Optimizing Resource Planning via Seasonal Weather Analysis in Climate-Sensitive Regions

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Abstract

Climate variability significantly influences agricultural productivity, water availability, and environmental planning worldwide. Understanding seasonal fluctuations can help address budgeting, planning, and resource allocation issues in advance. This study presents a comprehensive analysis of temperature and rainfall patterns in District Rajouri, Jammu and Kashmir (India) for the year 2023, emphasizing seasonal variability and its implications for short-term agricultural and water resource planning. Monthly data, including maximum and minimum temperatures, rainfall, relative humidity, sunshine duration, wind speed, and evapotranspiration, were collected from the Indian Meteorological Department (IMD), Krishi Vigyan Kendra at Tandwal, Rajouri. Using descriptive statistics and graphical tools in Python, seasonal fluctuations in various weather parameters were analysed. The findings highlight significant intra-annual variability, with peak temperatures and evapotranspiration during pre-monsoon months and maximum rainfall during the monsoon season. While the study focuses on a single year and avoids long-term seasonal variability interpretations, insights provide valuable information for short-term agricultural and water resource planning. The study recommends future research incorporating multi-decadal datasets for seasonal variability assessment. The study also evaluates the interrelationship among key meteorological parameters using statistical analysis to better understand seasonal climatic behaviour and its implications for agricultural and water resource planning.

Keywords: Temperature patterns; Rainfall analysis; Station-Level climate data; Agricultural planning; Water resource management; Python data analysis.

1. Introduction

Seasonal variability in meteorological conditions plays a critical role in shaping agricultural productivity, water availability, and ecosystem stability, particularly in climatically sensitive and topographically complex regions. Mountain-influenced areas governed by monsoon dynamics often experience pronounced intra-annual fluctuations in temperature, rainfall, humidity, and related weather parameters. Understanding these seasonal patterns is essential for informed decision-making in agriculture, irrigation scheduling, and short-term water resource planning.

In regions where livelihoods are closely tied to rain-fed agriculture and local hydrological systems, short-term climatic variability can significantly influence crop yields and water security. Despite the increasing availability of meteorological observations, the absence of localized seasonal assessments limits the effective translation of weather data into actionable planning strategies. This challenge is particularly acute in climatically heterogeneous regions where broad-scale climate summaries may fail to capture local variability.

Previous studies across India and the Himalayan region have primarily focused on long-term climatic seasonal variability using multi-decadal datasets. While these studies provide valuable insights into climate change, limited recent investigations have examined short-term, station-level seasonal behaviour using recent observational data. Moreover, many existing studies emphasize seasonal variability detection rather than providing detailed seasonal baselines that can support immediate agricultural and water management needs.

To address this gap, the present study analyses monthly meteorological observations for the year 2023 to characterise seasonal and intra-annual variability in temperature, rainfall, humidity, sunshine duration, wind speed, and evapotranspiration. The study aims to answer the following research question: *How do seasonal meteorological patterns vary within a single year in a monsoon-influenced, climatically sensitive region, and what implications do these patterns have for short-term agricultural and water resource planning?* By focusing on seasonal behaviour rather than long-term trends, the study provides a realistic and methodologically appropriate assessment.

The scientific contribution of this study lies in establishing a high-resolution seasonal baseline using recent station-level observations. While not intended for climate seasonal variability inference, the findings offer practical insights for seasonal decision-making and complement long-term climate studies by providing contemporary context. The study demonstrates how descriptive statistical analysis and visualisation can support applied climate assessments at local scales. The analysis is intentionally confined to intra-annual variability and does not attempt to detect climate trends. The year 2023 was selected as the observational period because continuous meteorological data from the installed automatic weather monitoring system in the study area were fully available for this year. Although climatological studies generally rely on long-term datasets, the present work aims to provide a detailed baseline assessment of seasonal meteorological variability for the region using high-resolution observations. This baseline assessment can serve as a reference for future multi-year comparative studies.

The paper is organised as follows: Section 2 reviews relevant literature; Section 3 describes the study area and methodology; Section 4 presents the results; Section 5 discusses the findings in relation to previous studies; Section 6 outlines recommendations; and Section 7 concludes the study.

2. Literature Review

Understanding seasonal and intra-annual variability of meteorological parameters is essential for climate-sensitive regions where agriculture and water resources are strongly influenced by monsoon dynamics and local topography. In India, numerous studies have investigated rainfall and temperature variability at national and regional scales, highlighting the role of monsoon systems in shaping hydro-climatic behaviour. Jain and Kumar (2012) and Jain et al. (2010) analysed long-term rainfall and temperature records across India and reported significant seasonal variability, emphasizing the importance of monsoon rainfall for water availability and agricultural planning.

