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Studies on Variation of Temperature and Rainfall using Climatological Data for the Plain and Hill Zones of Uttarakhand

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ABSTRACT

The present study examines long-term annual, seasonal and monthly changes and short-term fluctuations in monsoonal rainfall and temperature over plain and hill zones of Uttarakhand. Both rainfall and temperature data for period of 1981-2020 were analyzed in this study. Statistical trend analysis techniques namely Mann–Kendall test and Sen's slope estimator were used to examine and analyze the problems. The detailed analysis of the data for 40 years indicates that the annual range of temperature is increasing in the hill zone. In the context of agriculture, the observed trends in temperature and rainfall patterns pose significant implications for farming practices and crop yields in Uttarakhand. The increasing annual range of temperature, particularly in the hill zone, suggests a heightened risk of temperature extremes such as heat waves and cold spells. During the monsoon season, while rainfall levels may remain relatively stable or exhibit minor fluctuations, the variability highlighted by the box and whisker plots underscores the importance of preparedness for both excess and deficit rainfall scenarios.

Keywords Mann-Kendall, Sen's slope, Trend analysis, Climatic variability.

INTRODUCTION

For a variety of reasons, including water resource management, hydrological modeling, and climate change research, quantitative estimation of the spatial distribution of rainfall and temperature is needed anticipating floods, researching climate change, and water balance calculations, modeling soil moisture for agricultural productivity, scheduling irrigation. Among the most important effects of global warming because of an increase in the uncertainty of the rainfall would be caused by greenhouse gases and geographical distribution and temperature variation temporally. It is relevant in the context of climate change to determine if the change is noticeable in the Indian setting also (Yadav *et al.* 2014).

The rainfall and temperatures (Singh *et al.* 2013) are the most important fundamental physical parameters among the climate as these parameters determine the environmental condition of the particular region

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which affects the agricultural productivity. Long-term rainfall patterns may alter due to global climate change, which could affect water supply and increase the risk of droughts and floods (Pal and Mishra 2017). Any region's food security, energy security, and agriculture are critically dependent on timely access to sufficient water supplies and a hospitable environment (Panda and Sahu 2019).

Indian summer monsoon rainfall is critical for the availability of fresh water for drinking and irrigation, agricultural production, power generation, water resources management and the overall economy of the country (Das *et al.* 2014). The analysis of various time series data has demonstrated that both the trend in temperature and rainfall is either declining or increasing. Changes in land use brought on by the effects of agriculture and irrigation techniques are another example of how human interference is contributing to climate change (Kalnay and Cai 2003). Impact of climate change in future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change (Mondal *et al.* 2012).

MATERIALS AND METHODS

The weather data were collected from the agrometeorological observatory located at N. E. Borlaug Crop Research Center, GB Pant Univ of Ag and Tech, Pantnagar (29.02^{0}N and 79.48^{0}E and altitude of 244 m) and VCSG Uttarakhand University of Horticulture and Forestry, Ranichauri (30.3^{0}N latitude, 78.4^{0}E longitude and altitude of 1864 meters) as presented below in the Fig. 1, from 1981-2020 and 1985-2020 as per availability of data from 1981-2020 and 1985-2020 of the following parameters namely- maximum temperature (ºC), minimum temperature (ºC), rainfall (mm/day), rainy days and sunshine hours (hrs.). The statistical analysis was carried like maximum, minimum, mean, coefficient of variation, standard deviation, skewness and kurtosis was worked out with the following parameters on an annual, monthly and seasonal basis using MS EXCEL, WeatherCock and R studio software.

The trend analysis was done to detect the presence of increasing or decreasing trend using the regression equation and coefficient of determination (R^2) computed on the graph as well as by the non-parametric Mann-Kendall test and magnitude of trend was determined by Sen's slope estimator test. The trend analysis is done on the annual and seasonal basis. The fluctuations in the monthly temperature and rainfall was presented by box and whisker plot.

