Original Research Article

Analysis of Temperature Trends and Frequency of Cold and Heat Waves in Plain and Hill Zones of Uttarakhand

ABSTRACT

The study analyzes temperature trends in Uttarakhand's plain (Pantnagar: 1981–2020) and hill (Ranichauri: 1985–2020) zones using Weather Cock software to assess climate suitability for crop growth. Maximum and minimum temperature trends were examined seasonally and annually, revealing a decreasing temperature range in the plains due to declining maximum and increasing minimum temperatures, while the hill zone exhibited an increasing temperature range. This trend may lead to delayed crop maturity and reduced yield in the plains, whereas forced maturity and grain shrinkage in the hills. Seasonal analysis showed declining maximum temperatures in all seasons except Zaid in the plains, while hills experienced increasing trends except in Zaid due to pre-monsoon showers. Frequency analysis indicated more severe heat waves in hills and cold waves in plains. The observed temperature shifts, along with changes in heat unit accumulation impacts the crop productivity. The range of maximum and minimum temperature for the plain and hill zone is 39-46^{0}C & 24-33^{0}C and -1 to 8^{0}C & -3 to 5^{0}C respectively. The frequency of heat and cold waves were also assessed on daily, monthly and annual basis.

Keywords: Weather Cock, Markov Chain, MAI, WATBAL, Thornthwaite, PET

INTRODUCTION

The Climate is continuously changing with time due to natural as well as anthropogenic forces. In the post-industrialization era, there is an unprecedented change in the climate due to above stated two factors. Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals (IPCC, 2023).

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The changes in climate are likely to impact the developing countries significantly, where natural resource dependency is high (Kumar *et al.,* 2018). Plant growth is dependent on precipitation and temperature. The temperatures were consistently 3°C-8°C above normal for more than 6 days during the month of March and April 2022 breaking many decadal and some all-time records in several parts of the country, including the western Himalayas, the plains of Punjab, Haryana, Delhi, Rajasthan and Uttar Pradesh. The states of Odisha, Madhya Pradesh, Gujarat, Chhattisgarh, Telangana and Jharkhand also experienced heat waves, in some areas severe, with temperatures ranging from 40°C–44°C towards end of March. The heat wave conditions continued into April, reaching its preliminary peak towards the end of the month. Heat waves also increase the risk of forest-fires. By April 29, almost 70 percent of India was affected by the heat wave. Towards the end of April and in May, the heat wave extended into the coastal areas and eastern parts of India (IMD, 2022).

Extreme weather events have become remarkably more evident in recent decades like heat waves and cold waves. They may last from a few days to a few weeks, depending on the geography and climatology of the region. In the study conducted by (Bhattacharya *et al.,* 2023) frequency of the occurrence of heat waves increased by about 0.6 events per decade, while cold waves decreased by about 0.4 events per decade. Although most of northwest India is highly vulnerable to heat wave conditions, central peninsular India is also experiencing frequent heat waves in the recent decade. Concurrently, the average duration of cold waves decreased over montane, arid and semi-arid, and tropical wet and dry climate zones.

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 figure 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

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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.

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

The study has been conducted of the climate suitable for the growth and development of crop. The two stations have been selected as a sample study *i.e.*, Pantnagar for plain zone and Ranichauri for hill zones of Uttarakhand. The analysis of mainly temperature has been done which has direct impact on the crop yield. Hence to strengthen and supplement the existing data of information an attempt has been made to study the climatic variability over plain and hill zones of Uttarakhand.

MATERIALS AND METHODOLOGY

The weather 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^{0}N & 79.48^{0}E and altitude of 244 m) and VCSG Uttarakhand University of Horticulture & Forestry, Ranichauri (30.3^{0}N latitude, 78.4^{0}E longitude and altitude of 1864 meters) from 1981-2020 and 1985-2020 as per availability of data from 1981-2020 and 1985-2020 of the following parameters namely-

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Maximum Temperature (ºC) and Minimum temperature (ºC). The statistical analysis was carried out with the following parameters using MS EXCEL, WeatherCock:

The statistical analysis like pentadal annual and seasonal temperature 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 temperature mainly 3 crop seasons were considered:

a. Kharif season (June to September)
b. Rabi season (October to February)
c. Zaid 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 weather data on to weekly, monthly, seasonal and annual data, rainy days analysis, meteorological and agricultural drought analysis, probability analysis, water balance, extreme event analysis for temperature and rainfall and to estimate length of growing season have been brought out in to one umbrella (Rajavel *et al.*, 2022). 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).

