Variations and Trends of Main Climatic Indicators in the Mirzachul Region During 1991–2020

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Abstract: The Mirzachul region is one of the most important irrigated lowland areas of Uzbekistan, where climatic conditions directly influence land and water resource use, agricultural sustainability, and the development of natural-geographical processes. This study analyzes the seasonal characteristics, interannual variability, and long-term trend directions of the main climatic indicators—air temperature, precipitation, relative humidity, and wind speed—in the Mirzachul region during 1991–2020. The research is based on long-term observational data from the Jizzakh, Dostlik, Gulistan, and Syrdarya meteorological stations. Observational records of the Hydrometeorological Service of the Republic of Uzbekistan and the official 1991–2020 climatic normals were used as the primary data sources, while NASA POWER data were applied only as an auxiliary comparative source. The results show that the air temperature regime of the Mirzachul region is characterized by a high continental amplitude, with a positive tendency in annual mean temperature observed at all selected stations. The precipitation regime is distinguished by strong interannual variability and pronounced seasonal unevenness rather than by a stable directional trend. For relative humidity, the main signal is expressed through the seasonal contrast between a relatively humid winter period and a markedly dry summer period. The wind regime shows relatively stable mean wind speeds; however, maximum wind speeds indicate an increasing tendency at several stations. Overall, the modern climatic character of the Mirzachul region during 1991–2020 can be described as warming, seasonally dry, and highly continental.
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1. Introduction

The Mirzachul region is one of the major irrigated lowland areas of Uzbekistan and plays an important role in the country's agricultural production, water management system, and regional landscape structure. Its natural-geographical conditions are characterized by flat relief, open arid landscapes, high summer heat, and extensive irrigated lands. Under such conditions, seasonal and interannual fluctuations of climatic indicators directly affect land and water resource use, irrigation regimes, agroclimatic risks, and the development of natural-geographical processes. In arid Central Asia, climate and environmental changes have been closely associated with water scarcity, land degradation, and the need for adaptation strategies (Lioubimtseva and Henebry, 2009).

In recent decades, climate change in Central Asia has mainly been expressed through rising air temperature, increasing interannual instability of precipitation, intensification of extreme meteorological events, and changes in water resource regimes. Klein Tank et al. (2006) analyzed changes in daily temperature and precipitation extremes across Central and South Asia and emphasized the importance of extreme indicators in assessing regional climatic risks. Zhang et al. (2019) also demonstrated that temperature and precipitation extremes provide an important methodological basis for tracking climate change and understanding the modern climatic dynamics of Central Asia.

Central Asia is considered one of the regions sensitive to global climate change. Using multiple datasets, Hu et al. (2014) analyzed temperature changes in Central Asia for 1979–2011 and identified a persistent regional warming signal. Fallah et al. (2024) summarized trends, extremes, and future projections for Central Asia and emphasized that climate change has serious implications for water resources, drought risk, and agroecological stability. Therefore, the analysis of climatic indicators based on local station observations is of considerable scientific and practical importance for irrigated lowland regions such as Mirzachul.

In climatological studies, a 30-year period is commonly used as a reference interval for assessing long-term climatic normals. The 1991–2020 period is regarded as a modern baseline for characterizing current climatic conditions. Although gridded and satellite-based datasets provide broad spatial coverage, direct meteorological station observations remain the primary reference source for evaluating local climate conditions. This is particularly important for spatially heterogeneous, irrigated, and arid environments such as the Mirzachul region. Global datasets such as

NASA POWER can be useful as auxiliary comparative sources, but they cannot fully replace local station-based observations (White et al., 2008; Marzouk, 2021).

In the Mirzachul region, air temperature, precipitation, relative humidity, and wind speed need to be analyzed jointly in order to characterize the regional climate system more comprehensively. Rising air temperature increases evaporative demand; seasonal unevenness of precipitation limits natural moisture availability during the growing season; decreasing relative humidity in summer intensifies atmospheric dryness; and wind speed plays an important role in dust formation, wind erosion, and moisture loss. Studies conducted in arid and semi-arid regions indicate that changes in meteorological indicators are important signals for natural resource management (Modarres and da Silva, 2007).

However, broad regional studies of Central Asia do not always sufficiently reveal the internal spatial and seasonal differences of local irrigated lowland areas such as Mirzachul. Therefore, it is necessary to analyze the seasonal characteristics, interannual variability, and long-term trend directions of the main climatic indicators in the Mirzachul region during 1991–2020 using data from the Jizzakh, Dostlik, Gulistan, and Syrdarya meteorological stations. These stations cover the inner part of Mirzachul, irrigated lowland areas, and zones close to the Syrdarya valley, allowing the spatial differentiation of the regional climate to be assessed.

