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Hydro-meteorological investigation in Rispana river catchment, Uttarakhand, India

Sourabh Das, Rajesh Singh and VK Pandey

Abstract
The present study was carried out at Rispana River milli watershed located in Uttarakhand state. The Rispana river which is a tributaries of Ganga, flows from Mussoorie and passes through Dehradun. Rispana river catchment in different aspects of hydro-meteorological investigation, which include estimation of long-term annual and seasonal rainfall departure, probability distribution analysis of annual and seasonal rainfall, analysis of annual and analysis of seasonal meteorological drought years for the period of 1985 to 2018. The average annual, seasonal (Jun-Sep), and non-seasonal (Oct-May) rainfall of study area was found to be 2169.1 mm, 1877.6 mm and 291.5 mm respectively. It was also found that the highest annual rainfall deficiency in drought year was -25% (in 1988), -27% (in 1991), -28% (in 2002),-25% (in 2009) and -30% (in 2016). In case of seasonal rainfall, the highest rainfall deficiency in drought year was -30% (in 1986), -29% (in 1991), -36% (in 2002), -31% (in 2009), -27% (in 2016) and -25% (in 2017).The Rainfall departure indicated that the highest annual rainfall year was 37% (in1990), 25% (in 1997), 36% (in 1998), 50% (in 2010) and 51% (in 2013). In case of seasonal rainfall (Jun- September) highest rainfall deficiency year was 30% (in 1990), 28% (in 1999), 26% (in 2007), 63% (in 2010), 29% (in 2011) and 53% (in 2013).

Keywords: Hydro-meteorological, rainfall, annual and seasonal, rainfall departure, probability

Introduction
The watershed management programs for accurate measurement of parameters involved in hydrological and environmental processes has rapidly grown due to the acceleration in the watershed management programs for the conservation, development and evaluation of non-point source pollution pertaining to soil and water resources (Shukla *et al* 2009). The two most important variable in the climate science and hydrology are precipitation and air temperature. These two parameters plays an important role in the rainfall-runoff relationships, and influences flood/drought assessment as well as mitigation measures. Temperature plays an important role in evaporation, transpiration, and water demand (both animal and human), and thus significantly affects both water requirements and strategies to assure its availability (Chattopadhyay and Edwards 2016) [4].
The Rispana River has always played an important role in the development of Mussorie and Dehradun and is a vital part of the heritage of Dehradun & Mussorie. River flows starting from Mussoorie and passing through Dehradun. Suswa River are main tributaries of the Ganga in Dehradun district. It may be a seasonal river.

Materials and Methods
Rispana is a one of the important river in Dehradun city. The River is situated between latitude 30^0 29' 15" N and longitude to 78^0 06' 98" E used in Toposheets Nos. 53-J3, 53-J4 used map which provides information all topographical features. Total catchment area and Drainage length of Rispana river basin is 58.09 km^2 and 130.19 km with elevations ranging from 2249 to 565 m. Its Rispana river basin main stream top to bottom total length is 12.547 km. This region generally has a May-June is the hottest month with mean daily maximum temperature in the order of about 34-37 ^{0}C and the minimum of about 18-23 ^{0}C. December is the coldest month of the year with mean daily maximum and minimum temperatures of 22 ^{0}C and 4.6 ^{0}C respectively. The Rispana River is a milli-watershed receives average annual rainfall of 2169.1 mm and seasonal (Monsoon) june-september rainfall is 1877.6 mm. The topographical characteristics of the study area has been analysed using Digita Elevation Model (DEM). The analysis revealed that Rispana river has highest elevation of 2249 m and lowest elevation of 565 m and it is characterised as gently undulating and flat terrain. The Digital

