Identification of Drought Spells for
Almora and Dehradun Districts of Uttarakhand, India

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Abstract

In this study, 31 years (1989-2019) monthly rainfall dataset of Almora and Dehradun districts of Uttarakhand was analysed to determine occurrence of drought spells on monthly and yearly basis considering criterion given by researchers and some available drought indices namely, Dependable Precipitation Index (DPI), Precipitation Departure Index (PDI), Standard Index of Anomaly Precipitation (SIAP) and Standardized Precipitation Index (SPI). On the basis of monthly and yearly drought investigation, it was found that about 4.97 and 4.29 drought months per year may be observed at Almora and Dehradun districts, respectively. The analysis also revealed that 5 & 4 dry; 15 & 15 wet and 11 &12 normal years were observed at Almora and Dehradun districts with DPI, whereas, with PDI, 14 & 12 years were found to have more than average rainfall of 863.60 mm and 1590.53 mm at these two districts, respectively. The SIAP analysis showed that 6 and 4 extreme wet; 2 and 3 wet; 12 and 14 normal; 2 and 4 drought along with 9 and 6 extreme drought years were observed during study period of 31 years at Almora and Dehradun districts, respectively.
Keywords: Drought, DPI, PDI, SIAP.

1. Introduction

Drought is one of the main natural hazards which affects economy and environment of large areas and causes crop losses, degradation, desertification, ecosystem disturbance, famine, forest fire, homelessness, ill-health, people displacement, social disorder, water supply shortages, and in advanced stages, deaths as well (Odongkara, 2002). A drought is an extended period when a region notes a deficiency in normal precipitation for a region over a period of time sufficient to cause impacts (Beran and Rodier, 1985), however, a precise and clear-cut definition of drought remains vague (Vicente-Serrano *et al.*, 2012). Drought, in contrast to aridity, affects almost all climates in the world (WMO, 2006). There is no universal indicator to effectively measure different types of drought (Heim, 2002). Numerous specialized indices have been proposed to measure drought in different ways and extensive listings on drought indices are available (Heim, 2002; Hayes *et al.*, 1999; WMO, 1975). Based on impacts, 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 (WMO, 2006). All types of drought have distinctive characteristics that vary across different locations, climate types, populations and economic vulnerabilities. Considering the above, present study was undertaken with specific objective to identify drought spells by using criterion given by researchers and a number of drought indices namely, Dependable Precipitation Index (DPI), Precipitation Departure Index (PDI) and Standard Index of Anomaly Precipitation (SIAP) for Almora and Dehradun districts of Uttarakhand.

2. Materials and Methods

Description of Study Area and Meteorological Dataset

The Uttarakhand state lies on the south slope of large Himalaya range and consists of 13 districts, traditionally divided into two parts with eastern half as Kumaon while, western region is known as Garhwal. The districts of Almora and Dehradun lies at longitude 79˚30'E, latitude 29˚36'N and longitude 78˚04'E, latitude 30˚19'N, respectively. The monthly rainfall dataset of 31 years (1989-2019) each for both Almora and Dehradun districts was used to identify occurrence of drought spells.

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Drought spells investigations

(a) Monthly and Yearly Basis

The variation of drought on monthly and yearly basis was evaluated by following criterion proposed by Ramdas and Malik (1948) and Sharma *et al.* (1979) 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 (mm).

(b) Monthly rainfall seasonality: The rainfall seasonality (SI_i) on monthly basis can be calculated using mathematical expression:

$$SI_i = \frac{1}{R_i} \sum_{n=1}^{12} \left| X_{in} - \frac{R_i}{12} \right|$$

where R_i is total annual rainfall for particular year; and X_{in} is rainfall recorded for any specific month "n". The pertinent information on different precipitation regimes can suitably be interpreted using following information:

Symbol	SI	Precipitation regime
Pty	< 0.19	Precipitation spread throughout year.
Pws	0.20-0.39	Precipitation spread throughout year, but with a definite wetter season.
Ssds	0.40-0.59	Rather seasonal with a short dry season.
S	0.60-0.79	Seasonal.
Slds	0.80-0.99	Marked seasonal with a long dry season.
Mp in <3 months	1.00-1.19	Most precipitation in <3 months.
ES	> 1.20	Extreme seasonality, with almost all precipitation in 1-2 months.

