Original Research Article

Assessment of Rainfall Variability and Drought Impact on Crop Growth in the Plain and Hill Zones of Uttarakhand

ABSTRACT

The rainfall data for the two stations *i.e.*, Pantnagar (1981-2020) and Ranichauri (1985-2020) have been utilized to study the climate suitable for the growth and development of the crops in the plain and hill zones of Uttarakhand. The pentadal weekly, monthly and seasonal rainfall & rainy days have been calculated for these regions. An increasing trend in the pentadal mean rainfall and rainy days was experienced in the winter and southwest monsoon season and a decreasing trend could be observed in the summer and northeast monsoon season for both the stations. The frequency of meteorological drought for the plain zone is more as compared to hill zone. The Agricultural drought (Kharif & Rabi season) & Heavy rainfall events (at particular date of year) were assessed and there is no drought in the Rabi season for both the regions.

Commenté [AZ1]: Incorporate details regarding the methodology, such as the statistical models used, to increase the transparency of the analysis process.
Include remarks on the practical implications of the results for agricultural policies and water resource management.

Keywords: Pentadal, Drought, Trend, Rainy days

1. INTRODUCTION

According to the Intergovernmental Panel on Climate Change (2007), future climate change will have a direct impact on agriculture, heightening the risks of hunger and water scarcity while accelerating the melting of icebergs. This, in turn, contributes to an increase in hydro-meteorological disasters such as floods and droughts. Ensuring the sustainable development of agriculture in India requires robust research that identifies and quantifies climate change, a key driver of rainfall variability (Meshram et al., 2017). Chandrashekar and Shetty (2018) highlight that long-term rainfall variability is primarily influenced by deforestation, global warming, and rapid urban expansion. Similarly, Karuna Sagar et al. (2017) caution that these changes will result in heavy precipitation and intense rainstorms, increasing the likelihood of natural disasters such as landslides and floods.

Drought-prone districts in India comprise nearly 1/6th of this country in terms of area. These areas receive an annual rainfall of around 60 cm or less. The Irrigation Commission of

1972 had identified nearly 67 Indian districts that were prone to droughts. These include 326 talukas situated in eight Indian states. These situations can be attributed due to human malpractices such as over-irrigation, deforestation, pollution, urbanization etc. as well as natural causes such as poor rainfall, climatic conditions, high temperature, etc. The purpose of this study was to analyze the patterns of rainfall at both the plain and hill zones of Uttarakhand so that the agromet advisories could be given more precisely to the farmers, regarding irrigation scheduling, type of crop and other management practices.

Pantnagar is the town and a university campus, Govind Ballabh Pant University of Agriculture & Technology which is the state agricultural University that lie in Udham Singh Nagar district, Uttarakhand. Nainital, Kashipur, Rudrapur and Kiccha, Haldwani are the major cities surrounding Pantnagar. The area falls under the sub-humid subtropical climate of the *Tarai* belt, located in the foothills of the Himalayas at **29.02^{0}N latitude, 79.48^{0}E longitude** and at an altitude of **244.0 m** above the mean sea level as shown in Fig. 1. In Udham Singh Nagar, Haridwar, the Gangetic plain, Pauri Garhwal and some parts of Nainital were called the *Tarai* region. Its width is from 20 to 30 km. The geographical area of the town is 3055 km^2 and it ranks 9th in Uttarakhand state.

Ranichauri is a town and a university campus, Veer Chandra Singh Garhwali Uttarakhand University of Horticulture & Forestry, formerly Uttarakhand University of Horticulture and Forestry, is a state agricultural university located in Tehri Garhwal district. It is situated about 15 km from New Tehri, 71 km from Rishikesh and 110 km from Dehradun on Rishikesh - New Tehri Road. It is **30.3^{0}N latitude**, **78.4^{0}E longitude** and at an altitude of **1864 meters** above the mean sea level as shown in figure 2. The geographical and climatic conditions of the region are considered to be suitable for different forest species, wild fruits, horticultural crops, off season vegetables, medicinal, aromatic plants, minor millets and pulses.