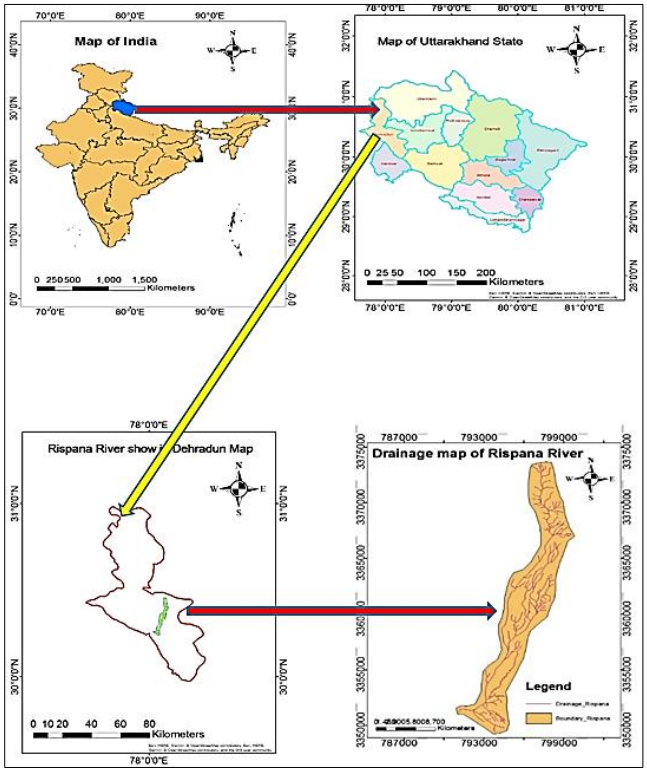

Fig 1: Drainage map with location of the study area

Meteorological data

The meteorological data such as rainfall (mm/day), temperature (°C), sunshine hours (hrs/day), evaporation (mm/day), wind velocity (kmph) and relative humidity (%), no of rainy day for the period from 1985 to 2018 was collected from Indian Meteorological division, Dehradun, Uttarakhand.

Analysis of data

Analysis includes arrangement of raw data in systematic manner according to need for the study. Systematically arranged data was considered for the further processing. Processed data were used to analyses the relationship between different Parameters on weekly, monthly, seasonally and annual basis. Relationship of different parameters were compared graphically and interpretation has been done.

Assessment of meteorological drought

According to WMO (1975) meteorological drought is characterized by the water shortage induced by the imbalance between precipitation and evaporation, in particular, water shortage based solely on precipitation e.g. rainless situation. Meteorological drought over an area is defined as a situation when seasonal rainfall over the area is less than 70%, 75%, 80%, 90% of its long term normal. It is further classified as "moderate drought" if the rainfall deficit is between 25% and 50% and "severe drought" when it exceeds 50%.

Computation of rainfall departure (Annual and Seasonal)

The computation of rainfall departure was carried out using annual, seasonal and monthly rainfall data. This computation was carried out for the assessment of frequency and severity of past drought events in the region. According to the India Meteorological Department (IMD) an area/region is considered to be drought affected if it receives seasonal total rainfall less than 75% of its normal value (Appa Rao, 1986) [1]. A simple approach to mark out good or bad monsoon year has been suggested by Banerjee and Raman (1976) [2-3]. They considered a year to be a bad monsoon year if in more than two-third number of meteorological stations the seasonal rainfall is inadequate. For our calculation purpose a year/season is considered as drought year/season if the total amount of annual rainfall over an area is deficient by more than 25%.

The mean annual rainfall at a given raingauge station was obtained as the arithmetic average of annual rainfall values over the period of record. The annual rainfall departures were computed as the deviation of the rainfall from mean divided by mean rainfall for the station (Equation 1). The year having annual departure value equal to –25% or less is considered as a drought year. The sum of rainfall from June to October month has been taken as the seasonal rainfall. Similarly, seasonal rainfall departures were also estimated (Equation 2).

ADRi = Type equation here.

$$ADRi = \frac{ARi-AR}{AR} \quad (1)$$

Where,

ADRi = Annual rainfall departure in i^{th} year.
ARi = Annual rainfall of ith year.
AR = Average annual rainfall.

$$SDRi = \frac{SRi-SMR}{SMR} \quad (2)$$

Where,

SDRi = Seasonal rainfall departure in i^{th} year.
SRi = Rainfall record in i^{th} year, i = 1, 2… n.
SMR = Seasonal mean rainfall.