The aim of this study is to analyze the long-term variability and trends of the main climatic indicators, including air temperature, precipitation, relative humidity, and wind speed, in the Mirzachul region during 1991–2020 based on meteorological station observations. The study uses data from the Jizzakh, Dostlik, Gulistan, and Syrdarya meteorological stations as the main reference source, while NASA POWER data are considered only as an auxiliary comparative source.

2. Materials and Methods

2.1. Study Area

The Mirzachul plain, located in the central part of Uzbekistan, was selected as the study area. Mirzachul is one of the country's major irrigated agricultural lowlands, where climatic conditions play an important role in land and water resource use, agricultural production, evaporation processes, and the formation of agroclimatic risks. From a natural-geographical perspective, the region is characterized by flat open terrain, arid and strongly continental climatic conditions, high summer temperatures, and pronounced seasonal unevenness of precipitation. In arid Central Asia, climate change is closely associated with water scarcity, land degradation, and agroecological stability (Lioubimtseva and Henebry, 2009; Fallah et al., 2024).

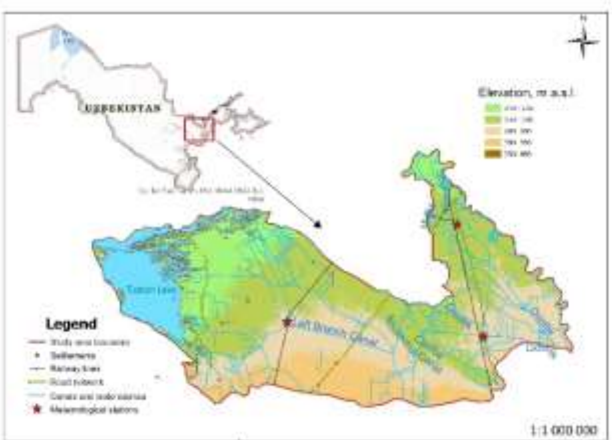

Figure 1. Location of the study area and selected meteorological stations in the Mirzachul region

To assess the climatic characteristics of the Mirzachul region, four meteorological stations were selected: Jizzakh, Dostlik, Gulistan, and Syrdarya. These stations represent different parts of the Mirzachul plain, including the inner irrigated lowland areas and zones located near the Syrdarya valley. Therefore, they were considered sufficiently representative observation points for evaluating spatial differences in the regional climate.

2.2. Data Sources

The main data source used in this study was meteorological observation records provided by the Hydrometeorological Service of the Republic of Uzbekistan. The analysis covered the period from 1991 to 2020. This 30-year interval was used as the baseline period for assessing modern climatic conditions. Long-term observation data from the Jizzakh, Dostlik, Gulistan, and Syrdarya meteorological stations were used as the primary reference dataset. The spatial characteristics of the selected meteorological stations are presented in Table 1.

Table 1. Spatial characteristics of the meteorological stations selected for the analysis of climatic variability in the Mirzachul region.

Meteorological station	Geographical position	Elevation above sea level (m)	Climatic sub-area represented	Data period used in this study
Jizzakh	40.1654°N, 67.8345°E	345	Western and slightly elevated part of the Mirzachul region	1991–2020
Dostlik	40.5266°N, 68.0229°E	273	Central irrigated lowland area	1991–2020
Gulistan	40.4833°N, 68.7833°E	271	Eastern lowland and irrigated agricultural zone	1991–2020
Syrdarya	40.8120°N, 68.6805°E	264	Northeastern part influenced by the Syrdarya valley	1991–2020

Note. Although the selected meteorological stations have different historical starting years, only the common 1991–2020 period was used in this study to ensure temporal comparability among the stations.

NASA POWER Data Access Viewer data were used as an additional auxiliary source. NASA POWER data were not treated as a substitute for station observations, but rather as a supplementary dataset for checking the regional background and providing comparative context. Although satellite- and reanalysis-based meteorological datasets provide broad spatial coverage, ground-based meteorological station observations remain the primary reference source for local-scale climate assessment. Therefore, station-based observational data were prioritized in this study. The use of NASA POWER data was considered in accordance with previous approaches that compare satellite- or model-derived meteorological datasets with ground-based observations (White et al., 2008; Marzouk, 2021).

2.3. Climatic Variables

The following meteorological indicators were analyzed to characterize the main climatic conditions of the Mirzachul region:

- mean air temperature — Tavg;
- maximum air temperature — Tmax;
- minimum air temperature — Tmin;
- precipitation;
- relative humidity — RH;
- wind speed at 10 m height — WS10M.

