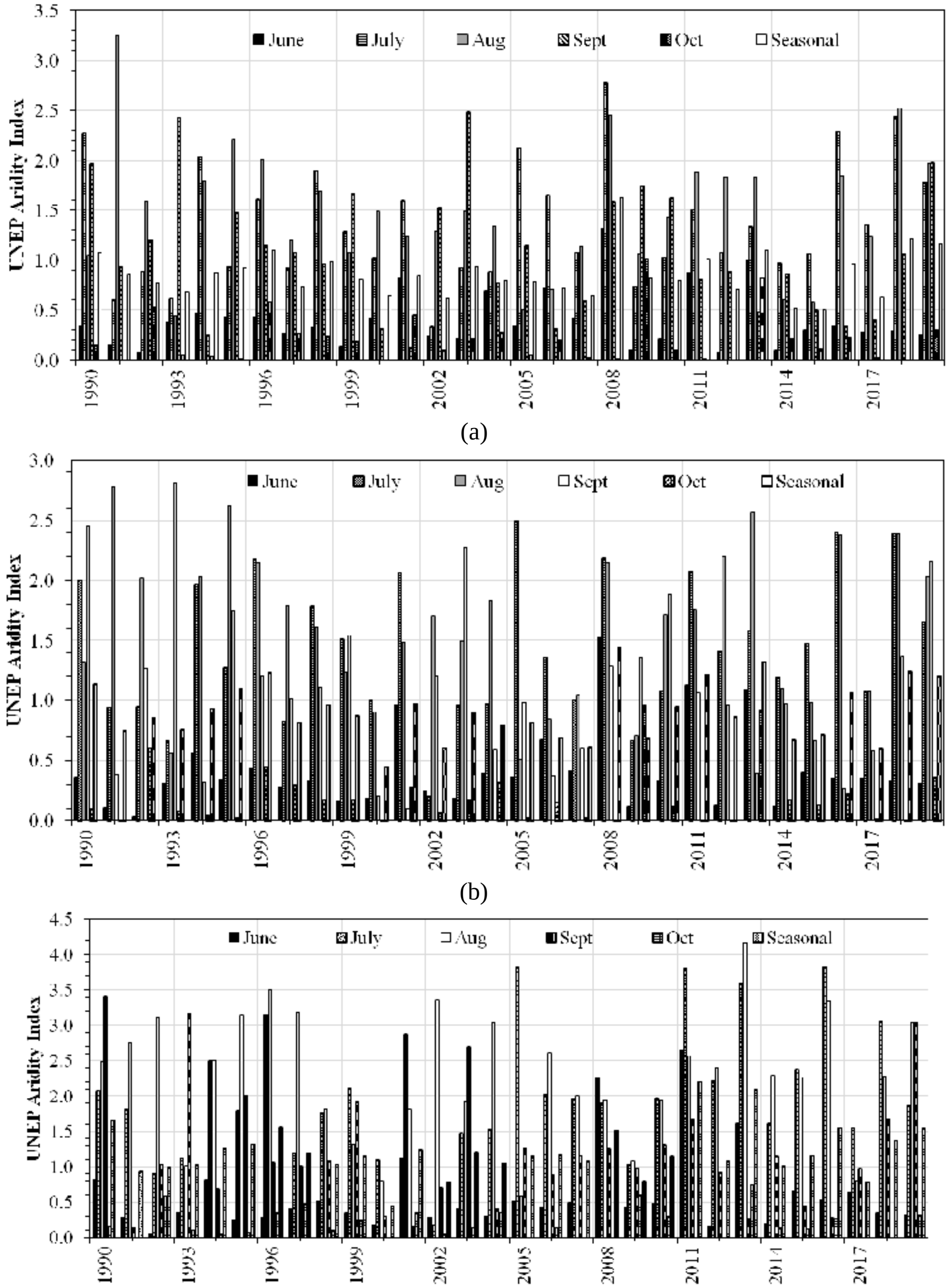


(c)

Fig. 2. Temporal variation in the UNEP Aridity Index for the growing season (June-October) for (a) Damoh (b) Datia and (c) Hamirpur of Bundelkhand region.