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

$$DPI = 0.8 \times \sqrt[n]{P_1 \times P_2 \times P_3 \times \dots \dots \dots \times P_n}$$

where DPI is dependable precipitation index, P's are annual rainfall (mm) of different years, n is number of years and 0.8 is constant coefficient.

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

Classification	Range
Normal year	$DPI \leq P \geq GM$
Dry year	$P < DPI$
Wet year	$P > GM$

where P is total rainfall occurred in a particular year (mm) and GM is geometric mean of rainfall values observed during study period.

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(d) Precipitation Departure Index (PDI): It is also 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.

$$PDI = \frac{P_i - \overline{P}}{100}$$

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

(e) Standard Index of Annual Precipitation (SIAP): The values of SIAP was computed by using equation:

$$SIAP = \frac{P_i - \overline{P}}{PSD}$$

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 study period. The trend of drought and wet years can be ascertained on following basis:

Classification	SIAP value
Extremely wet	$\geq$ 0.84
Wet	0.52 to 0.84
Normal	- 0.52 to 0.52
Drought	- 0.84 to - 0.52
Extreme drought	$\leq$ - 0.84

(f) Rainfall Anomaly Index (RAI): This is an index used to describe annual rainfall variability (van Rooy, 1965) and is calculated using mathematical expression:

$$RAI = 3 \left[\frac{RF - M_{RF}}{M_{H10} - M_{RF}} \right] \times 100$$

where RF is actual rainfall for a given year, M_{RF} is mean for total length of record and MH_{10} is mean of 10 highest rainfall values. The RAI is adjudged as a very effective index for detecting drought periods. The positive value of RAI represents rainy/wet years while negative values represent dry years.

3. Results and Discussion

(a) Drought investigation on monthly and yearly basis: By following criterion given by Ramdas and Malik (1948) and Sharma *et al.* (1979), drought analysis on monthly and yearly basis was conducted and results are presented as:

 Monthly basis: Rainfall based criteria for drought, abnormal and normal months and their distribution pattern for Almora and Dehradun districts (Table 1) reveals that average monthly rainfall at Almora district varied in the range from 4.00 mm (November) to 223.46 mm (July). From Table 1, it is clear that least number of drought months (4 times) were observed in the months of July and August, whereas it occurred maximum during December (23 times), followed by 22 times during November. From analysis, it was found that during the study period, 41.40% drought months were observed and about 5 drought months per year are expected to occur at Almora district.

 At Dehradun district, average monthly rainfall varied in between 5.38 mm (November) and 493.05 mm (July) with least number of drought (2 times) observed during months of July and August while, it occurred maximum (19 times each) during months of November and December, followed by 17 times during October. The analysis revealed that 35.75% drought months were observed and it is expected that Dehradun district may also experience 5 drought months in a year.

 Yearly basis: The value for average precipitation P_{av} and standard deviation (SD) of annual rainfall during study period at Almora district were calculated as 863.60 mm and 193.89 mm, respectively. Thus, as per

prescribed criteria, any year which received rainfall less than or equal to 669.71 mm (P_{av}–SD) was considered "drought" year, whereas years receiving rainfall equal to or greater than 1057.49 (P_{av}+SD) was designated as "abnormal" and any year with rainfall in between 669.71 mm and 1057.49 mm was considered "normal". Considering above criterion, 5 drought years, 5 abnormal years and 21 normal years were observed at Almora district during 31 years study period.

At Dehradun, on annual basis, average precipitation (P_{av}) of 1590.53 mm with standard deviation (SD) as 325.18 mm was observed. Thus, as per prescribed criteria, any year receiving rainfall less than or equal to 1265.35 mm (P_{av}–SD) was considered "drought", whereas year receiving rainfall equal to or greater than 1915.71 mm (P_{av}+SD) was designated as "abnormal" and year experiencing rainfall in between these two values i.e. 1265.35 mm and 1915.71 mm were considered as "normal". From analysis, it was found that during study period of 31 years, 5 drought, 4 abnormal and 22 normal years were observed at Dehradun.

