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Rainfall variability and probability analysis in Tarai and mid Himalayan regions of Uttarakhand

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सार – वर्षा विश्लेषण किसी भी क्षेत्र में बदलते परिवेश में उचित फसल नियोजन के लिए सहायक होता है। इसलिए इस अध्ययन में उपलब्धता के अनुसार दीर्घकालिक वर्षा के आंकड़ों, यानी 1981-2020 (तराई क्षेत्र) के 40 वर्ष और 1985-2020 (मध्य हिमालयी क्षेत्र) के 36 वर्षों का विश्लेषण करने का प्रयास किया गया है और उगाई जाने वाली फसल के प्रकार, बुवाई का समय, सिंचाई समय-सारिणी आदि के आधार पर तुलना की जा रही है। मार्कोव चेन मॉडल का उपयोग करके विभिन्न स्तरों, यानी >5 मिमी, >10 मिमी, >20 मिमी, >30 मिमी, >40 मिमी और >50 मिमी पर साप्ताहिक आधार पर वर्षा की प्रारंभिक और सशर्त संभावना का विश्लेषण किया गया। इसके अलावा, विभिन्न संभाव्यता स्तरों यानी 10, 25, 50, 75 और 90 प्रतिशत पर वर्षा की घटनाओं की घटना का पता लगाने के लिए अपूर्ण गामा वितरण का भी उपयोग किया गया।

परिणामों से पता चला कि यद्यपि तराई क्षेत्र में वर्षा की मात्रा मध्य हिमालयी क्षेत्र की तुलना में अधिक है, लेकिन उनमें से अधिकांश केवल दक्षिण-पश्चिम मानसून के मौसम तक ही सीमित है। मध्य हिमालयी क्षेत्र में फसलें पूरे वर्ष आसानी से उगाई जा सकती हैं क्योंकि मानसून के बाद के मौसम को छोड़कर सभी मौसमों में वर्षा का एक समान वितरण होता है और हल्की/मध्यम/गंभीर सूखे की स्थिति में फसलों को उगाने के लिए केवल उपलब्ध प्राकृतिक झरनों/बारहमासी धाराओं/जल संकट वाले सप्ताहों के दौरान अपवाह जल से ही जीवन रक्षक सिंचाई की व्यवस्था की जाती है। दूसरी ओर, तराई क्षेत्र में उत्पादक उपज प्राप्त करने के लिए दक्षिण-पश्चिम मानसून के मौसम को छोड़कर सभी मौसमों के दौरान उचित सिंचाई सुविधाएँ सुनिश्चित की जानी चाहिए।

ABSTRACT. The rainfall analysis is helpful for proper crop planning under changing environment in any region. Therefore in this study an attempt has been made to analyze long term rainfall data, *i.e.*, 40 years from 1981-2020 (Tarai region) and 36 years from 1985-2020 (mid Himalayan region) as per availability and comparison is being done on the type of crop to be grown, sowing time, irrigation scheduling etc. The initial and conditional probability of rainfall on weekly basis was analyzed at different levels, *i.e.*, >5mm, >10mm, >20mm, >30mm, >40mm and >50mm using Markov chain model. In addition to this, incomplete gamma distribution was also used to find out the occurrence of rainfall events at different probability levels, *i.e.*, 10, 25, 50, 75 & 90 per cent.

The results revealed that though the amount of rainfall in the Tarai region is higher when compared with mid Himalayan region but most of them is limited to southwest monsoon season only. The crops can be raised easily throughout the year in the mid Himalayan region because of uniform distribution of rainfall in all the seasons except in the post monsoon season year and by arranging lifesaving irrigation to growing crops during light/moderate/severe dry spells conditions only from available natural springs/perennial streams/harvesting run off water during the water stress weeks. On the other hand, in the Tarai region proper irrigation facilities must be ensured during all the seasons except in the southwest monsoon season in order to have productive yield.

Key words – Markov chain, Gamma distribution, Rainfall probability, Dry spells.

1. Introduction

Rain is usually seen as a benefit to crops and fields, but there is an "ideal" amount of rainfall in any given growing season for most crops. If the average rainfall is much lower or higher than the ideal, it can lead to significant problems, from drowned crops to lower yields (Dugal *et al*., 2022). Knowing when to water, as well as how much to water, required skill and experience by the farmers. Too much watering could drown the crops, especially if there has been rainfall. However, a combination of not enough watering and no rainfall could also lead to dying of the crops. Soil is also greatly affected by rainfall. If it is too wet or too dry, nutrients in the soil can run off and not make it to the plants' roots, leading to poor growth and overall health. Additionally, as mentioned previously, overwatering or too much rain can also lead to bacteria, fungus, and mold growth in the soil.

Rainfall is essential to crop health, as it provides the water and nutrients needed for the growth and development of plants. When rain is plentiful, crops can absorb the water and nutrients they need, and the soil around them remains moist and fertile (Mahadevaswamy *et al*., 2016). This allows the plants to grow and produce large, healthy yields. Therefore, its amount, time of occurrence and spatial variability controls the agricultural practices adopted in the region. Occurrence of continuous dry spell in monsoon season is a common phenomenon. Hence, the probability analysis of occurrence of initial wet and dry spells as well as conditional probabilities of wet followed by dry, dry followed by wet and dry followed by dry, may be utilized for minimizing risk factor due to weather in crop cultivation.

The *Tarai* is a lowland region in northern India and southern Nepal that lies south of the outer foothills of the Himalayas, the Shivalik Hills and north of the Indo-Gangetic Plain. Pantnagar is a town and the campus of Govind Ballabh Pant University of Agriculture & Technology, the state agricultural university of Uttarakhand. It is located in Udham Singh Nagar district at approximately 29.02°N latitude and 79.49°E longitude. The area falls under the sub-humid subtropical climate of the *Tarai* belt, located in the foothills of the Himalayas with the annual rainfall ranging between 1400-1500 mm. Ranichauri is a town and the campus of Veer Chandra Singh Garhwali Uttarakhand University of Horticulture & Forestry, formerly known as Uttarakhand University of Horticulture and Forestry. It is a state agricultural university located in Tehri Garhwal district, Uttarakhand, at approximately 30.31°N latitude and 78.41°E longitude (Fig. 1).