(a)

(b)

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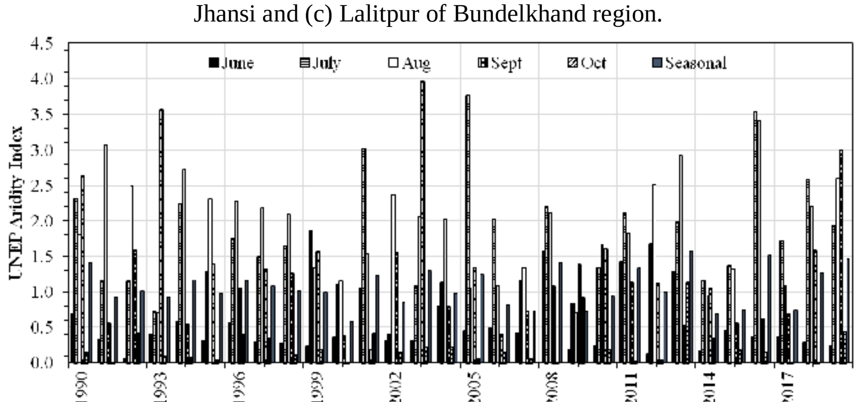
Fig. 3. Temporal variation in the UNEP Aridity Index for the growing season (June-October) for (a) Jalaun (b) Jhansi and (c) Lalitpur of Bundelkhand region.



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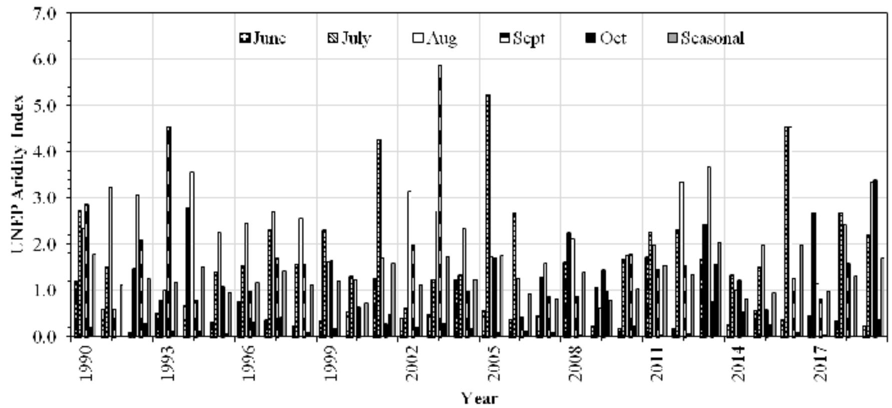

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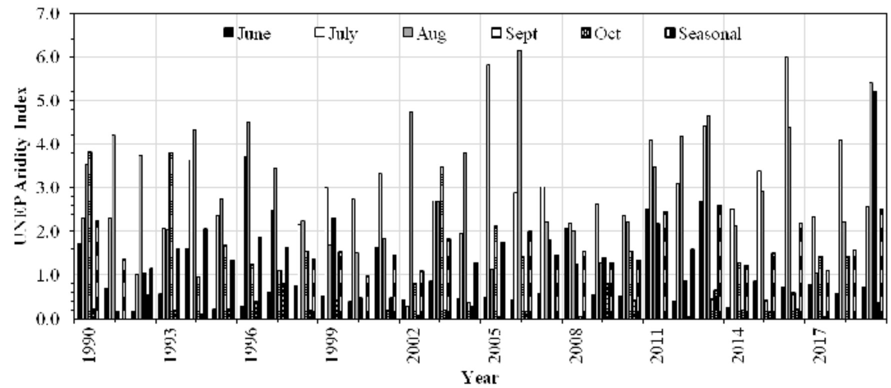

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Fig. 4. Temporal variation in the UNEP Aridity Index for the growing season (June-October) for (a) Mahoba (b) Panna and (c) Sagar of Bundelkhand region.