In the Himalayan and adjoining regions, climatic variability is further amplified by complex terrain and elevation gradients. Bhutiyani et al. (2007) documented pronounced seasonal and interannual temperature variability in the northwestern Himalayas, underscoring the sensitivity of mountainous regions to atmospheric circulation patterns. Similar regional-scale studies have highlighted the importance of station-level observations for capturing local climate behaviour that may not be evident in large-scale gridded analyses (Borgaonkar et al., 1996; Latif et al., 2020). These findings suggest that localized seasonal assessments are critical for understanding microclimatic conditions relevant to agriculture and water management.

Recent district- and state-level studies in India have increasingly focused on linking climatic variability with agricultural and socio-economic vulnerability. Kumar and Thangavel (2025) assessed livelihood vulnerability to climate change among tribal communities in Central India, demonstrating how seasonal temperature and rainfall variability directly affect resource-dependent populations. Kumar et al. (2024) further analysed district-level climate vulnerability patterns using agricultural and socio-economic indicators, highlighting the importance of localized climate assessments for policy and planning. Spatial–temporal analyses by Kumar et al. (2023a, 2023b) revealed significant seasonal variability in temperature and rainfall across Madhya Pradesh, reinforcing the relevance of district-scale studies for understanding seasonal climate behaviour in monsoon-dominated regions.

Studies focusing on seasonal rainfall and temperature dynamics have also emphasized the need for station-level observations to support short-term planning. Panda and Sahu (2019) analysed seasonal rainfall and temperature patterns in eastern India and demonstrated strong intra-annual variability linked to monsoon progression. Similarly, Meshram et al. (2018) highlighted how seasonal rainfall variability influences agricultural productivity and water resource availability in Central India. These studies collectively indicate that while long-term trend analyses are essential for climate change assessment, short-term seasonal analyses remain highly valuable for operational decision-making.

More recent studies, including those by Lewis and King (2016) and Meshram *et al.,* (2018), investigated temperature extremes and rainfall trends in Central India, employing statistical models to examine the variability in temperature and precipitation. These studies offered valuable forecasts on future climatic shifts, contributing insights essential for climate risk management. Neil and Notodiputro (2016) examined surface air temperature trends in the Arctic, reporting an increase in temperature extremes, while Haldar *et al.,* (2023) extended this approach by analyzing long-term meteorological data in urban areas, revealing higher temperatures in cities due to urban heat island effects. Meanwhile, Hossain *et al.,* (2015) and Praveen *et al.,* (2020) applied machine learning models to weather forecasting, demonstrating innovative approaches to understanding climatic interactions and enhancing prediction accuracy for policymakers.

Despite extensive research on climate variability across India and the Himalayan region, District Rajouri remains relatively understudied in terms of recent, station-level seasonal assessments. Existing studies in the region have largely focused on specific events or environmental perceptions rather than providing a comprehensive seasonal baseline of meteorological parameters. Addressing this gap, the present study analyses monthly meteorological observations for 2023 to characterise seasonal and intra-annual variability in temperature, rainfall, humidity, sunshine duration, wind speed, and evapotranspiration. By focusing on seasonal behaviour rather than long-term trends, this study complements existing climate literature and provides locally relevant insights for short-term agricultural and water resource planning. This study's contributions and pertinent articles from the literature are encapsulated in Table 1. This table elucidates the gaps existing in prior research, and our paper aims to address these gaps by offering innovative insights and solutions within the field.

Table 1: Comparison of the present study with selected station-level and regional climate studies

Author	Study Region	Temporal Scale	Primary Variables	Analytical Approach	Relevance to Present Study
Bhutiyani et al. (2007)	Northwestern Himalaya	Multi-decadal	Temperature	Trend analysis	Provides long-term Himalayan warming context
Jain & Kumar (2012)	India	Multi-decadal	Rainfall, Temperature	Non-parametric trend tests	National-scale monsoon variability reference
Panda & Sahu (2019)	Odisha, India	Long-term	Rainfall, Temperature	Trend and seasonal analysis	Demonstrates district-level seasonal behaviour
Sharma et al. (2020)	Rajouri, India	Short-term	Weather parameters	Descriptive analysis	Local station-level comparison
Zeeshan et al. (2021)	Rajouri, India	Survey-based	Environmental perception	Statistical analysis	Highlights local climate sensitivity
Kumar et al. (2023a)	M.P, India	Multi-year	Temperature	Spatio-temporal analysis	Regional seasonal variability comparison
Kumar et al. (2023b)	M.P, India	Multi-year	Rainfall	Seasonal and trend analysis	Monsoon-driven rainfall reference
Kumar & Thangavel (2025)	Central India	Multi-year	Climate vulnerability indicators	Index-based assessment	Links climate variability with livelihoods

Kumar et al. (2024)	M.P, India	Multi-year	Agro-climatic indicators	Vulnerability mapping	Methodological framing for applied planning
Present Study	Rajouri, India	Single year (2023)	Station-level meteorological variables	Descriptive statistics & seasonal characterization	Provides short-term baseline for local agricultural and water planning

3. Methodology

This section describe the methodology employed in the study, including the model assumptions, notations, and description.