Rai *et al.* (2009) used Markov chain analysis to analyzerainfall variability and probability for crop planning at Madhepura in Bihar. Weekly rainfall variability and probability analysis for Solapur in respect of crop planning has been done by Pawar *et al.* (2015). Goyal *et al*. (2015) also performed Probability distributions for long term rainfall data in Ludhiana. Similarly Singh *et al.* (2009) also suggested the use of Incomplete Gamma distribution of rainfall for sustainable crop production strategies at Palampur, Himachal Pradesh. Similarly, Weekly rainfall variability and probability analysis for Coimbatore in respect of crop planning has been done by Manikandan *et al.* (2014). Similarly, Manikandan *et al.* (2017) also analyzed wet and dry spells for agricultural crop planning using Markov Chain Probability Model at Bhavanisagar. Analysis of rainfall using probability distribution for crop planning in Daspalla region of Odisha based on rainfall data for 16 years (1995-2010) has been done by Mandal *et al.* (2014). Hence, an attempt has been made to analyze the rainfall in the *Tarai* region and mid Himalayan region to forecast the sowing time of the crops, irrigation scheduling etc. in order to have profitable yield as well as to reduce yield loss due to water stress during critical stages of the crop.

2. Materials and methodology

The daily rainfall data were collected from the Agrometeorological observatory located at N. E. Borlaug Crop Research Centre, G B Pant Univ. of Ag. & Tech., Pantnagar (29.02°N & 79.48°E and altitude of 244 m) and VCSG Uttarakhand University of Horticulture & Forestry, Ranichauri (30.3°N latitude, 78.4°E longitude and altitude of 1864 meters) from 1981-2020 and 1985-2020 as per availability. The statistical analysis was carried out with the following parameters using MS EXCEL and Weather Cock software.

Weather Cock software is developed by AICRPAM Unit of CRIDA, Hyderabad for the agroclimatic analysis of an area. This particular software is based on Visual Basic (VB) and easy to operate even by beginners.

2.1. *Number of rainy days along with Coefficient of Variation*

The number of rainy day analysis gives an idea on rainy days in a week / month / season / annual. Information of rainy days of a place over a period of time determine the need and design both for rainwater harvesting and structure to recharge groundwater aquifers. With the help of number of rainy days planners may plan cropping pattern/cropping systems. Rainy day : A day with rainfall amount equal or more than 2.5 mm considered as a rainy day according to India Meteorological Department for Indian region. We have to give input as daily rainfall for the study period for both the regions.

2.2. *Initial and conditional probabilities by Markov Chain model*

Markov chain probability model has been found suitable to describe the long term frequency behaviour of wet or dry weather spells based on the rainfall data. Markov chain probability model assumes that the probability of rainfall occurring on any week depends on whether the previous week was wet or dry. The model calculates the initial probabilities of getting a dry spell/wet spell in a given standard meteorological week. The calculation of conditional probabilities provides the information on the dry spell followed by dry spell or wet spell vice versa. The calculation of initial and conditional probabilities are given below:

Initial probability rainfall analysis will give percentage probability to get certain amount of rainfall in a given week. Probability of wet week is denoted as P(W) and dry week as P(D).

Conditional probability rainfall analysis will give the percentage probability for wet week followed by wet week [P(W/W)], wet week followed by dry week [P(W/D)], dry week followed by dry week [P(D/D)] and dry week followed by wet week [P(D/W)]. The input has to be given the form of weekly average rainfall.

$$\text{Initial Probability (\%) (W)} = \frac{\text{Number of year during which} > 20\text{ mm rainfall during } x \text{ week}}{\text{Total number of year}} \times 100$$

$$\text{Conditional rainfall probability for wet week (\%) (W/W)} = \frac{\text{Number of years during which next week received, when this week also received rainfall} > 20\text{ mm}}{\text{Number of years during which this week received} > 20\text{mm Rainfall}} \times 100$$

$$\text{Conditional rainfall probability for dry week (\%) (D/W)} = \frac{\text{Number of years during which next week received} > 20\text{ mm when this week received} < 20\text{ mm}}{\text{Number of years during which this week received} < 20\text{ mm Rainfall}} \times 100$$

2.3. *Incomplete gamma probability*

The model is used for computing the assured rainfall amount at different probability levels, *i.e.*, at 10, 25, 50, 75, 90 %. For efficient planning, research workers, farmers and planners stand to gain significantly by using quantified rainfall at different probability levels called assured rainfall.

3. Result and discussion

3.1. *Initial and Conditional Probability for Rainfall*

The initial and conditional probabilities were calculated for different years on weekly basis for both the regions. The 52 weeks of a year are divided into 4 quarters. 1st - 13th Standard Meteorological Weeks (SMWs) of the year represents Quarter 1 and consequently, 14th-26th, 27th-39th and 40th-52nd SMWs are representing 2nd, 3rd and 4th Quarters, respectively. The data pertaining to initial rainfall and conditional probability. It can be classified into three categories namely low, moderate and high rainfall level.

The low category is for rainfall > 5 mm up to ≤20 mm; moderate for > 20 to ≤40 mm whereas > 40 mm comes under high category. The lowest and highest rainfall probabilities in the form of percentage were worked out for different quarters for Pantnagar and Ranichauri. Similar study was conducted by Goyal *et al.* (2015) as they calculated weekly initial and conditional probability for the Ludhiana region. Similarly, Rama Rao *et al.*, (1975) analyzed the daily rainfall data for Bijapur from 1921 to 1970.

I[st] Quarter (> 5 mm, > 10 mm, > 20 mm, > 30mm, >40 mm, >50 mm)

For > 5mm the lowest initial and conditional rainfall probability P(W/W), *i.e.*, 18% & 11% occurs during SMW 12-13 (19th Mar- 1st Apr) & SMW 4 (22-28th Jan) and highest, *i.e.*, 40% & 75% during SMW 7 (12-18th Feb) & SMW 11 (12-18th Mar) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 39% & 37% occurs during SMW 5 (29th Jan- 4th Feb) & SMW 13 (26th Mar- 1st Apr) and highest, *i.e.*, 67% & 73% during SMW 11 (12-18th Mar) respectively.

For > 10 mm the lowest initial and conditional rainfall probability, *i.e.*, 8% & 0% occurs during SMW 12-13 (19th Mar- 1st Apr) & SMW 1, 6 & 13 (1st-7th Jan, 5-11th Feb & 26th Mar- 1st Apr) and highest, *i.e.*, 26% & 55% during SMW 1 (1st-7th Jan) & SMW 7 (12-18th Feb) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 31% & 23% occurs during SMW 5 (29th Jan- 4th Feb) & SMW 4 (22-28th Jan) and highest, *i.e.*, 61% & 82% during SMW 8 (19-25th Feb) & SMW 11 (12-18th Mar) respectively.