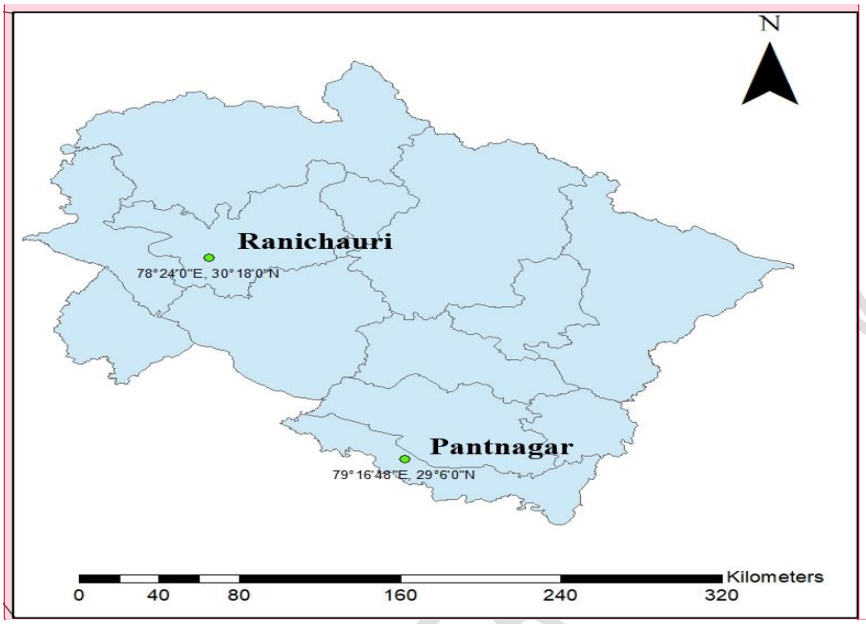

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Fig. 1. The study area depicting Pantnagar (plain) and Ranichauri (hill) regions of Uttarakhand

2. MATERIALS AND METHODOLOGY

The daily rainfall data are collected from the Agrometeorological observatory located at N. E. Borlaug Crop Research Centre, G B Pant Univ of Ag & Tech, Pantnagar (29.02^0N & 79.48^0E and altitude of 244 m) and VCSG Uttarakhand University of Horticulture & Forestry, Ranichauri (30.3^0N latitude, 78.4^0E longitude and altitude of 1864 meters) from 1981-2020 and 1985-2020 as per availability of data from 1981-2020 and 1985-2020. The statistical analysis was carried out with the following parameters using MS EXCEL and WeatherCock.

The statistical analysis like pentadal annual and seasonal rainfall changes from the average (1981-2020 for Pantnagar and 1985-2020 for Ranichauri) for these two zones has been calculated and trend can be observed by plotting the graph.

For calculation of average seasonal rainfall mainly 4 seasons were considered:

a. Southwest monsoon season (June to September month)

b. Northeast monsoon season (October & November)

c. Winter season (December to February)

d. Summer season (March to May)

WeatherCock software is developed by AICRPAM Unit of CRIDA, Hyderabad for the agroclimatic analysis of an area. Different agro-climatic analysis viz., converting daily rainfall data on to weekly, monthly, seasonal and annual data, rainy days analysis, meteorological and agricultural drought analysis. This particular software is based on Visual Basic (VB) and easy to operate even by beginners. Doing agro-climatic analysis with MS EXCEL for individual stations is drudgery and may lead to wrong results. The weathercock software reduces this drudgery and eliminates any mistakes associated with MS-EXCEL. Moreover, batch processing a special provision was made in the weathercock to facilitate to run the analysis for hundreds of stations at a moment if input files are prepared in the said format as doing agro-climatic analysis at localized scale have hundreds / thousands of stations (Sikdar et al., 2020).

2.1. Number of rainy days

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.

2.2. Drought analysis

Drought is a normal, recurrent climatic feature that occurs in virtually around the world causing huge loss for the farming community. Drought is universally acknowledged as a phenomenon associated with deficiency of rainfall. There is no single definition, which is acceptable universally. Droughts occur at random and there is no periodicity in its occurrence and cannot be predicted in advance. In semiarid stations, the occurrence of rainfall is seasonal and is known more for its variability with respect to space and time. Drought is characterized by moisture deficit resulting either from i) Below normal rainfall ii) erratic rainfall distribution iii) higher water need iv) a combination of all the three factors.