(b) Monthly rainfall seasonality: The results obtained for rainfall seasonality in terms of precipitation regime on monthly basis revealed that Almora district (Fig. 1a) experienced no "Precipitation spread throughout year (Pty)" and "Precipitation spread throughout year, but with a definite wetter season (Pws)", while 2, 4, 11, 5 and 9 years, respectively experienced "Rather seasonal with a short dry season (Ssds)", "Seasonal (S)", "Marked seasonal with a long dry season (Slds)", "Most precipitation in <3 months (Mp in <3 months)" and "Extreme seasonality, with almost all precipitation in 1-2 months (ES)" during study period. The results for Dehradun district (Fig. 1b) revealed that during study period, it experienced not even a single year as "Precipitation spread throughout year (Pty)", "Precipitation spread throughout year, but with a definite wetter season (Pws)", "Rather seasonal with a short dry season (Ssds)" and "Seasonal (S)", while 8, 16 and 7 years were observed in the category of "Marked seasonal with a long dry season (Slds)", "Most precipitation in <3 months (Mp in <3 months)" and "Extreme seasonality, with almost all precipitation in 1-2 months (ES)", respectively.

(c) Dependable Precipitation Index (DPI): The DPI values calculated with annual rainfall data series revealed that Almora district (Table 2a) experienced 5, 15 and 11 years as dry, wet and normal, respectively while 4 dry, 15 wet and 12 normal years were experienced at Dehradun district (Table 2b).

(d) Precipitation Departure Index (PDI): From variation in PDI values, it is clear that districts of Almora (Table 3a) and Dehradun (Table 3b) experienced higher than average rainfall in 14 and 12 years, respectively while, these two districts received less than average annual rainfall during 17 and 19 years, respectively.

(e) Standard Index of Annual Precipitation (SIAP): The variation in SIAP values revealed that Almora district (Table 4a) experienced 6 extreme wet, 2 wet, 12 normal, 2 drought and 9 extreme drought years while 4, 3, 14, 4 and 6 years were observed as extreme wet, wet, normal, drought and extreme drought years at Dehradun district (Table 4b), respectively.

(f) Rainfall Anomaly Index (RAI): The analysis (Table 5) revealed that Almora district experienced 14 rainy/wet years and 17 dry years while at Dehradun district, 12 and 19 years were observed as rainy/wet years and dry years, respectively.

4. Conclusions

The present study was carried out for Almora and Dehradun districts of Uttarakhand using monthly rainfall dataset of 31 years (1989-2019) each to identify drought spells using standard criterion and different indices given by researchers. On the basis of finding of this study, following conclusions were drawn:

- About 4.97 and 4.29 drought months per year may come into existence at Almora and Dehradun districts, respectively.
- 5 drought years each at Almora and Dehradun districts were observed and have 16.13% chance to experience any year as drought year.

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- Almora and Dehradun districts experienced 11 & 8 years as seasonal with a long dry season; 5 & 16 years with most precipitation in <3 months along with 9 & 7 years with extreme seasonality, with almost all precipitation in 1-2 months, respectively.
- On the basis of DPI, it was found that Almora district experienced 5, 15 and 11 years as dry, wet and normal years, respectively while, 4 dry, 15 wet and 12 normal years were observed at Dehradun district
- With PDI, out of 31 years, Almora and Dehradun districts experienced 17 and 19 dry years with less than average rainfall of 863.60 mm and 1590.53 mm, respectively.
- In terms of SIAP values, Almora district experienced 2 drought and 9 extreme drought years, while 4 and 6 years were observed as drought and extreme drought years at Dehradun district, respectively.

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Table 1: Distribution of Drought, abnormal and normal months at Almora and Dehradun districts.