Mann–Kendall trend test

The Mann-Kendall non-parametric test was used to evaluate the trend in rainfall or precipitation and temperature for each individual station (Mann 1945, Kendall 1975). The Mann-Kendall test is a rank-based method for detecting trends in rainfall, temperature, sunshine hours, and evaporation that has been used in many previous researches. This is one of the most effective approaches for determining rainfall and tem-

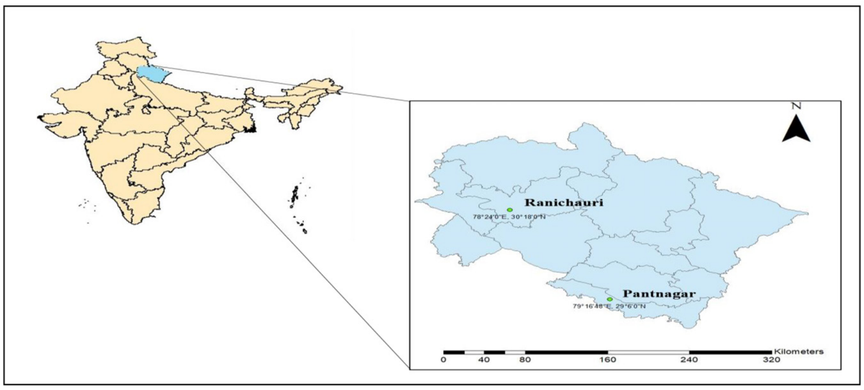

Fig. 1. The study area depicting Pantnagar (plain) and Ranichauri (hill) regions of Uttarakhand.

perature trends. The trend analysis for the historical period, i.e., observed data of rainfall and temperature from 1981 to 2020 was carried out in this work on an annual and seasonal basis. As an ordered time series, the data values were evaluated. Each data value was compared to the data values that came after it.

$$\sigma^2 \text{ or Var (S)} = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} tp\,(tp-1)\,(2\,tp+5)\right]$$

Where, g is the number of tied (zero difference between compared values) groups, and tp is the number of data values in the p^{th} group. The values of S and VAR(S) are used to compute the standard normal deviation (Z value) as:

$$Z = S-1/\sigma \quad \text{if } S>0$$
$$Z = 0 \quad \text{if } S=0$$
$$Z = S+1/\sigma \quad \text{if } S<0$$

A very high positive value of Z is an indicator of an increasing trend, and a negative value indicates a decreasing trend, when Z value lies between +1.96 to -1.96 then null hypothesis is accepted, and when the value of $Z > +1.96$ or $Z < -1.96$ then null hypothesis (H_0) is rejected at 95% confidence level.

For calculation of Mann Kendall's different parameters Rstudio software is used.

Sen's slope estimator test

The trend magnitude is calculated by slope estimator methods. The slope (Qi) between two data points is given by the Sen's equation (1968):

$$Qi = X_j - X_k \,/\, j-k, \text{ for } i = 1, 2, 3 \ldots N$$

Where X_j and X_k are data points at time j and k (j > k), respectively. When there is only a single datum in each time then, $N = n(n-1)/2$; n is several periods. However, if the amount of data in each year are many then $N < n(n-1)/2$; n is the total number of observations. The N values of the slope estimator are arranged from smallest to biggest.
Then, the median of slope (β) is computed as:

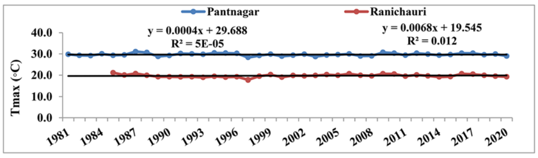

Fig. 2. Trend analysis of annual T_{max} variation in the plain and hill zones of Uttarakhand.

$$\beta = \frac{QN+1}{2} \quad \text{if n is Odd}$$

$$\beta = \tfrac{1}{2}\,\{(QN/2) + (QN+2/2)\} \quad \text{if n is Even}$$

The positive sign shows increasing trend whereas the negative sign shows a decreasing trend.

RESULTS AND DISCUSSION

Annual trend analysis

The annual trend analysis reveals notable patterns in three key weather parameters across Uttarakhand: Maximum Temperature (T_{max}), Minimum Temperature (Tmin) and Rainfall. T_{max} exhibits an increasing trend in both the plain and hill regions of Uttarakhand, with increments of 0.002^{0}C and 0.01^{0}C per year, respectively (Figs. 2–4). This gradual rise in Tmax may have significant implications, particularly for agriculture, potentially accelerating crop maturation due to heightened heat units. Conversely, T_{min} displays a declining trend specifically in the hill region,

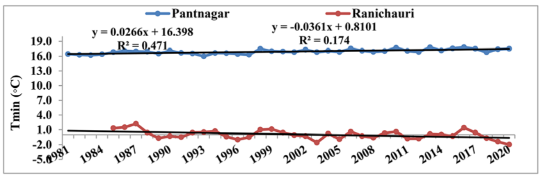

Fig. 3. Trend analysis of annual T_{min} variation in the plain and hill zones of Uttarakhand.