2.2.1. Meteorological drought: A period of prolonged dry weather condition due to below normal rainfall. According to India Meteorological Department 2 types: based on rainfall deficit from normal (Table 1):

Table 1. Criteria of meteorological drought condition (IMD)

Deviation (%)	Drought Condition
-25 and above	No Drought
-25 to -50	Moderate Drought
< -50	Severe Drought

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2.2.1. Agricultural drought: Agricultural impacts caused due to short-term precipitation shortages, temperature anomaly that causes increased evapotranspiration and soil water deficits that could adversely affect crop production. According to National Commission on Agriculture, 1976, at least four consecutive weeks receiving less than half of the normal rainfall during Kharif season and six such consecutive weeks during Rabi season is considered as agricultural drought period. Normal rainfall: Average rainfall for a location/region over a period of years (preferable 30 years).

In agroclimatic analysis, meteorological and agricultural drought study is important. The frequencies of occurrence of different type of meteorological droughts (moderate and severe) over a period of year would give insight for vulnerability of a particular location/region to drought on annual basis. Agricultural drought analysis would give idea about susceptibility of a region to drought on seasonal basis, i.e., main crop growing season.

Commenté [AZ4]: Please review the alignment.

2.3. Heavy Rainfall events: It calculates the frequency and amount of rainfall for the categories 25-50, 50-75, 75-100 mm and more than 100 mm occurred during annual and seasons (winter, summer, Southwest and Northeast). It also calculates highest rainfall event in a year with date (on which date) and amount of rainfall based on the daily rainfall as input file.

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3. RESULT AND DISCUSSION

The pentadal rainfall analysis has been done over the period from 1981-2020 & 1985-2020 for the plain and hill zones respectively on an annual and seasonal basis. As per the Fig. 2, there is an increasing trend in the hill zone and decreasing trend in the total annual rainfall because though the

amount of rainfall in plain zone is more but mostly it occurs during monsoon season and may sometimes leads to the water logged condition when compared to the hill zone, where there is uniform distribution of the rainfall as depicted in the Table 2. 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. If the CV is within the threshold limit of variability, it is considered that the rainfall is highly dependable and vice-versa (Manikandan et al., 2017).

The CV% is more during northeast season in Ranichauri, which means irrigation has to be provided but if we compare it with Pantnagar except in the southwest season, all other seasons has CV% > 50%, which means it has erratic distribution of rainfall. If we observe the figure 2 closely, there is a steep decreasing slope in the rainfall during 1991-95, as India experienced drought during 1992-93 (Zhang et al., 2017) so there was less rainfall comparatively. Similar steep slope could be observed in the Figs. 3, 4 and 5 which depicts the rainfall during summer, southwest and northeast season respectively.

Table 2: Descriptive seasonal and annual statistical analysis of rainfall for the plain and hill zones of Uttarakhand

Annual/ Seasons	Pantnagar		Ranichauri	
	Mean Rainfall (mm)	**CV (%)**	**Mean Rainfall (mm)**	**CV (%)**
Winter season	69.3	86.2	153.1	54.1
Summer season	91.5	73.1	190.9	41.4
Southeast season	1336.3	36.2	837.1	30.6
Northeast season	59.5	149.4	76.3	118.3
Annual	**1556.7**	**34.1**	**1257.3**	**23.3**

CV% is Coefficient of Variation in percentage

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In the Fig. 3, which shows the rainfall in the winter season, steep slope had been observed during the pentad 2006-10 because of the weak & moderate El Nino event occurred in the year 2006-07 & 2009-10 (Golden Gate Weather Services, 2023) respectively and resulting into reduced rainfall in the winter months. There is an increasing trend in the rainfall in the southwest monsoon and winter seasons and decreasing trend in the northeast monsoon (Fig. 6) and summer season for both the plain and hill zones of Uttarakhand due to western disturbance occurrences both the zones experience good amount of showers in the winter season. It has been observed as the Fig. 5, only

during southwest monsoon season amount of rainfall is more for the plain zone as compared to hill zone and else all others season opposite trend could be found. The deviation of rainfall from the mean that is depicted in the Fig. 7, also proves the reduced rainfall in the year 2009 as deviation in the rainfall due to El Nino event.