These indicators were selected to assess the thermal regime, moisture conditions, atmospheric dryness, and wind activity of the region. In arid and semi-arid environments, temperature and precipitation are among the key indicators for evaluating climatic variability and change (Modarres and da Silva, 2007). In the Mirzachul region, relative humidity and wind speed are also important because they influence evaporation, atmospheric dryness, dust formation, and wind erosion processes.

2.4. Data Processing and Statistical Analysis

First, the meteorological data were organized by station and harmonized for the common 1991–2020 study period. The data were then summarized at monthly and annual time scales. For each station, monthly mean values, annual mean values, annual minimum and maximum values, and seasonal amplitudes were calculated.

Temperature indicators were analyzed separately for Tavg, Tmax, and Tmin. For precipitation, annual and seasonal distribution patterns, differences between dry and wet years, and interannual variability were assessed. For relative humidity, the seasonal contrast between the relatively humid winter period and the dry summer period was evaluated. For wind speed, mean background values and interannual fluctuations of maximum wind speeds were analyzed.

A simple linear trend approach was used to identify long-term directional changes. The trend estimates were used to describe the general increasing or decreasing tendency of meteorological indicators during 1991–2020. In this study, trends were interpreted in a descriptive-statistical sense; additional non-parametric tests or complex modeling procedures were not applied.

2.5. Methodological Scope and Limitations

The methodological scope of this study is limited to a descriptive-statistical analysis of the main climatic indicators in the Mirzachul region based on meteorological station observations for 1991–2020. Methods that were not performed, including the Mann–Kendall test, Sen's slope estimation, CMIP6 projections, Random Forest modeling, bias correction, spatial interpolation, and regional downscaling, were not included in the analysis.

NASA POWER data were used only as an auxiliary comparative source, while the main results were derived from meteorological station observations. This approach ensures methodological consistency and allows the results to be interpreted strictly within the limits of the available observational data.

3. Results

3.1. Temperature Regime and Trends

The data from the Jizzakh, Dostlik, Gulistan, and Syrdarya meteorological stations for 1991–2020 show that the air temperature regime of the Mirzachul region has a clearly continental character. At all stations, the coldest period generally occurs in January–February, whereas the warmest period is observed in July. This indicates a pronounced seasonal redistribution of heat resources throughout the year and a strong summer heat load in the region.

Monthly mean temperatures show certain spatial differences among the stations. At the Jizzakh station, the long-term mean temperature is 2.25 °C in January and 28.15 °C in July, with a seasonal amplitude of approximately 26 °C. At Dostlik, the corresponding values are 1.88 °C and 28.47 °C, while at Gulistan they are 1.16 °C and 31.35 °C, and at Syrdarya 0.85 °C and 30.89 °C. These results indicate that the summer thermal background is stronger at the Gulistan and Syrdarya stations than at Jizzakh and Dostlik.

Annual mean temperatures demonstrate a general warming tendency at all stations, although this process is not uniform and occurs against the background of considerable interannual variability. At Jizzakh, annual mean temperature varied between 13.90 and 16.16 °C, with a long-term mean of 15.16 °C. At Dostlik, the range was 13.42–16.31 °C, with a long-term mean of 15.40 °C. At Gulistan, annual mean temperature ranged from 14.10 to 17.23 °C, with a mean of 15.96 °C, while at Syrdarya it ranged from 13.70 to 16.99 °C, with a mean of 15.60 °C. The year 1993 was characterized by a relatively cool background at several stations, whereas 2016 was distinguished by a higher thermal background.

Table 2. Main characteristics of air temperature regime at selected meteorological stations in the Mirzachul region during 1991–2020

Station	January mean temperature, °C	July mean temperature, °C	Seasonal amplitude, °C	Annual mean temperature range, °C	Long-term annual mean, °C	Linear trend, °C/10 years
Jizzakh	2.25	28.15	25.90	13.90–16.16	15.16	+0.19
Dostlik	1.88	28.47	26.59	13.42–16.31	15.40	+0.238
Gulistan	1.16	31.35	30.19	14.10–17.23	15.96	+0.22
Syrdarya	0.85	30.89	30.04	13.70–16.99	15.60	+0.29

Note. Seasonal amplitude was calculated as the difference between July and January mean temperatures.