Month(s)	Av. rains (mm)	For drought month (mm)	Number of months observed as		
			Drought	**Abnormal**	**Normal**
Almora district					
Jan	29.54	< 14.77	14	6	11
Feb	46.61	< 23.31	15	7	9
Mar	30.95	< 15.48	12	5	14
Apr	20.50	< 10.25	15	6	10
May	37.71	< 18.86	12	5	14
Jun	108.42	< 54.21	6	2	23
Jul	223.45	< 111.72	4	2	25
Aug	194.08	< 97.04	4	0	27
Sep	134.28	< 67.14	9	3	19
Oct	20.33	< 10.16	18	8	5
Nov	4.00	< 2.00	22	4	5
Dec	13.72	< 6.86	23	7	1
		Total	**154 (41.40%)**	**55 (14.78%)**	**163 (43.82%)**
Dehradun district					
Jan	39.03	< 19.52	12	3	16
Feb	59.71	< 29.85	11	3	17
Mar	40.49	< 20.25	11	4	16
Apr	21.07	< 10.54	12	5	14
May	34.15	< 17.08	13	4	14
Jun	178.33	< 89.17	7	1	23
Jul	493.05	< 246.52	2	0	29
Aug	454.04	< 227.02	2	0	29
Sep	223.17	< 111.59	8	1	22
Oct	22.74	< 11.37	17	5	9
Nov	5.38	< 2.69	19	5	7
Dec	19.36	< 9.68	19	5	7
		Total	**133 (35.75%)**	**36 (9.68%)**	**203 (54.57%)**

Table 2a: Classification of years based on Dependable Precipitation Index (DPI) values observed at Almora district (1989-2019).

Year	Annual rainfall (mm)	Year classified as		
		Normal	**Dry**	**Wet**
1989	758.00	Normal	---	---
1990	1059.80	---	---	Wet
1991	602.20	---	Dry	---
1992	603.70	---	Dry	---
1993	1210.20	---	---	Wet
1994	680.90	Normal	---	---
1995	934.80	---	---	Wet
1996	718.40	Normal	---	---
1997	935.00	---	---	Wet
1998	1284.00	---	---	Wet
1999	663.00	---	Dry	---
2000	811.40	Normal	---	---
2001	590.00	---	Dry	---
2002	773.20	Normal	---	---
2003	1166.00	---	---	Wet
2004	961.40	---	---	Wet
2005	877.40	---	---	Wet
2006	770.40	Normal	---	---
2007	990.00	---	---	Wet
2008	772.00	Normal		---
2009	698.00	Normal	---	---
2010	1270.51	---	---	Wet
2011	828.20	Normal	---	---
2012	682.90	Normal	---	---
2013	1036.61	---	---	Wet
2014	1009.60	---	---	Wet
2015	667.48	---	Dry	---
2016	925.82	---	---	Wet
2017	946.20	---	---	Wet
2018	688.10	Normal	---	---
2019	856.40	---	---	Wet
Total		**11**	**5**	**15**

Table 2b: Classification of years based on Dependable Precipitation Index (DPI) values observed at Dehradun district (1989-2019).

Year	Annual rainfall (mm)	Year classified as		
		Normal	**Dry**	**Wet**
1989	1803.50	---	---	Wet
1990	2086.60	---	---	Wet
1991	1163.50	---	Dry	---
1992	1258.30	Normal	---	---
1993	1572.20	---	---	Wet
1994	1678.60	---	---	Wet
1995	1528.40	Normal	---	---
1996	1860.00	---	---	Wet
1997	1667.80	---	---	Wet
1998	2003.70	---	---	Wet
1999	1584.50	---	---	Wet
2000	1521.30	Normal	---	---
2001	1448.10	Normal	---	---
2002	1155.20	---	Dry	---
2003	1439.20	Normal	---	---
2004	1248.00	---	Dry	---
2005	1375.60	Normal	---	---
2006	1375.60	Normal	---	---
2007	1297.60	Normal	---	---
2008	1720.20	---	---	Wet
2009	1144.50	---	Dry	---
2010	2551.30	---	---	Wet
2011	1701.20	---	---	Wet
2012	1469.10	Normal	---	---
2013	2349.80	---	---	Wet
2014	1403.40	Normal	---	---
2015	1573.70	---	---	Wet
2016	1318.50	Normal	---	---
2017	1538.90	Normal	---	---
2018	1778.90	---	---	Wet
2019	1689.30	---	---	Wet
Total		**12**	**4**	**15**

Table 3a: Classification of years based on Precipitation Departure Index (PDI) values observed at Almora district (1989-2019).