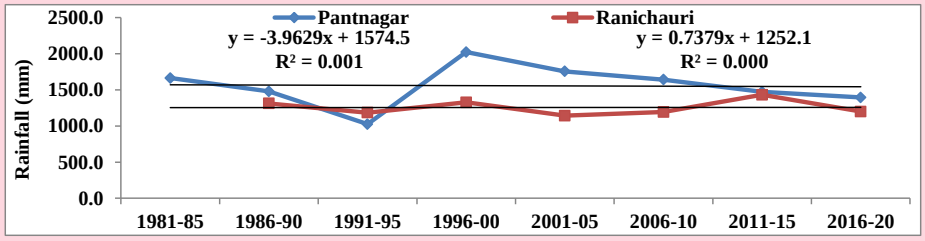

Fig. 2. Pentadal trend analysis of rainfall for both the plain and hill zones of Uttarakhand annually

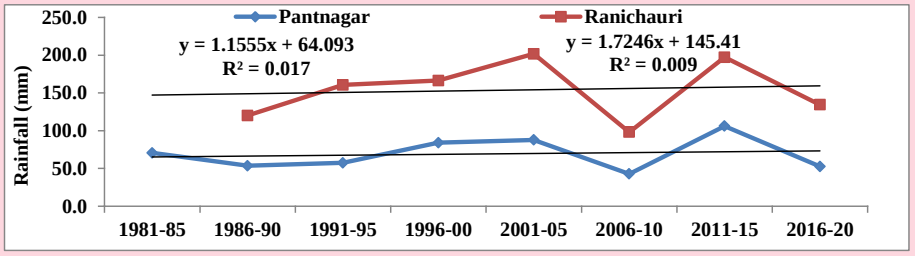

Fig. 3. Pentadal trend analysis of rainfall in the winter season for both the plain and hill zones of Uttarakhand

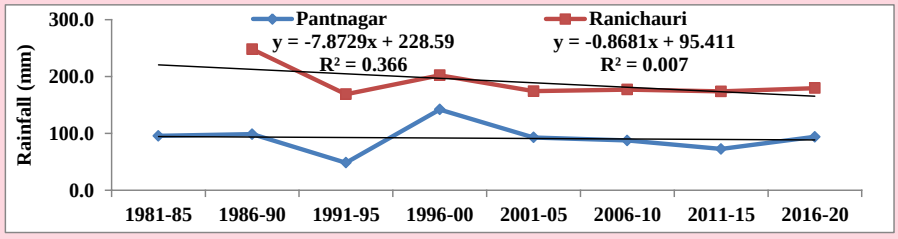

Fig. 4. Pentadal trend analysis of rainfall in the summer season for both the plain and hill zones of Uttarakhand

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- **R^2 = 0** means that the model explains none of the variance in the data.
- **R^2 = 1** means that the model explains all of the variance in the data.
The higher the R^2, the better the model is considered to explain the observed data.
However, your results show very low R^2 values. I suggest removing the "R^2" in order to maintain the scientific value of your document.

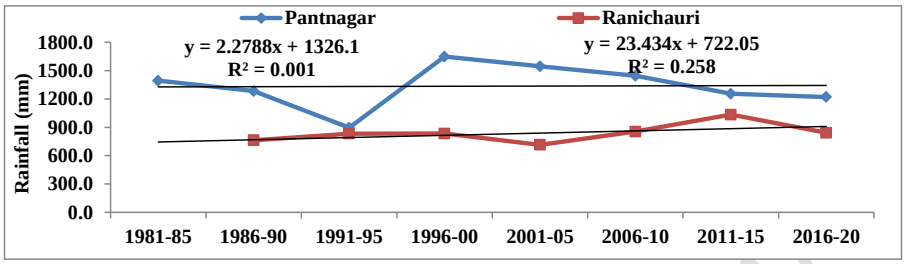

Fig. 5. Pentadal trend analysis of rainfall in the southwest monsoon season for both the plain and hill zones of Uttarakhand

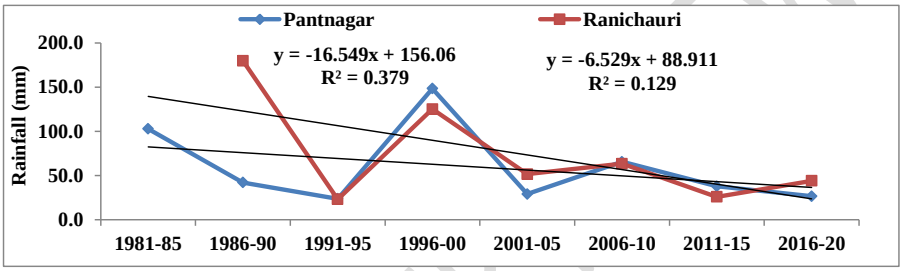

Fig. 6. Pentadal trend analysis of rainfall in the northeast monsoon season for both the plain and hill zones of Uttarakhand