Calculating annual and seasonal departure of rainfall gives indicative delineation of wet and dry year/ season for the respective observation station.

Probability distribution of annual and seasonal rainfall

Probability distribution of annual and seasonal rainfall is important to predict the relative frequency of occurrence of a given amount of annual and seasonal rainfall with reasonable accuracy. For calculating probability distribution of rainfall, the annual and seasonal rainfall values of each station were arranged in descending order and were ranked according to order of occurrence and their probability distribution were calculated using Weibull"s plotting position formula as shown in Equation (3).

$$Pi = \frac{Ri}{(n+1)} \quad (3)$$

Where,

Pi = Probability of exceedance of annual and seasonal rainfall in i^{th} year.
Ri = Rank of descending order of rainfall values in i^{th} year.
n = Total number of observation.
i =1, 2, 3… n

The plots of annual and seasonal probability distribution were prepared between the probability of exceedance and the corresponding rainfall value. Rainfall at 75% dependability level was obtained from graph. The percentage probability of occurrence of 75% of mean annual rainfall and mean seasonal rainfall has been worked out to evaluate the drought proneness of the study area. An area is considered to be drought prone if the probability of occurrence of 75% of normal rainfall is less than 80%. (Ramakrishna, 1986).

Results and Discussion

Hydro-meteorological investigation in rispana river catchment

Rainfall departure

The rainfall data for IMD station Dehradun in the study was analyzed for the period of (1985-2018) 34 year. The monthly rainfall data (1985-2018), annual, seasonal and non-seasonal rainfall data of station Dehradun given in Table 1. The monthly average rainfall data are annual 2169.1 mm, seasonal 1877.6 mm (Jun-Sep) and non-seasonal 291.5 mm (Oct-May) respectively. The monthly rainfall departure analysis indicates that the highest annual rainfall deficinency in drought year -25% (in 1988),-27% (in 1991), -28% (in 2002),-25% (in 2009) and -30% (in 2016), total five year drought year a annual rainfall out-off 34 year.in case of seasonal rainfall (Jun- September) highest rainfall deficinency in drought year -30% (in 1986), -29% (in 1991), -36% (in 2002), -31% (in 2009),-27% (in 2016) and -25% (in 2017) total six year drought a seasonal rainfall out-off 34 year.

The plot of annual and seasonal departure of Rispana River Dehradun station in Fig. 2(a) and 2(b). The estimation of average of annual and seasonal rainfall and percentage of departure and drought year occurred in the gauging station are also given in respective columns in Table 2 and 3. The monthly Rainfall departure analysis indicates that the highest annual rainfall year 37% (in 1990),25% (in 1997), 36% (in 1998), 50% (in 2010) and 51% (in 2013), total five year highest annual rainfall out-off 34 year.in case of seasonal rainfall (Jun- September) highest rainfall deficinency year 29% (in 1990), 28% (in 1999), 26% (in 2007), 63% (in 2010), 29% (in 2011) and 53% (in 2013) total six year highest seasonal rainfall out-off 34 year.