3.1. Study Area

District Rajouri is located in the southwestern part of the Union Territory of Jammu and Kashmir, India, between latitudes 33°23′N and longitudes 74°18′E. The district shares its northern boundary with Poonch district and is bordered by Jammu district to the south. Owing to its proximity to the Line of Control (LoC) and its location within the foothills of the Pir Panjal Range, Rajouri exhibits considerable geographical and climatic heterogeneity.

The district covers an area of approximately 2,630 km² and comprises several administrative tehsils, including Rajouri, Manjakot, Thanamandi, Darhal, Qila Darhal, Kotranka, Khawas, Teryath, Beripattan, Siot, Sunderbani, Kalakote, and Nowshera. Elevation varies substantially across the district, ranging from lower plains to mountainous terrain, which plays a critical role in shaping local meteorological conditions.

Climatically, Rajouri experiences subtropical conditions in the lower altitudes and temperate conditions in higher elevations. Seasonal weather is strongly influenced by the Indian monsoon system and western disturbances, resulting in marked intra-annual variability in temperature, rainfall, and humidity. Summers are generally warm, winters are relatively cold in higher elevations, and the monsoon season contributes a substantial proportion of annual rainfall. These characteristics make Rajouri a climatically sensitive region where seasonal weather variability has direct implications for agriculture, water resources, and environmental planning.

Figure 1 illustrates the geographical location of District Rajouri within the Union Territory of Jammu and Kashmir, India.