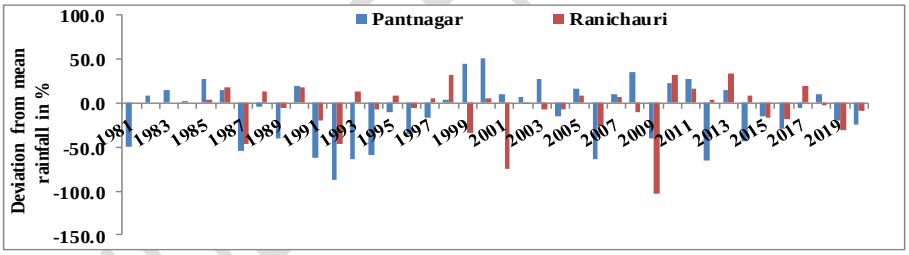

Fig. 7. Annual percent deviation from mean rainfall for both the plain and hill zones of Uttarakhand

The consolidated rainfall event was also calculated to find the frequency and no. of rainy days for the amount of rainfall in the range of 10-25, 25-50, 50-75, 75-100 mm and more than 100 mm that occurred during annual and different seasons. The frequency of rainy days within the rainfall limit of 10 < 25 mm is less in the hill region as compared to plain region (Fig. 8). If we go on increasing the rainfall limit as shown in the Fig. 9, 10, 11 & 12, then no. and frequency of rainy days decreases in the hill region and becomes almost nil for the rainfall limit of > 100 mm.

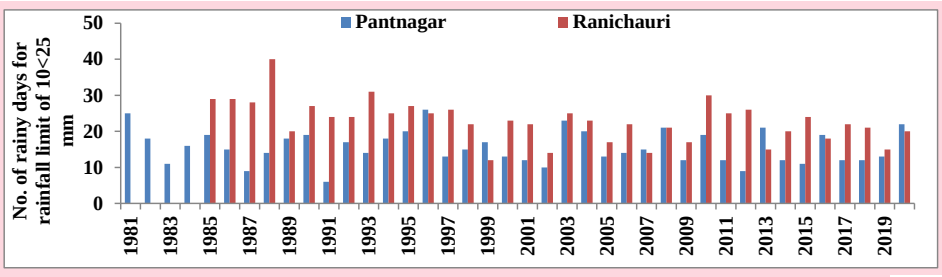

Fig. 8. Annual no. of rainy days for rainfall limit of 10 < 25 mm for both the plain and hill zones of Uttarakhand

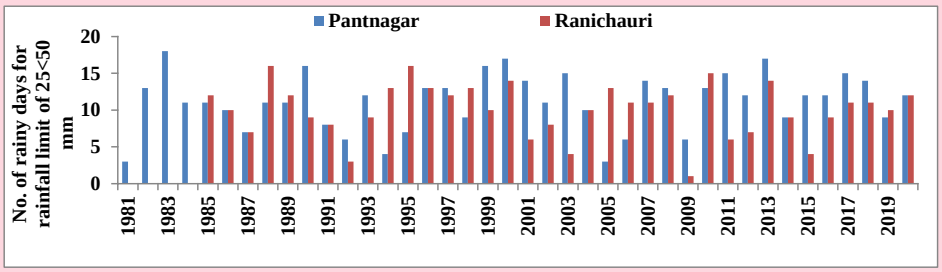

Fig. 9. Annual no. of rainy days for rainfall limit of 25 < 50 mm for both the plain and hill zones of Uttarakhand