Table 1: Detail of meteorological annual, seasonal and non seasonal data

Year ↓	Rainfall (mm)														
Month →	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Rainfall	Seasonal Jun -Sep Rainfall	Non Seasonal Oct -May Rainfall
1985	69.4	5.2	4.5	27.0	19.0	43.0	578.3	622.0	283.8	124.6	0.0	68.5	1845.3	1527.1	318.2
1986	11.3	90.4	46.2	32.0	19.0	213.0	386.2	519.0	188.5	147.0	7.5	38.0	1698.1	1306.7	391.4
1987	25.0	26.0	11.0	6.0	92.0	257.5	557.5	577.0	491.0	18.0	0.0	13.0	2074.0	1883.0	191.0
1988	31.0	0.0	108.0	8.0	14.0	223.0	388.0	618.0	240.0	0.0	0.0	6.0	1636.0	1469.0	167.0
1989	106.0	0.0	0.0	0.0	12.0	85.0	627.0	646.5	203.0	0.0	0.0	0.0	1679.5	1561.5	118.0
1990	1.2	121.2	98.2	35.1	114.4	183.8	903.4	887.1	460.7	33.6	7.2	121.9	2967.8	2435.0	532.8
1991	11.6	56.0	50.6	54.1	21.2	265.2	306.3	481.5	288.1	0.0	11.7	43.9	1590.2	1341.1	249.1
1992	81.6	40.5	13.5	1.8	26.3	156.1	571.1	980.0	191.0	0.0	6.8	0.0	2068.7	1898.2	170.5
1993	77.1	63.1	112.2	11.2	40.0	269.3	534.4	744.7	459.0	0.0	1.4	0.0	2312.4	2007.4	305.0
1994	57.2	56.9	1.9	78.2	9.4	217.7	724.2	776.9	65.0	0.0	0.0	2.2	1989.6	1783.8	205.8
1995	53.0	73.9	39.2	14.6	0.8	83.5	494.5	630.1	310.3	2.2	0.5	9.3	1711.9	1518.4	193.5
1996	40.3	106.2	45.5	13.4	10.0	355.8	604.0	962.1	282.3	57.7	0.0	0.0	2477.3	2204.2	273.1
1997	34.0	21.9	65.4	111.1	130.0	397.4	779.6	564.5	385.8	94.5	44.8	90.8	2719.8	2127.3	592.5
1998	5.4	72.4	117.7	78.6	86.3	110.4	835.8	1114.2	270.2	248.0	0.9	0.0	2939.9	2330.6	609.3
1999	57.3	4.2	4.9	0.0	6.9	398.4	795.3	535.9	671.3	75.8	0.0	9.9	2559.9	2400.9	159.0
2000	71.5	110.9	44.4	12.4	141.1	308.6	767.8	724.7	381.2	0.2	0.0	0.0	2562.8	2182.3	380.5
2001	42.0	2.2	30.8	52.1	130.5	505.4	803.4	613.2	134.2	2.9	1.4	9.4	2327.5	2056.2	271.3
2002	47.1	139.1	65.7	62.6	24.1	126.4	164.8	643.7	273.5	17.9	0.0	0.2	1565.1	1208.4	356.7
2003	38.6	98.9	49.6	13.8	31.2	138.5	515.7	601.3	436.1	0.0	6.6	21.8	1952.1	1691.6	260.5
2004	94.6	21.8	0.0	21.4	99.8	359.3	694.8	517.3	147.4	62.7	0.0	7.7	2026.8	1718.8	308.0
2005	62.4	82.1	61.6	0.3	22.5	98.7	767.7	655.5	412.6	5.2	0.0	0.6	2169.2	1934.5	234.7
2006	18.3	2.4	138.5	14.8	165.2	139.3	640.2	482.6	196.4	16.8	1.7	25.2	1841.4	1458.5	382.9
2007	0.4	110.0	98.0	15.9	22.9	78.0	896.0	1089.3	303.7	10.9	0.0	5.9	2631.0	2367.0	264.0
2008	13.1	21.8	2.6	76.1	51.8	593.8	773.8	711.9	161.0	40.8	10.5	0.0	2457.2	2240.5	216.7
2009	5.2	39.7	7.3	25.1	72.7	125.5	437.4	453.9	287.2	168.7	2.0	0.0	1624.7	1304.0	320.7
2010	14.5	60.2	2.0	3.4	33.6	134.0	955.8	1017.0	951.0	15.4	25.5	41.1	3253.5	3057.8	195.7
2011	15.0	46.6	13.8	30.5	113.2	386.5	788.7	878.9	371.6	37.4	15.0	6.3	2703.5	2425.7	277.8
2012	46.3	13.7	25.0	37.5	1.6	81.0	598.0	1025.6	439.6	2.1	5.8	18.9	2295.1	2144.2	150.9
2013	119.2	190.5	17.3	3.1	16.0	1094.8	707.2	806.2	257.0	34.2	13.7	6.0	3265.2	2865.2	400.0
2014	104.4	125.8	74.9	30.3	31.5	100.4	490.5	727.7	120.8	106.1	0.0	32.0	1944.4	1439.4	505.0
2015	29.0	23.0	181.4	60.9	10.7	144.9	566.0	654.2	78.0	27.3	3.5	8.8	1787.7	1443.1	344.6
2016	0.0	22.2	32.0	7.8	45.3	187.4	544.9	412.9	222.6	45.9	0.0	0.0	1521.0	1367.8	153.2
2017	42.7	9.4	19.2	52.2	116.2	456.5	543.5	404.4	0.0	0.2	0.2	19.3	1663.8	1404.4	259.4
2018	22.9	16.3	16.6	34.4	34.5	187.7	654.1	622.4	269.9	6.9	17.0	3.5	1886.2	1734.1	152.1
AVERAGE													2169.1	1877.6	291.5