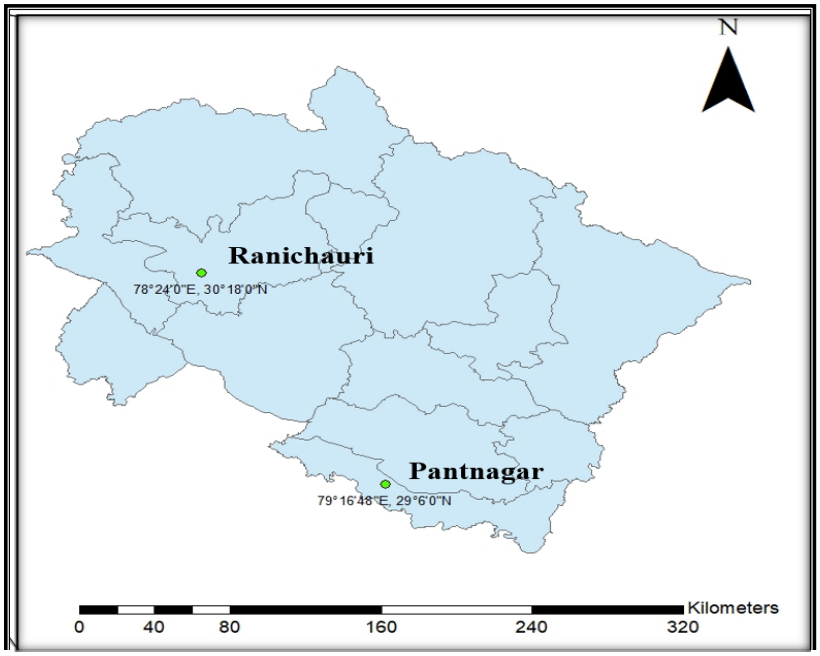

Fig. 1. The study area depicting Pantnagar (*Tarai*) and Ranichauri (mid Himalayan) regions of Uttarakhand

TABLE 1

Weekly initial and conditional rainfall probability percentage of 1st quarter at different rainfall levels for *Tarai* and mid Himalayan regions of Uttarakhand

	1-13 SMW							
	Pantnagar				Ranichauri			
	Initial Probability %		Conditional Probability (wet) %		Initial Probability %		Conditional Probability (wet) %	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
> 5 mm	18	40	11	75	39	67	37	73
> 10 mm	8	26	0	55	31	61	23	82
> 20 mm	0	18	0	33	17	44	17	63
> 30 mm	0	13	0	33	11	36	0	56
> 40mm	0	13	0	40	6	33	0	75
> 50 mm	0	8	0	33	3	22	0	75

For > 20 mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 12 (19-25th Mar) & SMW 1-2, 4-6 & 11-13 (1-14th Jan, 22nd Jan-11th Feb) and highest, *i.e*., 18% & 33% during SMW 6, 9 (5-11th Feb, 26th Feb-4th Mar) & SMW 3 (15-21st Jan) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability *i.e.*, 17% occurs during SMW 5 (29th Jan- 4th Feb) & SMW 1 (1-7th Jan) and highest, *i.e*., 44% & 63% during SMW 6-8 (5-25th Feb) & SMW 11 (12-18th Mar) respectively.

For > 30 mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 1-2, 4-6 & 11-13 (1-14th Jan, 22nd Jan-11th Feb) and highest, *i.e.*, 13% & 33% during SMW 6, 9 (5-11th Feb, 26th Feb - 4th Mar) & SMW 8-9 (19th Feb - 4th Mar) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e*., 11% & 0% occurs during SMW 4 (22-28th Jan) & SMW 1, 13 (1-7th Jan, 26th Mar-1st Apr) and highest, *i.e*., 36% & 56% during SMW 6 (5-11th Feb) & SMW 9 (26th Feb-4th Mar) respectively.

TABLE 2

The frequency of the 1st quarter getting weekly 50% initial and conditional rainfall probability at different levels of rainfall for *Tarai* and mid Himalayan regions of Uttarakhand

Regions	Frequency of getting ≥ 50% of wet week (Initial Probability %) out of 1-13 SMW						Frequency of getting ≥ 50% of wet week followed by wet week [Conditional Probability (w/w)] % out of 1-13 SMW					
	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm
Pantnagar	0	0	0	0	0	0	3	2	2	1	0	0
Ranichauri	6	4	0	0	0	0	7	5	2	1	1	2

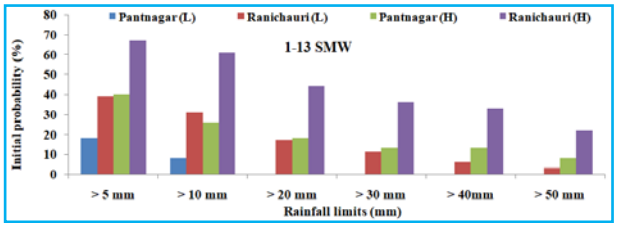

Fig. 2. Initial probability percent of the I[st] quarter at different rainfall limits for *Tarai* and mid Himalayan regions of Uttarakhand

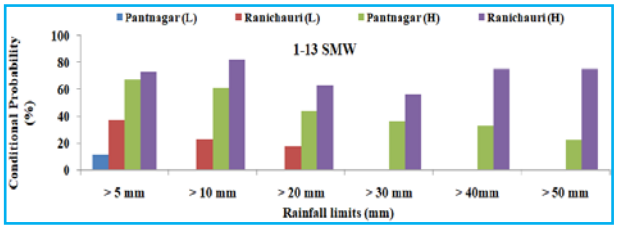

Fig. 3. Conditional probability percent of the I[st] quarter at different rainfall limits for*Tarai* and mid Himalayan regions of Uttarakhand

For > 40 mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 5, 12 (29th Jan-4th Feb, 19-25th Mar) & SMW 1-6, 10-13 (1st Jan- 10th Feb, 5th Mar - 1st Apr) and highest, *i.e.*, 13% & 40% during SMW 6-7 (5-18th Feb) respectively in the *Tarai* region In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 6% & 0% occurs during SMW 5 (29th Jan-4th Feb) & SMW 1, 3, 5, 10 & 13 (1-7th Jan, 15-21th Jan, 29th Jan-4th Feb, 5-11th Mar, 26th Mar- 1st Apr) and highest, *i.e.*, 33% & 75% during SMW 6 (5-11th Feb) & SMW 9 (26th Feb- 4th Mar) respectively.

For > 50 mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 4-5, 10, 12-13 (22nd Jan- 4th Feb, 10-16th Feb, 19th Mar- 1st Apr) & SMW 1-6 & 8-13 (1st Jan- 5th Feb & 19th Feb -1st Apr) and highest, *i.e.*, 8% & 33% during SMW 3, 6, 7-8 (15-21st Jan, 5-11th Feb, 12-25th Feb) & SMW 7 (12-18th Feb) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 3% & 0% occurs during SMW 1 (1-7th Jan) & SMW 1-6 & 12-13 (1st Jan- 11th Feb & 19th Mar-1st Apr) and highest, *i.e.*, 22% & 75% during SMW 9 (26th Feb- 4th Mar) respectively.