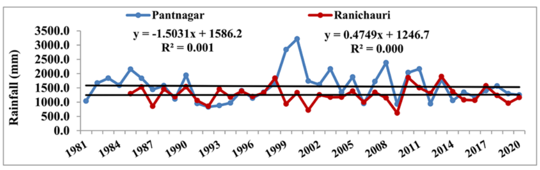

Fig. 4. Trend analysis of annual rainfall variation in the plain and hill zones of Uttarakhand.

Table 1. Annual descriptive Mann Kendall test analysis in plain and hill zones of Uttarakhand.

	Pantnagar				Ranichauri			
Weather parameters	Mann-Kendall statistic (Z)	Sen's slope (β)	p value	Trend significance at 95% confidence level	Mann-Kendall statistic (Z)	Sen's slope (β)	p value	Trend significance at 95% confidence level
Tmax (⁰C/year)	0.2	0.00	0.85	NS Increasing	0.8	0.01	0.43	NS Increasing
Tmin (⁰C/year)	3.9	0.03	0.00	S Increasing	-2.7	-0.04	0.03	S Decreasing
Rainfall (mm/year)	-0.3	-1.74	0.74	NS Decreasing	0.3	1.32	0.73`	NS Increasing

indicative of an expansion in the temperature range (T_{max}-T_{min}). This widening range could potentially impact agricultural cycles, prompting crops to mature earlier and potentially reducing yields. Interestingly, findings from Murthy *et al*. (2004) echo this phenomenon, reporting opposing trends in T_{max} and T_{min} for the Ranichauri region during the period of 1982-2002.

In terms of rainfall, there's a discernible trend of increasing precipitation by approximately 1.32 mm annually in the hill region, contrasting with a decrease of 1.74 mm per year in the plain region of Uttarakhand (Table 1) with a mean rainfall of 1257.3 mm and 1555.4 mm respectively (Table 2). Notably, the variability in rainfall is more pronounced in the plain region. Further examination of the data reveals a significant peak in rainfall around the year 2000, coinciding with a La Nina event, as documented by ggweather.com/enso. This event led to widespread flooding across North India, underlining the impact of larger climate phenomena on regional weather patterns. Overall, these trends underscore the complex interplay of various factors influencing Uttarakhand's climate, with implications ranging from agricultural practices to disaster preparedness.

Seasonal trend

It is evident from the results obtained from the Table 3, that there is declining trend in the maximum temperature because of good amount of rainfall in the plain region of Uttarakhand during the monsoon and winter season (Figs. 5–7) while in the hill region, an increasing trend in the Tmax occurs during all

Table 2. Annual descriptive statistical analysis in plain and hill zones of Uttarakhand.

Statistical parameters	T_{max}(◦C) Pantnagar	Ranichauri	T_{min}(◦C) Pantnagar	Ranichauri	Rainfall (mm) Pantnagar	Ranichauri
Maximum	31.1	21.1	17.8	2.2	3217.0	1894.2
Minimum	28.3	17.8	16.0	-2.0	831.0	617.8
Mean	29.7	19.7	16.9	0.0	1555.4	1257.3
SD	0.6	0.7	0.7	0.9	528.1	288.8
CV%	2.00	3.28	4.00	-	33.95	23.0

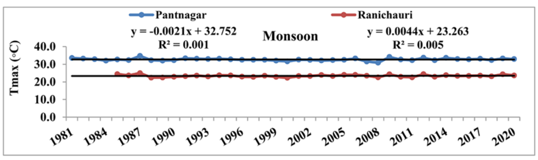

Fig. 5. Trend analysis of T_{max} variation for monsoon season in the plain and hill zones of Uttarakhand.

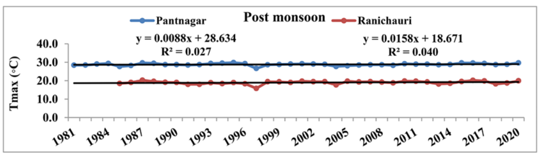

Fig. 6. Trend analysis of T_{max} variation for post monsoon season in the plain and hill zones of Uttarakhand.

Table 3. Seasonal descriptive Mann Kendall test analysis of T_{max} in the plain and hill zones of Uttarakhand.