Table 2: Detail of meteorological annual, seasonal rainfall, percentage of departure, of gauging station.

Year	Annual rainfall (mm)	% of DEP	Seasonal (Jun -Sep) Rainfall (mm)	% of DEP
1985	1845.3	-15	1527.1	-19
1986	1698.1	-22	1306.7	-30
1987	2074.0	-4	1883.0	0
1988	1636.0	-25	1469.0	-22
1989	1679.5	-23	1561.5	-17

1990	2967.8	37	2435.0	30
1991	1590.2	-27	1341.1	-29
1992	2068.7	-5	1898.2	1
1993	2312.4	7	2007.4	7
1994	1989.6	-8	1783.8	-5
1995	1711.9	-21	1518.4	-19
1996	2477.3	14	2204.2	17
1997	2719.8	25	2127.3	13
1998	2939.9	36	2330.6	24
1999	2559.9	18	2400.9	28
2000	2562.8	18	2182.3	16
2001	2327.5	7	2056.2	10
2002	1565.1	-28	1208.4	-36
2003	1952.1	-10	1691.6	-10
2004	2026.8	-7	1718.8	-8
2005	2169.2	0	1934.5	3
2006	1841.4	-15	1458.5	-22
2007	2631.0	21	2367.0	26
2008	2457.2	13	2240.5	19
2009	1624.7	-25	1304.0	-31
2010	3253.5	50	3057.8	63
2011	2703.5	25	2425.7	29
2012	2295.1	6	2144.2	14
2013	3265.2	51	2865.2	53
2014	1944.4	-10	1439.4	-23
2015	1787.7	-18	1443.1	-23
2016	1521.0	-30	1367.8	-27
2017	1663.8	-23	1404.4	-25
2018	1886.2	-13	1734.1	-8
Average →	2169.1		1877.6	

Table 3: Detail of meteorological annual and seasonal drought year occurred in the gauging station

Station IMD, Dehradun Annual Rainfall	**Mean Rainfall (mm) ↓**	**Annual Drought year (%)**					
	year →	1998	1991	2002	2009	2016	
	2169.1	-25	-27	-28	-25	-30	
Station IMD, Dehradun Seasonal Rainfall	Mean Rainfall (mm) ↓	Seasonal (Jun-Sep) Drought Year (%)					
	year →	1986	1991	2002	2009	2016	2017
	1877.6	-30	-29	-36	-31	-27	-25