So overall we can conclude from the Table 1 for the 1st Quarter (1st Jan - 1st Apr) that rainfall distribution is more erratic in the *Tarai* region as compared to the mid Himalayan region of Uttarakhand. Most of the rainfall is limited in the month of mid-February to mid-March in both of these regions but as per the Table 2, the frequency of getting ≥ 50% rainfall probability (Vaidya *et al.*, 2008) is more in the mid Himalayan. The frequency of initial probability is nil for *Tarai* region at different rainfall limit while it is 6 (> 5 mm) & 4 (> 10 mm) weeks for the mid Himalayan region and the frequency of conditional rainfall probability is nil for higher category of rainfall for the *Tarai* region. Similarly, the initial percent probability as well as is lower in the *Tarai* region as compared to the mid Himalayan region as depicted in Figs. 2 & 3. So, there is good amount of rainfall in the month of Feb in the mid Himalayan region as probability of having good rainfall is higher so rabi pulses and vegetables can be grown without irrigation thus reducing the stress on water resources but in the *Tarai* region, irrigation has to be provided for raising the crops.

IInd Quarter (> 5 mm, > 10 mm, > 20 mm, > 30mm, >40 mm, >50 mm).

For > 5mm the lowest initial and conditional rainfall probability *i.e.*, 20% & 11% occurs during SMW 14-16 (2-8th Apr, 16-22 Apr) & SMW 16 (16-22nd Apr) and highest, *i.e.*, 90% & 91% during SMW 26 (25th Jun to 1st Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 39% & 20% occurs during SMW

TABLE 3

Weekly initial and conditional rainfall probability percentage of IInd quarter at different rainfall levels for *Tarai* and mid Himalayan regions of Uttarakhand

Rainfall limits	14-26 SMW							
	Pantnagar				Ranichauri			
	Initial Probability %		Conditional Probability (wet) %		Initial Probability %		Conditional Probability (wet) %	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
> 5 mm	20	90	11	91	39	86	20	89
> 10 mm	13	88	0	87	31	78	17	77
> 20 mm	0	75	0	79	17	69	0	67
> 30 mm	0	68	0	74	6	53	0	67
> 40mm	0	60	0	60	3	36	0	67
> 50 mm	0	55	0	56	3	31	0	75

17 (23-29 Apr) and highest, *i.e.*, 86% & 89% during SMW 26 (25th Jun to 1st Jul) respectively (Table 3).

For > 10mm the lowest initial and conditional rainfall probability, *i.e.*, 13% & 0% occurs during SMW 15 (9-15th Apr) & SMW 16 (16-22nd Apr) and highest, *i.e.*, 88% & 87% during SMW 26 (25th Jun to 1st Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 31% & 17% occurs during SMW 14 (2-8th Apr) & SMW 16-17 (16-29th Apr) and highest, *i.e.*, 78% & 77% during SMW 26 (25th Jun to 1st Jul) respectively.

For > 20mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 15 (9-15th Apr) & SMW 14-18 (2nd Apr- 6th May) and highest, *i.e.*, 75% & 79% during SMW 25 (18-24th Jun) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 17% & 0% occurs during SMW 14-16 (2-22nd Apr) & SMW 17 (23-29th Apr) and highest, *i.e.*, 69% & 67% during SMW 26 (25th Jun to 1st Jul) respectively.

For > 30mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 15 (9-15th Apr) & SMW 14-18 (2nd Apr- 6th May) and highest, *i.e.*, 68% & 74% during SMW 26 (25th Jun to 1st Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 6% & 0% occurs during SMW 16 (16-22nd Apr) & SMW 17-18 (23rd Apr-6th May) and highest, *i.e.*, 53% & 67% during SMW 26 (25th Jun to 1st Jul) & SMW 21 (21-27th May) respectively.

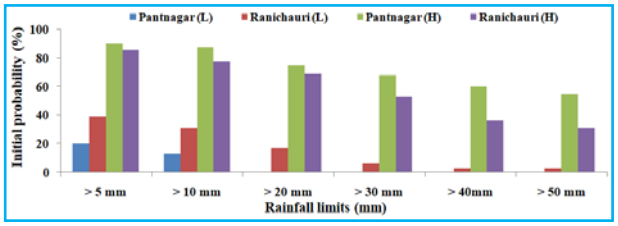

Fig. 4. Initial probability percent of the IInd quarter at different rainfall limits for *Tarai* and mid Himalayan regions of Uttarakhand

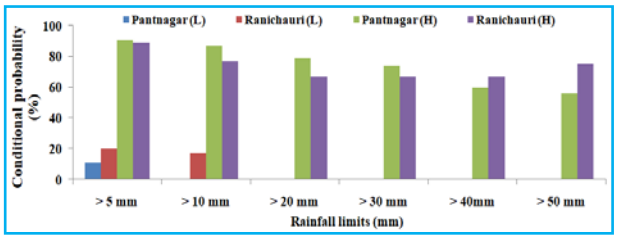

Fig. 5. Conditional probability percent of the IInd quarter at different rainfall limits for *Tarai* and mid Himalayan regions of Uttarakhand

For > 40mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 15 (9-15th Apr) & SMW 14-19 (2nd Apr-13th May) and highest, *i.e.*, 60% during SMW 26 (25th Jun to 1st Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 3% & 0% occurs during SMW 16 (16-22nd Apr) & SMW 14,17-18, 20-23 (2-8th Apr, 23rd Apr-6th May, 24th May-10th Jun) and highest, *i.e.*, 36% & 67% during SMW 26 (25th Jun to 1st Jul) respectively.

TABLE 4

The frequency of the IInd quarter getting weekly 50% initial and conditional rainfall probability at different levels of rainfall for*Tarai* and mid Himalayan regions of Uttarakhand

Regions	Frequency of getting ≥ 50% of wet week (Initial Probability %) out of 14-26 SMW						Frequency of getting ≥ 50% of wet week followed by wet week [Conditional Probability (w/w)] % out of 14-26 SMW					
	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm
Pantnagar	4	4	2	2	1	1	6	7	5	4	3	3
Ranichauri	9	6	1	1	0	0	14	8	3	2	1	1

TABLE 5

The monthly mean rainfall, rainy days and CV% for *Tarai* and mid Himalayan regions of Uttarakhand