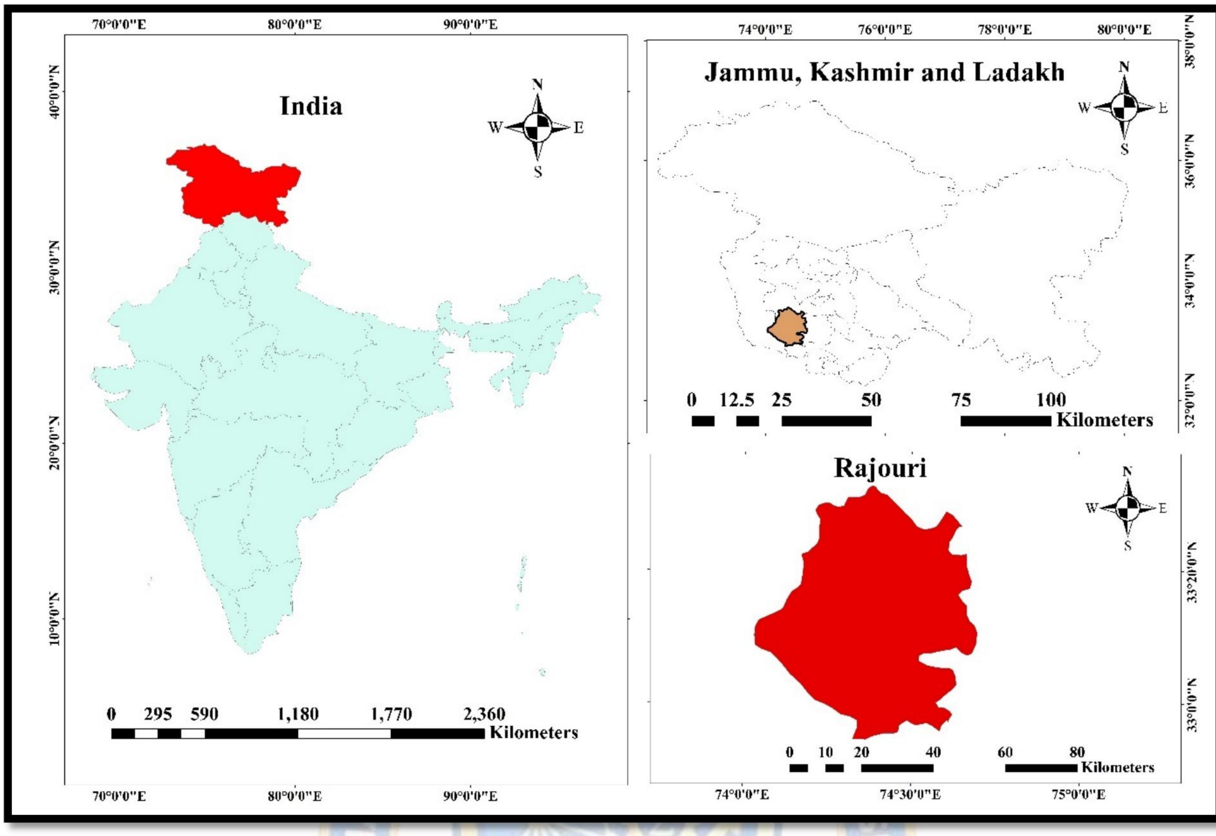

Fig 1: Location of District Rajouri in Jammu and Kashmir (India), highlighting the study area used for station-based meteorological analysis.

3.2. Data Source and Collection

Meteorological data used in this study were obtained from the Indian Meteorological Department (IMD), Krishi Vigyan Kendra (KVK), Tandwal, Rajouri, for the calendar year January–December 2023. The dataset consists of monthly aggregated station-level observations, recorded using standard IMD protocols and instrumentation.

The variables collected include maximum temperature (Max T) (°C), minimum temperature (Min T) (°C), monthly rainfall (mm), morning and evening relative humidity (%), sunshine duration (hours), wind speed (m s^{-1}), and evapotranspiration (mm). These parameters were selected due to their direct relevance to seasonal climate characterization and their importance for agricultural productivity and water resource planning in monsoon-influenced regions.

All data were obtained in digital format and represent observed values rather than modelled or reanalysis outputs. The use of station-level observations ensures that the analysis captures local-scale meteorological variability, which is particularly important in topographically complex regions such as the western Himalayan foothills.

3.3. Data Preprocessing

Before analysis, the dataset underwent systematic preprocessing to ensure data quality and consistency. Monthly records were first examined for completeness, and no missing observations were identified in the dataset for the study period. Basic consistency checks were performed to detect anomalous or physically implausible values by comparing observed ranges with known climatological limits for the region.

Units of measurement were standardized across all variables, and the dataset was organised into a structured time-series format suitable for statistical analysis. No gap-filling, interpolation, or smoothing techniques were applied, as the dataset was complete and internally consistent. This approach preserves the original observational integrity of the data, ensuring transparency and reproducibility of the analysis.

3.4 Estimation of Reference Evapotranspiration

Reference evapotranspiration (ETo) was estimated using the FAO-56 Penman–Monteith equation, which is widely accepted as the standard method for determining atmospheric evaporative demand. The equation is expressed as:

$$ETo = [0.408\Delta(Rn - G) + \gamma(900/(T + 273))u_2(es - ea)] / [\Delta + \gamma(1 + 0.34u_2)]$$

where

ETo = reference evapotranspiration (mm day^{-1})

Rn = net radiation at crop surface (MJ m^{-2} day^{-1})

G = soil heat flux density (MJ m^{-2} day^{-1})

T = mean daily air temperature (°C)

u_2 = wind speed at 2 m height (m s^{-1})

es = saturation vapor pressure (kPa)

ea = actual vapor pressure (kPa)

Δ = slope of saturation vapor pressure curve (kPa $°C^{-1}$)

γ = psychrometric constant (kPa $°C^{-1}$)

3.5. Data Type

The study employs secondary, observational meteorological data collected at a single monitoring station. The data represent monthly averages or totals, depending on the variable, and are classified as station-based, non-gridded time-series data. No satellite-derived, reanalysis, or climate model outputs were used in this study. Given the single-year temporal coverage, the dataset is suitable for examining seasonal and intra-annual variability, rather than long-term climate trends. Consequently, all interpretations are confined to short-term seasonal behaviour and avoid inferences related to climate change or long-term warming.

3.6. Analytical Methods

The analysis in this study was designed to examine intra-annual and seasonal variability in key meteorological parameters rather than to infer long-term climatic trends. Monthly observations of maximum temperature, minimum temperature, rainfall, relative humidity (morning and evening), sunshine duration, wind speed, and evapotranspiration were analysed using descriptive statistical techniques and graphical visualisation methods.

Descriptive statistics, including mean, median, standard deviation, minimum, maximum, and quartile values, were computed for each meteorological variable to summarise central tendency and variability across the study period. These statistics provided a quantitative overview of the magnitude and dispersion of seasonal weather conditions during 2023.