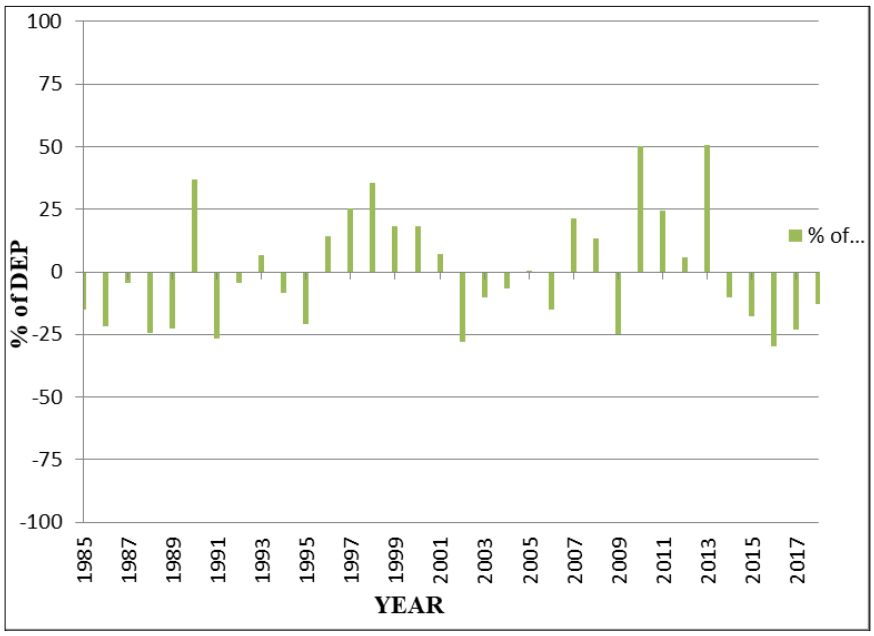

Fig 2(a): Percentage of annual departure from 1985- 2018 at IMD Dehradun Station of Rispana River

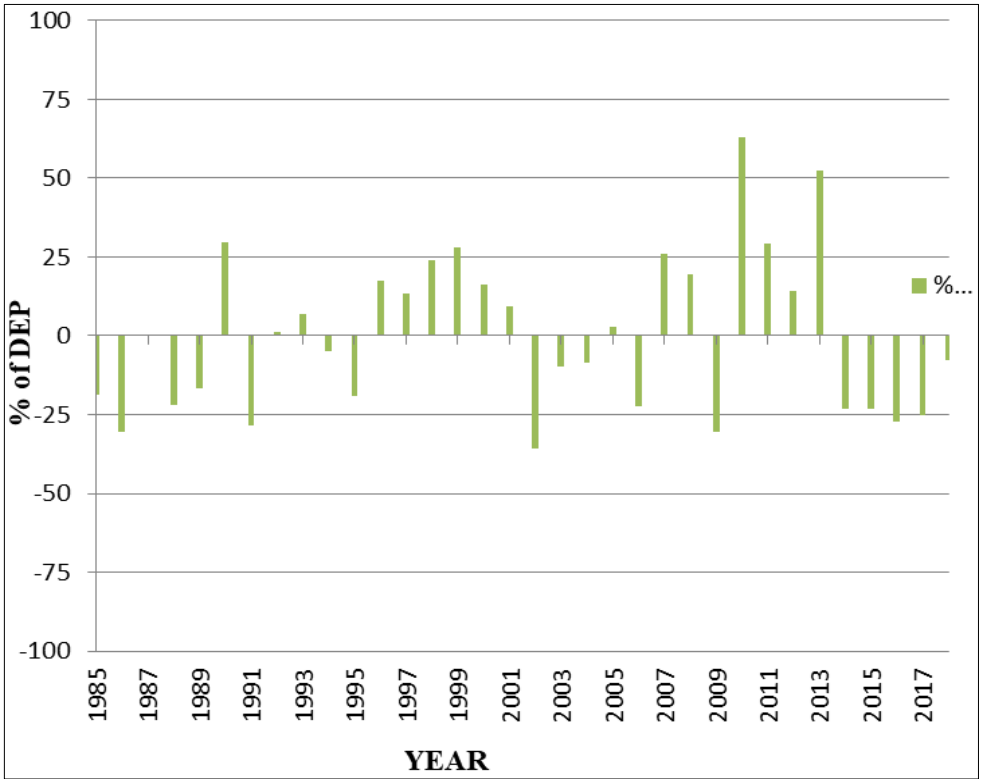

Fig 2(b): Percentage of seasonal (Jun-Sep) departure from 1985- 2018 at IMD Dehradun station of Rispana River