Cold Wave: Criteria for Cold Wave (Source IMD)

a. When normal minimum temperature is equal to 10°C or more.

Cold Wave Departure from normal is -5°C to -6°C.

Severe Cold Wave Departure from normal is -7°C or less

b. When normal minimum temperature is less than 10°C.

Cold Wave Departure from normal is -4°C to -5°C.

Severe Cold Wave Departure from normal is -6°C or less.

c. Cold Wave should be declared when minimum temperature is 0°C or less and normal minimum temperature is above 0°C. Input as daily minimum temperature should be given and software will give the frequency of cold wave and severe cold wave.

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Heat Wave: Criteria for Heat Wave (Source IMD)

Heat wave need not be considered till maximum temperature of a station reaches at least 40º C for Plains and at least 30º C for Hilly regions.

a. When normal maximum temperature of a station is less than or equal to 40º C

Heat Wave Departure from normal is 5º C to 6º C

Severe Heat Wave Departure from normal is 7º C or more

b. When normal maximum temperature of a station is more than 40º C

Heat Wave Departure from normal is 4º C to 5º C

Severe Heat Wave Departure from normal is 6º C or more

c. When actual maximum temperature remains 45ºC or more irrespective of normal maximum temperature. Input as daily maximum temperature should be given and software will give the frequency of heat wave and severe heat wave.

Minimum and Maximum temperature analysis: It is used to calculate the frequency and date of occurrence of particular range of maximum and minimum temperature based on the daily temperature range.

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RESULT AND DISCUSSION

The pentadal trend in the maximum and minimum temperature has been analyzed over the period from 1981-2020 & 1985-2020 for the plain and hill zones respectively on an annual and seasonal basis. In the plain zone, there is a declining trend in the maximum temperature and increasing trend in the minimum temperature as depicted in the figure 2 while as per the figure 3 there is an increasing trend in the maximum temperature and decreasing trend in the minimum temperature for the hill zone. So it can be concluded that range of temperature for the plain zone is decreasing which would decrease the yield of the crop as it leads to late maturity and crop duration increases (Hatfield *et al*., 2015) while opposite occurs in case of hill zones as depicted in the figure 4, where range of temperature increases on an annual basis thereby leads to increase in the heat units thus causes forced maturity and shrinkage of the grains, resulting in reduced crop yield.

The study conducted on the apple orchards of Himachal Pradesh, data catalogued from different time periods indicates that the northward shift (towards higher altitude *i.e.* orchards have shifted to 1500–2500 meters in the 2000s compared to the cultivated elevation of 1200–1500 meters during 1980s) is due to changes in chilling hours, total annual rainfall and mean surface

temperature during the apple growing season (Sahu *et al.*, 2020). These changes are directly related to global warming.

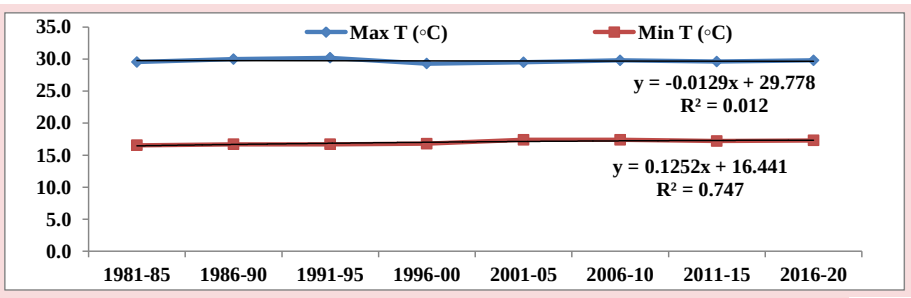

Figure 2: Pentadal trend analysis of maximum and minimum temperature in the plain zone of Uttarakhand over the period from 1981-2020 annually