Year	Annual rainfall (mm)	Departure	Higher than mean rainfall (HTMR)	Lower than mean rainfall (LTMR)
1989	758.00	-1.06	---	LTMR
1990	1059.80	1.96	HTMR	---
1991	602.20	-2.61	---	LTMR
1992	603.70	-2.60	---	LTMR
1993	1210.20	3.47	HTMR	---
1994	680.90	-1.83	---	LTMR
1995	934.80	0.71	HTMR	---
1996	718.40	-1.45	---	LTMR
1997	935.00	0.71	HTMR	---
1998	1284.00	4.20	HTMR	---
1999	663.00	-2.01	---	LTMR
2000	811.40	-0.52	---	LTMR
2001	590.00	-2.74	---	LTMR
2002	773.20	-0.90	---	LTMR
2003	1166.00	3.02	HTMR	---
2004	961.40	0.98	HTMR	---
2005	877.40	0.14	HTMR	---
2006	770.40	-0.93	---	LTMR
2007	990.00	1.26	HTMR	---
2008	772.00	-0.92	---	LTMR
2009	698.00	-1.66	---	LTMR
2010	1270.51	4.07	HTMR	---
2011	828.20	-0.35	---	LTMR
2012	682.90	-1.81	---	LTMR
2013	1036.61	1.73	HTMR	---
2014	1009.60	1.46	HTMR	---
2015	667.48	-1.96	---	LTMR
2016	925.82	0.62	HTMR	---
2017	946.20	0.83	HTMR	---
2018	688.10	-1.76	---	LTMR
2019	856.40	-0.07	---	LTMR
		Total	**14**	**17**

Table 3b: Classification of years based on Precipitation Departure Index (PDI) values observed at Dehradun district (1989-2019).

Year	Annual rainfall (mm)	Departure	Higher than mean rainfall (HTMR)	Lower than mean rainfall (LTMR)
1989	1803.50	2.13	HTMR	---
1990	2086.60	4.96	HTMR	---
1991	1163.50	-4.27	---	LTMR
1992	1258.30	-3.32	---	LTMR
1993	1572.20	-0.18	---	LTMR
1994	1678.60	0.88	HTMR	---
1995	1528.40	-0.62	---	LTMR
1996	1860.00	2.69	HTMR	---
1997	1667.80	0.77	HTMR	---
1998	2003.70	4.13	HTMR	---
1999	1584.50	-0.06	---	LTMR
2000	1521.30	-0.69	---	LTMR
2001	1448.10	-1.42	---	LTMR
2002	1155.20	-4.35	---	LTMR
2003	1439.20	-1.51	---	LTMR
2004	1248.00	-3.43	---	LTMR
2005	1375.60	-2.15	---	LTMR
2006	1375.60	-2.15	---	LTMR
2007	1297.60	-2.93	---	LTMR
2008	1720.20	1.30	HTMR	---
2009	1144.50	-4.46	---	LTMR
2010	2551.30	9.61	HTMR	---
2011	1701.20	1.11	HTMR	---
2012	1469.10	-1.21	---	LTMR
2013	2349.80	7.59	HTMR	---
2014	1403.40	-1.87	---	LTMR
2015	1573.70	-0.17	---	LTMR
2016	1318.50	-2.72	---	LTMR
2017	1538.90	-0.52	---	LTMR
2018	1778.90	1.88	HTMR	---
2019	1689.30	0.99	HTMR	---
		Total	**12**	**19**

Table 4a: Classification of years based on SIAP values observed at Almora district (1989-2019).