Tmax (°C) seasons	Pantnagar				Ranichauri			
	Mann-Kendall statistic (Z)	Sen's slope (β)	p value	Trend significance at 95% confidence level	Mann-Kendall statistic (Z)	Sen's slope (β)	p value	Trend significance at 95% confidence level
Monsoon	-0.4	0.00	0.69	NS Decreasing	0.9	0.01	0.36	NS Increasing
Post monsoon	1.1	0.01	0.27	NS Increasing	1.5	0.02	0.14	NS Increasing
Winter	-1.7	-0.03	0.10	NS Decreasing	0.9	0.02	0.39	NS Increasing
Summer	0.8	0.02	0.42	NS Increasing	-0.5	-0.01	0.61	NS Decreasing

the seasons (Fig. 6) except summer season (Fig. 8) because of declination in the sunshine hours as well as this region experiences good amount of rainfall in the pre monsoon season. Similar results were reported by (Yadav *et al.* 2014) as they analyzed trend analysis of precipitation and temperature by Mann Kendall for Uttarakhand. As expected the highest maximum temperature is in the summer season followed by monsoon season in the plain region while in the hill region highest maximum temperature occurs in the monsoon season when compared with the summer season (Table 4) because of inclination in the trend of sunshine hours during monsoon season (Fig. 9) in the hill region. It has been observed that there is a

Table 4. Characterstics of temperature in the plain and hill zones of Uttarakhand.

Seasons	Maximum temperature(°C)		Minimum temperature (°C)		Mean temperature (°C)	
	Pantnagar	Ranichauri	Pantnagar	Ranichauri	Pantnagar	Ranichauri
Monsoon	32.9	23.4	24.7	15.8	28.8	19.6
Post monsoon	26.1	17.4	11.5	6.6	18.8	12.0
Winter	21.8	12.5	7.9	2.7	14.9	7.6
Summer	34.2	21.8	18.2	10.3	26.2	16.1
Annual	**29.7**	**19.7**	**17.0**	**10.1**	**23.4**	**14.9**

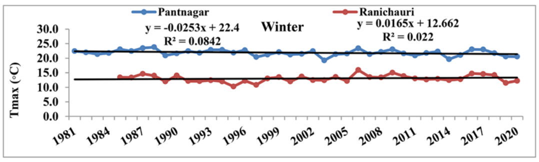

Fig. 7. Trend analysis of T_{max} variation for winter season in the plain and hill zones of Uttarakhand.

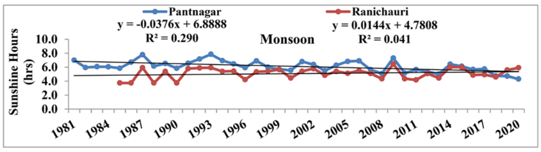

Fig. 9. Trend analysis of sunshine hours for monsoon season in the plain and hill zones of Uttarakhand.

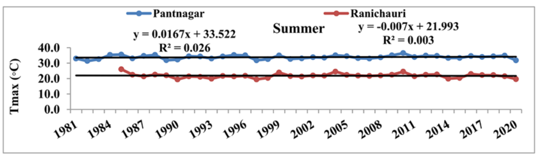

Fig. 8. Trend analysis of T_{max} variation for summer season in the plain and hill zones of Uttarakhand.

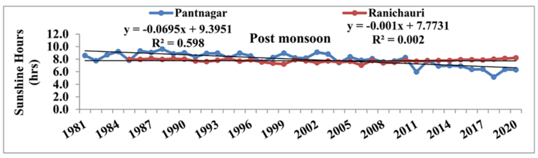

Fig. 10. Trend analysis of sunshine hours for post monsoon season in the plain and hill zones of Uttarakhand.

Table 5. Seasonal descriptive Mann Kendall test analysis of T_{min} in the plain and hill zones of Uttarakhand.

Tmax (°C) seasons	Pantnagar Mann-Kendall statistic (Z)	Sen's slope (β)	p value	Trend significance at 95% confidence level	Ranichauri Mann-Kendall statistic (Z)	Sen's slope (β)	p value	Trend significance at 95% confidence level
Monsoon	5.1	0.03	0.00	S Increasing	-1.9	-0.03	0.05	NS Decreasing
Post monsoon	1.3	0.02	0.18	NS Increasing	-2.5	-0.05	0.01	S Decreasing
Winter	2.6	0.03	0.01	S Increasing	-1.7	-0.04	0.09	NS Decreasing
Summer	2.4	0.02	0.02	S Increasing	-1.1	-0.03	0.28	NS Decreasing

Table 6. Characterstics of rainfall in the plain and hill zones of Uttarakhand.