Months	Mean Rainfall		Rainy Days		Coefficient of Variation (CV%)	
	Pantnagar	Ranichauri	Pantnagar	Ranichauri	Pantnagar	Ranichauri
January	31.2	59.7	2	4	106.8	67.6
February	38.1	93.4	2	5	123.0	78.6
March	20.3	73.3	2	5	127.5	75.8
April	19.8	44.3	1	4	118.0	73.8
May	51.4	73.2	3	6	115.4	59.8
June	191.1	128.9	7	8	75.6	78.5
July	440.9	294.7	14	14	39.1	39.9
August	448.7	276.7	14	14	45.1	40.6
Sep	255.7	136.9	8	7	72.9	82.1
October	38.9	31.0	1	1	210.0	212.9
November	4.3	11.9	0	1	192.0	187.6
December	16.4	33.4	1	2	151.5	132.9

For > 50mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 14-15 (2-15th Apr) & SMW 14-19, 21 (2nd Apr- 13th May, 21-27th May) and highest, *i.e.*, 55% & 56% during SMW 26 (25th Jun to 1st Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 3% & 0% occurs during SMW 15-18 (9th Apr-6th May) & SMW 14-18, 20-23, 25 (2-6th May, 14th May-10th Jun, 18-24th Jun) and highest, *i.e.*, 31% & 75% during SMW 26 (25th Jun to 1st Jul) respectively.

From the above discussion, it has been observed that in the Quarter IInd (2nd Apr - 1st Jul) that least rainfall occurs in the month of April and May while maximum rainfall occurs at the end of June in both the *Tarai* and mid Himalayan regions of Uttarakhand. The initial probability % (highest) is more for moderate and higher category of rainfall for the *Tarai* region and the conditional probability % for higher category is more for mid Himalayan region as per Figs. 4&5.

The frequency of getting > 50% initial and conditional rainfall probability of having wet weeks is lesser for moderate and higher category of rainfall in mid Himalayan region when compared with the *Tarai* region as presented in Table 4. The comparison of rainfall patterns between the *Tarai* (Pantnagar) and mid-Himalayan (Ranichauri) regions of Uttarakhand reveals distinct climatic variationsas depicted in Table 5. Overall, Ranichauri receives higher rainfall in the winter and pre-monsoon months (January to May), whereas Pantnagar experiences significantly higher rainfall during the monsoon months (June to September). The monsoon peak is observed in July and August, with Pantnagar receiving around 440-448 mm, nearly 1.5 times more than Ranichauri. Rainy days follow a similar pattern, with both regions experiencing 14 rainy days in peak monsoon months, though Pantnagar generally has fewer rainy days in non-monsoon months. The coefficient of variation (CV%) is higher in Pantnagar, especially in October and November, indicating greater rainfall variability. This

TABLE 6

Weekly initial and conditional rainfall probability percentage of IIIrd quarter at different rainfall levels for *Tarai* and mid Himalayan regions of Uttarakhand

Rainfall limits	27-39 SMW							
	Pantnagar				Ranichauri			
	Initial Probability %		Conditional Probability (wet) %		Initial Probability %		Conditional Probability (wet) %	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
> 5 mm	53	100	57	100	39	97	48	100
> 10 mm	40	100	42	100	31	94	41	97
> 20 mm	30	90	30	94	28	92	38	93
> 30 mm	30	90	33	91	25	81	29	85
> 40mm	25	83	35	87	19	69	24	76
> 50 mm	25	75	33	78	17	61	13	64

contrast suggests that the mid-Himalayan region has a more evenly distributed rainfall pattern throughout the year, while the *Tarai* region experiences a sharper monsoonal concentration of rainfall. So, some summer vegetables and pulses can be grown in the mid Himalayan region after harnessing some stored water thereby conserving the natural resources but proper irrigation has to be provided for the growth of crops as well as for the nursery preparation of paddy in the *Tarai* region of Uttarakhand.

IIIrd Quarter (> 5 mm, > 10 mm, > 20 mm, > 30mm, >40 mm, >50 mm).

For > 5mm the lowest initial and conditional rainfall probability, *i.e.*, 53% & 57% occurs during SMW 39 (24-30thSep) and highest, *i.e.*, 100% during SMW 29, 33 (16-22nd Jul, 13-19th Aug) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 39% & 48% occurs during SMW 39 (24-30th Sep) and highest, *i.e.*, 97% & 100% during SMW 28 (9-15th Jul) & SMW 33 (13-19th Aug) respectively.

For > 10mm the lowest initial and conditional rainfall probability, *i.e.*, 40% & 42% occurs during SMW 39 (24-30th Sep) and highest, *i.e.*, 100% during SMW 29, 33 (16-22nd Jul, 13-19th Aug) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 31% & 41% occurs during SMW 39 (24-30th Sep) and highest, *i.e.*, 94% & 97% during SMW 28, 30-31 & 33 (9-15th Jul, 23rd Jul-5th Aug, 13-19th Aug) & SMW 33 (13-19th Aug) respectively.

For > 20mm the lowest initial and conditional rainfall probability, *i.e.*, 30% occurs during SMW 39 (24-30th Sep) and highest, *i.e.*, 90% & 94% during SMW 28 (9-15th Jul) & SMW 29 16-22nd Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 28% & 38% occurs during SMW 39 (24-30th Sep) and highest, *i.e.*, 92% & 93% during SMW 30 (23-29th Jul) respectively (Table 6).

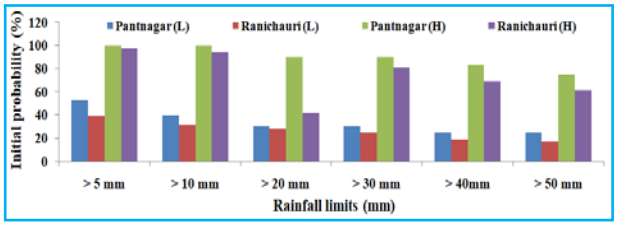

Fig. 6. Initial probability percent of the IIIrd quarter at different rainfall limits for *Tarai* and mid Himalayan regions of Uttarakhand

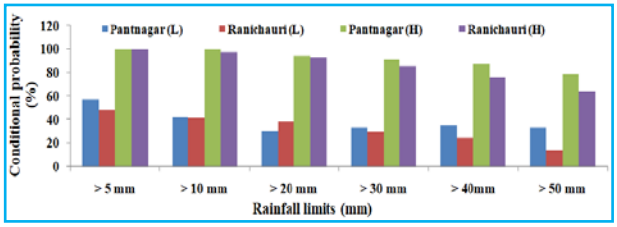

Fig. 7. Conditional probability percent of the IIIrd quarter at different rainfall limitsfor *Tarai* and mid Himalayan regions of Uttarakhand

For > 30mm the lowest initial and conditional rainfall probability, *i.e.*, 30% & 33% occurs during SMW 39 (24-30th Sep) and highest, *i.e.*, 90% & 91% during SMW 29 (16-22nd Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 25% & 29% occurs during SMW 38 (17-23rd Sep) and highest, *i.e.*, 81% &

TABLE 7

The frequency of the III[rd] quarter getting weekly 50% initial and conditional rainfall probability at different levels of rainfall for *Tarai* and mid Himalayan regions of Uttarakhand

Regions	Frequency of getting ≥ 50% of wet week (Initial Probability %) out of 27-39 SMW						Frequency of getting ≥ 50% of wet week followed by wet week [Conditional Probability (w/w)] % out of 27-39 SMW					
	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm
Pantnagar	13	12	12	11	10	10	13	12	12	11	11	11
Ranichauri	12	11	9	9	8	7	12	11	10	10	10	9

85% during SMW 31 (30[th] Jul-5[th] Aug) & SMW 32 (6-12[th] Aug) respectively.