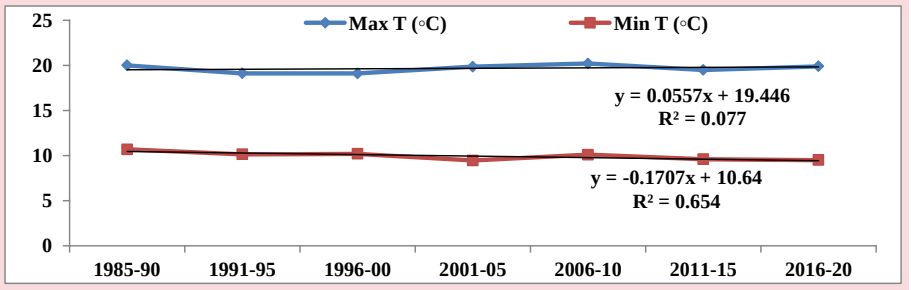

Figure 3: Pentadal trend analysis of maximum and minimum temperature in the hill zone of Uttarakhand over the period from 1985-2020 annually

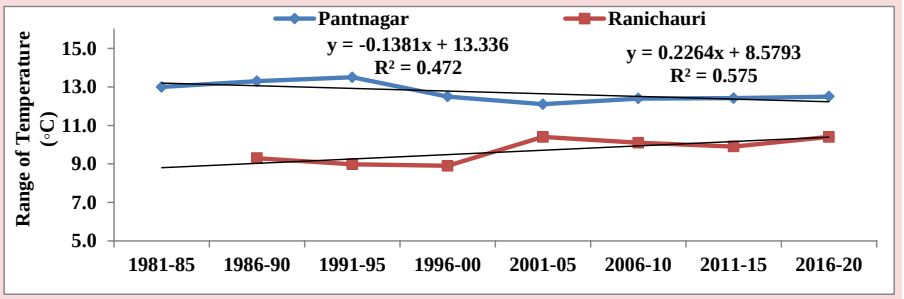

Figure 4: Pentadal trend analysis of range of temperature for both the plain and hill zones of Uttarakhand annually

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Similarly there is a decreasing trend in the maximum temperature during all the crop seasons except in the Zaid seasons (March – May) i.e. during the summer months in the plain zone whereas, there is an increasing trend in the maximum temperature in all the seasons except in the

Zaid season due to good pre monsoon showers in the hill zone thereby, decreasing the maximum temperature when compared with the plain zone as depicted in the figure 5 & 6. Similar trend has been observed in the minimum temperature during all the cropping seasons i.e., increasing and decreasing trend for the plain & hill zones respectively as per the figure 8, 9, 11, 12. The range of temperature is decreasing in the plain zone and increasing in the hill zone during all the cropping seasons as depicted in the figure 7, 10, 13 and it is more constant in the kharif season as per figure 10, because of less fluctuations in the temperature during monsoon season in both plain and hill zones of Uttarakhand.

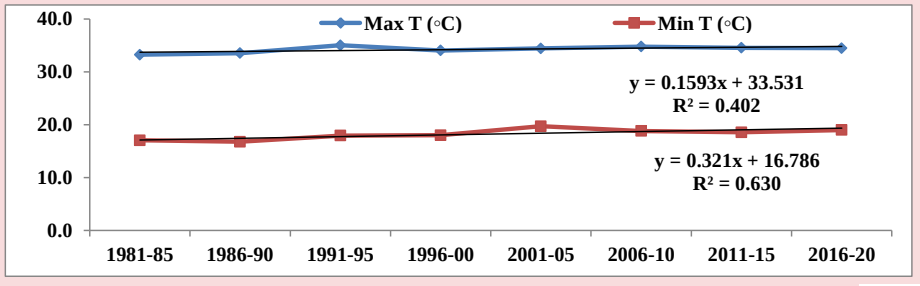

Figure 5: Pentadal trend analysis of maximum and minimum temperature in the Zaid season for plain zone of Uttarakhand

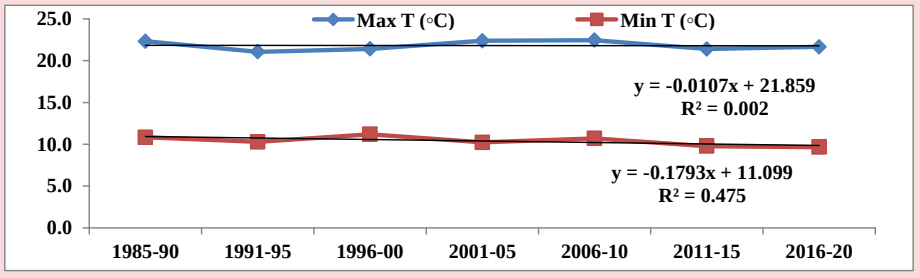

Figure 6: Pentadal trend analysis of maximum and minimum temperature in the Zaid season for hill zone of Uttarakhand