Seasons	Mean rainfall (mm)		Rainy days		Coefficient of variation (CV %)	
	Pantnagar	Ranichauri	Pantnagar	Ranichauri	Pantnagar	Ranichauri
Monsoon	1336.3	837.1	44	43	36	31
Post monsoon	59.5	76.3	3	4	149	118
Winter	69.3	153.1	4	9	86	54
Summer	91.5	190.9	7	14	73	41
Annual	**1556.7**	**1257.3**	**57**	**70**	**34**	**23**

declination in the trend of sunshine hours during all the seasons in the plain region (Figs. 9–12) while there is an increasing trend during monsoon and winter season as expected due to rainfall and fog in the hill region of Uttarakhand. Over all if we observe, then there is a difference of 10°C in the mean maximum temperature in both of these zones of Uttarakhand.

The opposite trend has been observed for the minimum temperature during all the seasons for both of these regions. As per the Table 5, there is a significant increasing trend during all the seasons of about 0.03°C and 0.02°C except during post monsoon which has non-significant increasing trend in the plain zone while a decreasing trend (Figs.13–16) in the hill

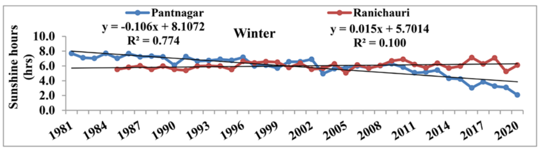

Fig. 11. Trend analysis of sunshine hours for winter season in the plain and hill zones of Uttarakhand.

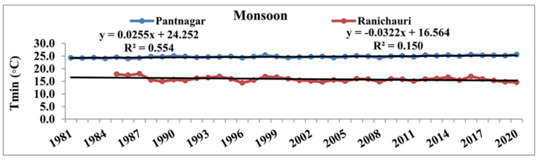

Fig. 13. Trend analysis of T_{min} variation for monsoon season in the plain and hill zones of Uttarakhand.

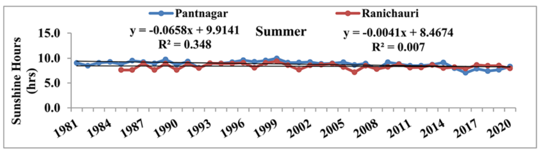

Fig. 12. Trend analysis of sunshine hours for summer season in the plain and hill zones of Uttarakhand.

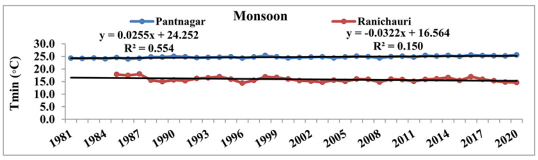

Fig. 14. Trend analysis of T_{min} variation for post monsoon season in the plain and hill zones of Uttarakhand.

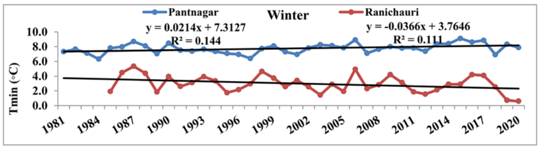

Fig. 15. Trend analysis of T_{min} variation for winter season in the plain and hill zones of Uttarakhand.

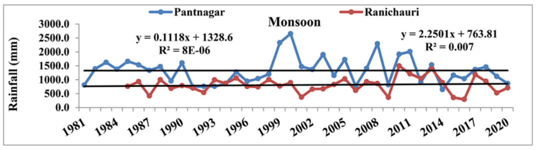

Fig. 17. Trend analysis of rainfall variation for monsoon season in the plain and hill zones of Uttarakhand.

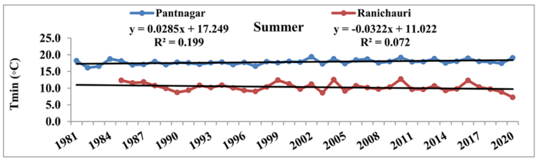

Fig. 16. Trend analysis of T_{min} variation for summer season in the plain and hill zones of Uttarakhand.

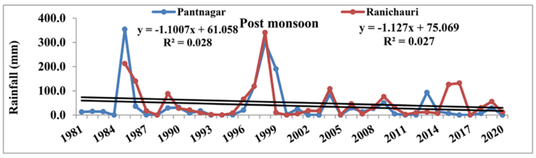

Fig. 18. Trend analysis of rainfall variation for post monsoon season in the plain and hill zones of Uttarakhand.

regions of Uttarakhand. So the range of temperature is less in the plain region during monsoon and winter season due to inclination the Tmax in these seasons which leads to the late maturity of the crops while in the hill region during the post monsoon season there is significant decrease in the Tmin of about 0.05°C (Table 5) and increase in Tmax of about 0.02°C (Table 4) so the range of temperature increases thus leading to early maturity and decreased productivity of crops especially vegetable crops which are more affected by variation in the temperature. Similar results were reported by Ayankojo and Morgan (2020) as worked on increasing air temperatures and its effects on growth and productivity of tomato in the South Florida. As there is less variation in the Tmax and Tmin during monsoon season so the highest minimum temperature occurs in both of these zones (Table 4).