For > 40mm the lowest initial and conditional rainfall probability, *i.e.*, 25% & 35% occurs during SMW 39 (24-30[th] Sep) and highest, *i.e.*, 83% & 87% during SMW 29 (16-22[nd] Jul) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 19% & 24% occurs during SMW 38 (17-23[rd] Sep) & SMW 36 (3-9[th] Aug) and highest, *i.e.*, 69% & 76% during SMW 31 (30[th] Jul-5[th] Aug) & SMW 29 (16-22[nd] Aug) respectively.

For > 50mm the lowest initial and conditional rainfall probability, *i.e.*, 25% & 33% occurs during SMW 39 (24-30[th] Sep) and highest, *i.e.*, 75% & 78% during SMW 29 (16-22[nd] Jul) & SMW 33 (13-19[th] Aug) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 17% & 13% occurs during SMW 38 (17-23[rd] Sep) & SMW 36 (3-9[th] Aug) and highest, *i.e.*, 61% & 64% during SMW 31, 33 (30[th] Jul-5[th] Aug, 13-19[th] Aug) & SMW 27, 32 (2-8[th] Jul, 6-12[th] Aug) respectively.

In Quarter III[rd] (2[nd] Jul-30[th] Sep) there is good amount of rainfall in the month of July-August and reduction of rainfall occurs at the end of Sep month in both *Tarai* and mid Himalayan regions of Uttarakhand (Figs. 6 & 7). The rainfall is comparatively lesser in mid Himalayan region and early cessation occurs, *i.e.*, during SMW 38 (17-23[rd] Sep) at higher category of rainfall. As per the Table 7, the frequency of getting > 50% initial and conditional rainfall probability is more in the *Tarai* region. So the proper water harvesting structures should be built in order to provide the lifesaving irrigation during drought months. High water requiring crops like paddy can be grown in both of these regions with one or two flood irrigation in the mid Himalayan region.

IV[th] Quarter (> 5 mm, > 10 mm, > 20 mm, > 30mm, >40 mm, >50 mm)

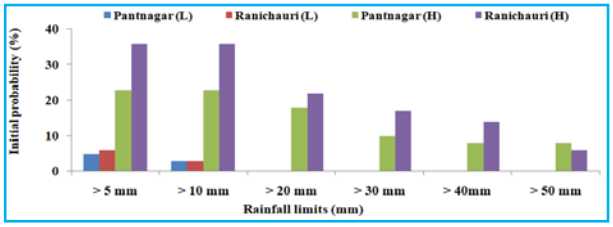

Fig. 8. Initial probability percent of the IV[th] quarter at different rainfall limits for *Tarai* and mid Himalayan regions of Uttarakhand

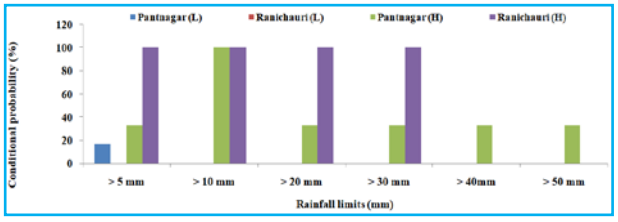

Fig. 9. Conditional probability percent of the III[rd] quarter at different rainfall limits for *Tarai* and mid Himalayan regions of Uttarakhand

For > 5mm the lowest initial and conditional rainfall probability, *i.e.*, 5% & 17% occurs during SMW 43,46 & 51 (22-28[th] Oct, 12-18[th] Nov, 17-23[th] Dec) and highest, *i.e.*, 23 & 33% during SMW 52 (24-31[st] Dec) & SMW 50 (10-16[th] Dec) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 6% & 0% occurs during SMW 49 (3-9[th] Dec) & SMW 43-44, 46-47 (22[nd] Oct-4[th] Nov, 12-25[th] Nov) and highest, *i.e.*, 36% & 100% during SMW 50 (10-16[th] Dec) respectively.

For > 10mm the lowest initial and conditional rainfall probability, *i.e.*, 3% & 0% occurs during SMW 45,47 & 51 (5-11[th] Nov, 19-25[th] Nov, 17-23[th] Dec) and highest, *i.e.*, 23 & 100% during SMW 40 (1-7[th] Oct) & SMW 48 (26[th] Nov-2[nd] Dec) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 3% & 0% occurs

TABLE 8

Weekly initial and conditional rainfall probability percentage of IVth quarter at different rainfall levels for *Tarai* and mid Himalayan regions of Uttarakhand

Rainfall limits	40-52SMW							
	Pantnagar				Ranichauri			
	Initial Probability %		Conditional Probability (wet) %		Initial Probability %		Conditional Probability (wet) %	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
> 5 mm	5	23	17	33	6	36	0	100
> 10 mm	3	23	0	100	3	36	0	100
> 20 mm	0	18	0	33	0	22	0	100
> 30 mm	0	10	0	33	0	17	0	100
> 40mm	0	8	0	33	0	14	0	0
> 50 mm	0	8	0	33	0	6	0	0

TABLE 9

The frequency of the IVth quarter getting weekly 50% initial and conditional rainfall probability at different levels of rainfall for*Tarai* and mid Himalayan regions of Uttarakhand

Regions	Frequency of getting ≥ 50% of wet week (Initial Probability %) out of 40-52 SMW						Frequency of getting ≥ 50% of wet week followed by wet week [Conditional Probability (w/w)] % out of 40-52 SMW					
	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm
Pantnagar	0	0	0	0	0	0	0	0	0	0	0	0
Ranichauri	0	0	0	0	0	0	3	3	3	1	0	0

during SMW 43 (22-28th Oct) & SMW 42-44, 46-47 (15th Oct-4th Nov, 12-25th Nov) and highest *i.e.*, 36% & 100% during SMW 50 (10-16th Dec) respectively. For > 20mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 43,47 & 51 (22-28th Oct, 19-25th Nov, 17-23th Dec) & SMW 43-52 (22nd Oct-31st Dec) and highest, *i.e.*, 18 & 33% during SMW 40 (1-7th Oct) & SMW 42 (15-21st Oct) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 43-44 & 46 (22 Oct-4th Nov, 12-18th Nov) & SMW 42-47, 49, 51 (15th Oct-25th Nov, 3-9th Dec, 17-23rd Dec) and highest, *i.e.*, 22% & 100% during SMW 50 (10-16th Dec) and SMW 50, 52 (10-16th Dec, 24-31st Dec) respectively.