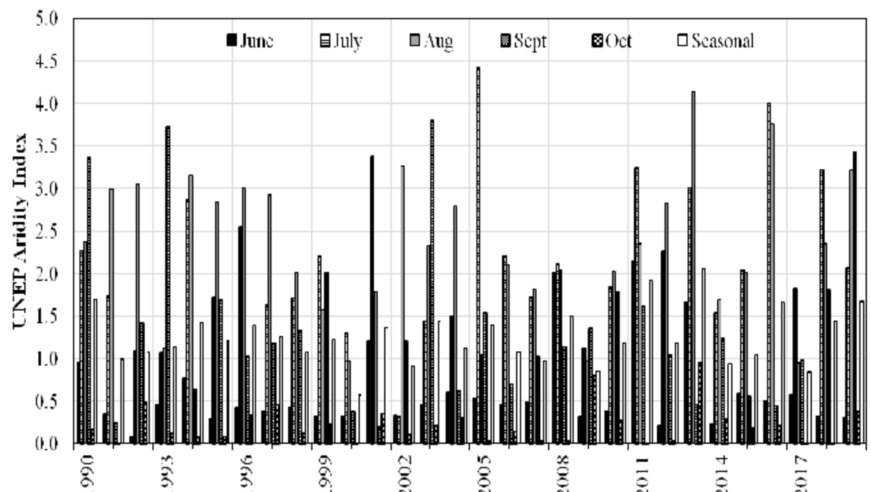

Fig. 5. Temporal variation in the UNEP Aridity Index for the growing season (June-October) for Tikamgarh of Bundelkhand region.

Probability of drought occurrences. The results of the Probability of drought occurrences based on UNEP Aridity Index (UNEP AI) for all 13 districts coming under Bundelkhand region have been shown in Table 2 for the months of June-October during 1990 to 2019 period. The highest probability of occurrence for Hyper arid (9.33 %) was monitored in Datia district whereas Jhansi district has probability for Hyper arid is less than that of Datia (8.00 %). The highest percentage for arid category was observed at Datia district again as 14.00 %, while Jhansi district had 12.00 % for arid category (Table 2). The highest percentage of occurrence probability of Semi-arid category was detected as 22.67 % at Jalaun and Tikamgarh districts followed by Chhatarpur district (22.00 %).

Table 2: Drought occurrence probability based on UNEP AI during June-October in different districts of Bundelkhand region.

Districts	Latitude	Longitude	Drought occurrence probability (%)				
			Humid	Dry Sub Humid	Semi-Arid	Arid	Hyper Arid
Banda	25.49	80.33	60.00	5.33	18.00	10.67	6.00
Chhatarpur	24.91	79.58	61.33	4.67	22.00	6.67	5.33
Chitrakoot	25.17	80.86	60.67	6.00	16.67	9.33	7.33
Damoh	23.83	79.44	64.67	8.00	16.67	6.67	4.00
Datia	25.66	78.46	54.67	4.67	17.33	14.00	9.33
Hamirpur	25.95	80.15	57.33	6.00	21.33	9.33	6.00
Jalaun	26.14	79.35	54.67	6.00	22.67	9.33	7.33
Jhansi	25.43	78.56	56.00	4.67	19.33	12.00	8.00
Lalitpur	24.68	78.41	59.33	4.67	18.67	10.00	7.33
Mahoba	25.29	79.87	59.33	4.67	19.33	10.00	6.67
Panna	24.71	80.18	62.00	7.33	16.67	10.00	4.00
Sagar	23.83	78.74	64.67	6.67	16.67	6.00	6.00
Tikamgarh	24.75	78.83	59.33	4.67	22.67	7.33	6.00