Probability distribution of rainfall

The probability distribution curves have been drawn by plotting the values of annual and seasonal rainfall against the probability of exceedance. Annual and seasonal rainfall at 70%, 75%, 80% and 90% probability level and probability of occurrence of rainfall equivalent to 70%, 75%, 80% and 90% of mean are shown in th "+e Table 4.3(a), 4.3(b) for the IMD station Dehradun (1985-2018) in Rispana river. It is show that the table that there is the mean annual rainfall value is 2169.1 mm, percentage of mean annual rainfall are 70% is 1518.4 mm, 75% is 1626.83 mm, 80% is 1735 mm and 90% is 1952.2 mm. The probability of occurrence of mean annual rainfall are 70% rainfall is 97.1% of probability, 75% is 88.6% of probability, 80% rainfall is 74.3% of probability and 90% is 57.1% of probability. And again the mean seasonal rainfall value is 1877.6 mm, percentage of mean annual rainfall 70% is 1314.3 mm, 75% is 1408.2 mm, 80% is 1502.1 mm and 90% is 1689.8 mm. The probability of occurrence of mean seasonal rainfall are 70% rainfall is 91.4% of probability, 75% is 82.9% of probability, 80% rainfall is 68.6% of probability and 90% is 60% of probability. The probability of occurrence of annual and seasonal rainfall at dehradun IMD stations at 70%,75%,80% and 90% dependability level are shown in Table 4(a) and Table 4(b), respectively. Plots of annual and seasonal probability distribution for Rispana river IMD station (1985-2018) Dehradun are shown in Fig 3(a) and 3(b).

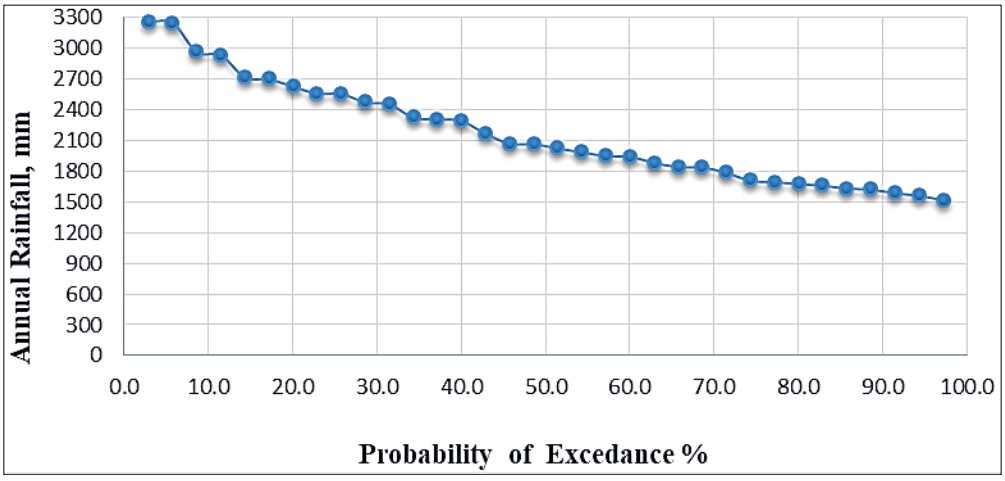

Fig 3(a): Probability of occurrence of annual rainfall Dehradun IMD station from year 1985-2018.