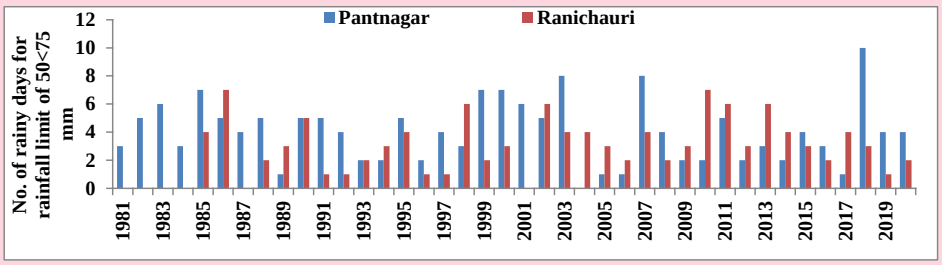

Fig. 10. Annual no. of rainy days for rainfall limit of 50 < 75 mm for both the plain and hill zones of Uttarakhand

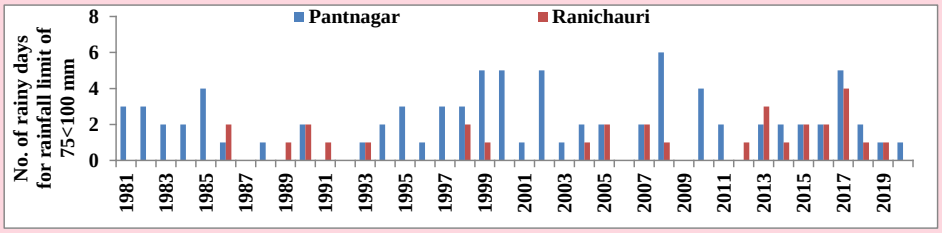

Fig. 11. Annual no. of rainy days for rainfall limit of 75 <100 mm for both the plain and hill zones of Uttarakhand

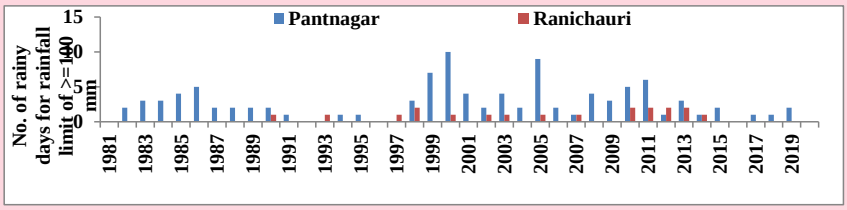

Fig. 12. Annual no. of rainy days for rainfall limit of ≤ 100 mm for both the plain and hill zones of Uttarakhand

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Similar results could be observed on the seasonal basis *i.e.*, no. of rainy days during all the seasons for the rainfall limit of 10 < 25 mm is more for the hill region as per Fig. 13 but if we observe Figs. 14 & 15 closely then it has been found that most of the rainfall was experienced in the southwest monsoon season in the plain region while in the hill region, rainfall was not only limited to southwest monsoon season but it was experienced in other seasons also at limit of 50 to < 75 mm of rainfall. It can be concluded from the above discussion that the rainfall distribution is more erratic and intense during southwest monsoon season in the plain region (Figs. 16 & 17) as compared to hill region, which is detrimental for the soil health and may get eroded. So the crops can be grown throughout the year in the hill region with minimal irrigation or water harnessed from natural springs while subsequent irrigation has to be provided for crops growth and productivity in the plain region.

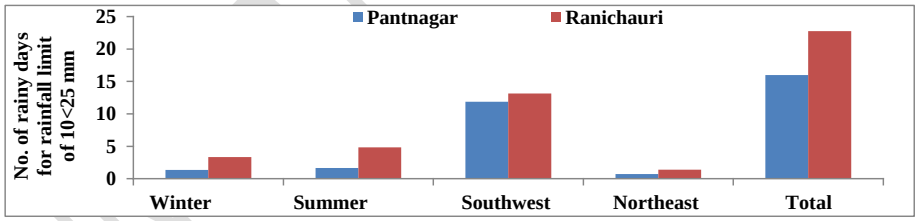

Fig. 13. Seasonal no. of rainy days for rainfall limit of 10 < 25 mm for both the plain and hill zones of Uttarakhand