Time relative frequency contribution of different classes of drought. In Banda district, Hyper-arid class contributed only 9.0 % of the cases, the arid class contributed 16.0 % and the semi-arid conditions recurred 27.0 % times out of the total number of cases (Table 3). Hyper-arid class contributed only 8.0 % of the cases, the arid class contributed 10.0 % and the semi-arid conditions occurred 33.0 % times out of the total number of months in Chhatarpur district. In case of Chitrakoot district, Hyper-arid class contributed only 11.0 % of the cases, the arid class contributed 14.0 % and the semi-arid conditions recurred 25.0 % times out of the total number of months. Hyper-arid class contributed only 6.0 % of the cases, the arid class contributed 10.0 % and the semi-arid conditions occurred 25.0 % times out of the total number of months in Damoh district. In Datia district, Hyper-arid class contributed only 14.0 % of the cases, the arid class contributed 21.0 % and the semi-arid conditions occurred 26.0 % times out of the total number of months. Hyper-arid class contributed only 9.0 % of the cases, the arid class contributed 14.0 % and the semi-arid conditions occurred 32.0 % times out of the total number of months in case of Hamirpur. In Jalaun district, Hyper-arid class contributed only 11.0 % of the cases, the arid class contributed 14.0 % and the semi-arid conditions occurred 34.0 % times out of the total number of months. In Jhansi district, Hyper-arid class contributed only 12.0 % of the cases, the arid class contributed 18.0 % and the semi-arid conditions occurred 29.0 % times out of the total number of cases. Hyper-arid class contributed only 11.0 % of the cases, the arid class contributed 15.0 % and the semi-arid conditions occurred 28.0 % times out of the total number of cases in Lalitpur district. In Mahoba district, Hyper-arid class contributed only 10.0 % of the cases, the arid class contributed 15.0 % and the semi-arid conditions occurred 29.0 % times out of the total number of months. Hyper-arid class contributed only 6.0 % of the cases, the arid class contributed 15.0 % and the semi-arid conditions occurred 25.0 % times out of the total number of months Panna district. In Sagar district, Hyper-arid class contributed only 9.0 % of the cases, the arid class contributed 9.0 % and the semi-arid conditions occurred 25.0 % times out of the total number of months. In Tikamgarh district, Hyper-arid class contributed only 9.0 % of the cases, the arid class contributed 11.0 % and the semi-arid conditions occurred 34.0 % times out of the total number of months.

Table 3: Time relative frequency of dry cases based on UNEP AI during June-October for the period (1990-2019) in different districts of Bundelkhand region.

			Time relative frequency of dry cases in %		
Districts	Latitude	Longitude	Semi-Arid	Arid	Hyper Arid
Banda	25.49	80.33	27.00	16.00	9.00
Chhatarpur	24.91	79.58	33.00	10.00	8.00
Chitrakoot	25.17	80.86	25.00	14.00	11.00
Damoh	23.83	79.44	25.00	10.00	6.00
Datia	25.66	78.46	26.00	21.00	14.00
Hamirpur	25.95	80.15	32.00	14.00	9.00
Jalaun	26.14	79.35	34.00	14.00	11.00
Jhansi	25.43	78.56	29.00	18.00	12.00
Lalitpur	24.68	78.41	28.00	15.00	11.00
Mahoba	25.29	79.87	29.00	15.00	10.00
Panna	24.71	80.18	25.00	15.00	6.00
Sagar	23.83	78.74	25.00	9.00	9.00
Tikamgarh	24.75	78.83	34.00	11.00	9.00

CONCLUSION

Vulnerability of crops in different districts due to drought may be assessed by using water availability and its demand for the area. These results and model obtained from the study can be used in future to improve the situation for the Bundelkhand region and it can be utilized for proper planning by Government and planners for long time to secure the crop yield and to reduce the cost on resources. In the future where effect of climate change is increasing day by day this indicator may be utilized to combat the effect of abnormalities due to climate change will be able to give proper plan to choose best suited crop in Bundelkhand region. This index can be used to warn the farmers in advance for proper management of crop so that loss may be minimized due to drought. It is able to bridge the gaps between the theoretical concepts of climate risk and decision making.

More no. of meteorological stations can be used to increase the spatial extent of effect of drought and long duration data may be used to improve the result further so more accuracy may be increased for right planning and preparation of strategy with which drought risk may be managed properly.

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Conflict of Interest. We both the authors declare that we do not have any conflict of interest for the manuscript entitled, "Drought characterization by using UNEP Aridity Index" for publication in the Journal "Biological Forum -an International Journal".

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