To enhance seasonal interpretation, monthly data were examined in relation to the standard Indian climatological seasons: winter (December–February), pre-monsoon (March–May), monsoon (June–September), and post-monsoon (October–November). This seasonal grouping enabled assessment of intra-annual variability and facilitated interpretation of weather behaviour in a monsoon-dominated Himalayan region.

Graphical techniques were employed to explore monthly and seasonal patterns visually. Line plots were used to depict monthly variations in temperature, rainfall, sunshine duration, wind speed, and evapotranspiration, while bar charts illustrated rainfall distribution across months. Box-and-whisker plots were applied to rainfall data to highlight inter-monthly variability and the presence of extreme values. All figures were designed to support the interpretation of seasonal dynamics rather than statistical trend detection.

All analyses were performed using Python, primarily utilising the Pandas library for data handling, NumPy for numerical computation, and Matplotlib for visualisation. Given the single-year temporal scope of the dataset, no trend detection tests (e.g., Mann–Kendall), regression analysis, or climate change attribution methods were applied to avoid over-interpretation beyond the data's statistical validity.

Overall, this analytical framework provides a transparent and reproducible approach for short-term climatic assessment, offering a seasonal baseline that can support agricultural planning and water resource management while serving as a foundation for future studies incorporating multi-year datasets.

3.7. Study Scope and Positioning

This study is intentionally positioned as a short-term, station-level assessment aimed at documenting intra-annual and seasonal variability rather than long-term climate trends. Such baseline analyses are particularly valuable for data-scarce Himalayan regions, where continuous multi-decadal station records are limited. The results provide an empirical reference for future multi-year or trend-based studies and support operational agricultural and water-management decisions at the district scale.

4. Results

The Results section highlights dominant seasonal patterns rather than reiterating individual monthly values. **Table 2** below presents the monthly weather data for the year 2023, detailing key climatic variables such as maximum and minimum temperatures, rainfall (in millimetres), relative humidity (morning and evening), sunshine duration (in hours), wind speed (in meters per second), and evapotranspiration (EPO in millimetres). This comprehensive dataset serves as a foundation for analysing climate patterns and seasonal variability, providing valuable insights for agricultural planning and water resource management in the region.

Table 2: Monthly Weather Data for 2023

Month	Max T(^{0}C)	Min T(^{0}C)	RF (MM)	RH (Morning) (%)	RH(Evening) (%)	Sunshine (hrs)	W. Speed (m/s)	EPO (MM)
Jan	16.3	1.8	76.2	90	59	3.6	0.6	0.7
Feb	21.9	5.2	22.4	85	47	5.5	0.5	1.6
Mar	23.0	8.1	49.9	85	52	5.1	0.7	1.8
Apr	26.6	13.8	107.6	83	48	7.1	0.8	2.7
May	28.7	13.2	139.2	78	50	6.3	0.5	3.2
Jun	31.9	18.4	113.2	75	56	7.6	0.5	4.6
Jul	30.3	21.1	207.2	84	69	5.2	0.4	3.1
Aug	32.0	21.3	113.4	87	66	7.7	0.5	3.2
Sep	31.2	19.0	105.2	85	61	7.4	0.3	2.8
Oct	26.9	10.7	57.6	86	55	7.6	0.4	2.1
Nov	23.8	6.8	29.0	88	55	6.1	0.2	1.9
Dec	21.5	1.9	2.2	88	55	6.8	0.1	1.4

4.1. Descriptive Statistics

The descriptive statistics for the variables are summarized in **Table 3**. The maximum temperature ranged from 16.3°C in January to 32.0°C in August, while the minimum temperature varied from 1.8°C to 21.3°C. Rainfall peaked in July with 207.2 mm.

Table 3: Descriptive Statistics of Climatic Variables

Variable	Mean	Standard Deviation
Max Temperature	25.0	5.68
Min Temperature	10.4	6.08
Rainfall	67.0	54.51
RH Morning	84.1	4.39
RH Evening	56.2	8.12
Sunshine	6.3	1.38
Wind Speed	0.4	0.17

4.2. Temperature Trends

This section examines the monthly variations and seasonal variability in maximum and minimum temperatures in District Rajouri for the year 2023. The maximum temperature displayed a distinct seasonal pattern, peaking at 32.0°C in August, a typical high for the monsoon season. The lowest maximum temperature was recorded in January (16.3°C), reflecting the colder winter months (Table 4). Similarly, minimum temperatures followed a comparable seasonal cycle, with January marking the lowest minimum temperature at 1.8°C and August reaching the highest at 21.3°C, highlighting the monsoon's warming effect on nighttime temperatures (Table 5).