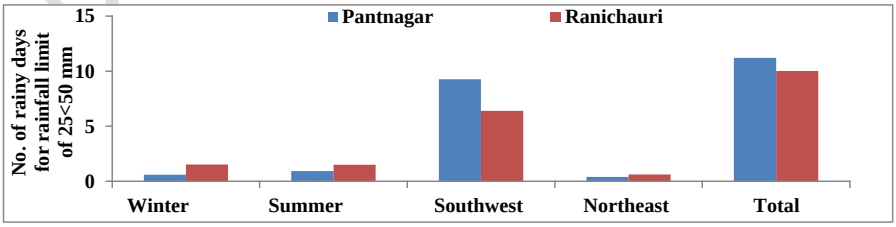

Fig. 14. Seasonal no. of rainy days for rainfall limit of 25 < 50 mm for both the plain and hill zones of Uttarakhand

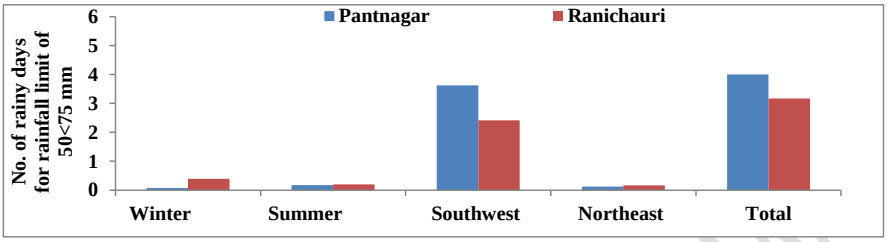

Fig. 15. Seasonal no. of rainy days for rainfall limit of 50 < 75 mm for both the plain and hill zones of Uttarakhand

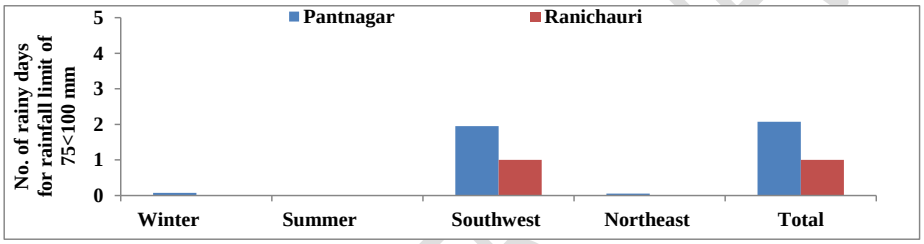

Fig. 16. Seasonal no. of rainy days for rainfall limit of 75 <100 mm for both the plain and hill zones of Uttarakhand

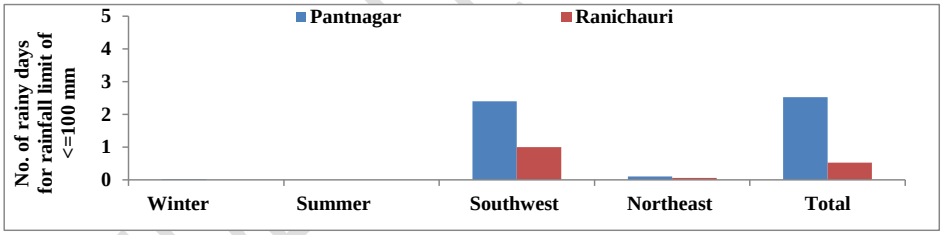

Fig. 17. Seasonal no. of rainy days for rainfall limit of ≤ 100 mm for both the plain and hill zones of Uttarakhand

The meteorological drought condition was also analyzed for both plain and hill zones of Uttarakhand in terms of percentage of year having particular type of drought based on the deviation of rainfall as per criteria given by IMD discussed above in the Table 1. It had been found that no. of years having moderate drought condition is more in the plain region when compared with the hill region (Table 3). In the hill region one out of the study years *i.e.*, in the year 2009 the deviation in the rainfall is less than -50 % due to El Nino year as explained before, so there was severe drought of 3% in the hill region.

Table 3. Meteorological drought condition for both plain and hill zones of Uttarakhand

Drought Condition	Pantnagar		Ranichauri	
	No. of years	Drought (%)	No. of years	Drought (%)
No Drought	28	70	32	89
Moderate Drought	12	30	3	8
Severe Drought	0	0	1	3
Total	40	-	36	-

Commenté [AZ9]: Absence of source.