Linear trend estimates indicate a positive tendency in annual mean temperature at all stations during 1991–2020. The warming rate was approximately +0.19 °C per decade at Jizzakh, +0.23–0.238 °C per decade at Dostlik, +0.22 °C per decade at Gulistan, and +0.29 °C per decade at Syrdarya. These results suggest that the general thermal background in the Mirzachul region increased over the last three decades. However, in this study, trends were interpreted only as simple linear tendencies; since statistical significance tests were not applied, the trends were not classified as statistically significant.

Maximum temperatures provide a clearer indication of summer heat stress. The long-term July maximum temperature reaches 40.43 °C at Jizzakh, 40.49 °C at Dostlik, 44.89 °C at Gulistan, and 44.31 °C at Syrdarya. The mean annual maximum temperature is approximately 41.4 °C at Jizzakh and Dostlik, 45.72 °C at Gulistan, and 45.14 °C at Syrdarya. These values show that the summer extreme heat background is more pronounced in the Gulistan and Syrdarya areas.

Minimum temperature records indicate that winter cold episodes persist despite the general warming background. Annual minimum temperatures ranged from −22.5 to −0.2 °C at Jizzakh, from −22.2 to −3.6 °C at Dostlik, from −21.97 to −7.08 °C at Gulistan, and from −23.03 to −7.70 °C at Syrdarya. The year 2008 stands out as a severe cold episode at all stations. Thus, the temperature regime of Mirzachul has a dual character: annual mean temperature is increasing, but strong winter cold episodes have not disappeared.

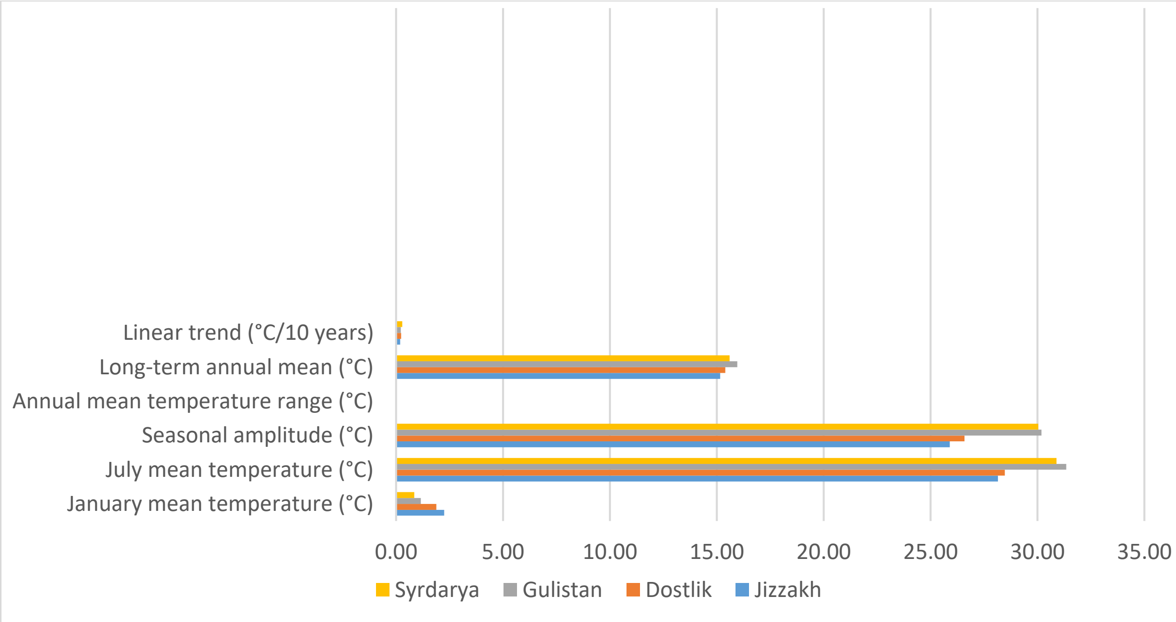

Figure 2. Main characteristics of the air temperature regime at selected meteorological stations in the Mirzachul region during 1991–2020.

3.2. Precipitation Variability

The precipitation regime of the Mirzachul region is arid-continental and is characterized by strong unevenness throughout the year. Observations show that most precipitation is concentrated in the winter–spring period, while precipitation decreases sharply during the summer months. In some years, July precipitation approaches nearly zero. This indicates that natural moisture supply is highly limited during the hottest stage of the growing season.

Long-term mean annual precipitation values are relatively close among the stations. Annual precipitation is approximately 313 mm at Jizzakh, 319 mm at Dostlik, 348 mm at Syrdarya, and 294 mm at Gulistan. However, these mean values do not imply stability of the precipitation regime. On the contrary, interannual fluctuations are strong, and the main feature of precipitation in Mirzachul is not a stable increase or decrease, but the frequent alternation of dry and wet years (Figure 3).