For > 30mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 43,45-48 & 51 (22-28th Oct, 5th Nov-2nd Dec, 17-23th Dec) & SMW 43-52 (22nd Oct-31st Dec) and highest, *i.e.*, 10 & 33% during SMW 40 (1-7th Oct) & SMW 42 (15-21st Oct) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 43-44, 46 & 49 (22 Oct-4th Nov, 12-18th Nov, 3-9th Dec) & SMW 40-51 (15th Oct-23rd Dec) and highest, *i.e.*, 17% & 100% during SMW 50 (10-16th Dec) and SMW 52 (24-31st Dec) respectively.

For > 40mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 43-49 & 51 (22th Oct-9th Dec, 17-23th Dec) & SMW 41, 43-52 (8-14th Oct, 22nd Oct-31st Dec) and highest, *i.e.*, 8 & 33% during SMW 41, 50 (8-14th Oct, 10-16th Dec) & SMW 42 (15-21st Oct) respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 43-46 & 49 (22 Oct-18th Nov, 3-9th Dec) & SMW 40-52 (1st Oct-31st Dec) and highest, *i.e.*, 14% & 0% during SMW 50 (10-16th Dec) and SMW 40-52 (1st Oct-31st Dec) respectively.

For > 50mm the lowest initial and conditional rainfall probability, *i.e.*, 0% occurs during SMW 43-49 & 51 (22th Oct-9th Dec, 17-23th Dec) & SMW 41, 43-52 (8-14th Oct, 22nd Oct-31st Dec) and highest, *i.e.*, 8 & 33% during SMW 41 (8-14th Oct) & SMW 42 (15-21st Oct)

TABLE 10

The overall frequency of getting weekly 50% initial and conditional rainfall probability at different levels of rainfall for*Tarai* and mid Himalayan regions of Uttarakhand

Regions	Frequency of getting ≥ 50% of wet week (Initial Probability %) out of 52 SMW						Frequency of getting ≥ 50% of wet week followed by wet week [Conditional Probability (w/w)] % out of 52 SMW					
	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm	> 5 mm	> 10 mm	> 20 mm	> 30 mm	> 40 mm	> 50 mm
Pantnagar	17	16	14	13	11	11	21	21	19	16	14	14
Ranichauri	27	21	10	10	8	7	36	26	18	14	12	13

TABLE 11

Charecterstics of rainfall in *Tarai* and mid Himalayan regions of Uttarakhand

Seasons	Mean Rainfall (mm)		Rainy days		Coefficient of Variation (CV %)	
	Pantnagar	Ranichauri	Pantnagar	Ranichauri	Pantnagar	Ranichauri
Winter(Jan-Feb)	69.3	153.1	4	9	86	54
Summer (Mar-May)	91.5	190.9	7	14	73	41
Southwest monsoon (Jun-Sep)	1336.3	837.1	44	43	36	31
Northeast monsoon (Oct-Dec)	59.5	76.3	3	4	149	118
Total	1556.7	1257.3	57	70	34	23

respectively in the *Tarai* region. In the mid Himalayan region, the lowest initial and conditional rainfall probability, *i.e*., 0% occurs during SMW 43-46 & 49 (22 Oct-18th Nov, 3-9th Dec) & SMW 40-52 (1st Oct-31st Dec) and highest *i.e.*, 6% & 0% during SMW 40-42, 47 & 50 (1-21st Oct, 19-25th Nov & 10-16th Dec) and SMW 40-52 (1st Oct-31st Dec) respectively.

From the Table 8 and Figs. 8 & 9, it can be concluded that there is less rainfall in the post monsoon season (Oct-Dec) in both of these regions. The frequency of getting > 50% initial and conditional rainfall probability is almost nil as per the Table 9, which proves the erratic distribution of rainfall in the *Tarai* region while there is good amount of rainfall (upto > 30 mm) during December month in the mid Himalayan region, so the rabi pulses and other off season vegetables can be grown after harnessing water from the natural springs but proper irrigation must be ensured in the *Tarai* region for proper growth of the crops.

If we observe the overall frequency > 50% initial and conditional probability of having wet weeks at different rainfall limits, then it is more for mid Himalayan region for low category of rainfall (upto > 10 mm) but it is more for moderate and higher category of rainfall in the *Tarai* region of Uttarakhand and most of the wet weeks is limited to the Southwest monsoon as explained above and depicted in the Table 10. The rainfed crops can be grown only during Southwest monsoon season while in other seasons proper irrigation must be assured in the *Tarai* region while rainfed crops can be grown in all the seasons except during post monsoon season in the mid Himalayan region.

3.2. *Seasonal and Weekly rainfall characteristics*

The coefficient of variation (CV) in percentage is an indicative of dependability of rainfall. The threshold levels for CV for any interpretation are < 25, < 50, < 100 and < 150 per cent for annual, seasonal, monthly and weekly rainfall respectively as per Manikandan *et al.* (2017). If CV is within the threshold limits of variability, it is considered that the rainfall is dependable (Veeraputhiran *et al*., 2003). The CV% for winter, summer and northeast monsoon season is 86%, 73%, 149% respectively, which is much more than the threshold limit of 50%, so the dependability of rainfall for raising the crops decreases for these seasons except during southwest monsoon season, which has CV% of 36% as depicted in the Table 11 in the *Tarai* region.