In the Table 4, Agricultural drought condition in the kharif season has been depicted and it had been observed that there is drought mostly occurs in the northeast monsoon and summer season as consecutively for four weeks (Kharif Drought) there is no or less rainfall which could not compensate the water requirement of the crops for both the plain and hill zones of Uttarakhand. The irrigation scheduling can be done *i.e.*, the decision of when and how much water to apply to a field. Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level. Irrigation scheduling saves water and energy as well as shifting towards more suitable crop, time of sowing and varieties can be done. Agricultural operations are determined by the certain amount of rainfall received in a period. There are specific amounts of rainfall required for the activities like land preparation, sowing and for various agricultural activities.

Table 4. Agricultural Drought condition for both for both plain and hill zones of Uttarakhand in the Kharif season

Commenté [AZ10]: Without a source, the table has no scientific value.

Year	Drought week	
	Pantnagar	Ranichauri
1981	35 - 38	N.A.
1982	25 - 28, 36 - 40	N.A.
1983	22 - 25	N.A.
1984	39 - 42	N.A.
1985	-	-
1986	-	-
1987	37 - 42	37 - 41
1988	39 - 42	24 - 27, 36-42

1989	39 - 42	-
1990	-	26 - 29, 38-42
1991	25 - 30, 38-42	22 - 27, 38-42
1992	-	-
1993	33 - 38	37 - 42
1994	34 - 42	38 - 42
1995	37 - 42	-
1996	-	-
1997	-	-
1998	35 - 38	-
1999	-	39 - 42
2000	39 - 42	30 - 42
2001	38 - 42	27 - 30
2002	38 - 42	22 - 25, 37-42
2003	-	-
2004	-	22 - 25, 32-36
2005	22 - 25	33 - 37
2006	24 - 27	22 - 25
2007	-	-
2008	-	23 - 28, 30-35
2009	-	39 - 42
2010	-	38 - 42
2011	38 - 42	22 - 25, 39-42
2012	22 - 27, 39-42	-
2013	-	23 - 26, 37-42
2014	32 - 39	33 - 37
2015	33 - 37, 39-42	36 - 42
2016	39 - 42	-
2017	22 - 25, 39-42	-

2018	-	34 - 38
2019	37 - 42	36 - 42
2020	38 - 42	-

4. CONCLUSION

This study indicated contrasting rainfall trends in both regions. While Pantnagar received higher total rainfall, most of it is concentrated in the southwest monsoon season, often leading to waterlogging. Conversely, Ranichauri experiences a more uniform distribution across seasons. The coefficient of variation (CV%) suggests higher rainfall variability in Pantnagar, particularly outside the monsoon season, making rain-fed agriculture less dependable. Analysis of rainy days shows that smaller rainfall events (10-25 mm) are more frequent in the plains, whereas heavier rainfall events (>100 mm) are rare in the hills. Seasonal analysis confirms that monsoonal rainfall dominates the plains, while the hills receive more evenly spread rainfall, supporting year-round cropping with minimal irrigation. Drought analysis indicated that, agricultural drought occurred during northeast monsoon and summer seasons for both the regions of Uttarakhand.

The findings highlight the need for region-specific water management strategies. In Pantnagar, excess monsoonal rainfall requires improved drainage and soil conservation, whereas Ranichauri relatively stable rainfall favoured diversified cropping with rainwater harvesting. Given the erratic rainfall trends, tailored advisories for irrigation scheduling, crop selection, and soil conservation are crucial to mitigate climate-induced risks in both agro-climatic zones.

5. REFERENCES

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Manikandan, M., Gurusamy, T., Bhuvaneswari, J., & Prabhakaran, N. (2017). Wet and Dry Spell

Commenté [AZ11]: The research is limited to a specific period (Pantnagar: 1981-2020, Ranichauri: 1985-2020), which may not fully reflect long-term climate trends or extreme weather events beyond this duration. Moreover, the analysis does not provide detailed information on the statistical significance of the results or the techniques used to examine the trends, a crucial aspect for assessing the credibility and robustness of the conclusions. Similarly, the idea that farming in Ranichauri is supported year-round with minimal irrigation due to a "uniform" distribution of precipitation might overlook local variations or factors such as soil type, crop variety, or agricultural methods that could influence water requirements. Nonetheless, the work offers a relevant study of climate trends and their impacts on agriculture, with practical advice likely to aid in better water resource management and more climate-resilient farming.

Commenté [AZ12]: The references should be expanded.

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