The amount of rainfall is more in the plain region (1557 mm) when compared with the hill region (1257 mm) of Uttarakhand as per the Table 6 but most of it is limited to the monsoon season and about 86% of the annual rainfall is contributed by this season followed by 6% in the summer season, 4.5% in the winter season and 3.5% in the post monsoon season in the plain zone. In the hill zone, no. of rainy days (>2.5 mm) is about 13 days more than the plain region and about 67% of rainfall is contributed by the monsoon season followed by 15% in the summer season, 12% in the winter season and 6% in the post

Table 7. Seasonal descriptive Mann Kendall test analysis of rainfall in the plain and hill zones of Uttarakhand.

Rainfall (mm) Seasons	Pantnagar				Ranichauri			
	Mann-Kendall statistic (Z)	Sen's slope (β)	p value	Trend significance at 95% confidence level	Mann-Kendall statistic (Z)	Sen's slope (β)	P value	Trend significance at 95% confidence level
Monsoon	0.1	0.71	0.89	NS Increasing	0.9	4.48	0.38	NS Increasing
Post monsoon	-0.9	-0.03	0.35	NS Decreasing	-1.2	-1.11	0.24	NS Decreasing
Winter	-0.9	-0.69	0.35	NS Decreasing	-0.4	-0.52	0.67	NS Decreasing
Summer	-0.7	-0.56	0.46	NS Decreasing	-1.1	-1.75	0.26	NS Decreasing

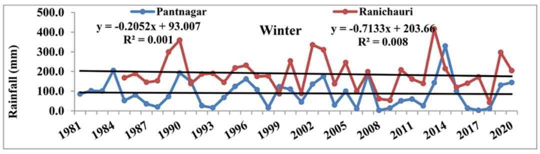

Fig. 19. Trend analysis of rainfall variation for winter season in the plain and hill zones of Uttarakhand.

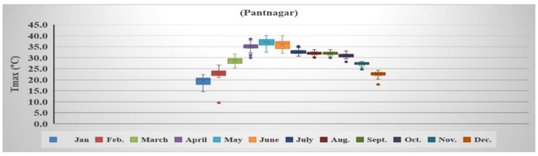

Fig. 21. Box and whisker plot of monthly maximum temperature (°C) in the plain zones of Uttarakhand from 1981-2020.

monsoon season. So overall we can conclude that the distribution of rainfall is more uniform in the hill region of Uttarakhand and off season vegetables can be grown easily as there is good amount of soil moisture in this region.

The coefficient of variation (CV) serves as a crucial indicator of rainfall dependability, with established threshold levels for different timescales. According to Manikandan *et al*. (2017), thresholds are set at < 25% for annual, < 50% for seasonal, < 100% for monthly, and < 150% for weekly rainfall. In the plain region, the CV of annual rainfall exceeds the threshold at 34%, indicating less dependability for crop growth. Proper irrigation is recommended for all seasons except monsoon, where the CV is 36%. Conversely, in the hill region, mean annual rainfall is dependable across seasons except post-monsoon, with a CV of 23%. However, the post-monsoon CV of 118% (Table 6) is significantly higher than the 50% threshold, suggesting less reliability.

Furthermore, a decreasing trend in rainfall is observed across all seasons except during the monsoon, as depicted in Figs 17–20. The Sen's slope indicates a more pronounced increase in monsoon rainfall in the hill zone (4.48) compared to the plain zone (0.71) of Uttarakhand (Table 7). This trend aligns with a similar study conducted by Bora *et al.* (2022) on long-term rainfall analysis in seven states of North East India, employing non-parametric methods. These findings highlight the variability and regional nuances in rainfall patterns, emphasizing the need for tailored agricultural and water management strategies to mitigate the impacts of changing precipitation trends.