In the mid Himalayan region the CV% for winter, summer, southwest and northeast monsoon seasons is

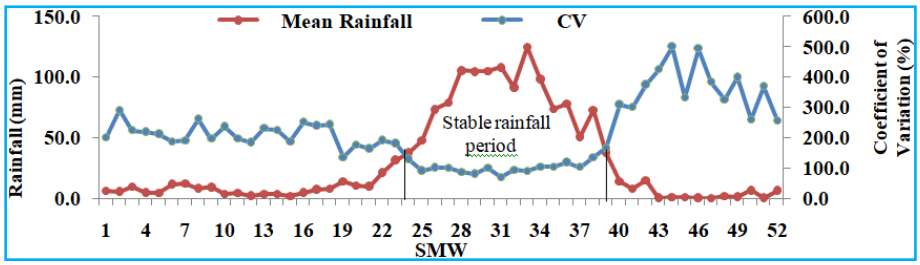

Fig. 10. The weekly mean rainfall pattern in *Tarai* region of Uttarakhand

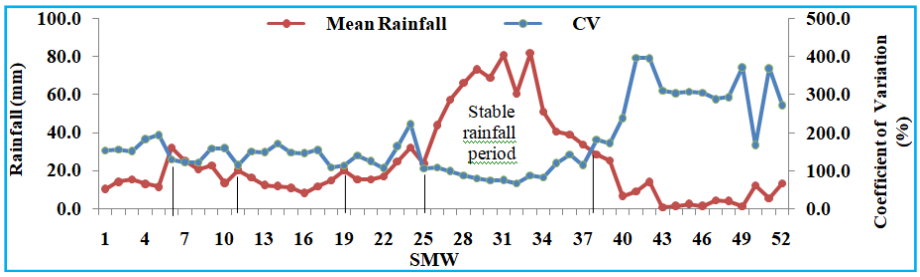

Fig. 11. The weekly mean rainfall pattern in mid Himalayan region of Uttarakhand

TABLE 12

Amount of rainfall at different probability percentagein *Tarai* and midHimalayan regions of Uttarakhand

Months	Amount of rainfall by Incomplete Gamma probability at different levels (mm)											
	90%		75%		50%		25%		10%		Mean	
	Pant	Rani	Pant	Rani	Pant	Rani	Pant	Rani	Pant	Rani	Pant	Rani
Jan	0.6	1.4	3.8	7.3	14.5	28.2	39.6	76.2	78.3	149.7	25.6	52.8
Feb	0.2	0.3	1	16.9	35.4	84.1	89.4	163.3	138	238.6	37.0	89.4
Mar	1.5	2.8	5.4	13.2	17	47.1	40.5	121.5	74.6	233.8	24.8	84.8
Apr	1	1.7	3.9	7.3	13.1	25.3	32.6	63.7	61.6	120.4	20.0	42.7
May	1.9	7.2	8.8	21.9	33.7	57.2	90	120.7	176.2	207.1	62.0	82.3
Jun	12.3	8.5	42.2	27.6	126.2	77.9	295.6	175.6	541.4	314.3	211.7	124.1
Jul	78.3	61.9	173.3	133.5	368	269.8	687.3	481.3	1100.6	745.6	496.1	345.6
Aug	39.4	42.4	114.5	93.8	300.6	200.6	645.1	379	1122.1	613.2	463.7	272.1
Sep	4.8	2.3	21.6	11.9	81.6	47.3	220.7	130.5	437.8	260.4	161.7	94
Oct	0.7	0.8	2.9	3.4	14.5	14.4	47.2	44.5	103.3	94.6	33.1	30.6
Nov	1.1	0.8	2.7	2.9	6.2	8.1	11.8	18.3	19.1	32.7	4.4	9.3
Dec	1.1	0.9	3.7	4.6	12	18.9	30.5	54.5	58.1	111	17.5	36.3
Annual	929.3	896.5	1166.2	1047.7	1474.3	1234.8	1832.6	1443	2200	1649.2	1529	1257

54%, 41%, 31% & 118% respectively, so except northeast monsoon season, rainfed crops can be raised. If we compare the annual CV%, then it is 34% & 23% in the *Tarai* and mid Himalayan region respectively which is more than the threshold limit for the *Tarai* region and almost 86% of the annual rainfall is contributed by the southwest monsoon season hence proves the erratic distribution of rainfall in this region while 28% of annual

rainfall is contributed by the winter and summer season and 67% is contributed by the southwest monsoon season in the mid Himalayan region.

If we plot the weekly mean rainfall and CV% for both of these regions, then the point where mean rainfall coincides the CV% is considered as stable rainfall period as presented below in the Figs. 10 & 11. The stable rainfall period is from SMW 23-39 (4^{th} Jun-30^{th} Sep), *i.e.*, during southwest monsoon season in the *Tarai* region of Uttarakhand as per Fig. 10. In the mid Himalayan region, tha stable rainfall period is from SMW 6-11 (5^{th} Feb-18^{th} Mar), 11-19 (12^{th} Mar-13^{th} May), 19-25 (7^{th} May- 24^{th} Jun) & 25-38 (18^{th} Jun-23^{rd} Sep). So, we can conclude that except in the post monsoon season the rainfall is almost uniform in this region as per Fig. 11.

Incomplete gamma distribution is used to predict the occurrence of rainy events of different probability for crop planning. The rainfall at different probability levels,*i.e.*, 90%, 75%, 50%, 25% & 10% has been computed as presented in the Table 12. As per IMD, rainfall at 75% probability is considered as assured rainfall and rainfall at 50% probability is the medium limit for taking risk as mean rainfall is closer to 50% probability. Similar results was found by Rai *et al.*, (2009) as they analyzed weekly rainfall data for crop planning at Madhepura district of Bihar. It has been found that the maximum rainfall occurs in the month of July followed by August in the *Tarai* and mid Himalayan regions of Uttarakhand.

The rainfall in all the seasons except in the southwest monsoon season is more in the mid Himalayan region when compared with the *Tarai* region. Hence farmers can grow off season vegetables like garden pea, cowpea, radish, and carrot; Rabi pulses like lentil, kidney bean, and chickpea with light irrigation in order to have more profitable productivity as compared to the *Tarai* region, where proper irrigation should be assured. The short duration and drought resistant crops like green gram, black gram and besides this, the less water demanding crops such as finger millet, foxtail millet (Gautam *et al.*, 2013) could also be taken successfully in the *Tarai* region.

4. Conclusion

The weekly rainfall analysis has been done by calculating maximum and minimum initial and conditional probability (wet and dry) for different standard meteorological weeks will be helpful for deciding the sowing time, irrigation/fertilizer scheduling and harvesting time in the *Tarai* and mid Himalayan regions of Uttarakhand. If the dry spell coincides with the critical moisture requiring stages of the crop, it is damaging whereas during ripening stage, it may be beneficial. In this way, knowledge of rainfall proability analysis, crop sowing dates can be adjusted in such a way that critical stages of the crop coincide with the period of higher rainfall probability.

This will help in reducing the stress on water resouces and energy conservation. Apart from saving crops from water deficit, insect-pest disease occurrence can also be predicted based on these sequences of dry and wet spells. Also the policy makers can adjust the timing of canal water releases to the farmers. The higher level of occurrence of rainfall event will be helpful in deciding the amount of run-off generated and hence can be used for deciding capacity of rain water harvesting structures. As per the results, there is sufficient amount of summer and winter rainfall in the mid Himalayan region as compared to the *Tarai* region of Uttarakhand so all round the year farmers can grow crops in the mid Himalayan region.

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