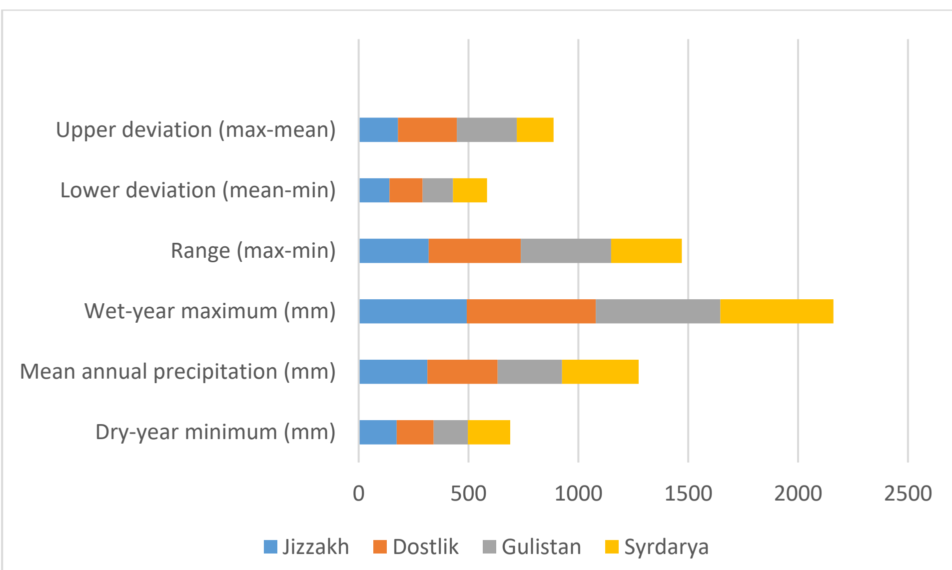

Figure 3. Precipitation variability characteristics at selected meteorological stations in the Mirzachul region during 1991–2020.

The seasonal distribution of precipitation is also an important factor shaping the agroclimatic conditions of the region. Although relatively higher precipitation is observed during the winter–spring period, the sharp decrease in summer precipitation, together with high temperature, low relative humidity, and increasing evaporative demand, intensifies moisture deficit. Therefore, under Mirzachul conditions, annual precipitation totals should not be evaluated as an isolated indicator; they should be assessed together with seasonal distribution and interannual variability.

Overall, the precipitation results show that natural moisture resources in the Mirzachul region are limited and that precipitation cannot serve as a sufficient compensating factor during the hot season. This increases the dependence of the region on irrigation and should be interpreted in relation to water resources and agroclimatic risks in the Discussion section.

3.3. Relative Humidity Regime

Observations for 1991–2020 show that relative humidity in the Mirzachul region has a clearly expressed seasonal cycle. Relative humidity is relatively high in winter, whereas it decreases sharply in summer. This pattern is associated with the arid-continental climatic conditions of the region, high summer temperatures, and intensive evaporation processes.

The seasonal amplitude of relative humidity is approximately 44 percentage points at Jizzakh and 50–53 percentage points at the Dostlik, Gulistan, and Syrdarya stations. This means that summer dryness is a stable and strongly expressed feature at all selected stations, although the contrast between winter humidity and summer dryness is more pronounced at some stations.

Monthly values show that the most humid period occurs in January–February and December, while the driest period occurs in July–August. At Jizzakh, relative humidity is about 66% in January and February, but decreases to 23.43% in July and 21.92% in August. At Dostlik, relative humidity reaches 74.62% in January, 71.66% in February, and 72.71% in December, while the summer minimum is about 21.76% in August and 22.53% in July. At Syrdarya, relative humidity is 71.33% in January and 21.14% in August, whereas at Gulistan it is 72.42% in January and 20.75% in August. These values indicate very strong atmospheric dryness in the Mirzachul region during the summer period (Figure 4).