Monthly trend analysis

Rainfall and temperature are crucial factors determining water availability in a region, making it imperative for researchers and policymakers to consider meteorological fluctuations when making decisions. Box and whisker plots, introduced by Tukey (1977), are utilized to effectively showcase changes in monthly rainfall. These plots offer a condensed format for comparing multiple datasets, facilitating easier interpretation compared to more complex visualizations like histograms (Banacos 2011). They provide a straightforward representation of statistical distribution, accessible to various stakeholders. The seasonal (July, August, and September) maximum and minimum temperatures exhibit a decreasing trend coinciding with peak rainfall in both the plain and hill regions of Uttarakhand. Conversely, in the

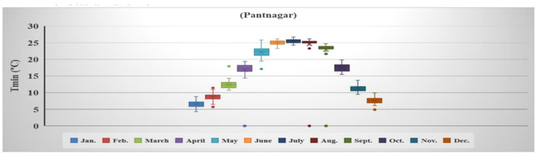

Fig. 22. Box and whisker plot of monthly minimum temperature (°C) in the plain zones of Uttarakhand from 1981-2020.

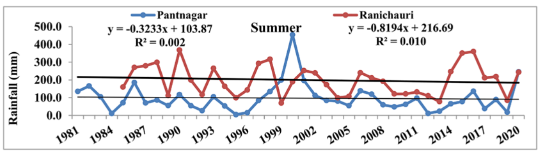

Fig. 20. Trend analysis of rainfall variation for summer season in the plain and hill zones of Uttarakhand.

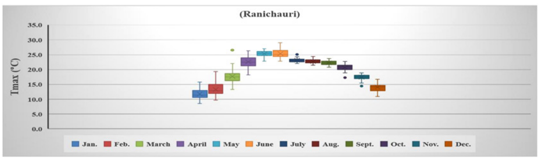

Fig. 23. Box and whisker plot of monthly maximum temperature (°C) in the hill zones of Uttarakhand from 1981-2020.

Table 8. Characteristics of climatic parameters and its variability in the plain zone of Uttarakhand.

Month	Maximum temperature				Minimum temperature				Rainfall			
	Mean (°C)	CV%	Sk	Ku	Mean (°C)	CV%	Sk	Ku	Mean (mm)	CV%	Sk	Ku
Jan	19.8	9.2	-0.8	0.0	6.7	15.2	-0.2	-0.1	31.2	106.8	1.1	0.5
Feb	24.0	11.0	-3.6	19.0	9.2	17.8	6.2	6.2	38.1	123.0	1.4	0.9
Mar	29.7	5.6	-0.1	0.5	13.3	10.5	1.9	1.9	20.3	127.5	1.5	1.3
Apr	35.8	5.1	-0.4	1.5	18.3	6.4	-0.1	-0.1	19.8	118.0	1.7	1.9
May	37.3	4.3	-0.3	0.2	23.1	7.7	-0.9	-0.9	51.4	115.4	2.9	11.4
Jun	35.3	5.8	-0.1	-0.9	25.0	2.8	-0.3	-0.3	191.1	75.6	1.6	2.6
Jul	32.4	3.1	0.9	0.6	25.5	2.0	0.0	0.0	440.9	39.1	0.4	-0.3
Aug	32.2	2.5	-0.2	0.4	25.1	2.0	-1.3	-1.3	448.7	45.1	1.1	2.8
Sept	31.7	2.5	-0.3	0.1	23.1	3.0	-0.6	-0.6	255.7	72.9	1.2	0.8
Oct	30.5	3.2	-0.6	1.4	16.1	6.3	0.0	0.0	38.9	210.0	2.8	7.4
Nov	26.5	2.6	-1.2	2.1	10.7	8.8	0.6	0.6	4.3	191.9	2.1	3.5
Dec	21.4	5.3	-1.5	4.2	7.5	14.7	-0.1	-0.1	16.4	151.5	2.1	3.9

CV%: Coefficient of variation, Sk: Skewness, Ku: Kurtosis.

pre and post-monsoon months, temperatures show an increasing pattern (Figs. 21–24).

In the plain zone of Uttarakhand, average monthly maximum and minimum temperatures show relatively stable patterns over the studied period, with coefficients of variation (CV) ranging from 2.5% to 11% for maximum temperature and 2.0% to 17.8% for minimum temperature (Table 8). However, both maximum and minimum temperatures display the highest coefficient of kurtosis in February, indicating negative skewness. In the hill zone, the variability is less for maximum temperature (CV < 20%), ranging from 2.7% to 15.2%, while minimum temperature

Table 9. Characteristics of climatic parameters and its variability in the hill zone of Uttarakhand.