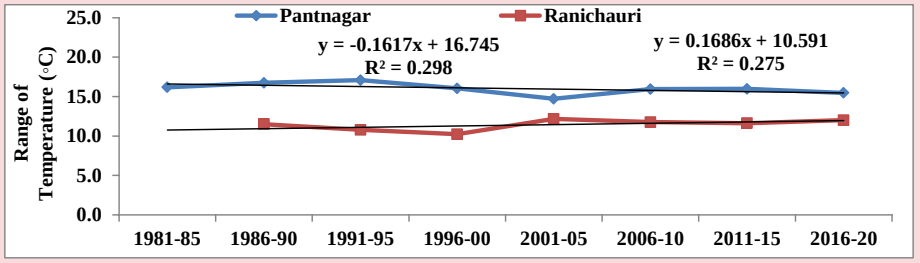

Figure 7: Pentadal trend analysis of range of temperature in the Zaid season for

both the plain and hill zones of Uttarakhand

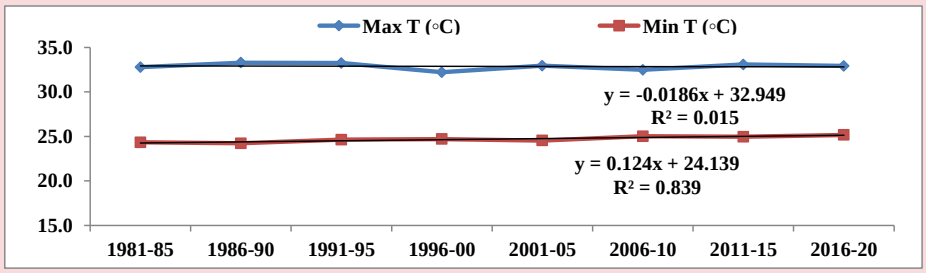

Figure 8: Pentadal trend analysis of maximum and minimum temperature in the Kharif season for plain zone of Uttarakhand

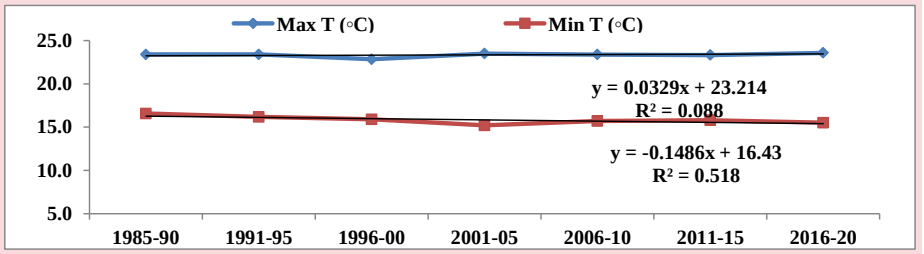

Figure 9: Pentadal trend analysis of maximum and minimum temperature in the Kharif season for hill zone of Uttarakhand

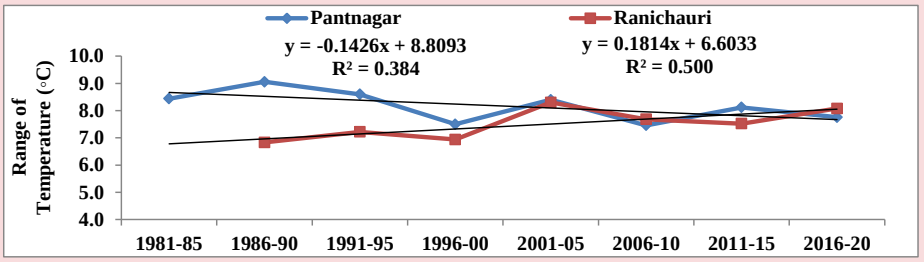

Figure 10: Pentadal trend analysis of range of temperature in the Kharif season for both the plain and hill zones of Uttarakhand