Year	Annual rainfall (mm)	SIAP value	Extremely Wet (EW)	Wet (W)	Normal (N)	Dry (D)	Extremely Dry (ED)
1989	758.00	-0.54	---	---	---	D	---
1990	1059.80	1.01	EW	---	---	---	---
1991	602.20	-1.35	---	---	---	---	ED
1992	603.70	-1.34	---	---	---	---	ED
1993	1210.20	1.79	EW	---	---	---	---
1994	680.90	-0.94	---	---	---	---	ED
1995	934.80	0.37	---	---	N	---	---
1996	718.40	-0.75	---	---	---	D	---
1997	935.00	0.37	---	---	N	---	---
1998	1284.00	2.17	EW	---	---	---	---
1999	663.00	-1.03	---	---	---	---	ED
2000	811.40	-0.27	---	---	N	---	---
2001	590.00	-1.41	---	---	---	---	ED
2002	773.20	-0.47	---	---	N	---	---
2003	1166.00	1.56	EW	---	---	---	---
2004	961.40	0.50	---	---	N	---	---
2005	877.40	0.07	---	---	N	---	---
2006	770.40	-0.48	---	---	N	---	---
2007	990.00	0.65	---	W	---	---	---
2008	772.00	-0.47	---	---	N	---	---
2009	698.00	-0.85	---	---	---	---	ED
2010	1270.51	2.10	EW	---	---	---	---
2011	828.20	-0.18	---	---	N	---	---
2012	682.90	-0.93	---	---	---	---	ED
2013	1036.61	0.89	EW	---	---	---	---
2014	1009.60	0.75	---	W	---	---	---
2015	667.48	-1.01	---	---	---	---	ED
2016	925.82	0.32	---	---	N	---	---
2017	946.20	0.43	---	---	N	---	---
2018	688.10	-0.91	---	---	---	---	ED
2019	856.40	-0.04	---	---	N	---	---
		Total	**6**	**2**	**12**	**2**	**9**

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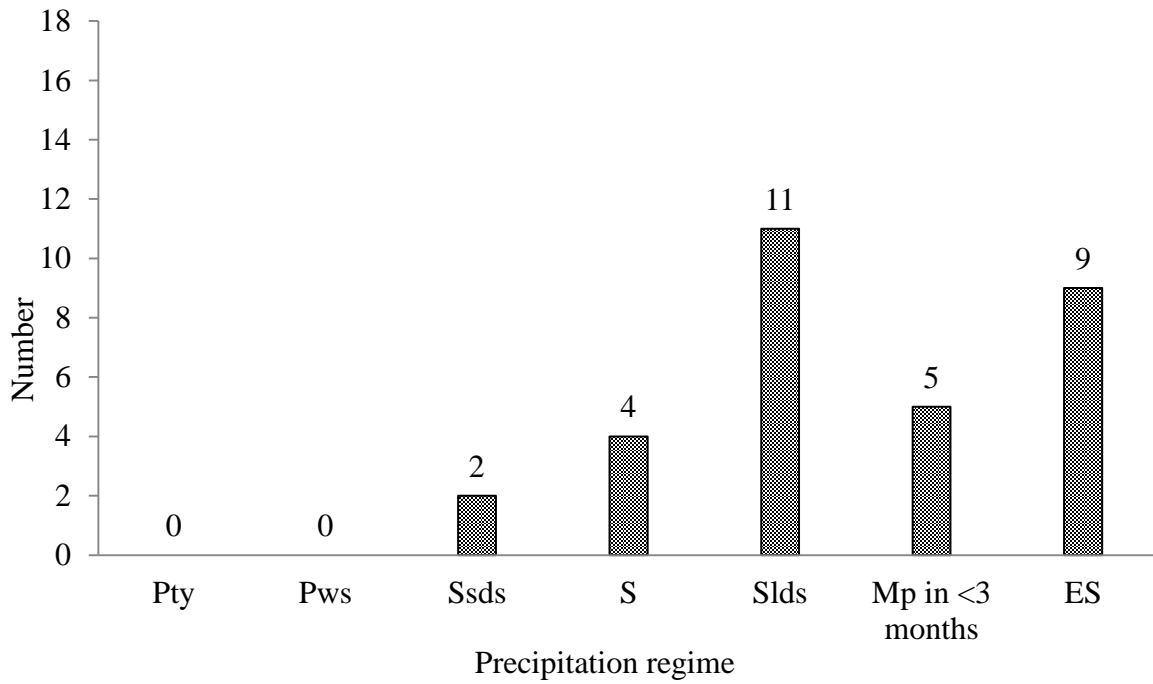*ISSN: 2395-3470*
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Table 4b: Classification of years based on SIAP values observed at Dehradun district (1989-2019).