A clear seasonal variation is evident, with a consistent warming trend from February through August, culminating in the monsoon period, followed by a cooling trend from September through December. This cycle aligns with Rajouri's climatic patterns, where temperatures rise during the pre-monsoon period and begin to decline after the monsoon, transitioning into winter. This monthly trend is visually represented in Figure 2, which captures the warming and cooling cycles throughout the year, as well as in Figure 3, which illustrates the broader seasonal rainfall trends.

The tables and figures underscore the cyclical temperature dynamics that are typical for Rajouri’s monsoon-influenced climate. The mean maximum temperature, as seen in Table 5, was 26.95°C, while the mean minimum temperature was 12.18°C (Table 6). The standard deviations of 5.01 for maximum and 7.12 for minimum temperatures indicate seasonal variability, essential information for agriculture and resource planning.

These trends reveal how temperatures rise and fall in sync with the monsoon cycle, underscoring the climatic conditions that govern Rajouri's seasonal behaviour and informing optimal planning for water management and agricultural practices.

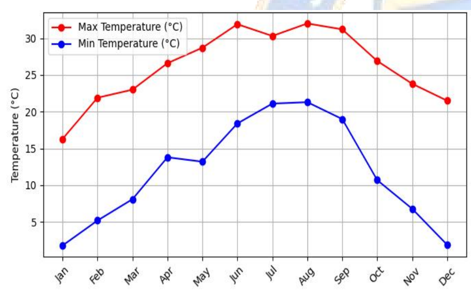

Fig 2: Monthly variation of maximum and minimum temperatures in District Rajouri during 2023, illustrating the seasonal warming from late winter to monsoon months and subsequent cooling during the post-monsoon and winter period.

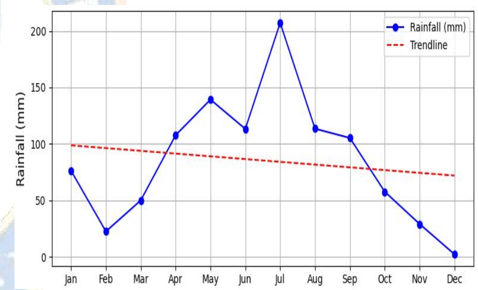

Fig 3: Seasonal distribution of rainfall during 2023, showing the dominance of monsoon months in annual precipitation

Table 4: Month-Wise Statistical Information of Maximum Temperature

Count	Mean	Standard Deviation	Minimum	25th Percentile	Median (50th Percentile)	75th Percentile	Maximum
12	26.95	5.01	16.3	23.6	26.75	31.55	32.0

Table 5: Month-Wise Statistical Information of Minimum Temperature

Count	Mean	Standard Deviation	Minimum	25th Percentile	Median (50th Percentile)	75th Percentile	Maximum
12	12.18	7.12	1.8	5.5	10.7	18.7	21.3

4.3. Rainfall and Humidity

This section outlines monthly seasonal variability in rainfall and relative humidity, illustrating distinct seasonal variations typical of Rajouri's monsoon climate.

Rainfall (RF): Rainfall showed substantial seasonal variation, with July recording the highest amount (207.2 mm) during the monsoon peak, while December had the least rainfall (2.2 mm), marking the dry winter season. This pattern reflects Rajouri's dependency on the monsoon for water resources and agricultural needs (Fig. 4).

Relative Humidity (RH): Morning humidity levels remained consistently high throughout the year, peaking at 90% in January. Evening humidity displayed more variability, with the lowest level in February (47%), showing drier conditions in the late winter (Fig. 5).

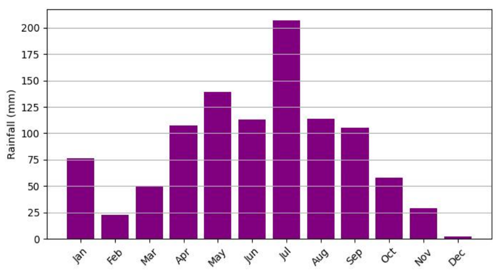

Fig 4: Monthly rainfall distribution during 2023 showing pronounced monsoon dominance (June–September), highlighting the region's dependence on seasonal precipitation.

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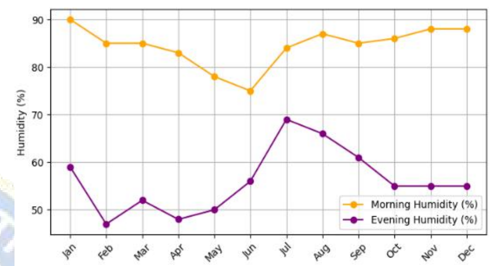

Fig 5: Monthly morning and evening relative humidity levels in District Rajouri during 2023, illustrating consistently high morning humidity and greater seasonal variability during evening hours

Table 5 summarizes monthly rainfall data, highlighting high variability, with July's peak rainfall (207.2 mm) significantly higher than the mean (78.43 mm) and standard deviation (59.64 mm). This peak underscore the role of the monsoon season in providing essential water resources.