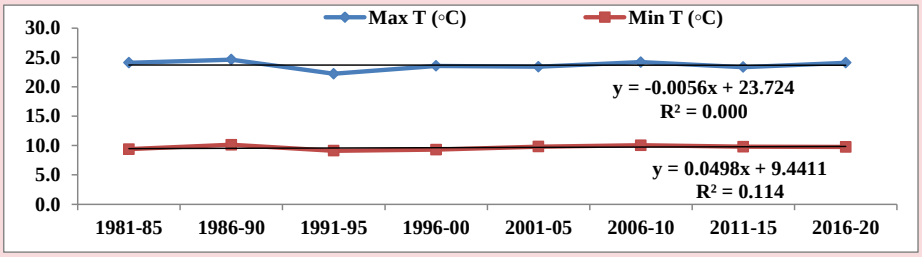

Figure 11: Pentadal trend analysis of maximum and minimum temperature in the Rabi

season for plain zone of Uttarakhand

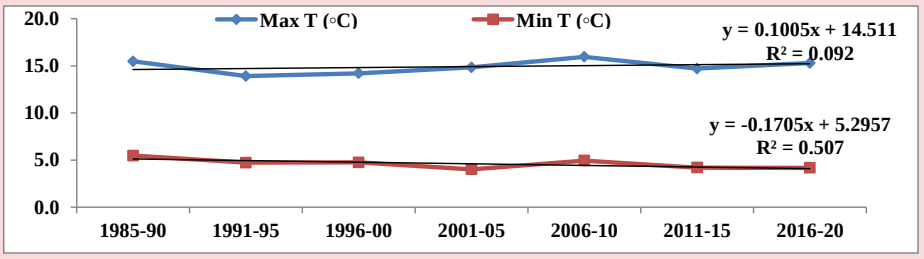

Figure 12: Pentadal trend analysis of maximum and minimum temperature in the Rabi season for hill zone of Uttarakhand

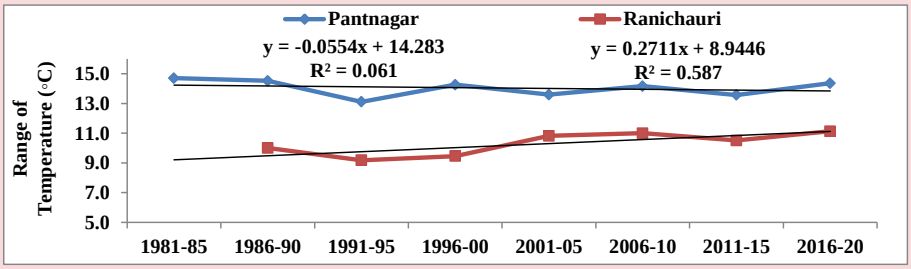

Figure 13: Pentadal trend analysis of range of temperature in the Rabi season for both the plain and hill zones of Uttarakhand

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If we examine the deviation of maximum temperature from mean as per the figure 14 in both the plain and hill zones of Uttarakhand then also similar results as above could be observed *i.e.*, more positive deviation in the Tmax was experienced annually in the hill region as compared to plain region and similarly, for the deviation of minimum temperature from mean as depicted in the figure 15 more positive deviation in the Tmin was observed in the plain region as compared to hill region, which also proves that range of temperature is decreasing in the plain region while it is increasing in the hill region of Uttarakhand.

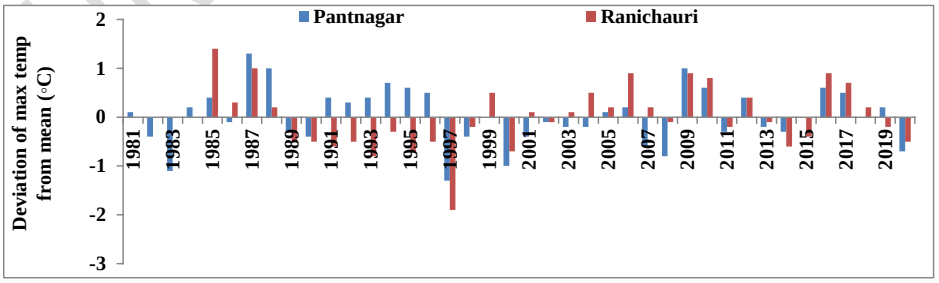

Figure 14: Annual percent deviation of Tmax for both the plain and hill zones of Uttarakhand