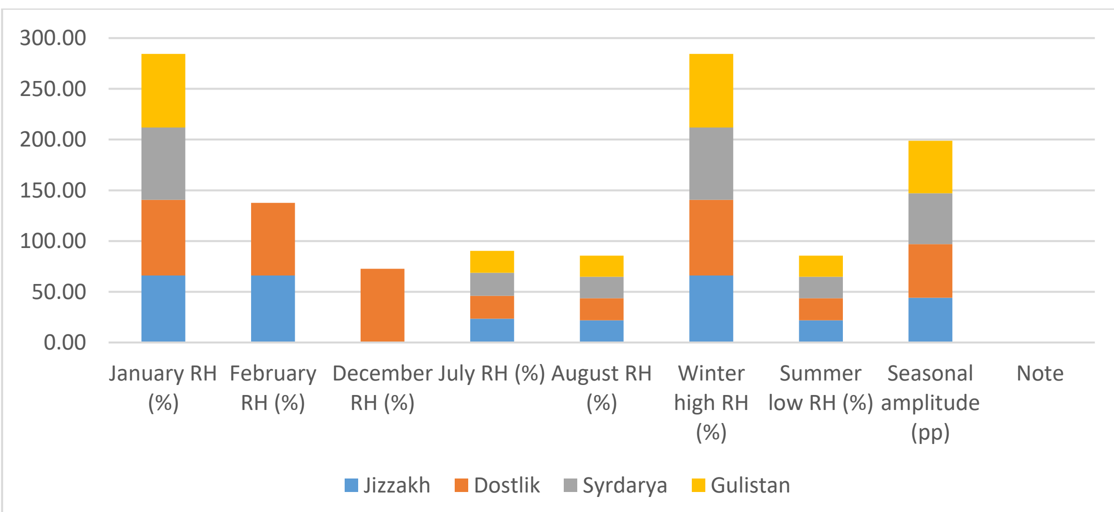

Figure 4. Seasonal contrast of relative humidity at selected meteorological stations in the Mirzachul region during 1991–2020.

Annual mean relative humidity ranges between 47% and 49% across the stations. The long-term mean RH is 47.13% at Jizzakh, 49.21% at Dostlik, 47.76% at Syrdarya, and 48.07% at Gulistan. The most humid annual background was observed at many stations in 1993, while the driest background occurred in 2001. Interannual differences generally remain within 10–11 percentage points. This indicates that the main signal in the relative humidity regime is expressed more through seasonal alternation than through sharp interannual fluctuations.

Long-term trends in relative humidity are weak and not uniform across the stations. RH shows an estimated tendency of approximately +0.77 percentage points per decade at Jizzakh, +0.55 percentage points per decade at Gulistan, and +0.38 percentage points per decade at Dostlik, while the trend at Syrdarya is nearly neutral. Therefore, relative humidity should not be interpreted as an independent strong transformation signal in the Mirzachul climate system, but rather as an indicator linked to temperature, precipitation, and seasonal dryness.

3.4. Wind Speed Characteristics

The wind regime of the Mirzachul region is characterized by two main features. The first is the relatively stable background of mean wind speed, and the second is the interannual variability of maximum wind speeds. This is especially important for open lowland landscapes, where wind conditions are associated with wind erosion, dust events, and moisture loss.

No sharp transformation was observed in mean wind speeds. Across the stations, the mean wind background remained relatively stable, while the main differences were expressed in maximum wind episodes. This indicates that the wind regime of Mirzachul cannot be assessed only by annual mean values; maximum wind speeds also require separate consideration.

At Jizzakh, annual maximum wind speed ranged from 10.26 to 19.77 m/s, with a long-term mean of 12.87 m/s. At Dostlik, the corresponding range was 10.67–19.70 m/s, with a mean of 13.24 m/s. At Gulistan, maximum wind speed ranged from 9.93 to 19.47 m/s, with a mean of 13.34 m/s. Trend estimates show that annual maximum wind speeds increased by approximately +0.86 m/s per decade at Jizzakh and Dostlik, and by +0.75 m/s per decade at Gulistan.

These results indicate that the extreme component of the wind regime provides a more important climatic signal than the mean wind background. In particular, when maximum wind episodes coincide with summer dryness, low relative humidity, and high temperature, they may increase surface drying, dust formation, and the risk of wind erosion. This aspect is further interpreted in the Discussion section in relation to arid landscapes and the sustainability of irrigated areas.

3.5. Integrated Climatic Characteristics of Mirzachul

When the results are summarized, the climatic regime of the Mirzachul region during 1991–2020 can be characterized by four main features. First, the temperature regime has a high continental amplitude, and annual mean temperature shows a positive tendency at all selected stations. This tendency is relatively more pronounced at the Syrdarya station.

Second, the precipitation regime is distinguished by strong seasonal and interannual variability rather than by a stable directional trend. Most precipitation falls during the winter–spring period, while natural moisture availability decreases sharply in summer. Therefore, precipitation in the Mirzachul region should be assessed not only by annual totals, but also by seasonal distribution and the frequency of dry years.

Third, the main signal in relative humidity is expressed through the seasonal contrast between strong summer dryness and a relatively humid winter background. Although annual mean RH ranges around 47–49% across the stations, it decreases to 20–25% during the summer months. This intensifies atmospheric dryness in combination with high summer temperatures.