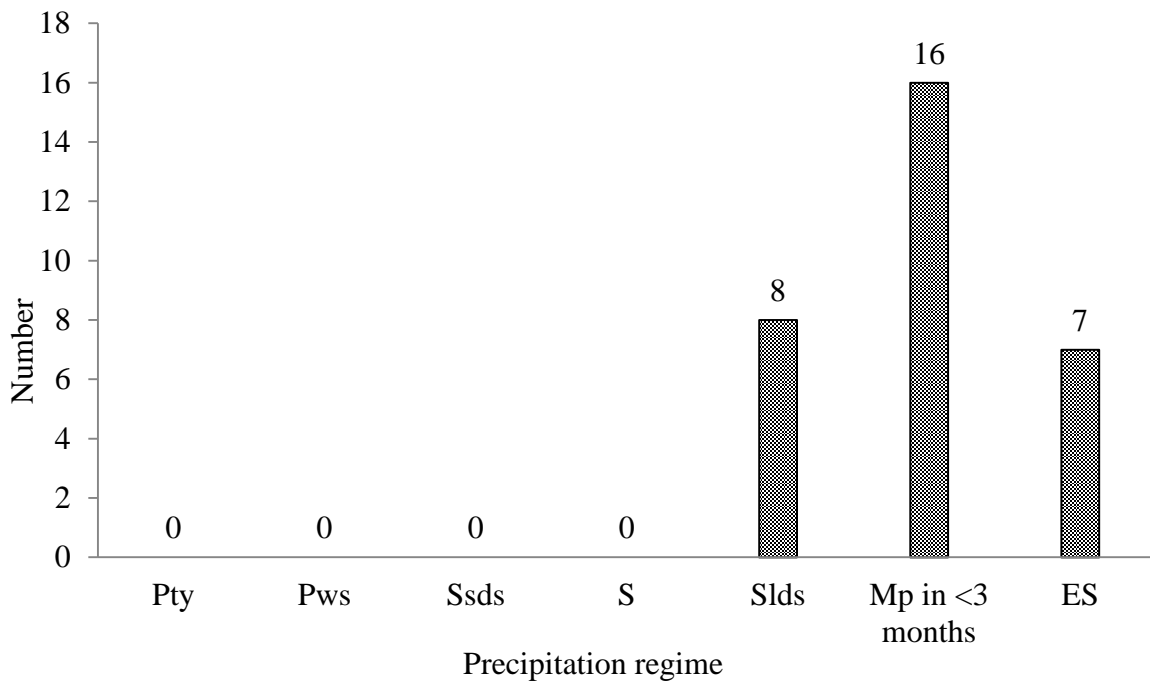| Year	Annual rainfall (mm)	SIAP value	Extremely Wet (EW)	Wet (W)	Normal (N)	Dry (D)	Extremely Dry (ED)
1989	1803.50	0.65	---	W	---	---	---
1990	2086.60	1.53	EW	---	---	---	---
1991	1163.50	-1.31	---	---	---	---	ED
1992	1258.30	-1.02	---	---	---	---	ED
1993	1572.20	-0.06	---	---	N	---	---
1994	1678.60	0.27	---	---	N	---	---
1995	1528.40	-0.19	---	---	N	---	---
1996	1860.00	0.83	---	W	---	---	---
1997	1667.80	0.24	---	---	N	---	---
1998	2003.70	1.27	EW	---	---	---	---
1999	1584.50	-0.02	---	---	N	---	---
2000	1521.30	-0.21	---	---	N	---	---
2001	1448.10	-0.44	---	---	N	---	---
2002	1155.20	-1.34	---	---	---	---	ED
2003	1439.20	-0.47	---	---	N	---	---
2004	1248.00	-1.05	---	---	---	---	ED
2005	1375.60	-0.66	---	---	---	D	---
2006	1375.60	-0.66	---	---	---	D	---
2007	1297.60	-0.90	---	---	---	---	ED
2008	1720.20	0.40	---	---	N	---	---
2009	1144.50	-1.37	---	---	---	---	ED
2010	2551.30	2.95	EW	---	---	---	---
2011	1701.20	0.34	---	---	N	---	---
2012	1469.10	-0.37	---	---	N	---	---
2013	2349.80	2.33	EW	---	---	---	---
2014	1403.40	-0.58	---	---	---	D	---
2015	1573.70	-0.05	---	---	N	---	---
2016	1318.50	-0.84	---	---	---	D	---
2017	1538.90	-0.16	---	---	N	---	---
2018	1778.90	0.58	---	W	---	---	---
2019	1689.30	0.30	---	---	N	---	---
		Total	**4**	**3**	**14**	**4**	**6**