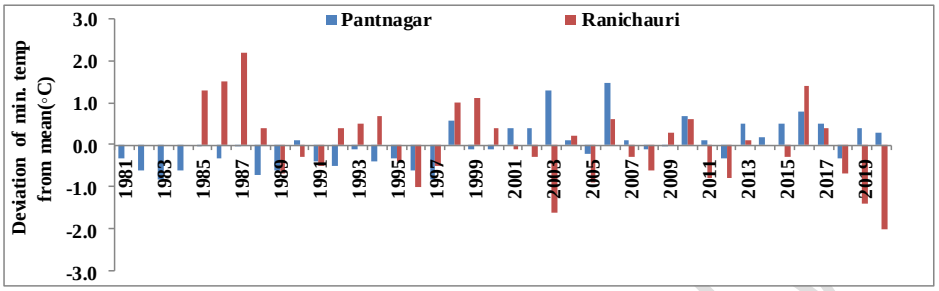

Figure 15: Annual percent deviation of Tmin for both the plain and hill zones of Uttarakhand

The frequencies of severe heat and cold waves was also analyzed by examining the deviation in the maximum and minimum temperature from the normals and accodingly criteria has been given to declare severe and moderate heat wave or cold wave as explained above. If we observe the figure 16 & 17 closely, then it has been found that frequency of severe heat waves is more in the hill region as compared to plain region because of more fluctuations in the maximum temperature for the hill region as stated above in the figure 14. Similarly, frequency and periodicity of severe cold waves was more in plain region as compared to hill region as shown in the figure 18 & 19 due to more deviation in the minimum temperature for the plain region as depicted above in the figure 15.