Table 6: Month-Wise Statistical Information of Rainfall

Count	Mean	Standard Deviation	Minimum	25th Percentile	Median (50th Percentile)	75th Percentile	Maximum
12	78.43	59.64	2.2	28.45	68.45	112.25	207.2

Fig. 6, a box and whisker plot of monthly rainfall, further illustrates the inter-month variability and extremes, which necessitate efficient water storage and management systems.

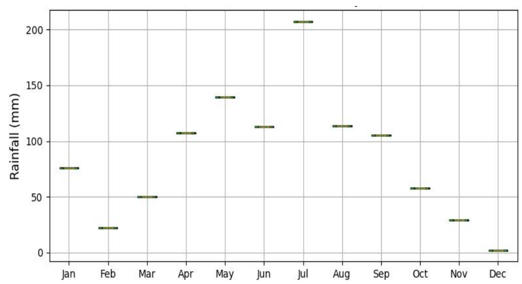

Fig 6: Box-and-whisker plot of monthly rainfall showing inter-month variability and precipitation extremes during the monsoon season.

These seasonal fluctuations stress the importance of developing climate-resilient agricultural practices and implementing sustainable water management strategies, especially for months with reduced rainfall, like December (2.2 mm).

4.4. Sunshine and Wind Speed

This section presents the monthly patterns in sunshine duration and wind speed, capturing seasonal characteristics of Rajouri's climate.

Sunshine Duration: The longest average sunshine duration was recorded in August (7.7 hours), corresponding to late summer, while January had the shortest duration (3.6 hours), aligning with the winter season's shorter days (Fig. 7). This seasonal variation reflects the typical daylight changes and cloud cover associated with monsoon and winter months.

Wind Speed: Wind speeds remained relatively stable throughout the year, peaking in April at 0.8 m/s, likely influenced by seasonal transitions, and reaching their lowest in December (0.1 m/s) (Fig. 8).

These seasonal variations in sunshine and wind speed provide insights for agricultural planning, particularly in assessing sunlight exposure for crop growth and wind as a factor in evapotranspiration rates.

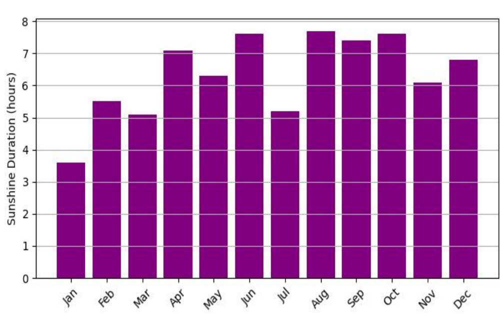

Fig 7: Monthly sunshine duration in hours, reflecting seasonal changes in cloud cover and daylight associated with winter, pre-monsoon, and monsoon periods.

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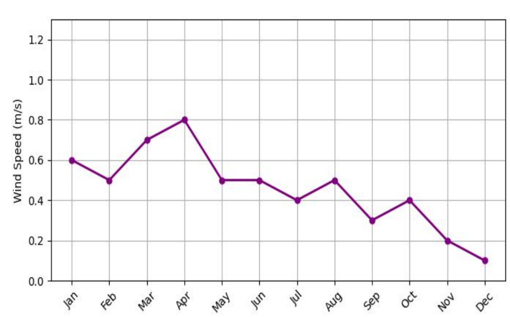

Fig 8: Monthly wind speed variation during 2023, indicating relatively low and stable wind conditions throughout the year

4.5. Evapotranspiration (EPO)

Evapotranspiration rates in District Rajouri displayed a clear seasonal pattern, with the highest rates observed in June (4.6 mm) during the warmer months, coinciding with increased temperature and longer sunshine duration, and the lowest rates recorded in January (0.7 mm), reflecting the cooler winter season. This seasonal variability, illustrated in Fig. 9, highlights the increased water demand during peak growing months, offering valuable insights for effective water resource management and agricultural planning in the region.

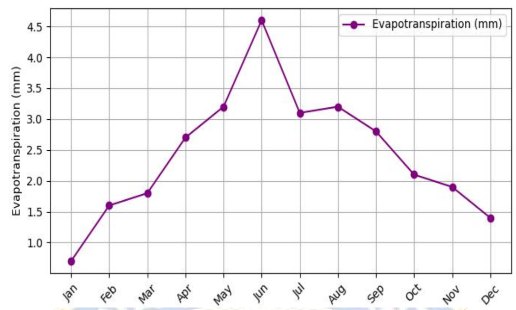

Fig 9: Monthly evapotranspiration variability in District Rajouri during 2023, demonstrating higher water demand during warmer months with increased solar radiation.