Month	Maximum temperature				Minimum temperature				Rainfall			
	Mean (°C)	CV%	Sk	Ku	Mean (°C)	CV%	Sk	Ku	Mean (mm)	CV%	Sk	Ku
Jan	11.8	14.8	0.5	-0.3	2.1	77.8	0.4	-0.5	59.7	67.6	0.5	0.0
Feb	13.3	15.2	0.7	0.7	3.3	44.8	0.8	0.6	93.4	78.6	1.0	0.9
Mar	17.7	13.7	1.3	4.0	6.7	24.1	0.1	0.2	73.3	75.8	0.7	-0.3
Apr	22.6	7.6	0.0	0.4	10.6	14.6	0.4	-0.7	44.3	73.8	1.9	4.9
May	25.3	4.2	-0.5	-0.3	13.5	10.1	-0.2	-0.7	73.2	59.8	0.7	0.1
Jun	25.4	6.5	0.3	-0.6	15.7	7.1	0.2	-1.1	128.9	78.5	2.2	6.9
Jul	23.1	2.7	0.6	1.2	16.7	4.8	-0.1	-0.5	294.7	39.9	-0.3	-0.8
Aug	22.7	2.8	0.4	-0.2	16.4	5.5	0.9	0.8	276.7	40.6	-0.1	0.0
Sept	22.2	3.1	0.0	-0.4	14.6	7.2	0.6	1.8	136.9	82.1	1.9	3.8
Oct	20.7	4.9	-0.9	2.3	10.1	12.0	0.4	0.1	31.0	212.9	3.3	12.3
Nov	17.4	5.2	-1.1	2.1	6.4	16.9	0.1	0.9	11.9	187.6	1.9	2.7
Dec	14.1	9.6	0.0	-0.4	3.4	36.7	-0.2	-0.1	33.4	132.9	1.9	4.2

CV%: Coefficient of variation, Sk: Skewness, Ku: Kurtosis.

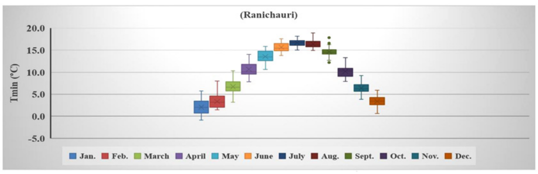

Fig. 24. Box and whisker plot of monthly minimum temperature (°C) in the hill zones of Uttarakhand from 1981-2020.

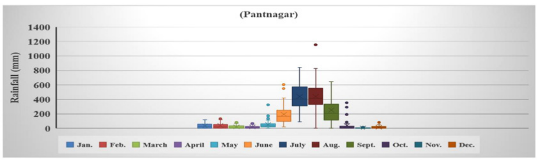

Fig. 25. Box and whisker plot of monthly rainfall (mm) in the plain zones of Uttarakhand from 1981-2020.

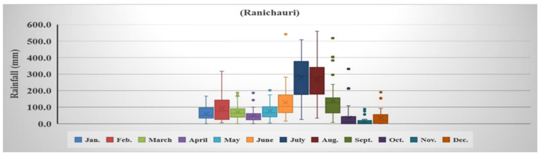

Fig. 26. Box and whisker plot of monthly rainfall (mm) in the hill zones of Uttarakhand from 1981-2020.

exhibits extremely high variability (CV > 40%), ranging from 4.8% to 77.8% (Table 9). The highest CV for maximum temperature is in February (15.2%), while for minimum temperature, it occurs in January (77.8%). In contrast to temperature, rainfall variability is much higher in both regions (Figs. 25–26). All months except the monsoon season exhibit CVs above 100%, indicating high precipitation variability during pre-monsoon and post-monsoon periods. This highlights the unpredictability of rainfall in the plain zone. In the hill zone, however, all months except the post-monsoon season have CVs below 100%, indicating comparatively less variability and higher dependability of rainfall throughout the year.

CONCLUSION

The two most crucial climatic variables are temperature and rainfall, as over 80% of the region's agricultural output depends on it. The climate data for Uttarakhand's plains and hills were examined in this study. We utilized the nonparametric Mann Kendall test and Sen's slope estimator, two popular tests for trend analysis, to examine the time series. The box and whisker plots are used to display the variability analysis, monthly rainfall, maximum temperature, and minimum temperature. In contrast to the variability of maximum temperature and minimum temperature, which is essentially the same for all months when compared to rainfall, the plots reveal a significantly maximum quantity of rainfall in monsoonal months, which are June to September in the plain as well as hill zones of Uttarakhand. To suggest that the plain area in particular is highly susceptible to the significant influences of climate variability mainly the rainfall variability and as rainfall is the main driver of agricultural growth in the studied region hence its extreme occurrence during the monsoon and variability is higher in the post and pre-monsoon months while in the hill zone the rainfall is almost uniform throughout the year.

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