Fourth, mean wind speeds remain relatively stable, but maximum wind speeds show an increasing tendency at some stations. Thus, the modern climatic character of Mirzachul can be described as a warming, seasonally uneven in precipitation, markedly dry in summer, and highly continental lowland region where wind extremes require particular attention.

4. Discussion

The findings of this study show that the dominant climatic signal in the Mirzachul region during 1991–2020 is reflected primarily in the warming tendency of air temperature. Annual mean temperature increased at all selected meteorological stations, although the rate of warming varied among Jizzakh, Dostlik, Gulistan, and Syrdarya. This spatial differentiation indicates that warming in Mirzachul is not uniform, but is influenced by local geographical factors such as elevation, openness of the plain, proximity to irrigated lands, and valley-related air circulation. Similar warming tendencies have been identified across broader Central Asia, where increasing temperature is regarded as one of the most consistent indicators of recent climate change (Hu et al., 2014; Zhang et al., 2019; Fallah et al., 2024).

The observed increase in mean and maximum air temperatures has important agroclimatic implications for the Mirzachul region. As one of Uzbekistan's major irrigated lowland areas, Mirzachul is highly sensitive to even moderate warming, because higher temperatures can intensify heat stress, increase atmospheric evaporative demand, and raise irrigation water requirements during the growing season. This is especially important in areas where summer maximum temperatures are already very high. Therefore, the warming tendency identified in this study should be interpreted not only as a meteorological trend, but also as a factor that may increase pressure on irrigated agriculture, water management, and land reclamation systems. Studies in arid and semi-arid regions have similarly shown that temperature increase is closely associated with stronger evaporative demand and higher agroecological stress (Tabari and Hosseinzadeh Talaee, 2011; Lioubimtseva and Henebry, 2009).

At the same time, the persistence of winter cold extremes indicates that the climate of Mirzachul has not lost its continental character. The results demonstrate that warming occurs together with strong seasonal contrasts: very hot summers and occasional severe winter cold events remain characteristic features of the regional climate regime.

This duality is important for agricultural planning, because crop systems, irrigation infrastructure, and land management practices must adapt not only to increasing summer heat, but also to the continued occurrence of cold episodes. Thus, the climate of Mirzachul can be described as warming, but still strongly continental.

The precipitation results reveal a pattern different from that of temperature. While temperature shows a clear increasing tendency, precipitation is mainly characterized by strong interannual variability and uneven seasonal distribution. The concentration of precipitation in winter and spring, combined with very low precipitation during summer, indicates that natural moisture supply is poorly synchronized with the period of highest agricultural water demand. This pattern is typical of arid Central Asia, where precipitation variability and dry-season moisture deficit are among the major climatic constraints for land and water resource management (Zhang et al., 2017; Yao et al., 2021).

For Mirzachul, this precipitation regime means that annual totals alone are insufficient for assessing climatic conditions. A year with near-normal annual precipitation may still experience severe summer moisture deficit if most precipitation occurs outside the growing season. Therefore, the practical significance of precipitation in the region is determined not only by its total amount, but also by its seasonal distribution, dry-year frequency, and timing. This supports the view that precipitation variability in arid environments should be evaluated through both annual and seasonal indicators (Modarres and da Silva, 2007; Chen et al., 2022).

The uneven precipitation regime also increases dependence on irrigation. During summer, when air temperature is highest and precipitation is minimal, agricultural systems cannot rely on natural rainfall. This strengthens the role of irrigation infrastructure and water allocation in maintaining crop productivity. In dry years, pressure on irrigation water may increase further, whereas wet years may not fully compensate for summer dryness if precipitation is concentrated mainly in the cold season. Thus, precipitation variability should be considered one of the key climatic factors affecting the sustainability of irrigated agriculture in Mirzachul.

Relative humidity provides another important dimension for interpreting the climatic conditions of Mirzachul. The results show a distinct seasonal pattern: winter months are relatively humid, while summer months are extremely dry. The decline of relative humidity to very low values in July–August indicates strong atmospheric dryness during the hottest period of the year. The combination of high air temperature and low relative humidity can substantially increase evapotranspiration demand and intensify water stress in irrigated fields. Recent studies on drying trends in Central Asia also emphasize that warming combined with atmospheric drying may increase drought-related risks in arid environments (Qiu et al., 2023; Fallah et al., 2024).