Table 5: **Classification of years based on Rainfall Anomaly Index (RAI) values observed at Almora and Dehradun districts (1989-2019).**

Year	Annual rainfall (mm)	RAI value	Wet or Dry year	Year	Annual rainfall (mm)	RAI value	Wet or Dry year
	Almora district				Dehradun district		
1989	758.00	-1.38	Dry	1989	1803.50	1.76	Wet
1990	1059.80	2.56	Wet	1990	2086.60	4.09	Wet
1991	602.20	-3.41	Dry	1991	1163.50	-3.52	Dry
1992	603.70	-3.39	Dry	1992	1258.30	-2.74	Dry
1993	1210.20	4.52	Wet	1993	1572.20	-0.15	Dry
1994	680.90	-2.38	Dry	1994	1678.60	0.73	Wet
1995	934.80	0.93	Wet	1995	1528.40	-0.51	Dry
1996	718.40	-1.90	Dry	1996	1860.00	2.22	Wet
1997	935.00	0.93	Wet	1997	1667.80	0.64	Wet
1998	1284.00	5.49	Wet	1998	2003.70	3.41	Wet
1999	663.00	-2.62	Dry	1999	1584.50	-0.05	Dry
2000	811.40	-0.68	Dry	2000	1521.30	-0.57	Dry
2001	590.00	-3.57	Dry	2001	1448.10	-1.17	Dry
2002	773.20	-1.18	Dry	2002	1155.20	-3.59	Dry
2003	1166.00	3.95	Wet	2003	1439.20	-1.25	Dry
2004	961.40	1.28	Wet	2004	1248.00	-2.82	Dry
2005	877.40	0.18	Wet	2005	1375.60	-1.77	Dry
2006	770.40	-1.22	Dry	2006	1375.60	-1.77	Dry
2007	990.00	1.65	Wet	2007	1297.60	-2.41	Dry
2008	772.00	-1.20	Dry	2008	1720.20	1.07	Wet
2009	698.00	-2.16	Dry	2009	1144.50	-3.68	Dry
2010	1270.51	5.31	Wet	2010	2551.30	7.92	Wet
2011	828.20	-0.46	Dry	2011	1701.20	0.91	Wet
2012	682.90	-2.36	Dry	2012	1469.10	-1.00	Dry
2013	1036.61	2.26	Wet	2013	2349.80	6.26	Wet
2014	1009.60	1.91	Wet	2014	1403.40	-1.54	Dry
2015	667.48	-2.56	Dry	2015	1573.70	-0.14	Dry
2016	925.82	0.81	Wet	2016	1318.50	-2.24	Dry
2017	946.20	1.08	Wet	2017	1538.90	-0.43	Dry
2018	688.10	-2.29	Dry	2018	1778.90	1.55	Wet
2019	856.40	-0.09	Dry	2019	1689.30	0.81	Wet

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Fig. 1a: Monthly rainfall seasonality at Almora (1989-2019).

Fig. 1b: Monthly rainfall seasonality at Dehradun (1989-2019).