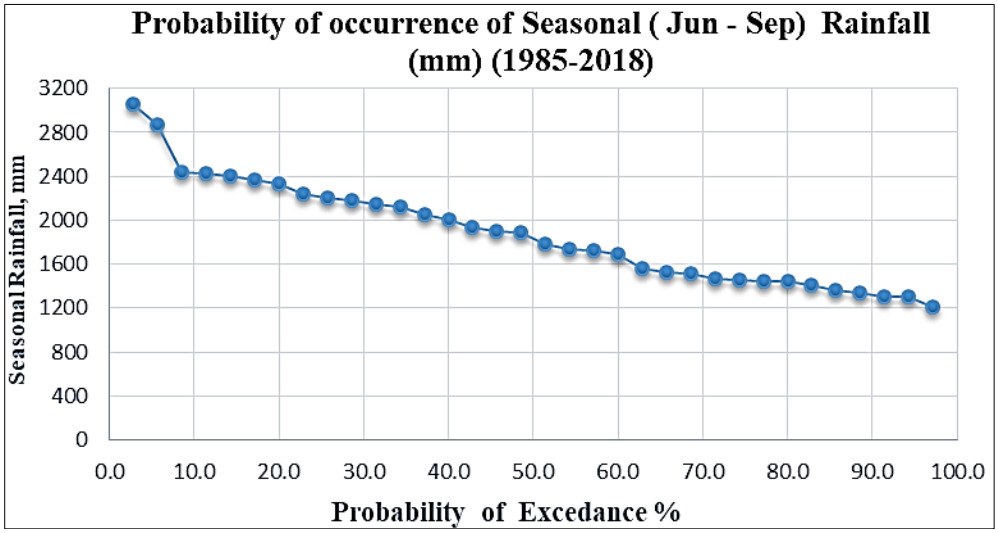

Fig 3(b): Probability of occurrence of seasonal rainfall Dehradun IMD station from Year 1985-2018

Table 4(a): Probability distribution of mean annual rainfall

Station	Mean Annual Rainfall (mm)	% of mean Annual Rainfall				Prob. of occurrence of mean Annual RF%				Dependability Rainfall (mm)			
IMD, Dehradun		70	75	80	90	70	75	80	90	70	75	80	90
1	2169.1	1518.4	1626.83	1735	1952.2	97.1	88.6	74.3	57.1	1815.1	1708.5	1679.5	1607.8

Table 4(b): Probability distribution of mean seasonal rainfall

Station	Mean Seasonal Rainfall (mm)	% of mean Seasonal Rainfall				Prob. of occurrence of mean Seasonal RF%				Dependability Rainfall (mm)			
IMD, Dehradun		70	75	80	90	70	75	80	90	70	75	80	90
1	1877.6	1314.3	1408.2	1502.1	1689.8	91.4	82.9	68.6	60	1494.2	1454.7	1439.4	1324.2

Conclusions

Based on the study following conclusions can be drawn-

1. The hydro-meteorological investigation, of study area include estimation of long-term seasonal and annual rainfall departure, probability distribution analysis of seasonal and annual rainfall, to analysis of seasonal and annual meteorological drought year for the period of 1985 to 2018. Out of 34 year, five year found to be annual hydro-metrological drought and six years as seasonally hydro-metrological drought.
2. The average annual, seasonal (Jun-Sep), and non-seasonal (Oct-May) rainfall of study area was found to be 2169.1 mm, 1877.6 mm and 291.5 mm respectively. It was also found that the highest annual rainfall deficiency in drought year was -25% (in 1988), -27% (in 1991), -28% (in 2002),-25% (in 2009) and -30% (in 2016). In case of seasonal rainfall, the highest rainfall deficiency in drought year was -30% (in 1986), -29% (in 1991), -36% (in 2002), -31% (in 2009), -27% (in 2016) and -25% (in 2017).
3. The Rainfall departure indicated that the highest annual rainfall year was 37% (in 1990), 25% (in 1997), 36% (in 1998), 50% (in 2010) and 51% (in 2013). In case of seasonal rainfall (Jun- September) highest rainfall deficiency year was 30% (in 1990), 28% (in 1999), 26% (in 2007), 63% (in 2010), 29% (in 2011) and 53% (in 2013).

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