Unlike temperature, relative humidity did not show a strong and uniform long-term trend across all stations. Its main signal was expressed through seasonal contrast rather than through a consistent annual directional change. Therefore, relative humidity should not be interpreted as an independent transformation indicator in the same way as temperature. Instead, it should be analyzed together with temperature, precipitation, and wind conditions. In Mirzachul, low summer relative humidity strengthens the effect of high temperature and contributes to increased evaporative demand, which is particularly important for irrigated agriculture and soil moisture management.

Wind speed also has important geographical and agroecological significance. The results show that mean wind speed remained relatively stable, whereas maximum wind speeds demonstrated an increasing tendency at several stations. This distinction is important because average wind speed may underestimate the role of wind-related hazards in open lowland landscapes. In Mirzachul, maximum wind episodes may be more important than annual mean wind values for understanding dust events, wind erosion, and surface moisture loss.

The increase in maximum wind speed at several stations may intensify land-surface vulnerability, especially during dry and hot periods. When strong winds coincide with low relative humidity and high temperature, the risk of soil surface drying, dust formation, and wind erosion increases. This is particularly relevant for irrigated landscapes, where soil structure, salinity, bare surface exposure, and drainage conditions may interact with climatic stress. Therefore, wind speed should be considered not only as a background climatic parameter, but also as a risk-related indicator in future agroclimatic and geoecological studies of the Mirzachul region.

The combined interpretation of temperature, precipitation, relative humidity, and wind speed shows that the modern climate of Mirzachul is shaped by interacting climatic pressures. Warming increases heat load and evapotranspiration demand; precipitation variability limits natural moisture availability; low summer relative humidity intensifies atmospheric dryness; and maximum wind episodes increase the likelihood of erosion and dust-related hazards. These factors do not operate independently. Their combined effect may increase climatic stress on irrigated lands, water demand, and agricultural sustainability.

An important methodological aspect of this study is the priority given to station-based observations. NASA POWER data were used only as an auxiliary comparative source and were not treated as a substitute for local meteorological observations. This approach is methodologically justified because global gridded and satellite-based datasets can provide useful spatial coverage, but they may not fully capture local climatic features of irrigated lowland regions. Previous studies have shown that NASA-derived meteorological datasets can be useful for climatic assessment, but their interpretation should be checked carefully against ground-based observations where local station data are available (White et al., 2008; Marzouk, 2021).

Thus, the main contribution of this study is the integrated station-based characterization of the 1991–2020 climatic baseline for the Mirzachul region. The results provide a clearer understanding of the region's modern climate: warming is evident, but the climate remains highly continental; precipitation is variable and seasonally uneven; summer atmospheric dryness is persistent; and wind extremes require particular attention. These findings can serve as a scientific basis for further research on agroclimatic risk, irrigation demand, soil salinity, wind erosion, and climate-change adaptation in the irrigated lowlands of Mirzachul.

5. Conclusion

This study analyzed the variability and trend directions of the main climatic indicators in the Mirzachul region during 1991–2020 based on observational data from the Jizzakh, Dostlik, Gulistan, and Syrdarya meteorological stations. The obtained results allow the following conclusions to be drawn.

First, the climate of the Mirzachul region is characterized by a high continental amplitude. At all selected stations, the temperature contrast between winter and summer is clearly expressed, indicating the persistence of hot summers and cold winter episodes in the region.

Second, during 1991–2020, annual mean air temperature showed a positive linear tendency at all meteorological stations. A warming signal was observed at the Jizzakh, Dostlik, Gulistan, and Syrdarya stations, although its intensity varied from station to station. This confirms that increasing air temperature is the main climatic signal in the modern climate regime of Mirzachul.

Third, the precipitation regime was characterized more by strong interannual variability than by a stable increasing or decreasing trend. Annual precipitation differed considerably between dry and wet years. Most precipitation occurred during the cold and transitional seasons, whereas natural moisture availability was sharply limited during the summer period.

Fourth, the main signal in the relative humidity regime was expressed through seasonal alternation rather than through a stable long-term trend. Relative humidity was relatively high in winter and sharply lower in summer. Therefore, the most important feature of relative humidity in Mirzachul is the contrast between winter humidity and summer atmospheric dryness.

Fifth, although mean wind speeds maintained a relatively stable background, maximum wind speeds showed an increasing tendency at several stations. This indicates that wind-related climatic risks in Mirzachul should be assessed not only through mean wind speed, but also through maximum wind episodes.

Overall, the modern climatic character of the Mirzachul region during 1991–2020 can be described as a warming, seasonally dry, and highly continental irrigated lowland environment. The findings provide an important station-based scientific baseline for further studies on agroclimatic risks, irrigation water demand, land degradation, soil salinity, and adaptation to climate change.

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