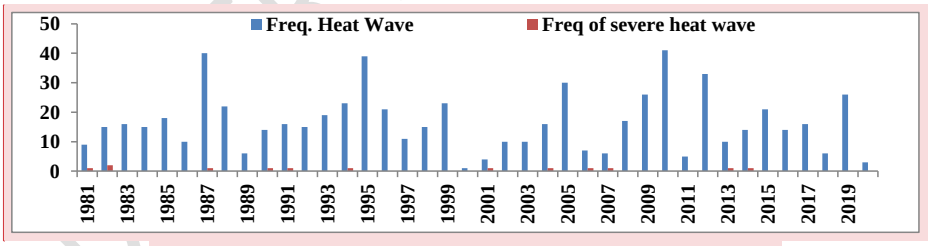

Figure 16: Frequency of heat waves in plain zone of Uttarakhand

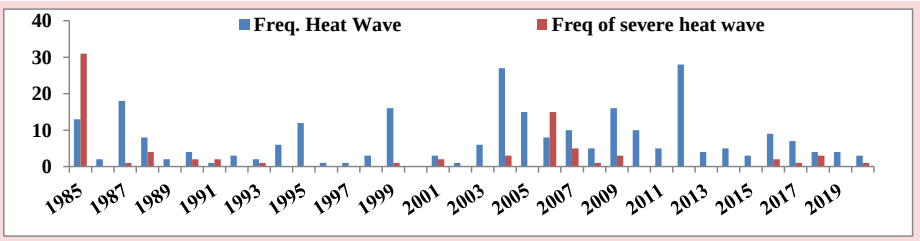

Figure 17: Frequency of heat waves in hill zone of Uttarakhand

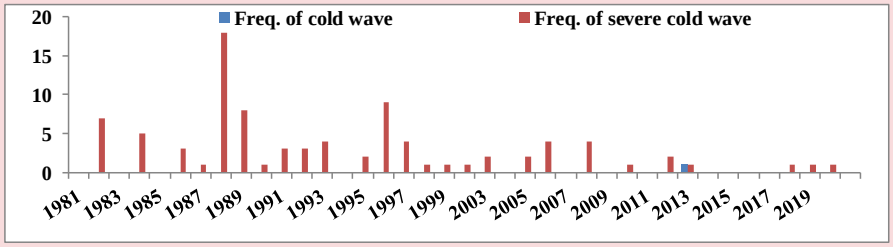

Figure 18: Frequency of cold waves in plain zone of Uttarakhand

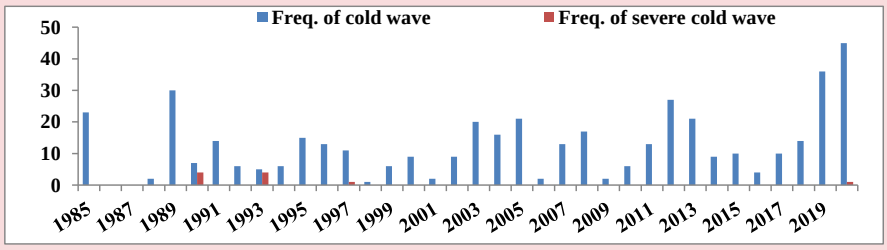

Figure 19: Frequency of cold waves in hill zone of Uttarakhand

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The range of maximum and minimum temperature was also analyzed for both plain and hill zones for Uttarakhand which is beneficial for deciding the cropping pattern and seasons of the particular region. It was examined based on the frequency in terms of days having that particular temperature out of the total study years. So, the range of maximum temperature and minimum temperature is 38-42^{0}C & 24-30^{0}C and 8-3^{0}C & 4 to -1 ^{0}C in the plain and hill region of Uttarakhand respectively as per the table 1 & 2. As we know range of temperature is very much important for the proper physiological growth of the crop and in deciding the date of sowing and type of crop to be grown so accordingly we can suggest the crops to the farmers for better productivity (Zhang *et al*., 2017).

Table 1: Frequency of maximum and minimum temperature for plain zone of Uttarakhand

Range of T max (◦C)	Frequency (days)	Range of T min (◦C)	Frequency (days)
> 38	1222	**> 8**	2348
> 39	828	**> 7**	1734
> 40	545	**> 6**	1242
> 41	309	**> 5**	786
> 42	137	**> 4**	438
> 43	40	**> 3**	200
> 44	9	**> 2**	75
> 45	2	**> 1**	17
> 46	1	**> 0**	1
> 47	0	**> -1**	0

Table 2: Frequency of maximum and minimum temperature for hill zone of Uttarakhand

Range of T max (◦C)	Frequency (days)	Range of T min (◦C)	Frequency (days)
≥ 24	2751	**≥ 4**	2627
≥ 25	1811	**≥ 3**	1908
≥ 26	1169	**≥ 2**	1313
≥ 27	748	**≥ 1**	818
≥ 28	448	**≥ 0**	441
≥ 29	247	**≥ -1**	202
≥ 30	112	**≥ -2**	78
≥ 31	37	**≥ -3**	27
≥ 32	14	**≥ -4**	4
≥ 33	0	**≥ -5**	0

CONCLUSION

The temperature anomalies is more for the hill zone as compared to the plain zone of Uttarakhand. The periodicity of the severe heat wave is more for the hill region as compared to the plain region and periodicity of severe cold wave is more for the plain region as compared to the hill zone of Uttarakhand. In the plains, a decreasing trend in maximum temperature and an increasing trend in minimum temperature indicate a narrowing temperature range, which prolongs crop maturation and reduces yield due to delayed physiological processes. Conversely,

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in the hills, the increasing trend in maximum temperature and decreasing trend in minimum temperature led to an expanding temperature range, resulting in forced maturity, grain shrinkage, and yield reduction.

Seasonal analysis further highlights distinct trends, with the plains experiencing decreasing maximum temperatures across all crop seasons except Zaid, while in the hills, an increasing trend is observed in all seasons except Zaid due to pre-monsoon showers. Minimum temperature trends mirror these patterns, reinforcing the contrast between the two regions. Deviations from mean temperature further validate these findings, with the hills showing higher positive deviations in Tmax and the plains showing higher positive deviations in Tmin. The frequency of extreme weather events also supports this trend, with severe heat waves being more prevalent in the hills due to Tmax fluctuations, while severe cold waves are more frequent in the plains due to Tmin deviations. The analysis of temperature frequency ranges suggests that the plains experience Tmax between 38–42°C and Tmin between 8–3°C, while the hills exhibit Tmax between 24–30°C and Tmin between 4 to -1°C. These findings are crucial for optimizing cropping patterns, sowing dates, and varietal selection to enhance productivity under changing climatic conditions.

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