5. Discussion

The seasonal variability observed in District Rajouri during 2023 closely aligns with patterns reported in other monsoon-influenced and mountainous regions of India. The progressive increase in maximum and minimum temperatures from February to August, followed by a decline during post-monsoon and winter months, corroborates findings from the northwestern Himalayas reported by Bhutiyani et al. (2007), who highlighted strong seasonal temperature contrasts driven by elevation and monsoon circulation. Similar intra-annual temperature behaviour has been documented at the district scale in Central India by Kumar et al. (2023a), indicating that pronounced seasonal temperature oscillations are a consistent feature across diverse Indian climatic zones. While these earlier studies relied on long-term datasets, the present study complements them by providing a recent station-level seasonal snapshot, which is particularly useful for short-term agricultural and water resource planning. These comparisons are intended to contextualize seasonal behaviour rather than infer long-term climatic change.

Rainfall patterns in Rajouri exhibited strong monsoon dominance, with peak precipitation in July and substantially lower rainfall during winter months. This seasonal concentration of rainfall is consistent with findings by Jain and Kumar (2012) and Meshram et al. (2018), who emphasized the central role of monsoon rainfall in shaping water availability and agricultural outcomes across India. The high intra-annual variability highlighted by the box-and-whisker analysis of monthly rainfall mirrors observations from Panda and Sahu (2019), who reported similar dispersion and extremes in monsoon-driven districts. Unlike long-term trend-based studies, the present analysis does not infer climatic change but instead complements existing literature by quantifying seasonal dispersion and variability within a single hydrological year, which is critical for operational decision-making such as crop scheduling and water storage management.

The observed seasonal behaviour of evapotranspiration, sunshine duration, and relative humidity further supports earlier regional findings that link higher pre-monsoon temperatures and longer sunshine hours with increased atmospheric water demand (Kumar and Gautam, 2014; Kumar et al., 2023b). Although previous studies focused on multi-year variability, the present results provide evidence that even within a single year, evapotranspiration responds sensitively to seasonal thermal and radiative conditions. This complements vulnerability assessments by Kumar and Thangavel (2025) and Kumar et al. (2024), which emphasize that seasonal climate variability—rather than long-term trends alone—plays a decisive role in shaping agricultural risk and livelihood vulnerability at the district level.

The present findings complement earlier Himalayan and monsoon-region studies by providing a high-resolution, station-level seasonal snapshot rather than long-term trend inference. Overall, the findings of this study neither contradict nor replace long-term climate analyses but instead fill an important gap by offering a short-term, station-based baseline of seasonal meteorological behaviour for District Rajouri. By explicitly situating the results within established regional literature, this study strengthens the understanding of how seasonal climate variability manifests locally in monsoon-dominated, climatically sensitive regions and provides a foundation for future multi-year analyses.

6. Recommendations

Agricultural Planning: Planting schedules should be adjusted to match the monsoon and peak rainfall months (June to July). High humidity in the monsoon season requires early intervention strategies to prevent crop diseases.

Water Resource Management: Effective water conservation strategies such as rainwater harvesting should be implemented, especially given the high evapotranspiration rates during the summer months.

Climate Adaptation: Local authorities should develop flood preparedness measures for the monsoon season while also considering drought-resistant crops for the drier months.

7. Conclusion

This study presents a station-level assessment of seasonal meteorological variability during 2023, highlighting pronounced intra-annual fluctuations in temperature, rainfall, humidity, sunshine duration, and evapotranspiration. The results demonstrate strong intra-annual seasonal dependence of key weather variables, with implications for short-term agricultural planning and water resource management. Rather than identifying climatic seasonal variability, the study establishes a short-term baseline that supports applied decision-making in a climatically sensitive region.

Future research should extend this framework to multi-year datasets to evaluate interannual variability and longer-term changes. The present analysis contributes by demonstrating the practical utility of seasonal climate assessments using recent observational data. The findings are limited by the use of a single year of observations and station-level data, which restrict inference to seasonal variability rather than climatic trends. Nevertheless, such short-term assessments are useful for operational planning and serve as a baseline for future long-term climate analyses.

A limitation of the present study is the reliance on a single year of observations. Future studies should incorporate long-term datasets (e.g., 10-year climatological averages) to evaluate inter-annual variability and determine whether the observed patterns represent typical or extreme climatic conditions for the region.

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